INITIAL EVALUATION OF ADVANCED AIR BAGS IN REAL WORLD CRASHES

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ABSTRACT

The performance of occupant protection systems, especially air bags, is of high interest to the National Highway Traffic Safety Administration (NHTSA). Since 1972, the NHTSA has operated a Special Crash Investigations (SCI) program, which provides the agency with the flexibility to acquire detailed engineering information quickly on high-visibility traffic crashes of special interest. The SCI program collects in-depth crash data on new and rapidly changing technologies in real world crashes. NHTSA uses the data collected in this program and others to evaluate rulemaking actions. The data are also used by the automotive industry and other organizations to evaluate the performance of motor vehicle occupant protection systems such as air bags.

In May of 2000, the NHTSA issued a Final Rule upgrading Federal Motor Vehicle Safety Standard Number 208. In this advanced air bag rule, significant changes were specified in the frontal occupant protection requirements for light passenger vehicles. These changes were to be phased in over several years. These changes included adding requirements for protecting small adult female occupants, adding requirements to minimize the risk of deploying air bags to out-of-position (OOP) children and small adult occupants, increasing the requirements for belted occupants, and reducing the test speed for the unbelted 50th percentile male occupants.

For the past two years, NHTSA's Special Crash Investigations office has been researching crashes involving of vehicles equipped with advanced air bag systems. The purpose of this effort was to keep the Agency and manufacturers informed of the real world performance of these advanced systems. This paper will discuss the protection afforded the occupants in vehicles equipped with these systems; also known as Certified Advanced 208 Compliant (CAC) systems. Since data collection is ongoing, this paper will be limited to those crashes that were researched in the SCI program.

Topics covered in this paper will include: case selection criteria; make and model applicability; age / sex of front seat occupants; airbag deployment stage; safety belt usage; event data recorder (EDR) download applicability; damage severity; injury outcomes in the selected cases; and sample case data. Completed SCI case studies are available via the World Wide Web at www.nhtsa.dot.gov. See the "**SCI DATA AVAILABILITY**" section at the end of this paper for further details.

BACKGROUND

NHTSA performs research and develops safety programs and standards in an effort to reduce the toll of deaths, injuries, and property damage from traffic crashes. In-depth field investigations on crashes with an air bag deployment are conducted in the SCI program under the auspices of the National Center for Statistics and Analysis (NCSA). SCI cases are an anecdotal data set used to examine and evaluate the latest safety systems. Unlike NHTSA's National Automotive Sampling System (NASS) the SCI program is not intended to be a statistically representative database. Therefore, national trends cannot, and should not be inferred from the data. These SCI investigations play a vital role by providing data relative to real world events. Added details on SCI investigations can be found in 17th ESV, Chidester and Roston (2001)[1].

Starting in the 2000 model year, some manufacturers started to incorporate advanced air bag "features" into certain products. These advanced features included things such as seat track sensors to disable air bags from deploying when the seat track was in the forward most position; dual stage air bag inflators to tailor air bag deployments to the crash severity; safety belt sensors to determine the relative risk to the occupant(s); safety belt pretensioners to remove excess slack in the early moments in the crash phase; and safety belt load limiters to spool out part of the safety belt during the crash phase for the occupants to "ride down" the crash forces.

As indicated in the May of 2000 Final Rule, manufacturers have until August 31, 2006 to phase-in compliance with advanced air bag requirements specified in Federal Motor Vehicle Safety Standard (FMVSS) 208. This new advanced air bag standard details the test parameters and conditions that must be met to be in compliance with this advanced requirement.

Starting in the 2003 model year Honda and General Motors introduced a total of 11 models that were certified advanced 208 compliant (CAC). In the 2004 model year that number grew to 13 manufacturers and 40 models. The SCI program utilized its network of resources to identify crashes where there was an above referenced CAC vehicle involved in the crash, and the vehicle damage was still available for inspection.

SCI performs roughly 200 case investigations a year for the NHTSA. These case investigations encompass all types of cases relative to NHTSA priorities and therefore the CAC cases are only a part of the annual cases SCI investigates.

CASE SELECTION

A total of seventy-one (71) cases were evaluated for the information contained in this paper. As indicated, SCI has a network of resources across the country to provide notification of cases of particular interest. This network includes: three SCI field offices; 27 National Automotive Sampling System (NASS) field offices located in 17 States; 10 field offices for NHTSA's Crash Injury Research and Engineering Network (CIREN); various law enforcement agencies; insurance companies; and emergency medical service providers; along with the general public.

In an effort to gain more exposure to these types of vehicles, Nationwide Mutual Insurance Company agreed to work with SCI on this effort. Nationwide was able to supply electronic listings of vehicles meeting our CAC criteria, and in turn we were able to identify a greater population of crashes in which to assign SCI cases for research.

To make notification as simple as possible, SCI provided the various organizations a listing of the vehicles that were certified to the new rule. The organizations were then requested to inform us when a crash occurred that involved one of these vehicles. No other specific parameters were indicated. The purpose of this effort was to collect information on a wide variety of crashes ranging from minor to severe.

Once the crash was identified to NHTSA, SCI screened the crash report and ascertained CAC vehicle involvement. SCI was specifically looking to target "near frontal" crashes in this data collection effort. Therefore rear plane impacts along with side impacts outside the 10 o'clock to 2 o'clock principle direction of force were generally excluded. As the breakdown will show, a wide spectrum of cases were identified and investigated ranging from minor frontal crashes to more severe multiple event crashes and various crash configurations. The purpose of this approach was to not limit the data collection efforts to only those cases where the air bag deployed. Crashes where the air bag system was not commanded to deploy provide valuable information as to any possible risks associated with not deploying the air bag in less severe crashes.

Additionally, strong emphasis was given to the availability of event data recorder (EDR) information. With these advanced systems, the only way the field crash investigators can determine the deployment level of the air bag (e.g., stage 1 or stage 2 deployment) was through retrieving the EDR data. The General Motors products had a commercially available tool to download the data from the air bag control module. These data were included in the case reports indicating certain precrash, and crash information. Other manufacturers do not have a commercially available tool to download stored air bag control module information. For these manufacturers, when owner permission was obtained, and the manufacturer indicated the potential availability of the data, the module was harvested from the vehicle and forwarded to the manufacturer for data retrieval, thus slowing down the case completion process.

Although manufacturers have different names for their air bag control modules, NHTSA refers to them generically as event data recorders (EDR). Throughout this paper the term "EDR" is used even though a specific manufacturer may use another name to identify their module.

VEHICLE MANUFACTURERS

Since the implementation of the CAC compliant vehicles in 2003, SCI has commenced investigations on over 100 cases. Due to the various stages of completion of active investigations, this paper utilizes the data from seventy-one (71) of the SCI cases.

These cases were either complete or nearing completion, thus would soon be available to the public via the NHTSA website. The breakdown of the manufacturers is indicated in Figure 1.

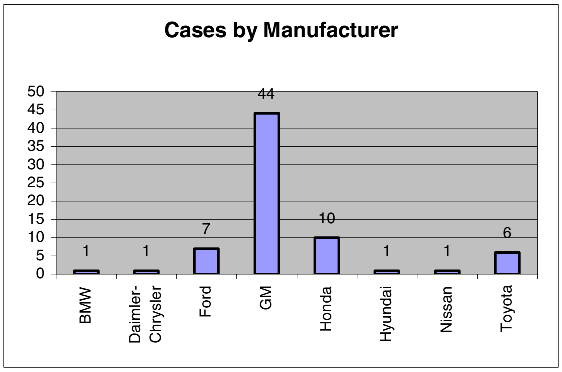

Figure 1: CAC cases by manufacturer investigated in the SCI Program as of December 31, 2004.

As Figure 1 indicates, 44 of the 71 cases (62%) were General Motor's products. Out of the eleven models that were introduced this first year, nine models were from General Motors, thus the high proportion of their products in our data. Additionally, a commercially available product that permits downloading of the air bag control module for General Motors and certain Ford products was available to all our field investigation teams.

Figure 2 indicates the types of vehicles involved in the 71 CAC cases investigated thus far in SCI cases.

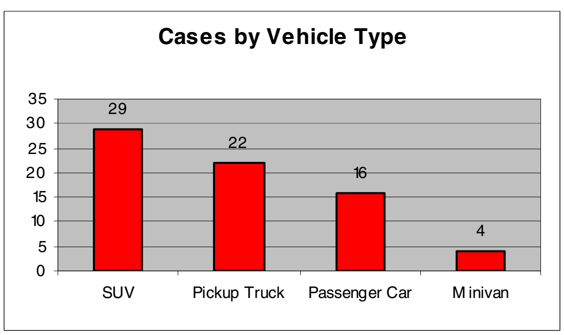

Figure 2: CAC cases by vehicle type investigated in the SCI Program as of December 31, 2004.

Manufacturers generally deployed this advanced technology in their pickup and sport utility line. These two vehicle types accounted for 51 of the 71 (72%) cases investigated by the SCI program. A key reason SCI sought out pickup trucks in these crashes was their propensity to not have a rear seat for a child occupant. SCI attempted to obtain as many cases as possible where a child was present in the right front seat. However, only two occupants age twelve and under were seated in the right front seat in the selected cases. In addition, one child aged twelve and under was seated in the center front seat in the selected cases. Even though certified advanced air bags must pass numerous performance standards, NHTSA continues to advise that children 12 and under to ride in the back seat of an air bag equipped vehicle. Minivans accounted for only four of the 71 cases. As the vehicle fleet nears 100 percent compliance to the new FMVSS certified advanced 208 standard, we expect to see a more even distribution of vehicle types investigated in the SCI cases.

CRASH SEVERITY AND CONFIGURATION

Figure 3 shows the impact configuration of the 71 CAC cases investigated.

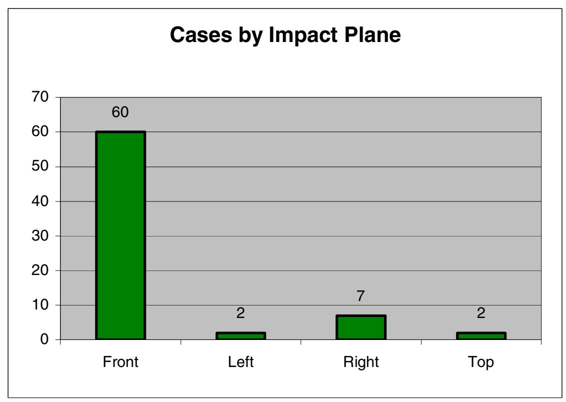

Figure 3: Impact configuration by impact plane in CAC cases investigated in the SCI Program as of December 31, 2004.

As mentioned earlier, SCI was specifically looking for "near frontal" crashes for this study. Single and multiple event crashes were included in this data collection effort. The impact plane detailed here is based on the most severe event in the crash. Therefore the large majority of investigated cases were classified as Front (60 cases / 84%). Right and left side impacts totaled nine cases (13%) combined. Two rollover (Top) cases were also included in the study making up 3% of the cases. Rear impacts were specifically excluded from the CAC program.

Figure 4 indicates the crash severity level of the case vehicles based on total delta V. Only cases where a Delta V was calculated are included in this breakdown. SCI attempted to investigate cases that had the propensity for a high-speed delta V; however, minimal cases were identified through our network of resources.

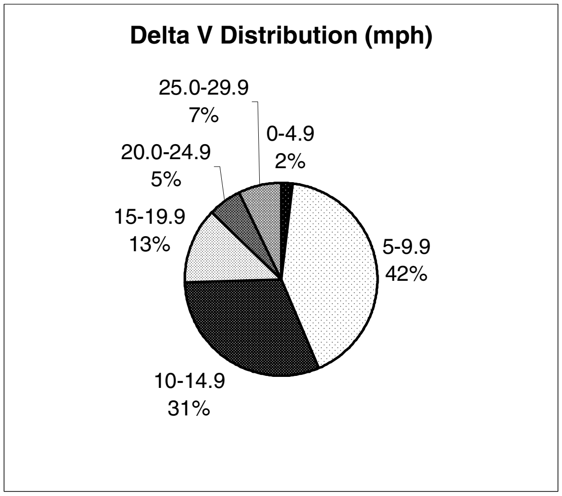

Figure 4: Crash severity distribution as measured by Delta V in CAC cases investigated in the SCI program as of December 31, 2004.

Almost three-quarters (73%) of the case vehicles inspected fell into the low to moderate range of 5-14.9 mph. One-quarter (25%) fell in the moderate to severe range of 15-29.9mph.

Total Delta V was calculated using the WinSmash algorithm; the standard reconstruction program used in NHTSA field crash data collection efforts.

CASE OCCUPANTS

Figure 5 gives the demographics of all of the front seat occupants included in the CAC program.

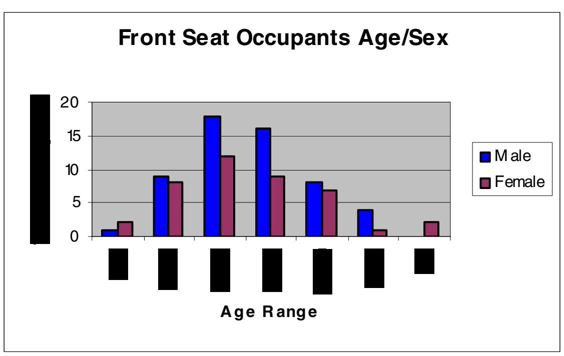

Figure 5: Front seat occupants demographics in CAC cases investigated in the SCI program as of December 31, 2004.

A total of 97 occupants were present in the front seats of the CAC case vehicles. Ages ranged from six to 84 with a median age of 34 and a mean age of 37.5. Males made up 58% of the study population; females 42%. Children aged 12 and under and adults aged 65 and over accounted for 4% each of the case occupants.

Figure 6 shows the seating positions of all front row occupants in the 71 case vehicles.

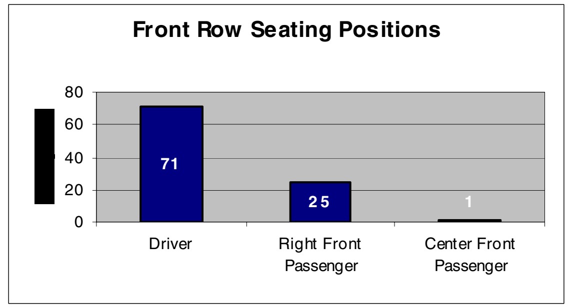

Figure 6: Front row seating positions of case vehicle occupants in CAC cases investigated in the SCI Program as of December 31, 2004.

In 45 of the 71 vehicles (63%) of the CAC cases investigated, there was a driver only (no other occupants) in the case vehicle. In 25 of the 71 case vehicles a front right passenger (35%) was present. In one case vehicle a front center passenger (1%) was present. Since the CAC vehicles are designed specifically to protect front seat occupants, rear seat occupants were not included in this breakdown.

Figure 7 indicates the belt usage for front seat occupants of the case vehicles.

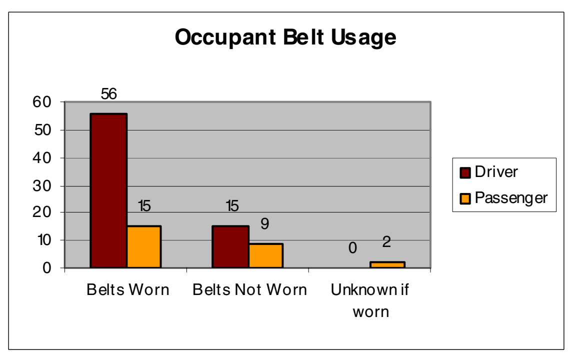

Figure 7: Safety belt usage of front seat occupants in CAC cases investigated in the SCI program as of December 31, 2004.

Of the 71 case vehicle drivers investigated in the CAC program, 79% (56) were using their available manual restraint while 21% (15) were unrestrained. Of the 26 front seat passengers, 58% (15) were using the available manual restraint; 34% (9) were unrestrained, and the safety belt usage could not be determined for 8% (2) of the occupants. There were no occupants restrained in child safety seats in the study.

Safety belt usage is of particular interest in CAC systems because certain manufacturers configure the air bag deployment levels (stage 1 or stage 2) to the belt usage status of the front seat occupants. Therefore, the belted occupants would generally require a higher severity crash for the air bag deployment threshold to be met. Typically the air bags deploy at a lower Delta V threshold for unrestrained occupants. This can create instances of asymmetrical deployments where one front air bag may deploy while of other front bag may not.

OCCUPANT INJURY LEVEL

Figure 8 shows the injury distribution among all front seat case occupants.

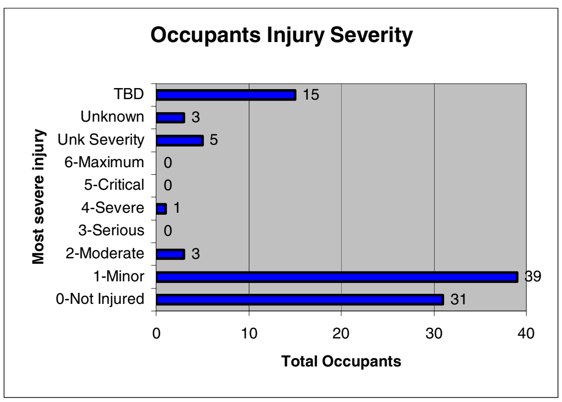

Figure 8: Most severe injury sustained by front seat CAC case occupants investigated in the SCI program as of December 31, 2004.

Of the known injury severities (Not Injured to AIS 6) the vast majority 95% (70 out of 74) of front seat occupants in the CAC vehicles sustained minor or no injuries. Only four front seat occupants (5%) sustained a moderate or higher severity injury.

In the first of these four cases a 2003 GMC Yukon was involved in a “moderate” severity rollover. The 23-year-old female driver was not using the manual lap and shoulder restraint. During the rollover sequence the driver was fully ejected from the vehicle. Her most severe injury was an AIS-4 (severe) concussive head injury which was due to her head contacting the ground.

The second case was a high severity frontal impact involving a 2003 Chevrolet Tahoe. The Delta V was calculated to be approximately 25 mph. The 32-year-old female driver was restrained by the lap and shoulder restraint. She sustained an AIS-2 (moderate) right fibula fracture attributed to loading of her foot with the floor pan.

The third case involves a front impact and a series of rollover events in a 2003 Chevrolet Tahoe. The vehicle struck a guardrail with the front plane, then rolled over, end-over-end, and struck a concrete bridge abutment with the back plane. The driver was a 37-year-old restrained female. Her most severe injury sustained was an AIS-2 (moderate) cerebral concussion. This was attributed to contact with the left roof side rail during the rollover sequence.

The final case involves a 2004 Cadillac Escalade striking two trees with the front plane. The first impact produced a longitudinal Delta V (-6.4 mph EDR recorded) high enough to deploy the driver’s air bag. The tree fractured and the vehicle went on to strike another tree producing a much higher longitudinal Delta V (-33.3 mph EDR recorded). The 67-year-old male driver was restrained, however he reported that he used two plastic clips on the shoulder belt to induce approximately 2-3” of slack into the belt system for reasons of comfort. This slack may have allowed for further forward movement of his torso than would normally be expected. This along with the air bag deploying during the lower severity impact contributed to his injury. The most severe injury sustained was an AIS-2 (moderate) rib fracture.

Out of the 97 total case occupants, the injury level has yet to be determined for fifteen occupants, and eight occupants had either injuries of an unknown level or it was not be determined if they were injured.

EVENT DATA RECORDERS

Case selection was at least partially biased towards vehicles with Event Data Recorders (EDR’s) that were downloadable by our field investigators. As mentioned above, this created an over representation of General Motors vehicles. With the help of other manufacturers SCI was able to also harvest EDR’s from some non-GM vehicles and ship them to the manufacturer to be read. The information from the manufacturer was included in the case data with respect to the information that was recorded.

Figure 9 shows the number of EDR's successfully downloaded.

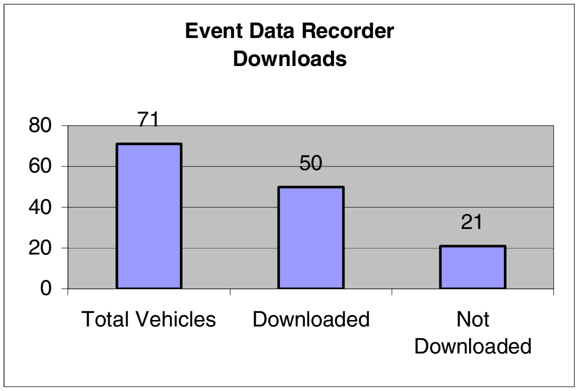

Figure 9: EDR's downloaded in CAC cases investigated in the SCI Program as of December 31, 2004.

EDR's were downloaded successfully, by either field staff or by the manufacturer, 70% of the time (50 out of 71). The information provided by the EDR (or the manufacturer) was included and coded into the SCI case data.

The 30% (21 out of 50) that were not downloaded were due to manufacturers indicating that there was no recorded information stored in their EDR, the manufacturer was not able to download the information, or in some cases, because of damage to the unit itself.

An important piece of data retrieved from the EDR's is the deployment level of the air bags. This deployment level indicates which stage of the dual-stage air bags deployed. A breakdown of air bag deployments is indicated in Figure 10 below.

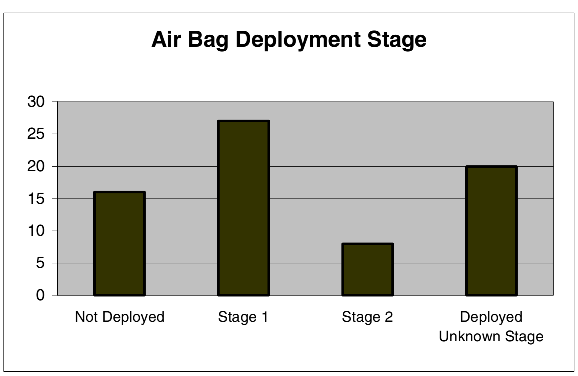

Figure 10: Driver's front air bag deployment stage in CAC cases investigated in the SCI Program as of December 31, 2004.

As indicated in Figure 10, there were a total of 71 CAC vehicle cases investigated for this paper. Of those 71 vehicles, 55 vehicles had a deployed air bag in the crash. By interrogating the EDR module, it was determined that 27 of the 55 (49%) had an air bag deployed at "Stage 1". Eight of the 55 air bags (15%) deployed at "Stage 2". The remainder, 20 out of the 55 deployments (36%) were not known as to which stage the air bag deployed because no interrogation or downloading of the air bag control, module or EDR was able to be performed.

SUMMARY

The ability to download the event data recorder is the most effective method to observe and/or measure and confirm the performance of CAC Safety System Features. In addition, EDR information is the only way our field investigators can determine what stage the air bag was commanded to deploy. Engineers and researchers are finding this piece of information extremely useful in crash analyses.

Certified advanced 208 compliant air bags appear to offer adequate occupant protection in the cases investigated thus far in NHTSA's SCI program.

In the 71 cases investigated in SCI for this paper, there were no serious or fatal injuries related to the deployment of a certified advanced compliant air bag.

As indicated in Figure 7, the safety belt usage rate for drivers in these anecdotal SCI cases is 79%. This percentage is consistent with recent safety belt information gathered in NHTSA's National Occupant Protection Use Survey (NOPUS) for 2004.

NHTSA's SCI program will continue to monitor certified advanced 208 compliant vehicles to assure adequate real world crash performance.

SCI DATA AVAILABILITY

Since 2001, SCI summary tables have been published quarterly on the NHTSA's Internet web site at the following web address:
http://www-nrd.nhtsa.dot.gov/departments/nrd-30/ncsa/SCI.html

The SCI online data access page is located at:
http://www-nass.nhtsa.dot.gov/BIN/logon.exe/airmislogon

Within the NCSA website http://www-nrd.nhtsa.dot.gov/departments/nrd-30/ncsa/.

The interface (Figure 11) is a data filter that offers users a wide array of choices when querying the SCI

Figure 11: NHTSA World Wide Web Query Interface for SCI cases.

database. For specific case access, the most efficient method of retrieval is to use the **SINGLE CASE SELECTION** by entering the Case Number (upper-case may be required) and clicking "Get Case". For a wider selection of cases, the user can use the pull down filters under the **MULTIPLE CASE SELECTION BASED ON FILTER CRITERIA** section. Users can choose to see cases by entering parameters from one or more selection criteria areas:

CASE TYPE – This selection is based on the type of case such as: Child Safety Seat, School Bus, Side Air Bag, etc. Using this selection criteria and no other will return the most cases for the selected type.

VEHICLE - Provides a selection method for limiting the output case list based on vehicle model and year make. Year make can either be a range or a single year. The parameters in the section can be used independently of the other selection criteria areas.

CRASH – A multi-filter selection area that allows the output case list to be more specific based on year, state, month and/or mortality. The parameters in the section can be used independently of the other selection criteria areas.

OCCUPANT - A multi-filter selection area that allows the output case list to be more specific based on where the occupant was located in the vehicle (role) and some physical characteristics (sex, age, and height). These parameters can be used independently of the other selection criteria areas.

As a general rule for using data filters, the fewer parameters used will mean a greater return of qualifying data, in this instance more cases. Additionally, the use of more than a few parameters can mean that the query becomes too granular and the results could be less data (cases) than expected. The best practice is to perform several practice retrievals using a variety of parameters until the right blend of parameters provides the desired results.

Complete reports can also be obtained at the address below. The reports contain images and accordingly there is a cost associated with reproduction of the crash report.

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USA

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REFERENCES

1. Chidester, Augustus, and Roston, Thomas, *Air Bag Crash Investigations*, 17th Enhanced Safety of Vehicles Conference 2001; U. S. Department of Transportation, National Highway Traffic Safety Administration

EVALUATION OF FRONTAL AIR BAG PERFORMANCE

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Abstract: In May of 2000, the NHTSA issued a Final Rule upgrading Federal Motor Vehicle Safety Standard (FMVSS) No. 208, 65 FR 30680. This advanced air bag rule specified significant changes in the frontal occupant protection requirements for light passenger vehicles (GVWR≤8500 lbs), to be phased in over several years. These included adding requirements for protecting small adult female occupants, adding requirements to minimize the risk of deploying air bags to out-of-position (OOP) children and small adult occupants, increasing the test speed for the belted 50th percentile male dummy, adding a rigid barrier test condition for the unbelted 50th percentile male test dummy and eliminating the unbelted sled test option.

In 2001, the agency initiated research to monitor the overall performance of advanced air bags. This paper updates the status of the research and presents results of the testing performed since the 18th ESV Conference. Results from static deployment tests for OOP occupants and dynamic crash tests are presented.

1.0 BACKGROUND

FMVSS No. 208 (49 CFR Part 571.208) is the occupant frontal crash protection regulation in the United States. In May 2000 and December 2001, NHTSA amended the standard to require future air bags to be less aggressive to small stature adults and young children, but still provide protection for all occupants. The new rule improved protection and minimizes risk by requiring new tests and injury criteria for the entire family (12 month CRABI (12MO), 3-year-old (3YO), 6-year-old (6YO), 50th percentile male (50th M) and 5th percentile female (5th F) Hybrid III) of test dummies.

Automobile manufacturers must meet one of the following minimum requirements designed to minimize air bag risks: Option 1 – Automatic Suppression feature, Option 2 – Dynamic Automatic Suppression system, or Option 3 – Low Risk Deployment (LRD) or (OOP) testing. This paper looks at Option 3- OOP testing on selected model year (MY) 2002 and 2004 vehicles.

NHTSA has been evaluating the performance of air bags in frontal crashes for the past few years, during the phase-in of the current FMVSS No. 208 regulations. In June of 2001, NHTSA published in the Federal Register a request for comments on a plan to monitor the performance of advanced air bags and to develop data for potential future air bag rulemaking. An ongoing research program was created to look at air bags by following the new procedures in FMVSS No. 208.

Crash tests with MY 1998 and 1999 vehicles, reported by Summers [1] and Beuse [2] showed the need for optimized crash protection for small female and mid-sized male occupants. Results from crash tests on MY 2001 vehicles showed similar results [3]. The results of OOP tests on model year 2001 vehicles (Honda Accord, Chevrolet Impala, Dodge Caravan, Toyota Echo, Ford Escape and Ford F150) were presented in Paper No. 427 at the 18th ESV [4]. This paper updates the findings from a similar ongoing study of MY 2002 through 2004 vehicles.

2.0 INTRODUCTION

Vehicles were chosen for this study depending on what advanced safety features they had. A wide variety of vehicles: passenger cars, light trucks and vans were included in this selection. Several vehicles had dual stage air bags and advanced air bags. Table 2.1 shows the vehicles selected and their safety features. After September 1, 2006, 100 percent of the fleet (GVWR≤8500 lbs and unloaded weight≤5500 lbs) shall be certified to the first phase of the new advanced FMVSS No. 208 rule.

Two vehicles selected for the tests, MY 2004 Honda Accord and Odyssey, were certified to the LRD option for the 6YO as required in S23.4 of the new FMVSS No. 208. As such, the other vehicles in the matrix were not expected to meet the current FMVSS No. 208 requirements for LRD tests. The MY 2002 vehicles were certified to the pre-advanced airbag version of FMVSS No. 208, which required crash tests or sled tests. MY 2004 vehicles were certified to the current FMVSS No. 208 regulations using the suppression option, except for the Honda Accord and Odyssey.

The LRD performance for MY 2004 was evaluated using a Hybrid III 10-year-old (10YO) dummy. This dummy was developed recently in order to study the injury risks to the large child occupant. These tests were used to understand the baseline safety performance of vehicle restraints systems for such occupants. The 10YO dummy is not a part of FMVSS No. 208.

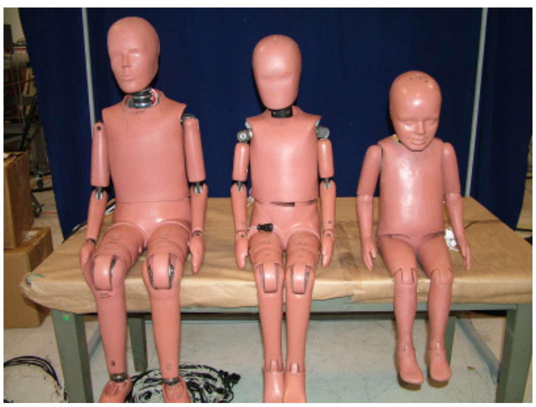

Figure 2.1 10YO, 6YO, and 3YO dummies.

A test program was initiated to study the injury risks to small child occupants in the proximity of the deploying air bags. FMVSS No. 208 uses two dummy positions in the LRD option that places the dummy's head/neck and chest close to the air bag. It is of interest, however, to understand how the injury risk to the occupant varies in the space around these LRD positions. This will allow the agency to assess injury potential for situations not covered by the two positions currently used in FMVSS No. 208.

Table 2.1
Vehicle Selection.

Vehicle	Dual Stage Air bags	Passenger Suppression System
2002 Saturn Vue		
2002 Honda Civic	X	
2003 Toyota Corolla	X	
2002 Ford Windstar	X	
2004 Honda Accord	X	X*
2004 Honda Odyssey	X	X*
2004 Chevy Avalanche	X	X
2004 Jeep Liberty	X	X
2004 Ford Taurus	X	X

*- The Accord and Odyssey use suppression for 12MO and 3YO and LRD for 6YO.

3.0 LOW RISK DEPLOYMENT TEST MATRIX

The vehicles selected for crash and LRD tests are shown in Table 3.1. The test conditions are the same as in the advanced air bag requirements of FMVSS No. 208 (Test Procedure 208-12, dated 1/14/03), and are described in [4]. Dual stage bags can typically be deployed with less energy or inflation rates (low mode) or higher energy or inflation rates (high mode). This is usually determined by changing the time elapsed between deploying the two sates of the inflator. Vehicles with the dual stage air bags were tested in the low mode first. If the dummy readings passed the injury assessment reference values (IARV) in the low mode, then the high mode was tested as well. Table 3.2 shows the different fire times used during testing. Only the MY 2004 Accord and Odyssey were certified to the LRD option of FMVSS No. 208 for the passenger side.

For the MY 2002 and 2003 vehicles, the OOP testing was done with the Hybrid III 5th percentile female dummy on the driver's side and Hybrid III 6-year-old (6YO) dummy on the passenger's side. For the MY 2004 vehicles, only the passenger side was tested (using the Hybrid III 10YO dummy). The 10YO positions (Figures 3.1 and 3.2) were based on the Hybrid III 6YO LRD Positions in FMVSS No. 208.

Table 3.1
Air Bag Fire Times.

MY2002 Vehicles	Time gap between stages, msec				Pass. Bag Loc.
	Driver		Passenger		
	Low	High	Low	High	
2002 Saturn Vue	N/A	N/A	N/A	N/A	Mid
2002 Honda Civic	20	0 ms	40	0	Top
2003 Toyota Corolla	30	0	100	0	Top
2002 Ford Windstar	100	15	100	15	Mid
2004 Honda Accord	N/A	N/A	130	5	Top
2004 Honda Odyssey	N/A	N/A	130	5	Top
2004 Chevy Avalanche			Primary only	22	Front
2004 Jeep Liberty			102	10	Front

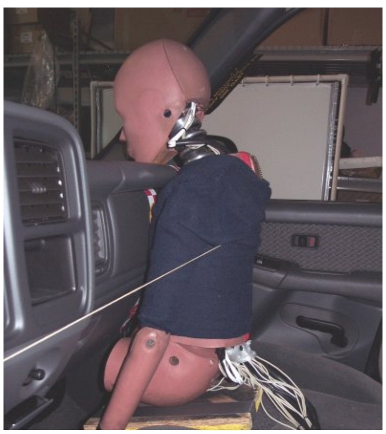

Figure 3.1 Chev. Avalanche, 10YO Position 1.

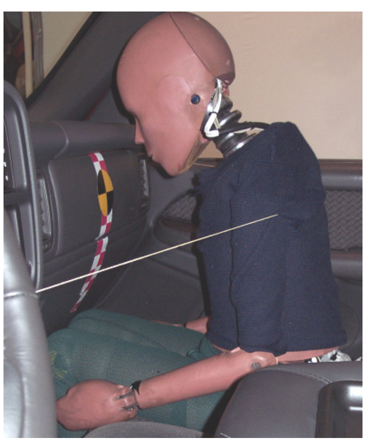

Figure 3.2 Chev. Avalanche, 10YO Position 2.

3.1 Injury Criteria

The results were analyzed using the FMVSS No. 208 injury criteria for out-of-position occupants for the Hybrid III 6YO, 5th percentile female dummies. The IARV for the 10YO dummy was obtained from [5]. The IARVs used for this study are listed in Table 3.2.

Table 3.2
Injury Values for OOP Testing.

OOP Injury Criteria	Injury Assesment Reference Values (IARV)		
	5th% Female*	6YO Child^	10YO Child^
15ms HIC	700	700	700
3ms Clip (g)	60	60	60
Chest Deflection (mm)	52	40	44
Neck Tension (N)	2070	1490	1810
Neck Compression (N)	2520	1820	2200
Nij	1.0	1.0	1.0
Critical Values to Calculate Nij			
Tension (N)	3880	2800	3390
Compression (N)	3880	2800	3390
Flexion (Nm)	155	93	128
Extension (Nm)	61	37	50

* Calculated on data recorded for 125 ms after the initiation of the final stage airbag
^ Calculated on data recorded for 100 ms after intial deployment

3.2 Observations

The test results are summarized in Tables 3.3 to 3.5. It should be noted that only the 2004 Honda Accord and Odyssey were certified to the LRD option on the passenger side.

3.2.1 MY 2002 and 2003 Vehicles

Four MY 2002 and 2003 vehicles were tested. The 2002 Honda Civic, 2002 Ford Windstar, and 2003 Toyota Corolla had dual stage air bags. The 2002 Saturn Vue had single stage air bags, which were considered 'high mode' for the purposes of the following discussion.

3.2.1.1 Passenger side (6YO)
A total of 14 tests were run on these vehicles and the results are summarized in Table 3.3 and Figures 3.3 and 3.4. Nij values and either neck tension or compression exceeded the IARVs in

six of the eight high mode tests, which included the Saturn Vue. None of the neck IARVs were exceeded in the six low mode tests. Only one test (Civic, high mode, position 1) exceeded the IARV for the 15 millisecond HIC. The other 13 were all below 80 percent of the IARV. Also, none of the chest responses exceeded either chest IARV. Only the Corolla produced responses that were below all the IARVs for all four of its tests.

3.2.1.2 Driver Side (5^{th} Female)

The results from these tests are shown in Table 3.4 and Figures 3.5 and 3.6. The 5^{th} F had low injury values for the head and chest. The neck values were somewhat higher for both positions and air bag modes, although only one of the neck responses exceeded an IARV (Nij for Windstar, position 1, high mode). All the other injury measures were below 80 percent of the IARVs.

3.2.2 MY 2004 Vehicles

Nineteen tests were conducted on the five vehicles, with an average of about four tests per vehicle (two positions, two air bag modes each), and the results are shown in Table 3.5 and Figures 3.7 and 3.8. The Nij values exceeded the IARV in four out of 19 tests. The 2004 Chevy Avalanche exceeded Nij, neck tension and chest deflection IARV's for Position 1 in both the low and high modes. This vehicle also had a high Nij value for Position 2 in the high mode. Position 1 produced higher neck values than Position 2, because of how the dummy sat in the vehicle. This particular vehicle had a grab handle on the instrument panel just below the air bag, which caused the dummy to be seated farther back for position 2 (see Figures 3.1 and 3.2). The Ford Taurus, in the test at position 1, low air bag mode, produced the other high Nij. This test also resulted in a neck compression response that exceeded that IARV.

Fifteen out of nineteen tests passed all the injury criteria for a 10YO OOP occupant. Only, the Honda Accord and Odyssey were certified for LRD with a Hybrid III 6YO. The Accord, along with the Honda Odyssey and Jeep Liberty, passed all IARVs at both positions and for both low and high modes.

4.0 PARAMETRIC TESTS

The purpose of this series of static tests was to study how air bags react with dummies in locations other than FMVSS No. 208 LRD, Position 1 and Position 2. Additionally, the baseline condition was repeated to examine the degree of repeatability achieved for seemingly identical test conditions.

Three vehicle platforms (2002 Ford Windstar, 2002 Honda Civic, and 2003 Honda Odyssey) were selected, with two test conditions, the 5^{th} F on the driver side, and 6YO on the passenger side. The test matrix is in Table 4.1.

For each vehicle, the air bag mounting location was replicated on a test buck, along with the windshield and the seat location (Figure 4.1). The dummy was seated according to the FMVSS No. 208 position, which was considered to be the baseline test condition. Tests at this baseline condition were repeated to study the repeatability of the overall test results, encompassing the variability of air bag modules, dummy seating, and bag interaction with the dummy. The dummy was reseated two and four inches, in the three principal directions, away from the baseline position (laterally to the left and right, longitudinally away from the air bag, vertically above and below). On the driver side, the baseline positions had a gap between the air bag and the dummy chest. Therefore, an additional test bringing the dummy two inches closer to the air bag was run.

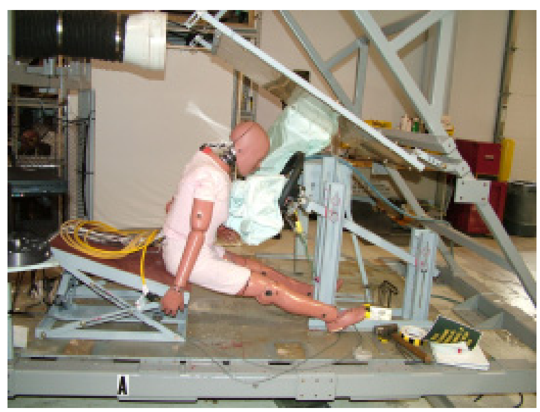

Figure 4.1 Buck with adjustable metal seat.

The dummy positions were documented using a digitizing arm for accurate measurements.

This is an ongoing program, and the results to date are in Tables 4.2 to 4.4 and Figures 4.6 to 4.17. Some of the test positions were omitted using engineering judgment, to reduce the number of tests involved. The small sample size (of mostly one test per condition) precludes any determination about the statistical significance of any findings.

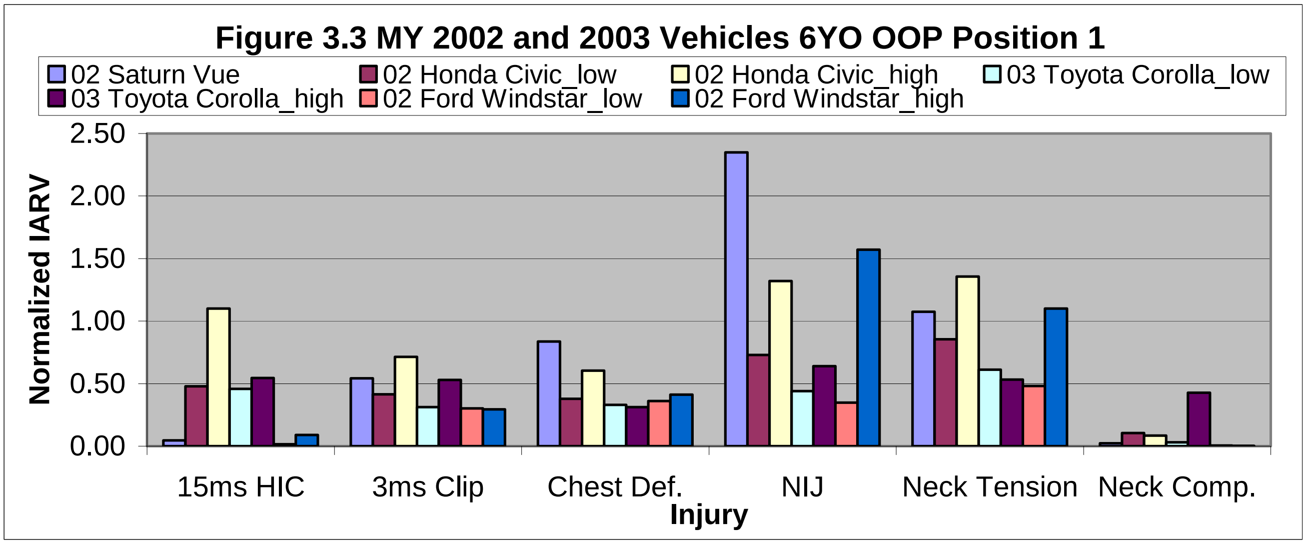
Figure 3.3 MY 2002 and 2003 Vehicles 6YO OOP Position 1
02 Saturn Vue
02 Honda Civic_low
02 Honda Civic_high
03 Toyota Corolla_low
03 Toyota Corolla_high
02 Ford Windstar_low
02 Ford Windstar_high
Normalized IARV
2.50
2.00
1.50
1.00
0.50
0.00
15ms HIC
3ms Clip
Chest Def.
NIJ
Neck Tension
Neck Comp.
Injury

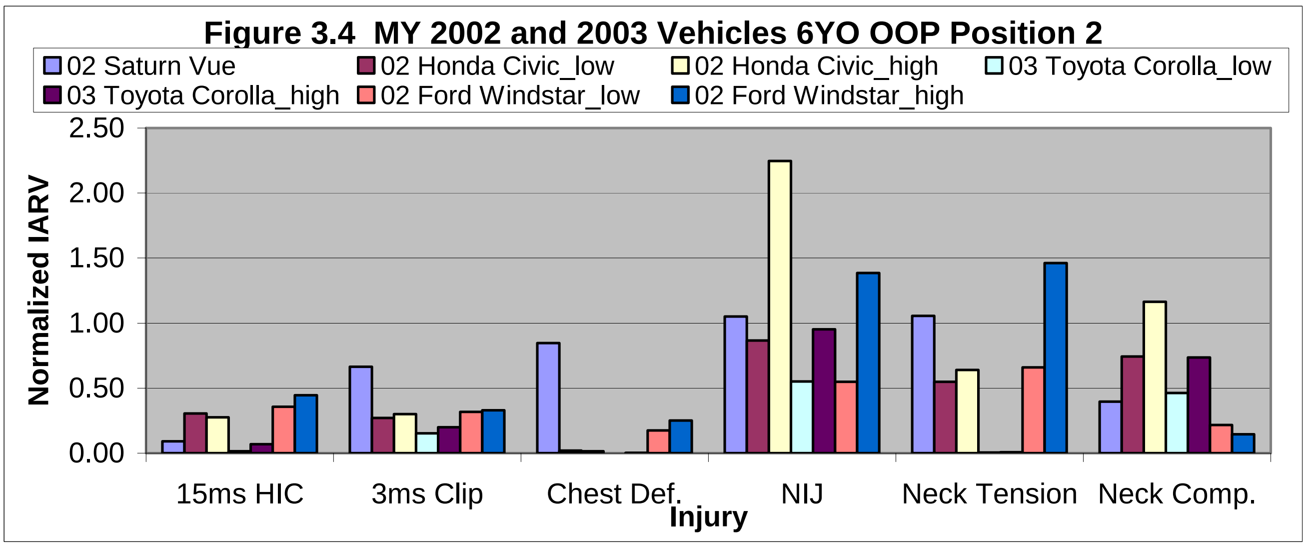
Figure 3.4 MY 2002 and 2003 Vehicles 6YO OOP Position 2
02 Saturn Vue
02 Honda Civic_low
02 Honda Civic_high
03 Toyota Corolla_low
03 Toyota Corolla_high
02 Ford Windstar_low
02 Ford Windstar_high
Normalized IARV
2.50
2.00
1.50
1.00
0.50
0.00
15ms HIC
3ms Clip
Chest Def.
NIJ
Neck Tension
Neck Comp.
Injury

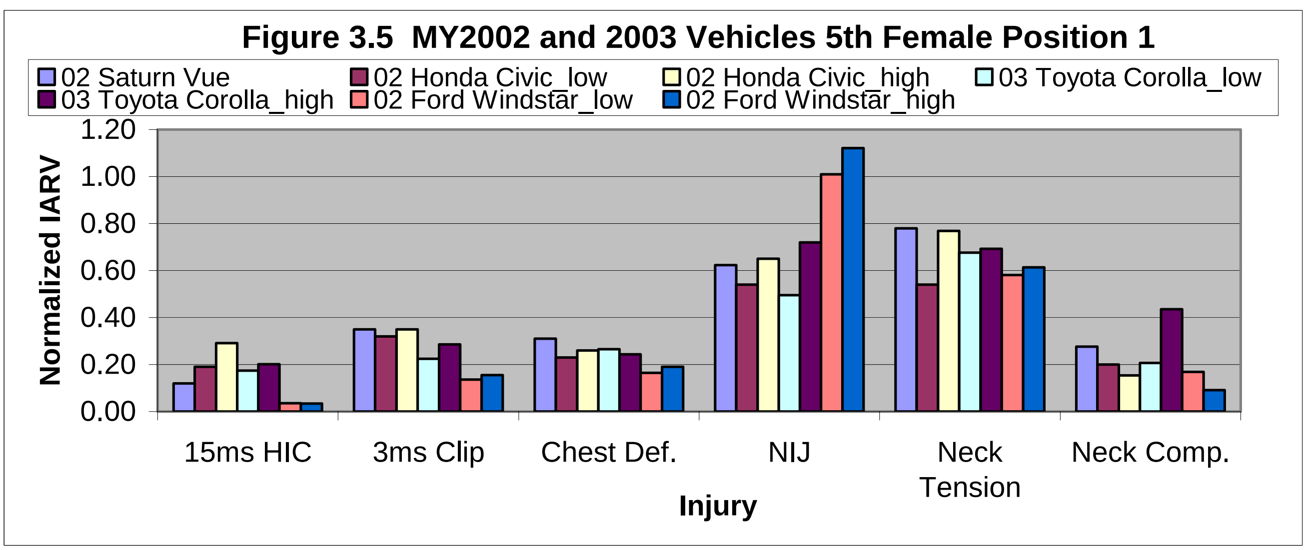
Figure 3.5 MY2002 and 2003 Vehicles 5th Female Position 1
02 Saturn Vue
02 Honda Civic_low
02 Honda Civic_high
03 Toyota Corolla_low
03 Toyota Corolla_high
02 Ford Windstar_low
02 Ford Windstar_high
Normalized IARV
1.20
1.00
0.80
0.60
0.40
0.20
0.00
15ms HIC
3ms Clip
Chest Def.
NIJ
Neck Tension
Neck Comp.
Injury

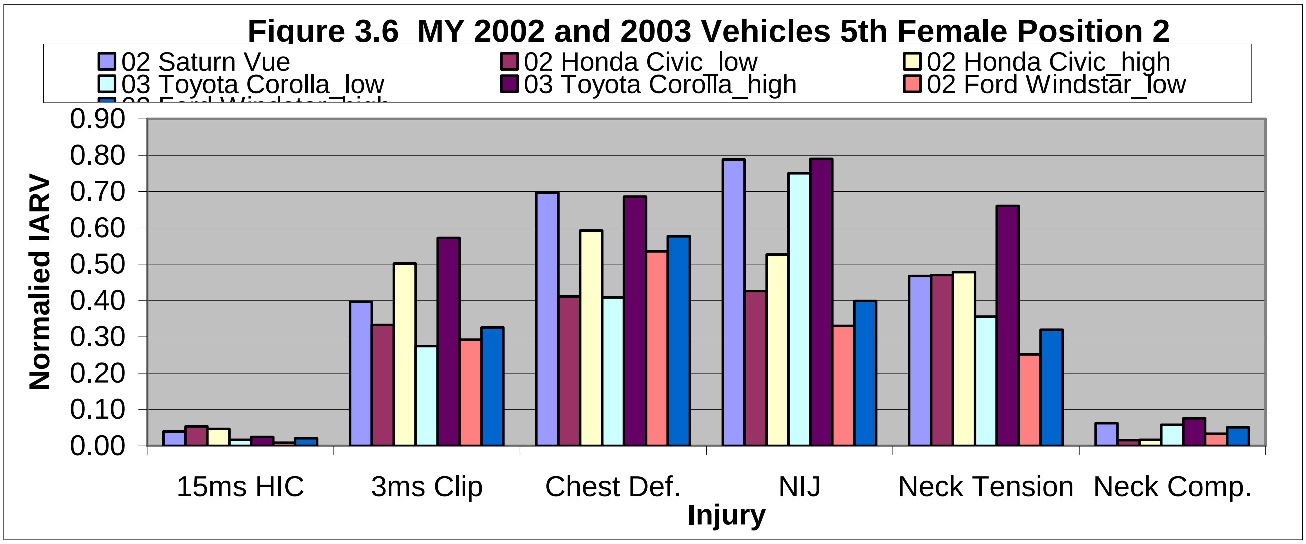

Figure 3.6 MY 2002 and 2003 Vehicles 5th Female Position 2
02 Saturn Vue
02 Honda Civic_low
02 Honda Civic_high
03 Toyota Corolla_low
03 Toyota Corolla_high
02 Ford Windstar_low
Normalied IARV
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
15ms HIC
3ms Clip
Chest Def.
NIJ
Neck Tension
Neck Comp.
Injury

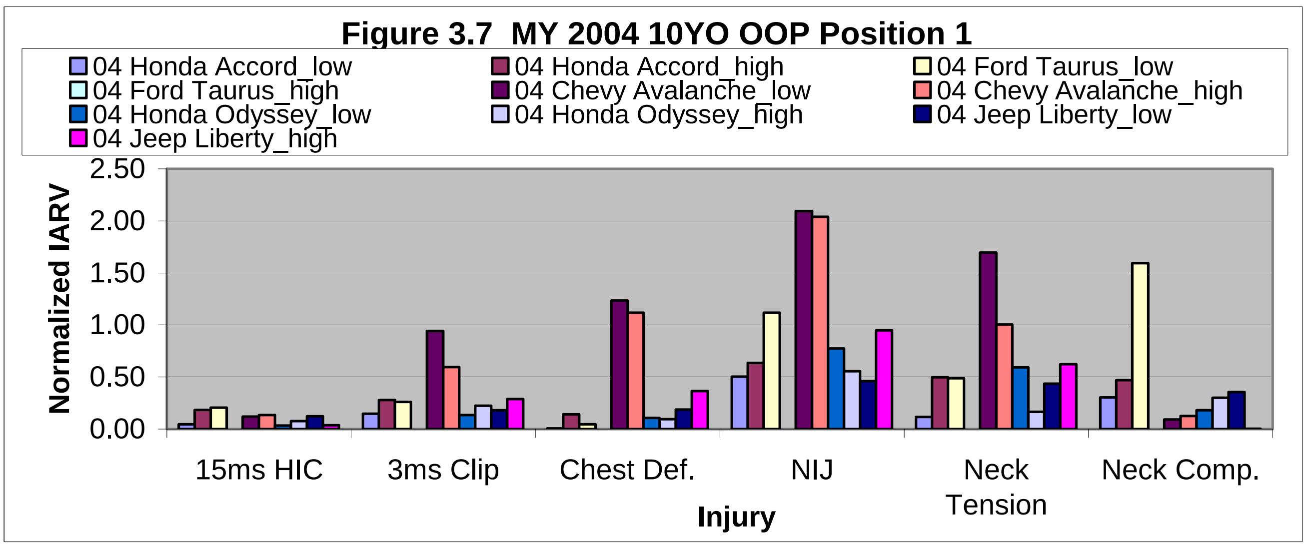

Figure 3.7 MY 2004 10YO OOP Position 1
04 Honda Accord_low
04 Honda Accord_high
04 Ford Taurus_low
04 Ford Taurus_high
04 Chevy Avalanche_low
04 Chevy Avalanche_high
04 Honda Odyssey_low
04 Honda Odyssey_high
04 Jeep Liberty_low
04 Jeep Liberty_high
Normalized IARV
2.50
2.00
1.50
1.00
0.50
0.00
15ms HIC
3ms Clip
Chest Def.
NIJ
Neck Tension
Neck Comp.
Injury

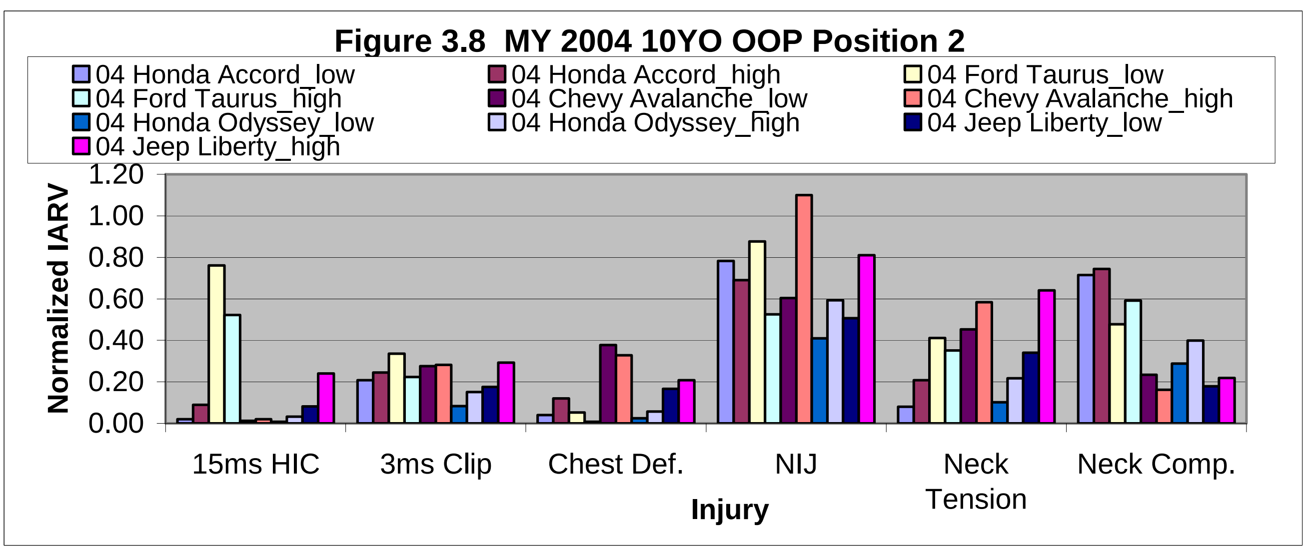

Figure 3.8 MY 2004 10YO OOP Position 2
04 Honda Accord_low
04 Honda Accord_high
04 Ford Taurus_low
04 Ford Taurus_high
04 Chevy Avalanche_low
04 Chevy Avalanche_high
04 Honda Odyssey_low
04 Honda Odyssey_high
04 Jeep Liberty_low
04 Jeep Liberty_high
Normalized IARV
1.20
1.00
0.80
0.60
0.40
0.20
0.00
15ms HIC
3ms Clip
Chest Def.
NIJ
Neck Tension
Neck Comp.
Injury

Table 3.3
MY 2002 and 2003 6YO OOP Test Results.

Vehicles	Test No.	Position	Air bag Mode	15ms HIC	3ms Clip g's	Chest Def. mm	Nij	Neck Tension N	Neck Comp. N
02 Saturn Vue	B02_002	1	single stage	32.0	32.5	33.5	2.4	1603.2	42.6
	B02_001	2	single stage	63.0	39.9	33.9	1.1	1572.0	722.4
02 Honda Civic	B02_004	1	Low Mode	335.0	24.8	15.1	0.7	1272.5	192.6
	B02_003	2	Low Mode	213.0	16.3	0.8	0.9	816.4	1350.9
	B02_005	1	High Mode	771.0	42.9	24.2	1.3	2020.3	152.7
	B02_014	2	High Mode	193.0	18.0	0.5	2.2	952.3	2120.1
03 Toyota Corolla	B02_006	1	Low Mode	320.0	18.8	13.2	0.4	910.0	54.3
	B02_007	2	Low Mode	11.0	9.2	0.0	0.6	6.3	840.8
	B02_013	1	High Mode	381.0	31.8	12.5	0.6	791.2	776.9
	B02_008	2	High Mode	48.0	11.9	0.1	1.0	10.9	1337.4
02 Ford Windstar	B02_011	1	Low Mode	10.0	18.1	14.5	0.3	717.2	10.2
	B02_009	2	Low Mode	249.0	19.0	7.0	0.5	987.1	395.2
	B02_012	1	High Mode	62.0	17.6	16.5	1.6	1640.8	5.5
	B02_010	2	High Mode	311.0	19.7	10.0	1.4	2177.5	263.1

Table 3.4
MY 2002 and 2003 5th FEMALE OOP Test Results.

Vehicles	Test No.	Position no.	High or Low Mode	15ms HIC	3ms Clip	Chest Def.	NIJ	+FZ Neck Tension	Neck Comp.
02 Saturn Vue	C02_002	2	not dual stage	28.0	23.8	36.2	0.8	967.5	156.8
	C02_001	1	not dual stage	83.0	20.7	16.0	0.6	1612.7	697.1
02 Honda Civic	C02_004	1	Low Mode	130.0	19.2	12.1	0.5	1122.5	502.7
	C02_003	2	Low Mode	37.3	20.0	21.4	0.4	972.9	39.7
	C02_005	1	High Mode	204.0	21.0	13.5	0.7	1590.0	386.8
	C02_006	2	High Mode	32.9	30.1	30.8	0.5	989.3	42.2
03 Toyota Corolla	C02_021	1	Low Mode	122.0	13.5	13.8	0.5	1400.3	522.0
	C02_025	2	Low Mode	12.0	16.5	21.2	0.8	736.6	145.4
	C02_022	1	High Mode	141.0	17.2	12.6	0.7	1432.6	1095.6
	C02_024	2	High Mode	17.3	34.4	35.7	0.8	1367.5	189.8
02 Ford Windstar	C02_014	1	Low Mode	25.0	8.2	8.6	1.0	1202.1	424.0
	C02_015	2	Low Mode	6.0	17.6	27.8	0.3	521.6	85.2
	C02_016	2	High Mode	15.0	19.5	30.0	0.4	661.2	129.7
	C02_017	1	High Mode	24.0	9.3	9.9	1.1	1271.4	229.9

Table 3.5
MY 2004 10YO OOP Test Results.

Vehicles	Test No.	Position no.	High or Low Mode	15ms HIC	3ms Clip	Chest Def.	Nij	+FZ Neck Tension	Neck Comp.
04 Honda Accord	10YO_002	1	LOW	31.4	8.9	0.2	0.5	212.0	669.1
	10YO_001	2	LOW	14.0	12.5	1.8	0.8	145.5	1572.0
	10YO_014	1	HIGH	128.8	16.7	6.2	0.6	898.2	1030.7
	10YO_015	2	HIGH	62.8	14.7	5.3	0.7	376.8	1637.6
04 Ford Taurus	10YO_003	1	LOW	145.0	15.6	2.0	1.1	882.7	3505.9
	10YO_004	2	LOW	533.0	20.2	2.3	0.9	743.9	1049.4
	10YO_005	2	HIGH	365.7	13.4	0.4	0.5	634.4	1301.0
04 Chevy Avalanche	10YO_008	1	LOW	83.3	56.7	54.3	2.1	3069.4	205.2
	10YO_006	2	LOW	9.0	16.5	16.6	0.6	820.0	515.5
	10YO_009	1	High	94.0	35.7	49.2	2.0	1817.6	279.4
	10YO_007	2	HIGH	14.0	17.0	14.5	1.1	1056.0	356.0
04 Honda Odyssey	10YO_010	1	LOW	24.0	8.1	4.7	0.8	1074.2	396.8
	10YO_011	2	LOW	5.0	5.0	1.1	0.4	184.1	634.9
	10YO_013	1	High	54.3	13.5	4.1	0.6	300.1	661.9
	10YO_012	2	High	23.0	9.0	2.5	0.6	393.3	878.6
04 Jeep Liberty	10YO_019	1	LOW	86.6	10.9	8.2	0.5	790.1	48.9
	10YO_016	2	LOW	56.6	10.6	7.3	0.5	615.8	393.6
	10YO_020	1	High	25.0	17.4	16.1	1.0	1129.3	4.0
	10YO_018	2	High	168.8	17.6	9.2	0.8	1159.7	482.7

4.1 Observations

4.1.1 Repeatability

Driver and passenger side tests for the Windstar air bags were done first with the dummy seated on wooden blocks (Figure 4.2). The baseline and repeat tests are shown as the first two columns in Figure 4.6. The tests were subsequently run (for the Windstar and all other tests) with the dummy seated on an adjustable metal seat (Figure 4.1). The baseline and repeat tests under these conditions are shown as the 3rd and 4th columns in Figure 4.6. The results were repeatable, except that the Nij values were different for the two methods of seating. Based on the ease of use, all further tests were conducted with the adjustable metal seat.

Passenger side tests on the Windstar (Figure 4.10) showed the head and chest injury values to be repeatable. The Nij and neck tension values were not similar in all three repeat tests. The results in the Odyssey tests were similar, with very low injury values (Figure 4.14).

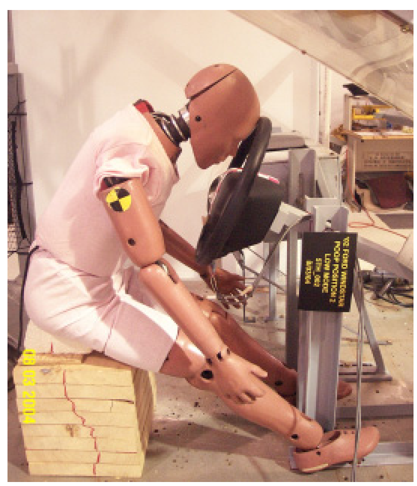

Figure 4.2 Test using wooden blocks

4.1.2 Lateral shifts

These tests examine the loads from deploying air bags on an occupant who is shifted laterally compared to the position in FMVSS No. 208. On the driver side, the Windstar tests showed no significant effect of the lateral shifting of the 5th

female dummy. That includes the chest injury and neck injury values (Figure 4.7)
Tests were conducted on the Windstar passenger side with the 6 YO dummy shifted laterally from the baseline position. The results are in Figure 4.11. The head and neck injury values reduced significantly when the dummy was shifted. However, the chest accelerations remained unchanged, with the chest deflection increasing in some of the shifted positions. The chest injury measures were still well below the IARVs.

Two series of lateral shift tests were conducted in the Odyssey. One series was with the dummy in the baseline position (Figure 4.3), shifted left by two and four inches, and right by two inches. These are the left four bars of each cluster in the accompanying Figure 4.15. HIC values and neck tensions were low in all such tests. The chest injury values were very low and unaffected by the shifting. The Nij increased with the dummy shift. The vehicle had a top mounted air bag, with a pocket shaped space that fit the 6 YO head when the dummy was located in the FMVSS No. 208 Position 2 (Figure 4.4). So, a second series of three tests (centered, shifted two inches left and two inches right) was run with the dummy elevated to bring the head/neck closer to the air bag location (Figure 4.4). As expected, the injury values in these tests were higher than the tests with the dummy at the FMVSS No. 208 Position 2 height. However, the injury values dropped significantly when the dummy was shifted laterally at this elevated position.

Figure 4.3 Baseline Odyssey position.

Figure 4.4 2004 Odyssey passenger air bag.

Figure 4.5 Elevated Odyssey position.

4.1.3 Longitudinal shifts

These tests examined the effect of increased distance from the air bag on the injury values. On the driver side in the Windstar, the injury numbers reduced with increasing distance from the air bag (Figure 4.8). This effect is especially noticeable for neck injury numbers (Nij reduced from 0.8 to 0.35 by moving the dummy two inches back from the baseline position).

For the passenger side, tests on the Windstar showed lower injury values as the dummy was placed two and four inches from the bag (Figure 4.12). This effect was especially noticeable for the neck injury numbers.

In the Odyssey, the results were counter-intuitive (Figure 4.16). The neck and chest numbers increased with distance from the air bag. This was thought to be because of the design of the air bag, which has a recess for the head of the dummy placed in close proximity to the bag (as in FMVSS No. 208, Position 2). Therefore, the air bag does not directly load the chest of the 6YO dummy when in FMVSS No. 208, Position 2. When the dummy was moved further away, the inflating bag got between the dummy chest and the vehicle instrument panel, directly loading the chest.

4.1.4 Vertical shifts

In the Windstar driver side, raising the dummy moved the head/neck away from the bag, while lowering the dummy had the opposite effect. This is reflected in the neck injury numbers (Figure 4.9)

In the Windstar passenger side, moving the dummy up placed the chest closer to the bag, increasing the chest injury numbers (Figure 4.13). Lowering the dummy increased the head injury numbers by bringing the head closer to the air bag.

The 3 tests in this series for the Odyssey were the baseline test, 2" lower than the baseline, and 2" shifted up (as in Figure 4.5) compared the baseline. The Odyssey is a top mounted bag with a pocket for the dummy head when the dummy is at the FMVSS No. 208 position. Thus, the dummy injury values were very low when in the baseline position. Moving the dummy up increased the head and neck loads significantly (Figure 4.17).

5.0 CRASH TESTS - INTRODUCTION

The purpose of this testing was to evaluate and compare vehicle and occupant responses in full frontal rigid barrier crash tests conducted using model year 2002, 2003 and 2004 vehicles in support of the FMVSS No. 208 implementation plan. Three matched vehicles were tested and evaluated with the 5th F, 50th M and 95th percentile male (95th M) dummies seated in both the driver and passenger front seating positions. Although the 95th percentile male dummy is not in FMVSS No. 208, it was decided to perform research tests using this dummy to assess the performance of air bags in these vehicles with very heavy occupants. This paper presents results of a series of full frontal crash tests with the unbelted and belted small adult female Hybrid III dummies, unbelted mid-sized male Hybrid III dummies and the belted and unbelted full-sized male Hybrid III dummies. The test matrices for these tests are found in Tables 5.1 and 5.2.

Table 5.1
Test Matrix for 95th M and 50th M.

		Occupant =>	50th Male	95th Male	
		Restraint =>	Unbelted	Unbelted	Belted
		Speed =>	48	48	56
Vehicle	Class	Model Year			
Saturn Vue	SUV	2002	X	X	
Honda Civic	Small Pass. Car	2002	X	X	
Ford Windstar	Minivan	2002	X	X	
Toyota Corolla	Small Pass. Car	2003	X	X	
Chevrolet Avalanche	Pickup Truck	2004	X		X
Honda Odyssey	Minivan	2004	X		X
Honda Accord	Midsize Pass. Car	2004	X		X
Toyota Camry	Midsize Pass. Car	2004	X		X
Jeep Liberty	SUV	2004	X		X

Table 5.2
Test Matrix for 5th F.

		Occupant =>	5th Female	
		Restraint =>	Unbelted	Belted
		Speed =>	40	56
Vehicle	Class	Model Year		
Saturn Vue	SUV	2002	X	
Honda Civic	Small Pass. Car	2002	X	
Ford Windstar	Minivan	2002	X	
Toyota Corolla	Small Pass. Car	2003	X	
Chevrolet Avalanche	Pickup Truck	2004		X
Honda Odyssey	Minivan	2004		X
Honda Accord	Midsize Pass. Car	2004		X
Ford Taurus	Midsize Pass. Car	2004		X
Jeep Liberty	SUV	2004		X

Table 4.1
Parametric OOP Test Matrix.

	5th Female Driver, Position 1 (Head on bag)							6 YO Passenger, Position 2 (Head on bag)						
	Baseline	Lateral Shift		Longitudinal Shift		Vertical Shift		Baseline	Lateral Shift		Longitudinal Shift		Vertical Shift	
		Left	Right	Front	Rear	Up	Down		Left	Right	Front	Rear	Up	Down
2002 Ford Windstar	4 tests	2”	2”	2”	2”	2”	2”	3 tests	2”, 4”	2”, 4”		2”, 4”	3.3”	3.3”
2002 Honda Civic	In Progress							In Progress						
2003 Honda Odyssey	Not planned							2 tests	2”, 4” 2”+up	2” 2”+up		2”, 4”	2”	2”

Table 4.2
Ford Windstar Passenger Side.

Vehicle: 02 Ford Windstar **Dummy**: 6 YO **LRD Position**: 2 **Bag Mode**: Low (100 ms delay)	**Test Number.**	**Injury values normalized to IARV**					
		15ms HIC	**3ms Clip**	**Chest Def.**	**Nij**	**Neck Tension**	**Neck Comp.**
Baseline	2	0.8	0.5	0.3	1.1	1.5	0.1
Repeat	3	0.5	0.6	0.3	1.6	2.5	0.0
Repeat	4	0.6	0.5	0.4	1.5	2.1	0.1
2" rear	5	0.5	0.4	0.3	0.7	0.8	0.1
4" left	6	0.3	0.5	0.4	0.9	1.0	0.0
3.3” up	7	0.1	0.8	0.7	0.8	1.4	0.0
4" right	8	0.2	0.4	0.1	0.6	0.7	0.0
2" right	9	0.3	0.5	0.5	0.9	1.2	0.1
2" left	10	0.4	0.6	0.5	1.0	1.3	0.0
3.3” down	11	1.2	0.3	0.1	0.9	0.8	0.4
4" rear	12	0.6	0.3	0.3	0.4	0.5	0.1

Table 4.3
Ford Windstar Driver Side.

Dummy: 5th F **LRD Position**: 1 **Bag Mode**: High (15 ms delay)	**Test Number**	**Injury values normalized to IARV**					
		15ms HIC	**3ms Clip**	**Chest Def.**	**NIJ**	**Neck Tension**	**Neck Comp.**
Baseline on wooden blocks	1	0.01	0.14	0.14	0.5	0.39	0.01
Repeat on wooden blocks	2	0.01	0.12	0.13	0.5	0.40	0.00
Baseline on metal seat	4	0.01	0.08	0.13	0.8	0.41	0.13
Repeat on metal seat	6	0.01	0.10	0.14	0.7	0.42	0.14
2 inches rear	7	0.02	0.16	0.11	0.4	0.20	0.01
2 inches forward	8	0.03	0.17	0.26	0.9	0.50	0.02
2 inches up	9	0.01	0.09	0.15	0.6	0.34	0.06
2 inches down	10	0.04	0.19	0.19	0.9	0.61	0.06
2 inches right	11	0.02	0.12	0.17	0.7	0.42	0.06
2 inches left	12	0.01	0.13	0.12	0.7	0.42	0.04

Table 4.4
Honda Odyssey Passenger Side.

Dummy: 6YO **LRD Position**: 2 **Bag Mode**: Low (130 ms delay)	**Test Number**	**Injury values normalized to IARV**					
		15ms HIC	**3ms Clip**	**Chest Def.**	**NIJ**	**Neck Tension**	**Neck Comp.**
Baseline	13	0.01	0.12	0.06	0.3	0.03	0.41
Repeat	14	0.01	0.12	0.01	0.3	0.07	0.44
2" left	15	0.00	0.09	0.03	0.5	0.07	0.23
4" left	17	0.00	0.09	0.01	0.5	0.01	0.29
2" right	18	0.00	0.10	0.02	0.3	0.04	0.23
2" rear	19	0.06	0.08	0.02	0.3	0.12	0.23
4" rear	20	0.01	0.12	0.56	0.3	0.16	0.40
Top of head at A/B Center (Baseline+ 4" up)	21	0.80	0.27	0.35	1.1	1.01	0.04
Top of head at ab/center + 2" left	22	No data	0.15	0.13	0.6	0.47	0.05
Top of head at ab/center + 2" right	23	0.38	0.22	0.17	0.6	0.81	0.07
Baseline + 2" down	24	0.00	0.08	0.40	0.3	0.04	0.31

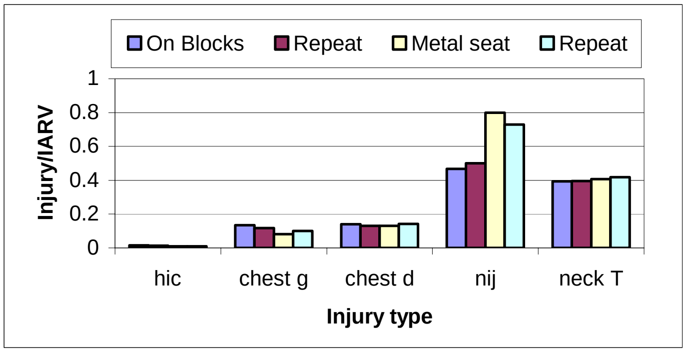

Figure 4.6 Windstar Driver 5th F repeatability.

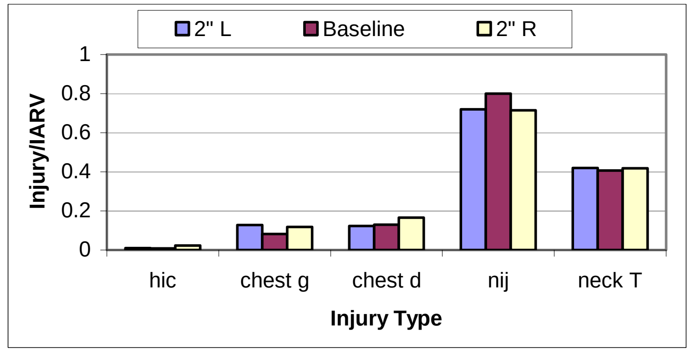

Figure 4.7 Windstar Driver 5th F lateral shift.

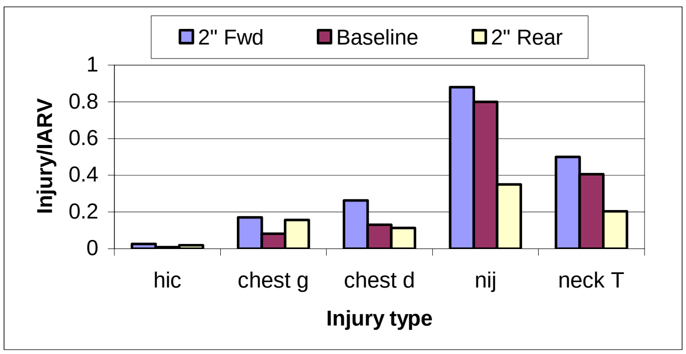

Figure 4.8 Windstar Driver 5th F longitudinal shift.

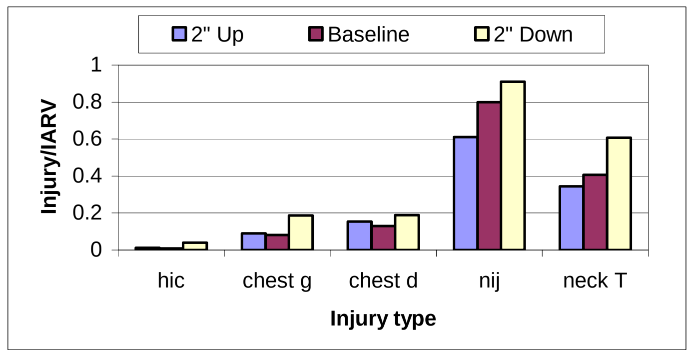

Figure 4.9 Windstar Driver 5th F vertical shift.

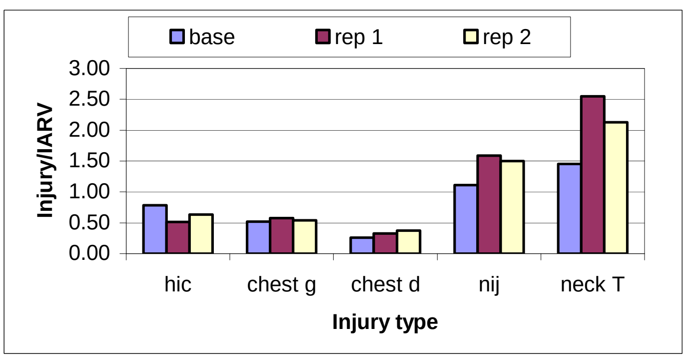

Figure 4.10 Windstar Passenger 6YO repeatability.

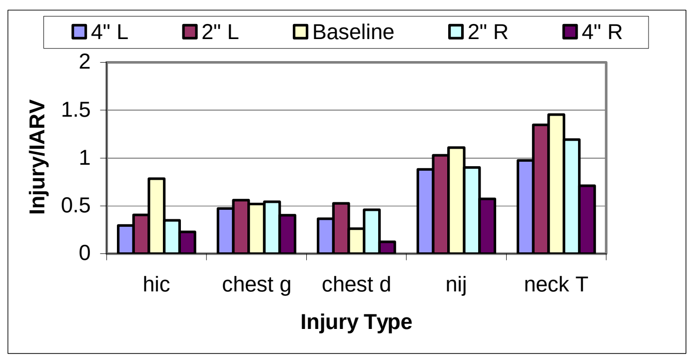

Figure 4.11 Windstar Passenger 6YO lateral shift.

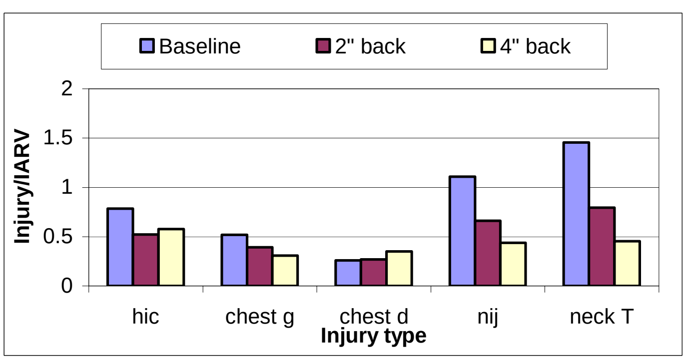

Figure 4.12 Windstar Passenger 6YO longitudinal shift.

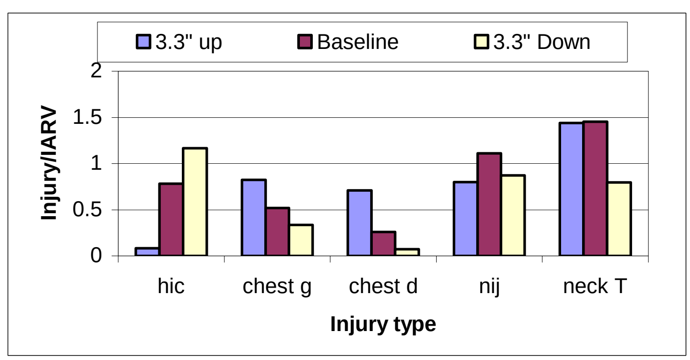

Figure 4.13 Windstar Passenger 6YO vertical shift.

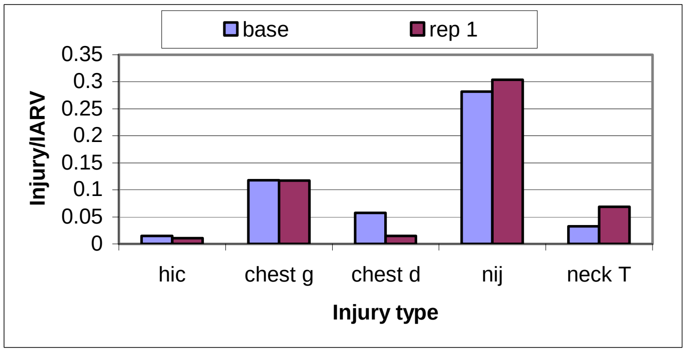

Figure 4.14 Odyssey Passenger 6YO repeatability.

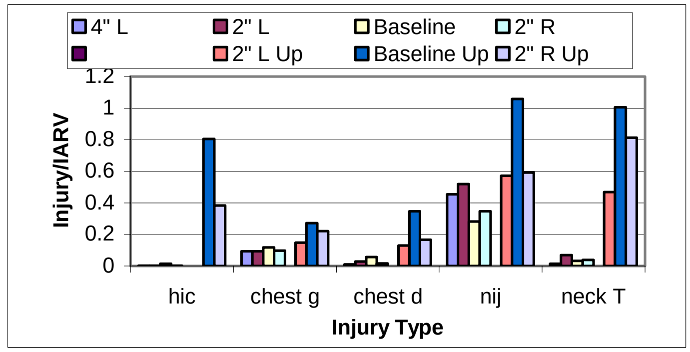

Figure 4.15 Odyssey Passenger 6YO lateral shift.

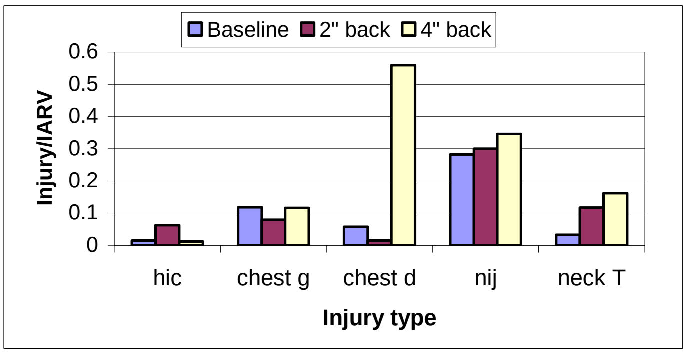

Figure 4.16 Odyssey Passenger 6YO longitudinal shift.

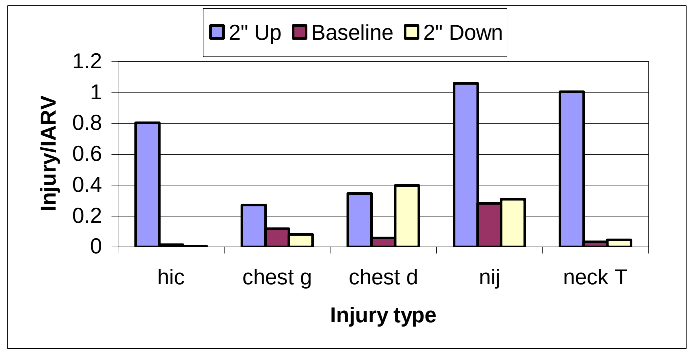

Figure 4.17 Odyssey Passenger 6YO vertical shift.

5.1 Methods

Thirty-six vehicles were purchased from dealer lots close to the test facilities. Vehicles with advanced air bag technology such as dual or multi-stage inflators were specifically considered for this test program. The Saturn Vue was the only single stage air-bag inflator that was tested. The Saturn Vue was chosen due to it being a new production vehicle for the model year tested. Vehicle body type and vehicle sales volume were considered when constructing the final test matrix. The vehicles were tested in accordance with procedures outlined in FMVSS No. 208 Sections 14, 15 and 17, except that the combination of dummy size, seat belt use, and test speed was varied for these research tests. Pre-test measurements quantified distance between various occupant body parts to vehicle interior components (i.e. chest-to-steering wheel). The vehicles were placed on a test track and accelerated to the prescribed test speed. The test vehicles struck a rigid barrier with the long axis of the vehicle perpendicular to the barrier face. The barrier engaged the entire front of the vehicle (no offset). Test speeds were either 48 or 56 kmph with a 50th M dummy and a 95th M Hybrid III dummy. The 56 kmph tests were performed only on the belted 95th dummy. The test speeds were 40 or 56 kmph for the 5th percentile female Hybrid III dummy. The 40 kmph were unbelted tests and the 56 kmph were belted tests for the 5th percentile female.

The IARVs for in-position occupants can be found in Table 5.3. The tests with the 50th M and the 5th F chest, head, neck and femur were evaluated using the IARVs for the FMVSS No. 208 advanced air bag rule. The 95th M chest, head, neck and femur were evaluated using IARV's developed by NHTSA's Office of Biomechanics Research Center.

Table 5.3
Injury Assessment Reference Values.

Injury Criteria	Units	IARV 5th Female	 50th Male	 95th Male
HIC 15	-	700	700	700
N_{ij}	-	1	1	1
Neck Tension	Newtons	2620	4170	5030
Neck Compression	Newtons	2520	4000	4830
Chest Acceleration	g	60	60	55
Chest Deflection	Millimeters	52	63	70
Femur Force	Newtons	6805	10008	12700

Transfer paint was applied to parts of the dummy and vehicle interior, leaving witness marks from which occupant contacts could be evaluated post-crash. Fifteen or more high-speed cameras documented vehicle and occupant kinematics during the event.

5.2 Results for 50th and 95th Male

The HIC15 responses were all below the thresholds for injury with exception of two tests (see Appendix A, Tables A1 & A2). For the 50th M all drivers and passengers were below the threshold for injury. For the 95th percentile male, the passenger in the unbelted 48 kmph Saturn Vue test and the driver in the belted 56 kmph Chevrolet Avalanche test exceeded the injury criteria.

The N_{ij} responses were all below the thresholds for injury with exception of two tests. For the 50th M all driver and passenger injury measures were below the threshold for injury. For the 95th M, the passenger dummy in the unbelted 48 kmph Saturn Vue test and the driver dummy in the unbelted 48 kmph Toyota Corolla test exceeded the injury criteria

Both the 50th M and 95th M were below the injury threshold for neck tension and neck compression in all tests.

For chest acceleration all dummy measures were below the injury threshold except in three tests. The 50th M exceeded the injury limit in one test and the 95th percentile male exceeded the injury limit in two separate tests. The 50th M passenger in the 48 kmph unbelted Jeep Liberty test exceeded the chest acceleration injury criteria (See Figure 5.1). Both the 95th M driver and passenger in the 48 kmph unbelted Saturn Vue test exceeded the chest acceleration injury criteria. The 95th percentile driver in the 56 kmph belted Chevrolet Avalanche test exceeded the chest acceleration injury criteria (See Figure 5.2).

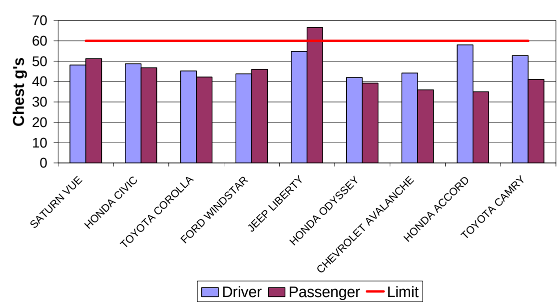

Figure 5.1 50th Percentile Male - Chest g's.

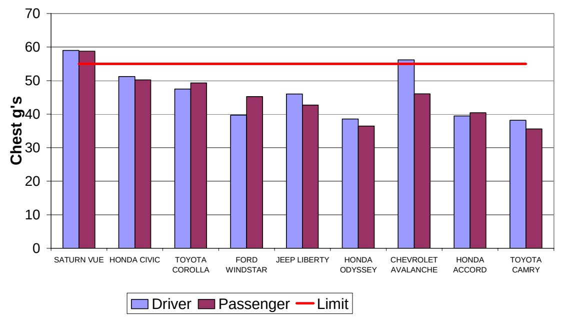

Figure 5.2 95th Percentile Male – Chest g's.

For chest displacement all occupants were below the injury threshold except in one test. The 50th M driver in the 48 kmph unbelted Honda Civic test exceeded the chest displacement injury criteria

All 50th M and 95th M driver and passenger responses in each test were below the injury threshold for femur load.

5.3 Results for 5th Female

The HIC15 responses were all below the thresholds for injury (see Appendix A, Tables A1 & A2

The N_{ij} responses were all below the thresholds for injury with exception of two tests. For the unbelted 40 kmph tests the passenger in the Toyota Corolla test exceeded the injury criteria (See Figure 5.3). For the 56 kmph belted tests the passenger in the Chevrolet Avalanche test exceeded the injury criteria (See Figure 5.4).

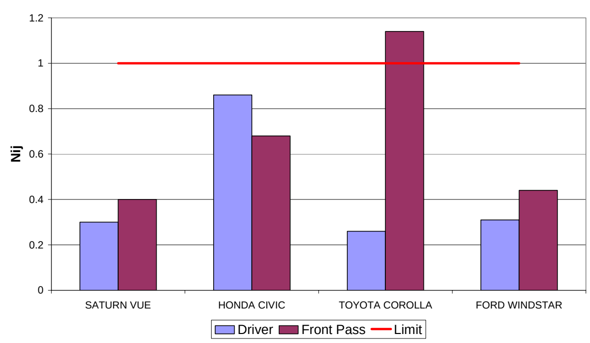

Figure 5.3. Unbelted 5th Percentile Female – N_{ij}.

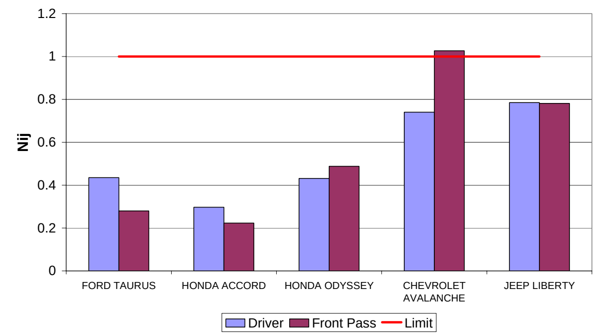

Figure 5.4 Belted 5th Percentile Female – N_{ij}.

The 5th percentile female dummy was below the injury threshold for neck tension and neck compression in both the unbelted 40 kmph tests and the belted 56 kmph tests.

For chest acceleration all dummy measures were below the injury threshold in all unbelted 40 kmph tests and all belted 56 kmph tests.

For chest displacement all 5th percentile dummy drivers and passengers were below the injury threshold except in one test. The driver in the 40 kmph unbelted Honda Civic test exceeded the chest displacement injury criteria (See Figures 5.5).

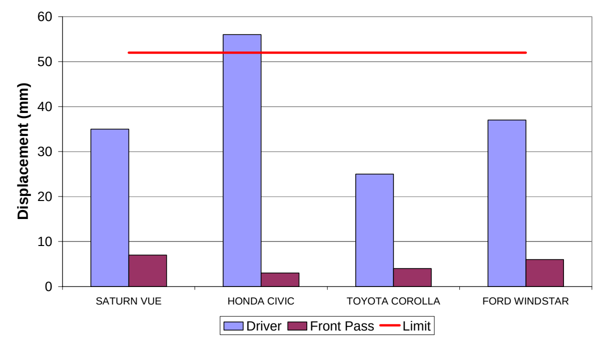

Figure 5.5 Unbelted 5th Percentile Female – Chest Displacement.

All 5th percentile female drivers and passengers responses for both the 40 kmph tests and the 56 kmph tests were below the injury threshold for femur load.

5.4 Observations

The restraint systems in these crash tests did a good job of mitigating head injury for the 5th female and the 50th M; however, it is not surprising that the air bag alone was not sufficient to mitigate head injury in the 95th male unbelted tests. Even with the aid of being belted along with an air bag, the 95th M exceeded the IARV for the head in one 56 kmph test.

The 5^{th} female exceeded N_{ij} injury criteria in an unbelted 40 kmph and a belted 56 kmph test.

Figure 5.6 shows the 50^{th} M driver during the crash event for the Honda Civic test #4613. It appears that the bag was high, which may account for the abdomen contact with the steering wheel. This contact can be seen in Figure 5.7. This could be the reason that the Civic in this test exceeded chest displacement.

Figure 5.6 Test #4613 - 50^{th} Male Driver in Honda Civic.

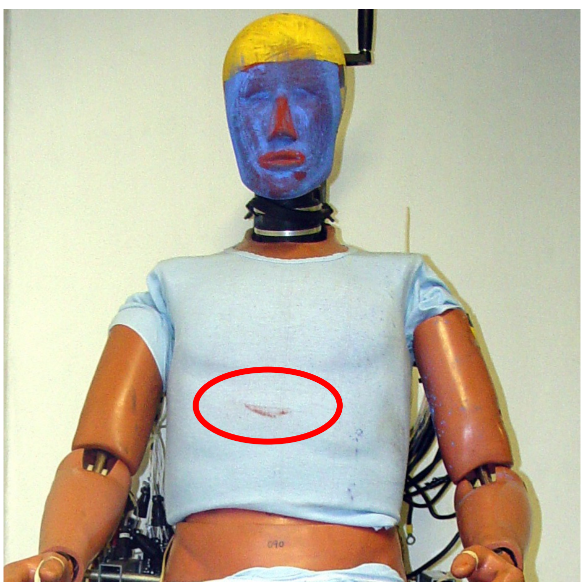

Figure 5.7 50^{th} Driver Post Crash Abdomen Contact Photo From Test #4613.

Figure 5.8 shows the 95^{th} male driver during the crash event for the Toyota Corolla test #4577. The 95^{th} M dummy exceeded N_{ij} in this test. Figures 5.8 shows how either the bag or head contact with the header pushed the head backwards. The driver head contact can be seen in Figure 5.9. These could be the reason for failing N_{ij} criteria for this test.

Figure 5.8 Test #4577 95^{th} Driver in Toyota Corolla.

Figure 5.9 95^{th} Driver Post Crash Head Contact Photo From Test #4577.

Figure 5.10 shows the 95^{th} male driver in the Saturn Vue test #4702., in which the dummy exceeded chest acceleration criterion. After film analysis, it is believed that the 95^{th} male driver rode through the air bag during this test. Figure 5.10 shows the dummy in its full forward position. Figure 5.11 shows how the bag did not restrain the dummy and allowed head contact with the windshield.

Figure 5.10 95^{th} Driver Saturn VueTest #4702.

Figure 5.11 Post Test 95th Driver Head Contact in Saturn Vue Test #4702.

Figure 5.12 shows the 95th male passenger in the unbelted Saturn Vue test #4714, in which the dummy exceeded chest acceleration, HIC and N_{ij} criteria. After film analysis, and as seen in Figures 5.12 and 5.13, the 95th male passenger contacted the header, thus restricting the head from moving forward with the torso, causing excessive neck extension.

Figure 5.12 95th Passenger Saturn Vue Test #4714.

Figure 5.13 Post Test 95th Passenger Head Contact in Saturn Vue Test # 4702.

6.0 SUMMARY

Research into performance of air bags is ongoing at NHTSA. Data from this research has been presented in the past [1][3][4]. This paper provides an update on the status of that effort, specifically, tests using dummies of different sizes not currently in FMVSS No. 208 (10YO, 95th M) and at test conditions not currently in the standard. Limited numbers of tests were conducted at OOP locations near those in FMVSS No. 208. Any additional research will be reported in future publications of technical reports or conference papers.

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2. Beuse, N. et al, "Performance of the 5th Percentile Dummy In a 56 KMPH (35 MPH) Frontal Barrier Crash", NHTSA Docket 2001-10687-12

3. Maltese, M. et al, "Vehicle Performance In Full-Frontal Crash Tests with Small Female And Mid-Sized male Occupants", Paper # 414, 18th ESV.

4. Prasad et al, "Injury Risks From Advanced Air Bags In Frontal Static Out-Of-Position Tests", Paper # 427, 18th ESV.

5. Stammen, Jason, "Hybrid III 10 Year Old Dummy (HIII-10C) Injury Criteria Development", NHTSA report in progress

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APPENDIX A, Table A1 – Crash Test Results – Driver

Dummy and Vehicle Information					Injury Criteria						
	Make	Model	Year	Test #	HIC 15	Nij ver. 10	Neck Tension (N)	Neck Comp (N)	Chest g's	Chest Disp (mm)	Max Femur (N)
				IARV 5th	**700**	**1.00**	**2620**	**2520**	**60**	**52**	**6800**
5th Female Unbelted 40 kmph	SATURN	VUE	2002	4579	55.0	0.3	654.0	341.0	31.0	35.0	4200.0
	HONDA	CIVIC	2002	4830	108.0	0.9	1555.0	360.0	39.4	56.0	2931.0
	TOYOTA	COROLLA	2002	4829	93.0	0.3	772.0	56.0	36.7	25.0	2282.0
	FORD	WINDSTAR	2002	4828	95.0	0.3	579.0	78.0	37.9	37.0	2405.0
5th Female Belted 56 kmph	FORD	TAURUS	2004	5143	152.2	0.4	1433.8	286.3	37.5	29.1	1135.1
	HONDA	ACCORD	2004	5145	279.9	0.3	914.9	161.3	32.1	26.0	4605.2
	HONDA	ODYSSEY	2004	5144	56.8	0.4	917.6	141.5	32.4	24.4	5522.4
	CHEVROLET	AVALANCHE	2004	5210	579.5	0.7	1727.7	555.0	58.6	44.4	1820.0
	JEEP	LIBERTY	2004	5211	232.4	0.8	1755.3	721.2	44.8	31.1	3073.4
				IARV 50th	**700**	**1.00**	**4170**	**4000**	**60**	**63**	**10008**
50th Male Unbelted 48 kmph	SATURN	VUE	2002	4714	86.8	0.3	1230.5	397.6	48.1	54.4	7103.5
	HONDA	CIVIC	2002	4613	92.1	0.3	1297.7	146.6	48.8	65.0	6835.3
	TOYOTA	COROLLA	2003	4578	216.9	0.3	753.7	255.6	45.2	32.4	4569.6
	FORD	WINDSTAR	2002	4556	99.8	0.2	1589.4	117.7	43.8	36.3	5422.7
	JEEP	LIBERTY	2004	5158	306.7	0.3	604.5	1201.6	54.8	41.6	7662.0
	HONDA	ODYSSEY	2004	5212	57.7	0.3	1371.7	94.7	42.0	48.2	7547.4
	CHEVROLET	AVALANCHE	2004	5213	193.3	0.3	1599.2	1489.1	44.2	47.5	6459.4
	HONDA	ACCORD	2004	5215	293.6	0.3	1383.2	71.3	58.1	54.5	5376.5
	TOYOTA	CAMRY	2004	5216	116.5	0.3	1650.1	200.7	52.8	33.1	6588.9
				IARV 95th	**700**	**1.00**	**5030**	**4830**	**55**	**70**	**12700**
95th Male Unbelted 48 kmph	SATURN	VUE	2002	4702	279.0	0.3	2044.0	333.9	59.0	56.8	7035.4
	HONDA	CIVIC	2002	4659	180.5	0.3	1924.2	654.7	51.3	61.6	9259.6
	TOYOTA	COROLLA	2003	4577	562.8	1.0	1167.3	3940.5	47.5	25.5	7127.9
	FORD	WINDSTAR	2002	4568	213.9	0.3	1175.2	2202.8	39.7	45.2	5756.4
95th Male Belted 56kph	HONDA	ODYSSEY	2004	5136	186.7	0.2	1176.5	63.6	38.6	27.3	3196.4
	JEEP	LIBERTY	2004	5137	575.2	0.3	2087.7	349.5	46.0	32.5	4631.8
	TOYOTA	CAMRY	2004	5138	381.7	0.5	1075.7	260.6	38.2	29.3	6041.9
	HONDA	ACCORD	2004	5139	589.0	0.2	1087.4	591.1	39.5	36.1	3118.6
	CHEVROLET	AVALANCHE	2004	5140	802.8	0.5	2960.5	772.2	56.2	24.4	8455.7

Note: Green shaded cells represent injury value between 0-80% of IARV
Yellow shaded cells represent injury value between 80-100% of IARV inclusive
Red shaded cells represent injury value greater than 100% of IARV

APPENDIX A, Table A2 – Crash Test Results – Passenger

Dummy and Vehicle Information					Injury Criteria						
	Make	Model	Year	Test #	HIC 15	Nij ver. 10	Neck Tension (N)	Neck Comp (N)	Chest g's	Chest Disp (mm)	Max Femur (N)
				IARV 5th	**700**	**1.00**	**2620**	**2520**	**60**	**52**	**6800**
5th Female Unbelted 40 kmph	SATURN	VUE	2002	4579	96.0	0.4	560.0	1048.0	28.0	7.0	4040.0
	HONDA	CIVIC	2002	4830	98.0	0.7	393.0	1030.0	33.7	3.0	5481.0
	TOYOTA	COROLLA	2002	4829	175.0	1.1	2339.0	263.0	36.8	4.0	2736.0
	FORD	WINDSTAR	2002	4828	360.0	0.4	838.0	901.0	38.8	6.0	4004.0
5th Female Belted 56 kmph	FORD	TAURUS	2004	5143	289.9	0.3	409.7	271.7	42.0	19.1	1597.6
	HONDA	ACCORD	2004	5145	181.5	0.2	738.0	295.7	38.3	28.8	3773.8
	HONDA	ODYSSEY	2004	5144	233.2	0.5	918.9	131.3	38.1	14.5	4207.8
	CHEVROLET	AVALANCHE	2004	5210	483.9	1.0	1770.2	230.5	53.6	14.9	3360.0
	JEEP	LIBERTY	2004	5211	527.1	0.8	1369.4	823.3	42.8	24.2	3586.3
				IARV 50th	**700**	**1.00**	**4170**	**4000**	**60**	**63**	**10008**
50th Unbelted 48 kmph	SATURN	VUE	2002	4702	319.4	0.38	1779.0	359.5	51.3	12.5	7014.4
	HONDA	CIVIC	2002	4659	196.3	0.52	544.4	1765.2	46.8	15.6	6466.9
	TOYOTA	COROLLA	2003	4577	230.1	0.35	788.2	1185.5	42.2	14.3	5301.6
	FORD	WINDSTAR	2002	4568	473.6	0.57	1312.5	2934.2	46.1	14.7	5303.8
	JEEP	LIBERTY	2004	5158	523.2	0.58	1342.5	830.3	66.6	12.0	8065.1
	HONDA	ODYSSEY	2004	5212	160.6	0.29	415.9	976.5	39.3	9.8	5377.0
	CHEVROLET	AVALANCHE	2004	5213	124.3	0.36	1632.3	233.6	35.9	9.0	6689.6
	HONDA	ACCORD	2004	5215	97.4	0.27	615.4	577.4	35.0	11.4	6864.4
	TOYOTA	CAMRY	2004	5216	138.1	0.36	559.5	692.7	41.1	14.7	5084.3
				IARV 95th	**700**	**1.00**	**5030**	**4830**	**55**	**70**	**12700**
95th Unbelted 48 kmph	SATURN	VUE	2002	4714	853.7	1.1	1835.7	2656.4	58.8	18.6	10025.5
	HONDA	CIVIC	2002	4613	222.4	0.6	2533.0	1634.2	50.2	ND	11500.5
	TOYOTA	COROLLA	2003	4578	668.2	0.4	732.6	2554.5	49.3	11.0	8900.2
	FORD	WINDSTAR	2002	4556	349.3	0.2	1118.9	814.6	45.3	22.8	7719.0
95th Belted 56kph	HONDA	ODYSSEY	2004	5136	222.1	ND	1071.5	718.6	36.5	26.2	5316.6
	JEEP	LIBERTY	2004	5137	513.1	0.4	1906.1	161.2	42.7	28.1	6888.3
	TOYOTA	CAMRY	2004	5138	242.3	0.2	1191.4	186.5	35.6	27.0	1596.3
	HONDA	ACCORD	2004	5139	272.0	0.2	771.0	213.4	40.4	38.9	3683.4
	CHEVROLET	AVALANCHE	2004	5140	587.2	0.4	2189.0	252.7	46.1	34.5	5792.1

Note: Green shaded cells represent injury value between 0-80% of IARV
Yellow shaded cells represent injury value between 80-100% of IARV inclusive
Red shaded cells represent injury value greater than 100% of IARV

NHTSA's FRONTAL OFFSET RESEARCH PROGRAM

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National Highway Traffic Safety Administration
United States
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ABSTRACT

The National Highway Traffic Safety Administration (NHTSA) is conducting research programs to develop test procedures to reduce death and injury, in particular debilitating lower extremity injuries in frontal offset collisions. This paper presents updated results of Offset Deformable Barrier (ODB) crash tests conducted for the NHTSA. The ODB crash tests were conducted with 50th percentile male and 5th percentile female Hybrid III dummies fitted with advanced lower legs, Thor-Lx/HIIIr and Thor-FLx/HIIIr, to assess the potential for debilitating and costly lower limb injuries. This paper also investigates the implications that the ODB test procedure may have on fleet compatibility by evaluating the results from vehicle-to-vehicle crash tests.

INTRODUCTION

In the United States, driver and right front passenger air bags are required in all passenger cars and light trucks under Federal Motor Vehicle Safety Standard (FMVSS) No. 208, "Occupant crash protection." However, NHTSA estimates that over 8,000 fatalities and 120,000 Abbreviated Injury Scale (AIS) 2+ injuries will continue to occur in frontal crashes even after all passenger cars and light trucks have frontal air bags. Therefore, NHTSA has focused on the development of performance tests not currently addressed by FMVSS No. 208, particularly high severity frontal offset crashes. These tests are planned to result in high decelerations to evaluate restraints and large occupant compartment intrusion that could compromise occupant survival space and thus increase the potential for lower leg injury.

Since the European Union directive 96/79 for frontal crash protection became effective in 1998, other countries and consumer rating programs have adopted the use of a fixed ODB crash test procedure. The Australian and European regulations require the ODB crash test at 56 km/h while the consumer rating programs, Euro NCAP (European New Car Assessment Program), Australian NCAP and IIHS (Insurance Institute for Highway Safety) conduct the ODB crash test at 64 km/h.

Research into the design of an improved ODB test procedure for the U.S. needs to evaluate the various test speeds to determine the best options. Saunders, et. al, [1] showed that a high speed ODB test procedure (combining 56, 60, or 64 km/h tests) appeared to correctly predict the risk and proportion of below-the-knee injuries in severe real world offset crashes, but under estimated the risk of thoracic and knee-thigh-hip injuries. Saunders also reported on three pairs of vehicle-to-vehicle crash tests in which the redesigned vehicle in each pair obtained a better rating in the IIHS ODB tests than its respective older model (the other vehicle in the pair). The redesigned vehicle models were found to be more aggressive in these crash tests than their older counterparts as demonstrated by the injury measures of the dummies in the target vehicle. However, Saunders could not establish a relationship between the increase in aggressivity of the redesigned vehicles and the corresponding increase in front end stiffness in the redesigned vehicle due to the confounding effects of vehicle mass and vehicle front end geometry of the redesigned vehicle. This paper begins with presentation and discussion of data to more fully examine the effect of speed and dummy size on a rigid barrier ODB crash test. The next part of the paper investigates the effect that the high speed rigid offset deformable barrier test procedure may have had on the fleet compatibility.

RIGID OFFSET DEFORMABLE BARRIER CRASH TESTS

This section summarizes results from ODB test series run for NHTSA that were conducted using the procedure defined in FMVSS No. 208, Occupant Crash Protection (S18). In all tests the driver and front seat passenger were two Hybrid III 50th percentile males (HIII 50M) with the Thor-Lx/HIII retrofit lower leg, or two Hybrid III 5th percentile females (HIII 5F) with the Thor-FLx/HIII retrofit lower leg. The HIII 50M and HIII 5F dummy positioning was done in accordance with FMVSS No. 208. The purpose of these tests was to study the effect of speed and dummy.

Injury Assessment Reference Values

The Injury Assessment Reference Values (IARV) for the HIII 50M and HIII 5F dummies that were developed for the FMVSS No. 208 Advanced Air Bag Final Rule were used. The IARV for the lower leg was conducted according to Kuppa et al., [2, 3]. The IARVs used to assess injuries below the knee are presented in Table 1.

Table 1

IARVs for injuries below the knee

Injury Criteria	IARV for HIII 50M	IARV for HIII 5F
knee shear	15 mm	13 mm
Upper tibia axial force	5600 N	4000 N
Lower tibia axial force	5200 N	3750 N
Upper tibia index *	F/12000+M/240<0.91	F/8640+M/146<0.91
Lower tibia index *	F/12000+M/240<0.91	F/8640+M/146<0.91
Dorsiflexion	35 deg	35 deg
Inversion/eversion	35 deg	35 deg

* F= axial force in N, M is resultant moment in Nm.

ODB Crash Tests Results

Table 2 shows the percentage of tests that exceed the IARVs for the HIII 50M and HIII 5F at both 56 kmph and 60 kmph. The general trend is that the 56 kmph tests had lower proportions of below the knee injuries as compared to the 60 kmph tests.

Table 2

ODB Crash Tests

	56 kmph		60 kmph	
	5th	50th	5th	50th
Number of tests	6	5	7	5
	Percentage That Exceeded IARV			
Chest g's	0.0	0.0	0.0	0.0
Chest Displacement	0.0	0.0	0.0	0.0
HIC 15	16.7[1]	40.0[2]	0.0	0.0
Nij ver. 10	16.7[1]	0.0	57.1	0.0
Neck Tension	16.7[1]	0.0	0.0	0.0
Neck Compression	0.0	0.0	0.0	0.0
Femur Load	0.0	0.0	0.0	0.0
Knee Shear	0.0	0.0	0.0	0.0
Upper Tibia Index	16.7	0.0	0.0	40.0
Lower Tibia Index	16.7	20.0	42.9	40.0
Upper Tibia Axial Force	0.0	0	0.0	20.0
Lower Tibia Axial Force	16.7	20.0	28.6	40.0
Dorsiflexion	16.7	40.0	57.1	60.0
Inversion/Eversion	0.0	0.0	14.3	0.0

[1] Due to delayed deployment of the air bag
[2] Due to the air bag did not deploy during the test

Comparison of 50th and 5th lower leg Injury Assessment Values (IAVs)

This section compares paired ODB crash tests of the same vehicle model and closing speed with both a HIII 50M and HIII 5F in the driver's position. Figures 1 and 2 show that in four out of the five paired vehicle tests the HIII 50M had a higher percent IARV for the femur load and knee shear, respectively, than the HIII 5F. The percent of IARV for upper and lower tibia index for the HIII 5F was higher for all paired vehicles tested compared to the HIII 50M, except the upper tibia index of the Quest. The HIII 50M upper tibia index was 2.23, whereas the HIII 5F was only 0.79 (Figures 3 and 4). The percent of IARV for the upper and lower tibia axial force was higher in four out of the five paired tests for the HIII 5F when compared to the HIII 50M (Figures 5 and 6). In four out of the five paired tests the percent IARV for dorsiflexion angle of the HIII 5F was higher than the HIII 50M (Figure 7). The inversion/eversion angle was higher for the HIII 50M compared to the HIII 5F in all the paired tests (Figure 8).

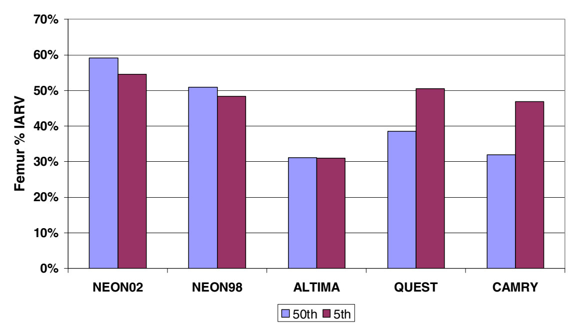

Figure 1. Comparison of femur percent IARV.

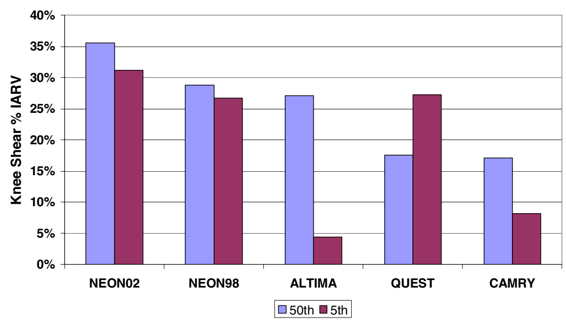

Figure 2. Comparison of knee shear percent IARV.

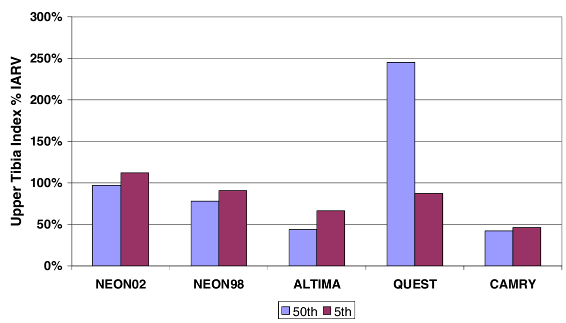

Figure 3. Comparison of upper tibia index percent IARV.

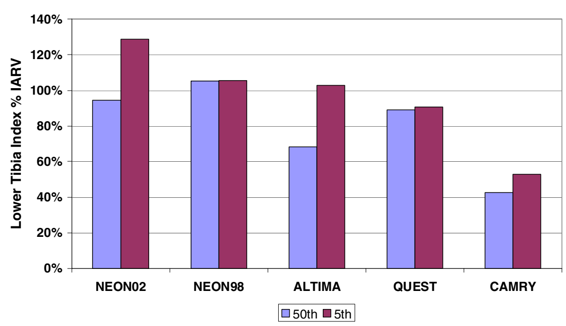

Figure 4. Comparison of lower tibia index percent IARV.

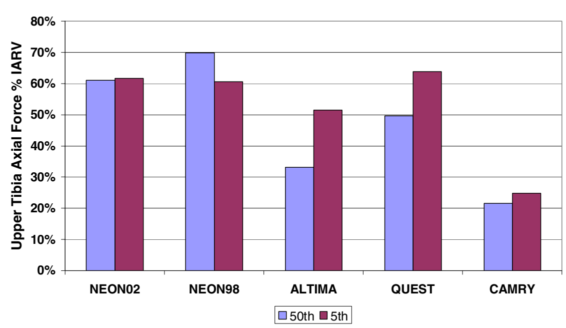

Figure 5. Comparison of upper tibia axial force percent IARV.

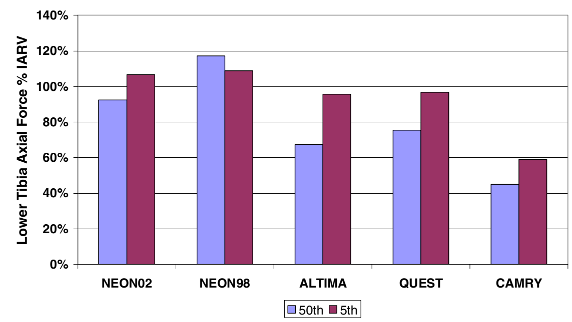

Figure 6. Comparison of lower tibia axial force.

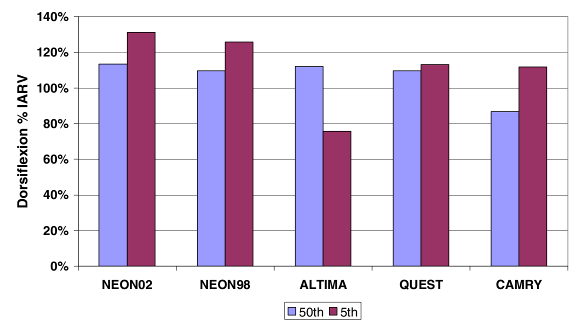

Figure 7. Comparison of dorsiflexion percent IARV.

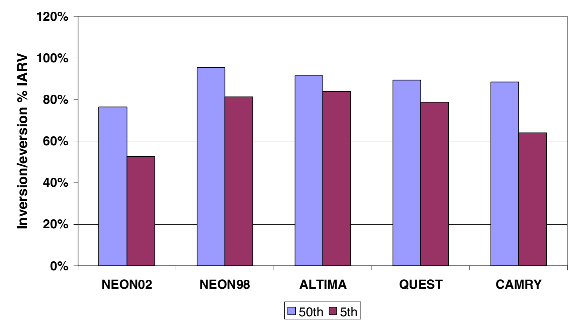

Figure 8. Comparison of inversion/eversion percent IARV.

VEHICLE-TO-VEHICLE CRASH TESTS

Vehicle Test Matrix

In order to build an improved understanding of the before-and-after fleet response to offset fixed barrier testing and redesign, an additional three pairs of vehicles were added to the three pairs of vehicle-to-vehicle tests reported in Saunders, et. al, [1]. The paired vehicles added to the test matrix were two mid-size vehicles (Avalon and Seville) and a van (Sienna,), thus creating the test matrix of Table 3. The paired bullet vehicles were to be crashed into a moving 1996 Honda Accord target, as was done in previous testing. The approach was to select the same vehicle make and model with one being an older model and rated "poor" or "marginal" in the

IIHS ODB test while the other was a newer redesigned model and rated "marginal" or "good" in the IIHS ODB test. The frontal oblique vehicle-to-vehicle crash test series was conducted using a test procedure developed under NHTSA's Advanced Frontal Offset Research Program (Stucki, et al., [4]).

Table 3

Striking vehicle-to-Accord test matrix

Original	After Re-design
1997 Chevrolet Blazer IIHS Rating = Poor Test weight = 2130 kg (4686 lb) NHTSA Test # = 4363	**2002 Chevrolet TrailBlazer** IIHS Rating = Marginal Test weight = 2355 kg (5181 lb) NHTSA Test # = 4364
1999 Mitsubishi Montero Sport IIHS Rating = Poor Test weight = 2112 kg (4646 lb) NHTSA Test # = 4474	**2001 Mitsubishi Montero Sport** IIHS Rating = Good Test weight = 2143 kg (4715 lb) NHTSA Test # = 4438
2001 Dodge Ram 1500 IIHS Rating = Poor Test weight = 2531 kg (5568 lb) NHTSA Test # = 4581	**2002 Dodge Ram 1500** IIHS Rating = Good Test weight = 2572 kg (5658 lb) NHTSA Test # = 4617
1996 Toyota Avalon IIHS Rating = Marginal Test weight = 1702 kg (3744 lb) NHTSA Test # = 4660	**2000 Avalon** IIHS Rating = Good Test weight = 1728 kg (3802 lb) NHTSA Test # = 4667
1997 Cadillac Seville IIHS Rating = Poor Test weight = 2012 kg (4426 lb) NHTSA Test # = 4937	**2000 Cadillac Seville** IIHS Rating = Good Test weight = 2007 kg (4415 lb) NHTSA Test # = 4955
1996 Toyota Previa IIHS Rating = Poor Test weight = 1953 kg (4297 lb) NHTSA Test # = 4924	**1998 Toyota Sienna** IIHS Rating = Good Test weight = 2024 kg (4453 lb) NHTSA Test # = 4925

To better understand the agressivity characteristics of the vehicles in the test matrix, we decided to evaluate their initial crash stiffness. NHTSA's New Car Assessment Program (NCAP) measures the total force applied to the rigid wall in a full frontal rigid barrier crash test. Figures 9 through 11 show the force-deflection profiles obtained from the NCAP tests of the original and redesigned RAM 1500, Blazer/TrailBlazer and the Avalon. Similar force-deflection profiles are not available for the other paired vehicles. The general trend of the force-deflection profiles is that the redesigned RAM 1500 and Trailblazer have a higher onset rate of force. They also have a peak force that is higher and occurs earlier in the event as compared to the original vehicles. In addition, the deflection of the redesigned RAM 1500 and Trailblazer was lower than the corresponding original vehicles. The redesigned and original Avalon had similar force-deflection profiles.

The initial stiffness of the vehicles was computed according to the method outlined by Swanson, et al., [5] and presented in Table 4. The initial stiffness is higher for the redesigned vehicles than for the original vehicles, except for the Avalon, which decreased slightly according to the method.

Table 4

Initial Stiffness of the Ram 1500, the Trailblazer and the Avalon.

Vehicle Model	Pre-redesigned	Redesigned
Ram 1500	1985 N/mm	2732 N/mm
Blazer/Trailblazer	1528 N/mm	2479 N/mm
Avalon	1334 N/mm	1266 N/mm

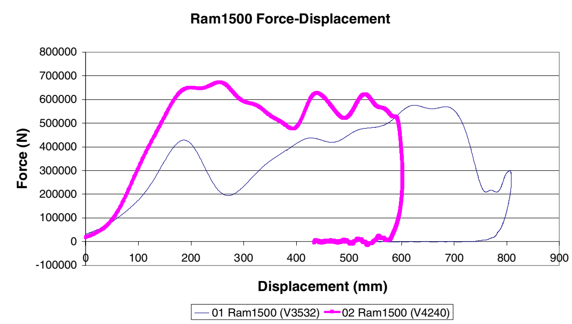

Figure 9. RAM 1500 Force deflection profile from NCAP test.

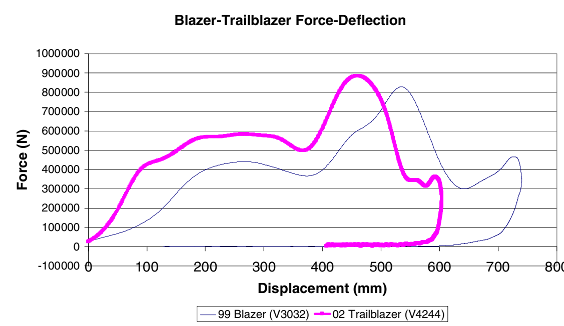

Figure 10. Blazer/Trailblazer Force deflection profile from NCAP test.

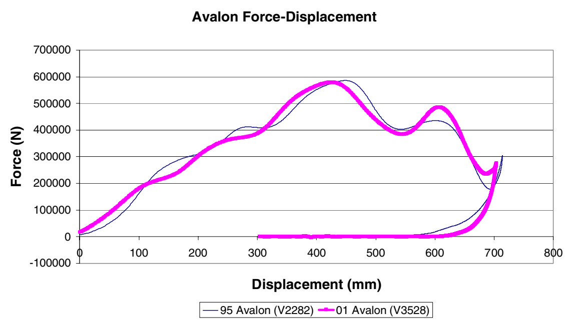

Figure 11. Avalon Force deflection profile from NCAP test.

Oblique Frontal Vehicle-to-Vehicle Crash Tests

In order to better understand the real world effects of redesigning a vehicle to meet the rigid offset deformable barrier tests, the vehicle test matrix was implemented in oblique frontal crash testing. The tests were conducted in the configuration of Figure 12.

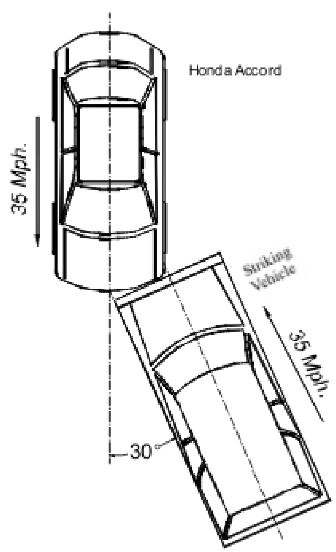

Figure 12. Oblique Offset Test Configuration.

Figures 13 through 16 present the injury measures for the HIII 50M driver of the Accord, along with the IARVs specified in the FMVSS No. 208 Advanced Air Bag Final Rule.

The HIC IARV for the driver of the Accord was exceeded in both the original and redesigned Trailblazer and the redesigned Montero (Figure 13). Four of the redesigned vehicles had higher HIC values, for the driver of the Accord, than the original vehicles. The high HIC for the driver in the Accord in the crash test with the redesigned 2002 TrailBlazer was due to head contact with the hood of the TrailBlazer. There was also head contact for the driver in the Accord with the hood of the corresponding older model (Blazer), but it was not as severe.

The Chest g's IARV were exceeded for the driver of the Accord in the redesigned Blazer, Montero and RAM 1500 (Figure 14). Four out of the six redesigned vehicles had higher Chest g's than the original vehicles for the driver of the Accord. At least one of the IARVs for the driver in the Accord were higher in the crash test with the redesigned vehicle than in the crash test with the corresponding older model. It should be noted that the original RAM 1500 overrode the Accord and eventually rolled over in the test. Though the rollover event occurred after the occurrence of peak injury measures, the overriding of the Accord by the original RAM 1500 may have occurred earlier.

Only the redesigned Trailblazer exceeded the IARV for chest displacement of the driver of the Accord (Figure 15). Three of the six redesigned vehicles had an increase in chest displacement for the driver of the Accord.

The redesigned Trailblazer and Montero and the original Blazer and Previa exceeded the IARV for the femur for the driver of the Accord (Figure 16). Five out of the six redesigned vehicles had a higher femur loads for the driver of the Accord.

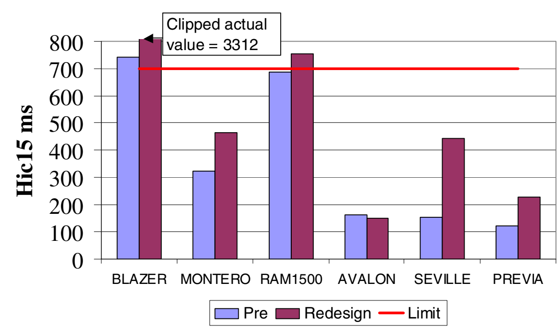

Figure 13. HIC 15 for the HIII 50M driver in the Accord.

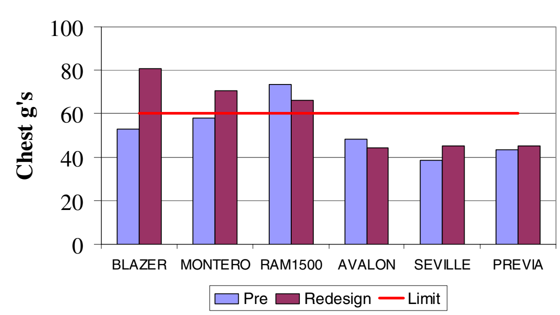

Figure 14. Chest Gs for the HIII 50M driver in the Accord.

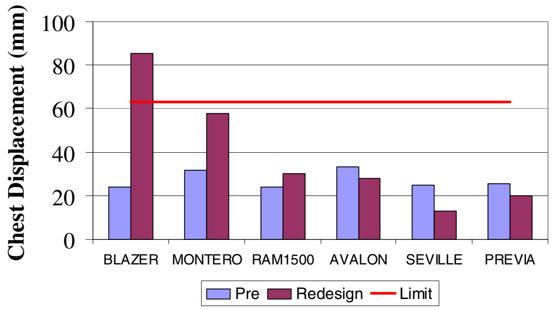

Figure 15. Chest displacement the HIII 50M driver in the Accord.

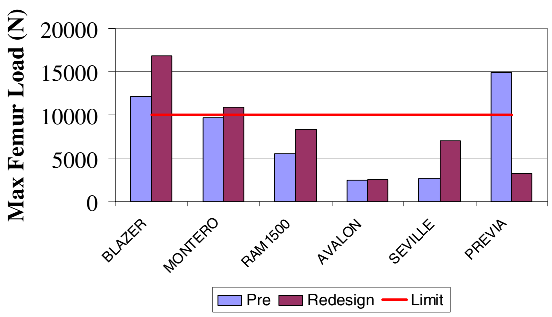

Figure 16. Maximum femur load for the HIII 50M driver in the Accord.

DISCUSSION

Rigid Offset Deformable Barrier Tests

In 2004, Saunders, et. al, [1] combined the ODB test results at 56 kmph, 60 kmph and 64 kmph and predicted the proportion of below the knee injuries when compared to real world data. However, in the present work, when the ODB tests are separated by test speed, we found that the 56 kmph tests do not predict the same proportion of below-the-knee injuries as the tests at 60 kmph, for this sample of vehicles tested, thus showing an important effect of test speed. This outcome needs to be further developed with additional testing.

Oblique Vehicle-to-Vehicle Crash Tests

The paired, redesigned vehicle-to-Accord crash test series generally showed an increased potential for head, chest, and femur injuries in the driver of the Accord as compared to the corresponding older models. This suggests that the redesigned vehicles were more aggressive than their corresponding older models. The redesigned vehicles generally showed an increase in all the injury values, compared to the original vehicles (Figures 13 through 16). However, only the redesigned SUVs and Pickup tested exceeded at least one of the FMVSS No. 208 IARVs for the driver of the Accord. As reported in Saunders, et al., [1] among the paired vehicle-to-vehicle crash tests, only the RAM 1500 demonstrated the most direct association of increased front-end stiffness of the redesigned vehicle to its increased aggressivity. For the other vehicles tested, the effect of stiffness on aggressivity was confounded by geometry and/or vehicle mass.

CONCLUSIONS

The ODB test procedure at 56 kmph predicts a lower proportion of below-the-knee injuries than the 60 kmph, for this set of vehicles tested. Also, there was no general trend in IAVs when comparing the lower leg IAVs of the HIII 50M and the HIII 5F driver. These data suggest that further testing is needed to clarify the effects of speed and dummy size on the results. These tests are currently being designed for implementation this calendar year.

In addition, the redesigned vehicles used in this study that obtained a better rating in the IIHS ODB tests than their respective older models were found to be more aggressive in vehicle-to-vehicle crash tests than their older counterparts. The front-end initial stiffness of the redesigned SUVs and pickup was considerably higher than that of their corresponding older models. However, the initial stiffness of the redesigned Toyota Avalon was not that different from the older counterpart. Though the injury measures on the dummies in the target vehicle were generally higher in oblique crash tests with the redesigned passenger cars than the older counterparts, none of them exceeded their prescribed limits. However, the crash tests with the larger vehicles (SUVs and pickups) resulted in at least one injury measure of the driver in the target vehicle exceeding its prescribed limit. We are exploring this finding in our current program.

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[1] Saunders, J., Kuppa, S., Prasad, A., “NHTSA’s Frontal Offset Research Program,” Paper 2004-01-1169, Society of Automotive Engineers, March 2004.

[2] Kuppa, S., Wang, J., Haffner, M., Eppinger, R., “Lower Extremity Injuries and Associated Injury Criteria,” 17th International Technical Conference on the Enhanced Safety of Vehicles, Amsterdam, The Netherlands, June 4-7, 2001.

[3] Kuppa, S., Haffner, M., Eppinger, R., Saunders, J., “Lower Extremity Response and Trauma Assessment using the Thor-Lx/HIIIr and the Denton leg in Frontal Offset Vehicle Crashes,” 17th International Technical Conference on the

Enhanced Safety of Vehicles, Amsterdam, The Netherlands, June 4-7, 2001.

[4] Stucki, Sheldon L., Hollowell, William T., and Fessahaie, Osvaldo, "Determination of Frontal Test Conditions Based on Crash Data," Sixteenth International Technical Conference on Enhanced Safety of Vehicles, Windsor, Canada, June, 1998.

[5] Swanson, J., Rockwell, T., Beuse, N., Summers, L., Summers, S., Park, B., "Evaluation fo Stiffness Measures from the U.S. New Car Assessment Program," 18th International Technical Conference on the Enhanced Safety of Vehicles, Nagoya, Japan, May 19-22, 2003.

Table A 1

IAVs for the HIII 50M

			Closing Speed (kmph)	Test #	Chest G	Chest Disp (mm)	HIC 15	Nij ver. 10	Neck Ten	Neck Comp	Max Femur	Max Knee Shear	Max Up TI	Max Low TI	Max Upper Tibia Axial Force	Max Lower Tibia Axial Force	Max Dorsi-flexion Angle	Max Inversion / Eversion Angle
				IARV	60	63	700	1	4170	4000	9040	15	0.91	0.91	5600	5200	35	35
NISSAN	QUEST	2002	56.0	4439	27.6	26.2	148.8	0.21	602	134	2894	3.27	0.51	1.11	3242	5555	42.2	20.5
LINCOLN	NAVIGATOR*	2003	56.0	4441	31.7	20.1	731.5	0.35	1758	234	3608	2.62	0.25	0.44	931	2192	27.4	16.2
DODGE	NEON	2002	56.1	4428	40.0	26.5	610.5	0.40	1499	51	5351	5.33	0.88	0.86	3418	4803	39.7	26.8
CHEVROLET	TRAILBLAZER*	2003	56.7	4873	41.0	31.1	731.1	0.74	2040	565	6112	0.37	0.35	0.54	1842	3265	33.2	ND
CADILLAC	SEVILLE	2003	56.5	4874	25.1	23.8	46.9	0.61	804	187	1524	0.96	0.43	0.42	1666	2596	24.9	29.0
TOYOTA	CAMRY	1996	60.7	3459	30.7	24.5	245.6	ND	944	693	2893	2.56	0.38	0.39	1206	2344	30.4	31.0
DODGE	NEON	1998	60.8	3466	38.6	28.9	271.4	ND	1708	442	4611	4.32	0.71	0.96	3916	6099	38.4	33.4
NISSAN	QUEST	2000	59.5	3857	28.1	23.3	304.8	0.31	1724	207	3491	2.64	2.23	0.81	2778	3920	38.4	31.3
CHEVROLET	TAHOE	2000	60.4	3855	46.5	21.2	180.5	0.29	1565	171	6304	7.50	1.13	0.94	7649	9404	28.4	26.6
NISSAN	ALTIMA	2002	60.2	4461	36.1	24.6	132.6	0.24	705	402	2810	4.06	0.40	0.62	1857	3506	39.2	32.0

* Air bag did not deploy during tests

Table A 2

IAVs for the HIII 5F

Make	Model	Year	Closing Speed (kmph)	Test #	Chest G	Chest Disp (mm)	HIC 15	Nij ver. 10	Neck Ten	Neck Comp	Max Femur	Max Knee Shear	Max Up TI	Max Low TI	Max Upper Tibia Axial Force	Max Lower Tibia Axial Force	Max Dorsi-flexion Angle	Max Inversion / Eversion Angle
				IARV	60	52	700	1	2620	2520	6510	13	0.91	0.91	4000	3750	35	35
DODGE	NEON	2002	56.0	4377	44.133	35.294	1202	1.511	3533	183.4	3550.08	4.06	1.022	1.172	2468.72	4005.33	45.96	18.47
NISSAN	ALTIMA	2002	56.1	4431	37.094	22.001	39.35	0.583	1009	307.7	1911.57	0.545	0.292	0.385	1230.63	1986.04	30.45	17.81
DODGE	RAM1500*	2003	56.5	4869	28.884	23.412	160.3	0.295	772.8	398.9	1792.06	4.036	0.594	0.242	572.13	692.32	3.32	15.36
TOYOTA	AVALON	2003	56.7	4870	30.901	23.22	116.7	0.629	1219	177.1	2228.51	1.569	0.386	0.415	750.8	1007.59	4.63	ND
MITSUBISHI	MONTERO SPORT	2003	56.3	4875	48.393	24.842	61.96	0.783	1267	108.8	2062.15	5.212	0.589	0.618	2380.39	2954.75	21.04	ND
TOYOTA	SIENNA	2003	56.0	4669	28.476	25.355	303.6	0.787	1919	49.03	1556.82	0.897	0.523	0.523	566.63	715.42	3.06	10.35
TOYOTA	CAMRY	1996	59.9	3664	31.778	32.894	141.7	1.24	1601	158.8	3050.82	1.068	0.42	0.48	995.39	2213.49	39.12	22.43
SUBARU	LEGACY	2000	59.9	3665	36.385	26.192	146	1.068	1702	77.45	2935.58	1.55	0.38	0.58	1545.85	3006.35	34.74	34.74
NISSAN	ALTIMA	2000	60.0	3666	33.541	22.567	110.9	1.28	1630	349.7	4582.93	3.776	0.82	1.55	2930.04	5519.34	41.71	37.11
DODGE	NEON	1998	60.4	3667	45.399	28.071	611	0.557	2081	842.9	3152.16	3.476	0.825	0.96	2425.64	4086.57	44	28.45
NISSAN	QUEST	2000	60.0	3856	28.774	15.552	96.72	0.49	1081	119.6	3291.03	3.541	0.792	0.826	2555.15	3628.3	39.65	27.56
FORD	EXPLORER	2000	59.85	3850	31.788	30.956	111.3	1.317	1742	444.9	3700.77	0.559	0.383	0.423	1519.39	1908.33	22.4	18.72
NISSAN	ALTIMA	2002	59.8	4440	32.226	26.578	76.83	0.429	907.9	337.3	2019.3	0.576	0.605	0.936	2058.94	3585.99	26.55	29.33

* Air bag did not deploy during test

ADAPTIVE FRONTAL STRUCTURE DESIGN TO ACHIEVE OPTIMAL DECELERATION PULSES

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ABSTRACT

To minimize the injury of car occupants during a frontal crash not only the restraint system must be optimized, but also the crash pulse generated by the vehicle structure. It is clear that a low velocity crash with full overlap requires less structure stiffness than a high velocity offset crash. Ideally for each serious crash situation the whole available deformation length must be used and all the impact energy must be absorbed without deforming the passenger compartment. For compatibility it is necessary to have a stiffer structure in case of a heavy opponent and a softer structure in case of a lighter opponent. This paper discusses possibilities to design an adaptive vehicle structure that can change the stiffness real time for optimal energy absorption in different crash situations. Besides that all the energy is absorbed it is also important to manage the intensity during the crash time, because the resulting crash pulse has a large influence on the injury level. Especially at high crash velocities a stiff structure in the first phase of the crash followed by a softer part is effective but difficult to realize with traditional structures. Therefore a comparison between several energy absorbing methods is made and friction is found as the best controllable way for adaptable energy absorption. In a proposed new concept design the right amount of energy could be absorbed by means of friction generated by hydraulic brakes on two rigid backwards moving beams. In case of an offset or oblique crash a mounted cable system moves the missed beam backwards. With this new intelligent design with interactive control, an optimal vehicle deceleration pulse can be possible for each crash velocity independent on the struck car position, yielding the lowest levels of the occupant injury criteria, also in case of compatibility problems.

INTRODUCTION

The improved frontal crashworthiness of cars necessitates totally new design concepts, which take into account that the majority of collisions occur with partial frontal overlap and under off-axis load directions against other cars with much larger or smaller masses and structure stiffnesses. Realistic crash tests with partial overlap have shown that conventional longitudinal structures are not capable of absorbing all the energy in the car front without deforming the passenger compartment. For improved frontal car safety it is necessary to design a structure that absorbs enough energy in each realistic crash situation. To protect the occupants, the passenger compartment should not be deformed and intrusion must be avoided too.

To prevent excessive deceleration levels, the available deformation distance in front of the passenger compartment must be used completely for a predetermined crash velocity. This implies that in a given vehicle concept the structure must have a specific stiffness. Normally, the two main longitudinal members have to absorb most of the crash energy with a progressive folding deformation of a steel column [1,2]. The main problem is that in real car collisions these two longitudinal members often are not loaded in a synchronous fashion. The majority of collisions occur with partial frontal overlap or with an oblique crash direction, in which only one longitudinal is loaded and often only a bending collapse occurs in stead of the much more energy absorbing progressive folding pattern. A design conflict is that the same amount of energy must be absorbed either with a single or with both longitudinals. This problem can not be solved by just definitively increasing the stiffness of the longitudinals in such a way that each longitudinal is capable of absorbing all of the energy. To absorb enough energy, a stiff longitudinal is needed for the offset crash or the oblique crash direction (also to have enough bending resistance) in which normally only one longitudinal is loaded. The same longitudinal must be suppler in case of a full overlap crash, since both longitudinals must not exceed the desired deceleration level.

To absorb all the kinetic energy, which is proportional with the square of the velocity, the deformable structure length must have a specific stiffness. This stiffness results in an average mean force, which multiplied with the deformation shortening gives the absorbed energy. For an acceptable injury level of the occupants, the total deceleration level must be as low as possible, using the maximum available deformation length without deforming the passenger compartment. This means that for example in a 64 km/h crash compared with a 32 km/h crash, a four times longer deformation distance is needed for the same deceleration level. Although the stiffness normally increases during the crash and at higher crash speeds there is made use of the stiff engine; the only way to generate an optimal crash pulse at different collision speeds is variable structure stiffness. After detection of the crash velocity, the optimal stiffness of the frontal structure should be realized.

The objective of the research project presented here was to design a concept structure that substitutes the conventional energy absorbing longitudinal members in a frontal vehicle structure and that yields optimized deceleration pulses for different crash velocities, overlap percentages and collision partners. If pre-crash sensing is used in future the system can be adjusted before the crash instead of during the crash. To this aim the structure must have a stiffness that can be varied in accordance with the specific crash situation.

Also the increasing trend of deployment of short front-end cars makes adaptive structures a must to overcome the impossible task of improving crashworthiness while shortening the front-end crash zone.

In the next section the problem is further analyzed, a summary is given on optimal crash pulses and finally a conceptual design will be presented which can fulfill the specifications of different deceleration levels for an optimal deceleration pulse in each crash situation.

ANALYSIS OF THE CRASHWORTHINESS PROBLEM

The novel design has to cope with the following four crashworthiness problems:

1. ***Crash position:*** in the case of a full overlap crash (both longitudinals and engine involved) as in the case of an offset or oblique crash (at 40 per cent overlap only one longitudinal directly involved) a similar amount of energy must be absorbed by the front structure.
2. ***Crash velocity:*** With a not much longer deformation length, much more energy must be absorbed at high crash velocities (resulting in less fatal injuries) and a lower injury level must be obtained at lower crash velocities.
3. ***Crash pulse:*** A deceleration pulse must be obtained which is optimal (lowest injury level) for the concerning relative collision speed and the chosen dummy restraint parameters.
4. ***Crash compatibility:*** The structure stiffness must also be optimized for the mass and stiffness of the struck object.

To minimize the injury of car occupants during a frontal crash, the car structure must generate a predetermined optimal deceleration pulse (specific curve) on the assumed undeformable passenger compartment to absorb all the kinetic energy. However, this optimal pulse is dependent on the final relative crash velocity and the occupant properties (for example initial distance occupant to airbag). The crash pulse must be independent on the struck car position. The absorbed energy must be dependent on the own accompanying mass (including passengers and luggage) and the relative final crash velocity, which is dependent on the original velocities of both crash partners and their mass relation (compatibility). This complex problem can only be solved if all the necessary parameter values in front of the crash are present by means of pre-crash sensing and a vehicle structure stiffness that can be regulated by an intelligent system immediately before and also during the crash (necessary if the crash parameters change or the deceleration has not the level as programmed). Especially the structure stiffness can influence the deceleration level and the absorbed energy within the available deformation length.

With this new intelligent design, an optimal vehicle deceleration curve must be possible for each crash velocity over the entire frontal collision spectrum, yielding the lowest levels of the occupant injury criteria, also in case of compatibility problems.

The compatibility of vehicles is an important issue. There could be adverse effects on vehicle fleet compatibility after structural changes. A vehicle which has a stiffer or more aggressive front structure for his own increased frontal safety could be more dangerous for another car, especially if that other car is involved in a side impact crash. Also the use of the same fixed deformable barrier in crash tests for light and heavy cars could lead to less compatibility in crashes between small and large cars. The amount of energy absorbed by the barrier is for a light car a larger proportion of the total crash energy as for a heavy car. To achieve a level of performance comparable to a small car, the front structure of the large car must be designed to crush more or to crush at a higher force level to absorb the additional energy. It is possible that a small car becomes softer because a lot of its energy was absorbed by the barrier. The increased crash velocity by Euro-NCAP from 56 km/h to 64 km/h has also a negative influence on the compatibility. This velocity increase yields a 30 per cent higher amount of crash energy. That means that for the same deformation length the force level and thus the stiffness of all cars has to grow with 30 per cent. This effect increases the absolute difference in force levels between light and heavy cars, which deteriorates the compatibility. Otherwise the test velocity must be higher as where collision statistics ask for, because for a comparable vehicle deformation as in a car to car crash the initial kinetic energy must be higher to compensate the absorbed energy in the barrier. Another interesting test for the compatibility problem is a test with a moving deformable barrier. Such a test simulates much better collisions between cars and could improve the fleet compatibility. In this case the smaller vehicle is subjected to a harsher crash environment due to the higher energy absorption and a higher velocity change yielding a stiffer structure. On the other hand the large car would be subjected to a less severe crash environment in terms of velocity change, so a softer front structure gives a temperate crash pulse.

OPTIMAL DECELERATION PULSES

An occupant is primarily protected by the restraint system, so an optimal vehicle crash pulse must always be defined in combination with the restraint system characteristics. For structural adaptivity much effort is needed in finding the properties of a well-tuned seatbelt and airbag system combined with a proper crash pulse shape. For an adaptive frontal stiffness system an optimized set of restraint system and crash pulse parameters should be defined for all types of frontal collisions. From previous research [3] it is known that a traditional deceleration curve with an increasing deceleration level, from the beginning with a relatively soft structure to the end of the crash with a high force level, is far from optimal. For a low crash velocity a constant crash pulse is ideal while for higher crash velocities a high-low-high crash pulse is optimal. An active control of the structural response is necessary in order to minimize restraint system loads in low speed impacts and to create high-low-high pulses for higher crash velocities.

Researchers Witteman [3], Motozawa and Kamei [4] studied the possibility of reducing occupant injury severity without increasing vehicle deformation by actively controlling the vehicle deceleration in a crash. The influence of the change in vehicle deceleration with time (the deceleration curve) on occupant injuries in crashes has been studied by modifying the deceleration curve of an actual vehicle and optimizing it in order to reduce occupant injury by using the sensitivity analysis method applied to dummy simulations.

Witteman [3] gave a method to calculate an overall severity index based on bio-mechanical injury criteria. An integrated numerical model of dummy and car interior was described with corresponding restraint parameters yielding the lowest overall severity index (OSI). With an ideal not deforming passenger compartment, it is acceptable to use an uncoupled model of the dummy and the frontal deforming structure. A common method is, to predefine a deceleration pulse as input on the passenger cage. With the aid of this interior model, variations of the deceleration pulse are compared on basis of the OSI, and an optimal pulse is obtained for several crash velocities. The conclusions are comparable with Brantman [5] that the pulse can be described by three phases, ensuring minimal risk for the occupants:

1. Crash initiation phase. In this phase, the sensor triggering for the belt pretensioners and airbags must take place. For optimal sensor triggering, the front-end of the car should be sufficient stiff to generate within a short time interval a velocity change that lies above the triggering value. The occupants are not directly connected with the car, because they are not yet captured by the restraint systems, so the deceleration can be high without causing unacceptable injury. Loss of valuable deformation shortening during a still high velocity is reduced.

2. Airbag deployment phase. In this phase the airbags are inflated and the occupants tighten the belts while moving forwards with a relative velocity with respect to the car. This relative velocity should be sufficient low, because in practice many injuries are the result of reaching a still inflating airbag or hitting a full inflated bag with a relative high velocity. The deceleration should be low.

3. Occupant contact phase. In this phase, the occupants have hit the airbags and there is stiff contact between the occupant and the car. High decelerations may occur because the occupants will not be subjected to further shock loads caused by contact with the interior, deceleration should be substantially in the remaining time.

The optimal deceleration pulse for this realistic interior at a crash speed of 56 km/h into a rigid full-width barrier is given in figure 1, figure 2 illustrates the pulse of a normal realistic deceleration.

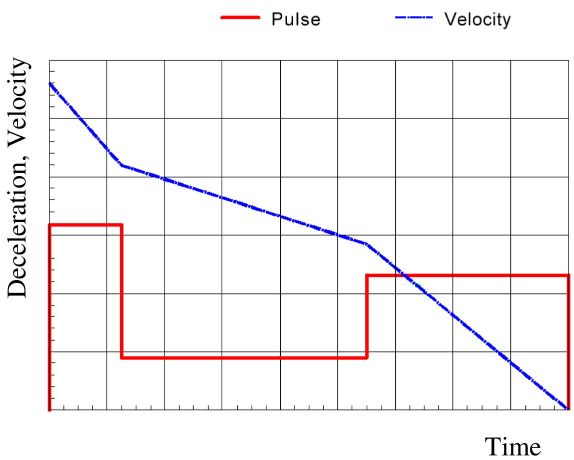


Figure 1. Optimal deceleration pulse.

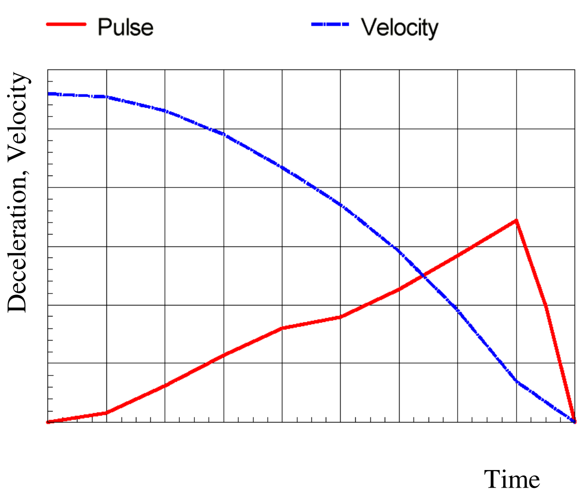


Figure 2. Deceleration pulse of nowadays cars.

From this research [3] it is concluded that the OSI of the optimal crash pulse, at this velocity, is 35 per cent lower than the OSI of realistic pulses. As an example optimal pulses for 3 different velocities are shown in figure 3. For design reasons it is plotted as function of the deformation length.

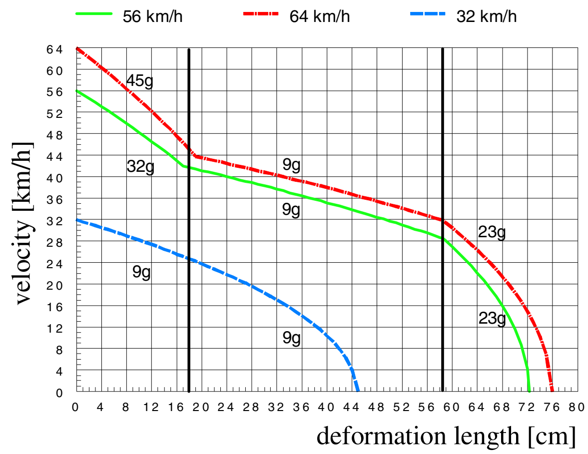


Figure 3. Three optimal decelerations curves in three phases [3].

This high-low-high pulse shape can also be found with the application of Newton's second law for motion in the x-direction while modeling the mechanical relationship among the occupant, vehicle and seat belts as shown in figure 4. Consider the occupant as a point mass with a mass of m and the vehicle as a point mass with a mass of M, and the seatbelt as a linear spring with coefficient of k.

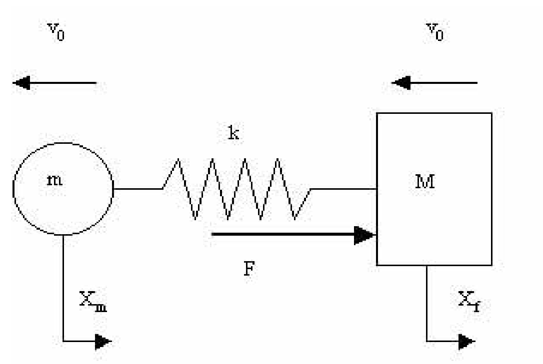


Figure 4. Two mass, one dimensional model.

The moment at the start of the crash is the origin for the time axis (t=0). v_0 is the initial velocity of each point mass, and the co-ordinates for each point mass are X_m and X_f (see figure 4), which are respectively measured from the position of each at the start of the crash. F is the crash load acting on the vehicle point mass. The equations of motion can be expressed by equation 1,

$$M\ddot{X}_f = k(X_m - X_f) + F \qquad (1).$$

This gives as result that for a constant deceleration (C) of the vehicle the deceleration of the occupant is described by figure 5.

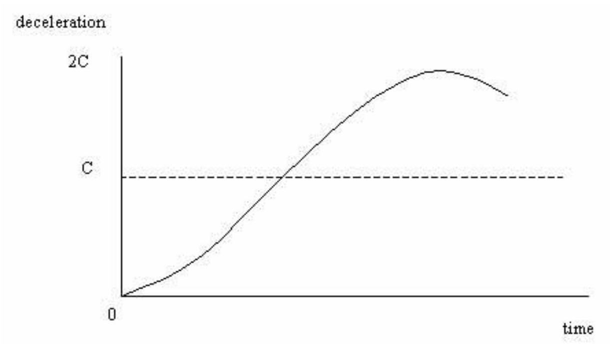


Figure 5. Typical occupant deceleration model for conventional vehicle.

In order to smooth the peak in figure 5, the deceleration of the vehicle has to be altered and can no longer be constant. The mathematical solution gives a cosine type equation for the vehicle deceleration that leads to a smaller and smoother pulse for the occupant; both can be seen in figure 6.

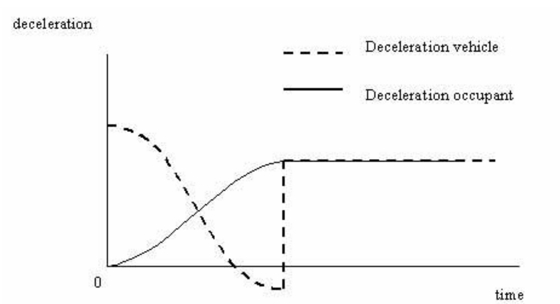


Figure 6. Deceleration of vehicle and occupant.

In the above figure it is seen that the vehicle deceleration pulse can be divided in to three phases; high, low and moderate level. This result is unanimous to the research described earlier [3]. Motazawa and Kamei [4] conclude the same.

Regarding the feasibility of the "high-low-high" crash pulses, there is one major difficulty that a vehicle structure will always start buckling or bending at its weakest point. This means that even if the front structure is stronger in its most forward parts, but weaker in parts closer to the firewall, the weaker part will always buckle first. Thus a pulse with an initial deceleration peak can almost only be created by inertial effects or by actively controlling the stiffness of the energy absorbing members during deformation. A nice example of a fixed structural element is from Motazawa and Kamei [4]. They have designed a structural concept that is able to create a fixed high-low-high pulse. The fundamental model (see figure 7) is a hollow member designed to act as a longitudinal. It consists of a front zone for axial collapse, and a center zone for bending. The axial collapse zone incorporates a stress concentration in order to induce regular buckling deformation, while the bending zone has a mildly cranked shape to stabilize the bending deformation direction. Each of the cross-sections is set so that the deformation load of the axial collapse zone will be slightly less than the maximum load of the bending zone.

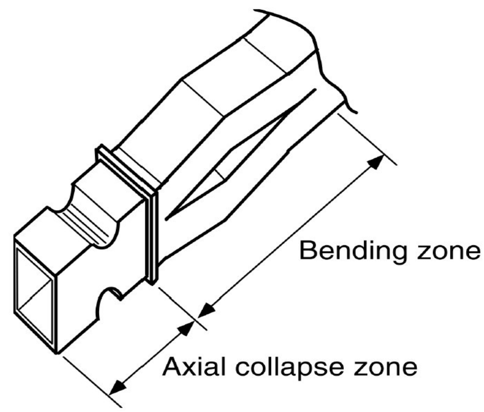


Figure 7. Fundamental model of a crash load control structure [4].

However, if this fundamental model is applied in an actual vehicle body, in a low speed crash, there is a possibility that the initial stage would not be completed and a large crash load is maintained until the vehicle stops.

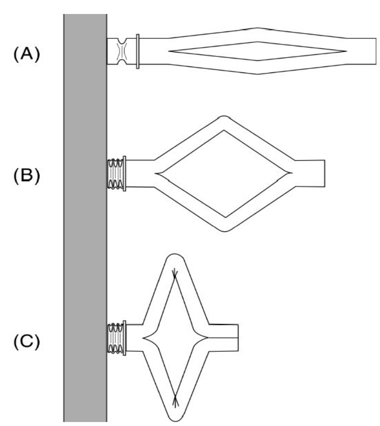
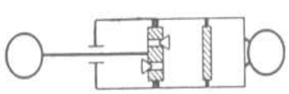


Figure 8. Deformation process in the fundamental model [4].

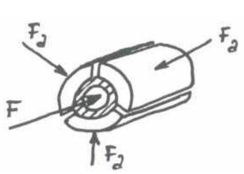
Figure 8 illustrates the deformation process for this fundamental model. The A-section in the figure shows the first stage, during which the axial collapse zone starts to deform immediately after the start of the crash due to its inherent stress concentration. After the axial collapse zone has started to deform a nearly constant load is maintained. When the regular buckling deformation has proceeded through the length of the axial collapse zone, the load increases and eventually reaches the maximum load for the bending zone. Figure 8B illustrates the second stage. When the maximum bending load is exceeded, the bending zone rapidly deforms, and the load drops to a fraction of its former level. Figure 8C illustrates the third and final stage after the bending deformation is completed. The load again starts to increase as the deformable members bottom out.

ADAPTABLE ENERGY ABSORPTION BY FRICTION

To design a structure from which the energy absorption can be varied depending on the crash situation, a traditional structure with crumpling beams with a fixed force level is not usable. Therefore alternative ways of energy absorption which can be influenced must be searched for. In figure 9 two interesting principles for frontal crash application are showed. One possible solution is a hydraulic system (figure 9a), two cylinders (placed along or instead of the two longitudinal members) with controllable flow restriction valves could control the oil flow and therefore the force level required to move the pistons backwards during a frontal crash. These idea is also used by Witteman [6] and Jawad [7]. Disadvantage could be the weight and space requirements for automotive.



a



b

Figure 9. Examples of energy absorption by a hydraulic cylinder with variable restriction (a) or by axial friction (b).

The other practical method to absorb kinetic energy is by means of friction (figure 9b). Changing the pressure force on a friction block regulates the energy absorption. The well functioning idea of hydraulic vehicle brakes can be used during a crash on very stiff longitudinal beams moving backwards, which must be positioned in such a way that the profiles move under the vehicle floor.

To determine the necessary friction force, the velocity information of the vehicle must be used. Since most modern cars use ABS which continuously detects the speed of each wheel, the current speed (or before the last 100 ms from memory to prevent crash influence) of the car is always well known.

In a new designed front-end structure that can adapt its frontal stiffness during a crash, the crushable longitudinals have been replaced by (plastically) undeformable U-profiles, see figure 10. The beams have not to crumple to absorb energy so they can be made very stiff with a high bending resistance yielding no risk for a premature bending collapse in case of an oblique crash direction. In a crash the profiles are forced backwards and slide each along two active friction pads (supported by two break cylinders) absorbing the energy, the friction pressure can be hydraulically altered leading to variable stiffness. It is calculated that for a 1100 kg vehicle the pressure for the brake pads has to vary between 5 and 25 bar. The temperature increase after a 64 km/h crash is only about 85 degrees for the pads and the profiles. This designed structure makes it possible to decelerate a car as described in figure 1. For the regulation process servo valves are available for the required pressure and volume flows, which can regulate within a few milliseconds, see figure 12 for the hydraulic circuit. In a crash the slant profiles slide under the occupant compartment or, in case of a Multi Purpose Vehicle, in the floor compartment without jamming the occupants. The system is equipped with a cable connection system, as designed by Witteman [8]. If only one side of the vehicle front is loaded (offset or oblique crash), the backwards moving profile takes the mounted cable that is guided along two cable guide disks to the other side also backwards. This cable generates a tensile force on the other profile which pulls that profile also backwards, yielding a symmetric force distribution. The designed structure is able to involve the whole frontal structure into an energy dissipation process, even in an offset crash. See figure 11. Because both profiles always slide together backwards, the same crash behavior is shown for the whole frontal part with the engine and other aggregates for each frontal crash position and a stiff bumper part can be mounted in front for a very high bending resistance of the whole frame and for a better car to car interaction.

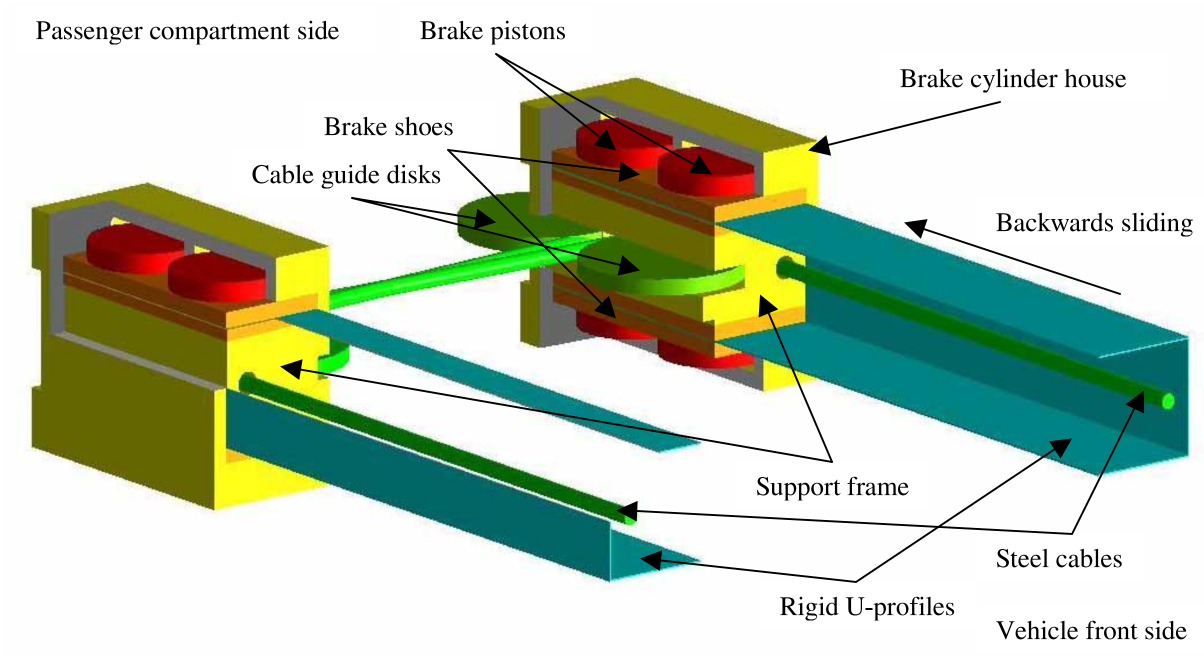


Figure 10. Open view of frontal structure with cable and brake system.

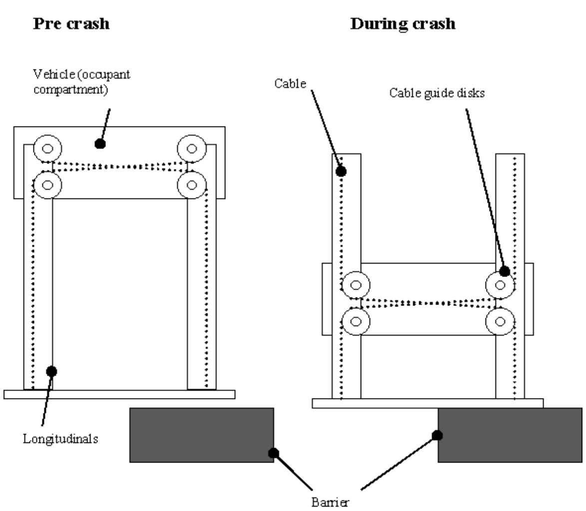


Figure 11. Frontal structure with cable system to involve the not directly loaded beam in an offset crash.

With this structure the car is able to adapt its frontal stiffness, depending on the crash velocity. The maximum length of the crumple zone can always be used, without intrusion of the occupant compartment. Of course the packaging of the engine and other stiff aggregates influence the available deformation length. High crash loads from these parts can be compensated by less friction force on the profiles. Now the front-end is *'as soft as possible, as hard as necessary'*.

An optimal regulation for the whole deformation length is of course with a computer controlled system, which measures continuously the actual deceleration level and adjusts at the same time the pressure for the friction pads to reach the programmed optimal deceleration pulse. In this way, it is also possible to compensate for the stiffness, velocity or weight of the colliding obstacle. This would be an ideal solution for the compatibility problem between small and large vehicles.

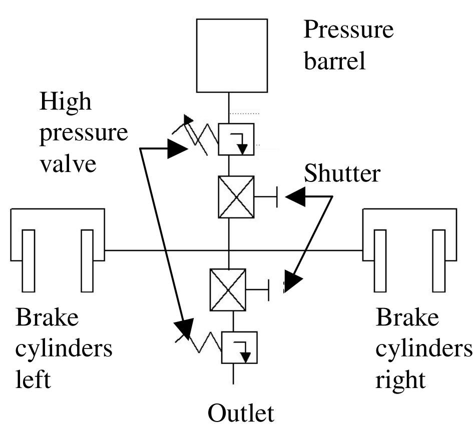


Figure 12. Schematic view of hydraulic regulation circuit.

CONCLUSIONS

With the presented new frontal structure design the amount of absorbed energy for each crash situation (full, offset, oblique, high or low speed) can be adapted to fully utilize the available deformation length with an optimal deceleration curve without deforming the passenger compartment yielding the lowest injury values. This intelligent structure with adaptable stiffness based on very fast adjustable friction forces before and during the crash is also a solution for the compatibility problem between different vehicle masses and stiffnesses or for compensating the measured additional occupant and luggage masses.

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A NUMERICAL INVESTIGATION INTO THE EFFECTIVENESS OF "SMART" RESTRAINT SYSTEMS IN MITIGATING INJURY RISK UNDER "REAL WORLD" ACCIDENT CONDITIONS

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Paper 05-0097

ABSTRACT

This paper presents the value of "smart" restraint systems in mitigating the injury risk to occupant's in a greater range of impact conditions than those presently considered in current regulatory and consumer impact tests. The work was carried out under the European 5th framework project PRISM (**P**roposed **R**eduction of car crash **I**njuries through improved **SM**art restraint development technologies). A generic MADYMO compartment model of a typical European midi-MPV was developed with a conventional restraint system for the modelled driver. To identify variables that need to be considered in the performance of a "smart" restraint system and subsequently assess potential adaptations that could be made to a restraint system, two simulation studies were carried out with the developed model. The first of these studies investigated the influence that the following variables have on driver injury risk: occupant size (using both a Hybrid-III and human body models), the reclined position of the seat, the bracing response of the driver and thoracic fracture. Based on the models' predictions it is implied that the kinematics and predicted injury risk of various sizes of human model are very different from those of a 50th percentile Hybrid-III dummy and that the reclined position of the seat and bracing response of the driver increases injury risk. It was not clear if fractures in the thoracic region would contribute to an increase in injury risk to other body regions. In the second simulation study investigations were performed to assess alterations that could be made to the modelled restraint system to adapt its performance to better protect different occupant sizes. It was concluded that if it were possible to adapt restraint characteristics to the specific occupant size, injury risk could be lowered.

INTRODUCTION

Current regulatory and consumer impact tests generally assess the effectiveness of restraint systems in protecting an averaged size dummy in a standard seated posture under a limited range of impact conditions. In comparison, the potential variables influencing a real occupant's injury risk are more numerous and include the type and severity of the impact and the specific characteristics of the occupant (stature, weight, gender, seated posture, injury tolerance, etc.). Such issues have been discussed and highlighted in previous research (Holding *et al*, 2001, Schöneburg *et al,* 2003) and accident data studies (McCarthy *et al*, 2001, Cuerden *et al* 2001, Frampton *et al,* 2000). The potential therefore exists for hazardous impact conditions to arise that are not assessed by current testing protocols and conventional restraint systems are possibly not optimally developed for protecting occupants in these more diverse impact conditions.

To cope with the wider circumstances of occupant injury risk it is expected that "smart" restraint systems will be needed that are able to adapt to the specific impact conditions and react to different occupant positioning and biomechanical tolerances. In response to the expected development and implementation of these systems in European cars the European 5th Framework project PRISM (**P**roposed **R**eduction of car crash **I**njuries through **SM**art restraint development technologies) was started in December 2002. Overall, the objectives of PRISM are to investigate the likely benefits of implementing "smart" restraint system technologies and to develop guidelines on how best to assess and validate the performance of these "smart" restraint systems.

The objective of Work Package 3 (WP3) of the PRISM project was to assess the value of "smart" restraint systems in mitigating the injury risk to occupants in a greater range of impact scenarios than those presently considered in current regulatory and consumer impact tests. For this reason, an assessment of the injury risk to occupants in a greater range of impact conditions has been made. These results were used to identify injury risks that could be mitigated by the implementation of "smart" restraint systems and assess their applicability through potential "smart" alterations in a series of different scenario simulations. This paper details some of the predicted results obtained from the simulations completed under WP3 of the PRISM project.

METHODOLOGY

In order to assess the value of "smart" restraint systems in mitigating the injury risk to occupants the following methodology was adopted (WP3 of the PRISM project). A MADYMO compartment model of a generic midi-MPV with a conventional restraint system was developed to represent the majority of the European, post-2001, midi-MPV fleet. As EuroNCAP is the current measure against which occupant protection is tested in Europe it was decided to use EuroNCAP as a baseline to assess the performance of the developed model. A midi-MPV EuroNCAP frontal impact was simulated with this generic model including a Hybrid-III model and evaluated against a variety of midi-MPV EuroNCAP test results. With the evaluated model two simulation studies were carried out. The first was to identify variables that needed to be considered in the performance of a "smart" restraint system such as occupant size, posture and bracing and the second to assess potential changes that could be made to a restraint system to better protect different occupant sizes. For the studies it was decided to include human body models since they allow the injury risk of varying occupant sizes to be investigated and potentially provide a more general insight into human-like behaviour during a crash.

Two further MADYMO compartment models were developed representing the confines of a generic super-mini and a small family vehicle so that investigations of the influence that vehicle size have on occupant injury risk could be completed. However, only samples of the predictions from the midi-MPV compartment model are reported in this paper.

Development of the models

Generic midi-MPV compartment model - The geometry of the midi-MPV compartment model was based on an average of basic measures taken from four post-2001 European MPV vehicles. The emphasis was to develop a generic midi-MPV compartment model representing the typical confines of a European midi-MPV. The term 'midi' used for the model describes the fact that the measures were made of the larger vehicles found in the EuroNCAP small MPV class.

The compartment model was developed with no simulated intrusion and the motion of the modelled seat, steering wheel and column was rigidly fixed to that of the modelled compartment for simulated impacts. It was felt that this model setup was sufficient for simulating the injury risk in EuroNCAP impacts where it is normal to observe relatively little intrusion or relative displacement of the internal compartment structures.

Restraint and airbag models - The initial setup of the modelled restraint system for simulating EuroNCAP impact conditions consisted of a belt with 4 kN load limiting at the shoulder, buckle pre-tensioning and a 55 litre single-stage frontal airbag model, as adapted from the standard MADYMO 6.2-alpha frontal impact application. An overview of the modelled belt setup is provided in Figure 1 and additional nominal values for the setup of the modelled restraint system for simulating EuroNCAP impact conditions are provided later in Table 1 of the paper. In the absence of specific data for developing the restraint system model these were estimated from the project consortiums working knowledge of these systems. Overall, the intention was to develop a modelled restraint system with a performance of safety consistent with that found in the majority of vehicles being released in the current European market.

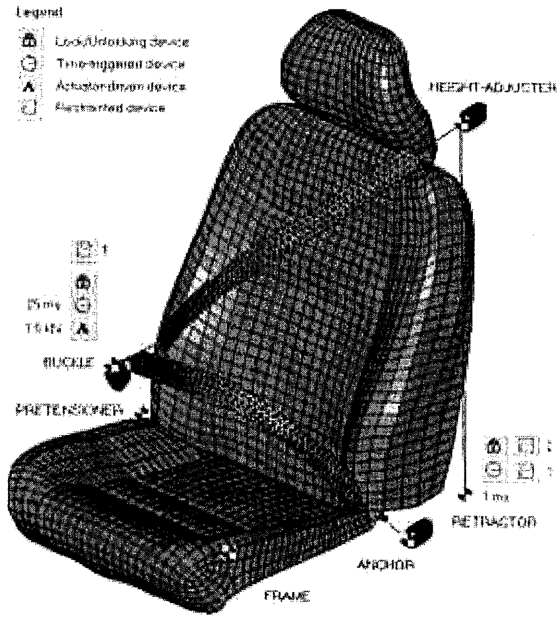
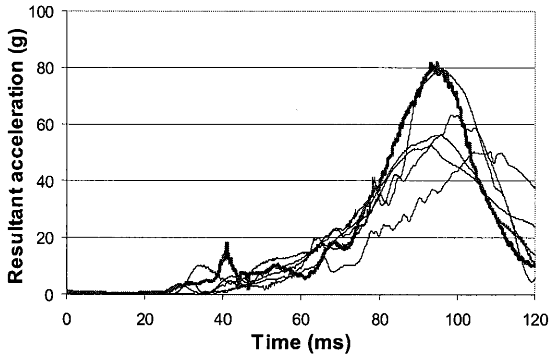


Figure 1. Setup of the modelled belt system.

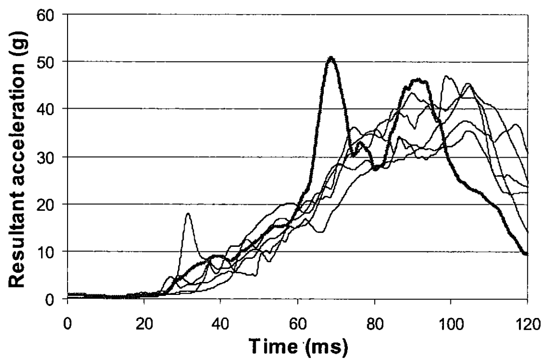
Evaluation of the compartment model

It was anticipated that coupled with the compartment model the performance of the restraint system would provide a predicted level of safety consistent with that of a generic European midi-MPV. This anticipated performance of safety for the model was tested by comparing model predictions against equivalent measures obtained from a series of EuroNCAP tests completed on an equivalent size of vehicles. For the EuroNCAP simulation a MADYMO 50th percentile Hybrid-III dummy model was positioned in the driver seat of the midi-MPV compartment model and the EuroNCAP pulse from one of the tested vehicles was applied to the compartment model.

Figure 2 provides examples of the comparisons made. It was found that the predictions from the Hybrid-III dummy model were comparable in magnitude to equivalent measures of the Hybrid-III dummies in the EuroNCAP impact tests. The predicted dummy chest acceleration in Figure 2 does deviate from that measured at approximately 70 ms. This was found to be due to a vertical component of chest acceleration coinciding with the contact of the legs with the modelled submarine bar and not a problem associated with the manner in which the restraint system had been modelled. Therefore, despite this deviation in the model's behaviour, it was felt that it was sufficiently developed for assessing the relative rather than absolute influence that alterations in impact conditions have on an occupant's injury risk.



Driver head



Driver chest

Figure 2. Comparison of predicted 50th percentile Hybrid-III dummy responses (red lines) with equivalent measures (black lines) from EuroNCAP impact tests of five different midi-MPV vehicles.

PARAMETER VARIATION STUDIES

The following frontal impact simulation studies were completed with the midi-MPV compartment model:

- An assessment of potential variables that may need to be considered in the performance of a "smart" restraint system.
- An assessment of adaptations that could be made to a restraint system in order to better protect different occupant sizes.

Assessment of potential variables to consider in the performance of a "smart" restraint system

The purpose of this study was to investigate how selected accident variables influence occupant injury risk in order to determine possible factors that may need to be considered in the operation of "smart" restraint systems. Chosen accident variables investigated in this study were identified from accident data analysis, photographic studies (Bingley *et al,* ESV 2005, paper 319), simulated driver (Couper and McCarthy, 2004) and passenger (Morris *et al,* ESV 2005, paper 320) pre-impact response investigations completed in earlier stages of the PRISM project. The accident variables investigated and reported on in this paper and the reasons behind their inclusion in the investigation were as follows:

Occupant size (baseline model runs) - Current regulatory and consumer impact tests concentrate on the impact response of a 50th percentile Hybrid-III dummy. Results from McCarthy *et al* (2001) and the accident data analysis of the PRISM project (not currently reported) indicated that there was an increased injury risk to larger and smaller vehicle occupants. It is also questionable that dummy responses provide an adequate representation of the real human response in vehicle impacts. As such a series of frontal EuroNCAP simulations were completed with the 5th, 50th and 95th percentile human body models released with the 6.1 version of the MADYMO code. It was anticipated that these models would provide a more representative biofidelic response compared with that of the Hybrid-III dummy model providing an insight into the potential injury risk to real humans in an impact. Injury predictions from these model runs were then compared against equivalent predictions obtained from the evaluation model run using the 50th percentile Hybrid-III dummy model detailed above. For the model runs involving the 5th and 95th percentile human body models the seat position and upper anchorage for the belt were altered to comfortably fit the various occupant sizes in the compartment model. Changes made to the seat and belt anchorage positions matched limits for these variables measured in the vehicles on which the dimensions of the compartment model were based. Furthermore, the predictions from the human body models detailed in this section provided a baseline against which predictions from additional model runs using the human models could be compared.

Reclined 95th percentile driver - It was found from the results of the PRISM '*Photographic Study*' (Bingley *et al*, 2005) that larger occupants tend to adopt a more reclined driving posture. This deviates from the seat setup for regulatory and consumer impact tests. Results from the PRISM '*Accident Data Study*' implied that this could be a contributory factor to injury risk, which is supported by the increased injury risk to larger occupants discussed above. To consider this setup a simulated EuroNCAP impact was completed in which the 95th percentile human model was set in a reclined posture with the seat reclined a further 20° from the baseline EuroNCAP frontal simulations detailed above. Predictions from this model run were then compared against equivalent predictions from the baseline 95th percentile human body model run.

Occupant bracing - In the PRISM pre-impact braking studies of Couper and McCarthy (2004) it was noticed that drivers, on perceiving a simulated hazard, tended to brace themselves prior to an imminent vehicle impact. The bracing response was characterised by the drivers pushing against the steering wheel and bracing their feet against the brake and footwell. However, this response does not match the setup of current regulatory and consumer impact tests, which are possibly more representative of occupants who are unaware of or have insufficient time to react to an impending impact. Occupant bracing in the model was represented by locking the motion of the hands and feet to that of the compartment model up until the point that the loading through the modelled occupant's arms exceeded a defined limit. During this period all joints in the occupant model were locked. When the loading in the arms exceeded the defined loading limit the hands were then freed from the motion of the compartment model and the joints in the occupant model were unlocked. This then allowed the human model to passively interact with the modelled restraint system and the confines of the compartment model. It was not certain what load a typical adult could support through their arms in an impact. As such this limit was set at 1 kN through each arm, which was considered a reasonable upper limit that could be supported by an adult with locked arms. The use of the 1 kN limit served an initial purpose of investigating the influence of this bracing response on an occupant's injury risk. Further investigations with more accurate loading limits for the arms could be conducted if the limit was found to have a significant influence on the predicted injury risk or if the loading limit for the arms was later found to be considerably greater than 1 kN. Predictions from this bracing simulation were compared against equivalent predictions from the 50th percentile EuroNCAP baseline model run detailed above.

Thoracic fracture - It was rationalised, following the PRISM '*Accident Data Analysis*', that fractures in the thoracic body region could affect the performance of the restraint system during an impact and consequently influence the injury risk to body regions other than the thorax. This was considered to be a greater concern for older occupants who, as found in the PRISM '*Accident Data Analysis*' and the study completed by McCarthy *et al* (2001), were at a greater risk of injury than their younger counterparts. In order to consider the possible consequences of this behaviour simulations were completed in which additional belt length was introduced to the modelled belt system when the shoulder belt load exceeded a defined limit. It was anticipated that this belt representation in the model would approximate the sudden failure of thoracic features, such as the ribs, sternum or clavicle and the redistribution of load onto alternative body regions. For this investigation 6 cm of belt was introduced at the shoulder under shoulder belt loads of 1, 2 and 5 kN resulting in three model runs in total. These belt length and belt loads were estimated to fulfil the immediate requirement of investigating the influence that thoracic fracture has on the injury risk to body regions other than the thorax. The occupant model used in these model runs was the 50th percentile human body model and the compartment model was subjected to the EuroNCAP frontal impact pulse. Predictions from these model runs were then compared against those obtained for the baseline 50th percentile human body model run.

Restraint system adaptations for different occupant sizes

A series of parameter studies were completed to determine the required setup of the modelled restraint system to limit the injury risk under EuroNCAP frontal impact conditions of a 50th percentile Hybrid-III dummy and 5th, 50th and 95th percentile human body models. In these studies a number of restraint system parameters were varied across a specified range, presented in Table 1. The stochastic pre-processor ADVISER (Dalenoort *et al*, 2005) was used to generate the model run files for the parameter study. Altogether 50 model parameter runs were completed with each occupant model resulting in 200 model runs in total. Best Latin Hypercube sampling was used to determine the setting of the restraint system parameters in the model runs. This sampling distributes the samples over the design space, while maintaining its random character.

An overall injury risk prediction from the baseline model runs was used as a baseline against which improvements in the performance of the adapted restraint systems could be assessed. The overall injury risk prediction used to assess performance improvements in the modelled adapted restraint systems was a predicted form of the Injury Severity Score (ISS). Predictions of HIC_{36}, the highest of Chest 3ms, Combined Thoracic Injury (CTI) criterion, the knee forces for the human model and the femur forces for the Hybrid-III dummy model were obtained. These predictions were then compared against injury risk curves available on the US National Highways Traffic Safety Administration (NHTSA) website (www.nhtsa.dot.gov) to obtain Abbreviated Injury Scores (AIS). A reduced form of the ISS was then calculated for each model run based on these estimated AIS scores. A femur load cell was not available in the human models and explains why knee force was used to assess predicted injury risk in the legs. From all the estimated ISS values, the lowest ones were considered to correspond to the best performing restraint systems, within the variations performed in the current study.

RESULTS

Analysed predictions from the model runs were to injury criteria associated with the head and chest: HIC_{36}, Chest deflection and CTI. Lap belt loads were analysed in some of the model studies to provide a relative measure of the potential injury risk to the abdomen in the absence of an accepted injury criterion for assessing abdominal injuries. Analysis of the modelled occupant kinematics was also performed in order to capture potentially hazardous conditions that may not be highlighted by conventional injury criteria.

Table 1
Parameters varied in the restraint system adaptation study for different occupant sizes

Restraint system parameter	Range of variability (nominal value)
Airbag mass flow	50–150% (100%)
Airbag fire time	10-40ms (25ms)
Load limiter	2–7kN (4.1kN)
Pre-tensioner	1-4kN (always < load limiter) (1.5kN)
Pre-tensioner fire time	10-40ms (25ms)

Results – Assessment of potential accident variables that would need to be considered in the performance of a "smart" restraint system

Occupant size (baseline model runs) -
Occupant kinematics: Figure 3 provides the initial and 120 ms posture of the occupant models for the comparable EuroNCAP simulations completed with the 50^{th} percentile Hybrid-III dummy model and the 5^{th}, 50^{th}, and 95^{th} percentile human models. It was noticed in the simulations that unlike the 5^{th} percentile human model and 50^{th} percentile Hybrid-III models the heads of the 50^{th} and 95^{th} percentile human models struck the roof/windscreen of the compartment model. The head of the 50^{th} percentile human model struck the roof/windscreen following rebound from the frontal airbag. Due to the rebound from the airbag the head contact with the roof/windscreen was of relatively low severity as indicted by the low head injury risk predictions obtained for this model run discussed later. In contrast the 95^{th} percentile human model struck the roof/windscreen as it went forward into the airbag and experienced a much greater predicted head injury risk. The predicted head strikes with the roof/windscreen were partly attributed to the 50^{th} and 95^{th} percentile human models' spines that experienced a large amount of rotation about the vertical axis, which allowed the unrestrained shoulder and head to move further forward with respect to the compartment. This was found to be greatest in the 50^{th} percentile human model as shown in Figure 4. In comparison there was very little vertical spine rotation in the 5^{th} percentile human model and no noticeable rotation in the 50^{th} percentile Hybrid-III model.

A further factor contributing to the head strike was that the pelvis's of the 50^{th} and 95^{th} percentile human models translated rather than penetrated into the seat during the impact and the pelvis of the models (though more so in the 95^{th} percentile human model) rotated over the top of the lap belt, so elevating the position of the head within the confines of the compartment model. This was coupled with a considerable amount of stretching in the thoracic and cervical spines of the 50^{th} and 95^{th} percentile human models. In contrast the pelvis's of the 5^{th} percentile human and 50^{th} percentile Hybrid-III models penetrated into the seat and dropped under rather than rotated over the lap belt and experienced considerably less stretching in the spine. This point is emphasised by the differences in the peak seat loads predicted for the 50^{th} percentile Hybrid-III model and the 50^{th} percentile human models, which were respectively 9.0 kN and 2.3 kN.

Injury predictions: The injury predictions from the models were normalised to allow for the different injury tolerances of the various occupant sizes. The normalising process was based on the experimental data gathered by Mertz *et al* (2003). It was determined from this work that in order to normalise the injury risk of a 5^{th} percentile occupant to that of a 50^{th} percentile occupant the HIC_{15}, chest deflections, neck extensions, and lap belt loads should be scaled by 0.9, 1.96, 1.22 and 1.37 respectively. Comparable scaling factors determined for a 95^{th} percentile occupant were respectively 1.04, 0.75, 0.9 and 0.84. Although predicted HIC_{36} rather than HIC_{15} was obtained from the models in this present study it was still considered more meaningful to use the proposed scaling factors for HIC_{15} than compare absolute head injury risk predictions for the various occupant sizes. No additional normalisation was made to allow for differences in the behaviour of human and Hybrid-III dummy model responses.

Figure 5 provides the percentage difference between the normalised predictions from the human body models against those predicted by the 50^{th} percentile Hybrid-III model. It shows that all the 5^{th} percentile human model's predictions of injury risk, with the exception of neck extension were at least 50% lower than those predicted by the 50^{th} Hybrid-III dummy model. The predicted neck extension for the 5^{th} percentile was 13% greater than that of the 50^{th} percentile Hybrid-III dummy model. It was unexpected to find that the lap belt load for the 95^{th} percentile human model was 64% lower than that predicted by the 50^{th} percentile Hybrid-III dummy model. Further examination of the model animations and predictions attributed this response to the fixed anchorages defined for the restraint systems in the model. Moving the seat backwards for the 95th percentile human model run placed the belt buckle in a more vertical alignment with its anchorage point. During the model run the belt buckle rotated a greater amount about its anchorage point for the 95th percentile model run than it did for the other occupant sizes. This effectively introduced additional belt slack into the belt system and limited the loads through the lap belt. All other analysed injury predictions for the 95th percentile human model were above those predicted by the 50th percentile Hybrid-III dummy model. Higher neck extensions for the 50th and 95th percentile human models were found to occur at the initial stages of the heads' contacts with the inflated airbag. Chest compression for the 50th percentile human model was over 50% greater than that predicted by the 50th percentile Hybrid-III model. Overall it was implied from the model's predictions that the injury risk for a 50th and 95th percentile human models is greater than that of a 50th percentile Hybrid-III dummy model. In contrast, the overall lowest injury risk was predicted for the 5th percentile human model.

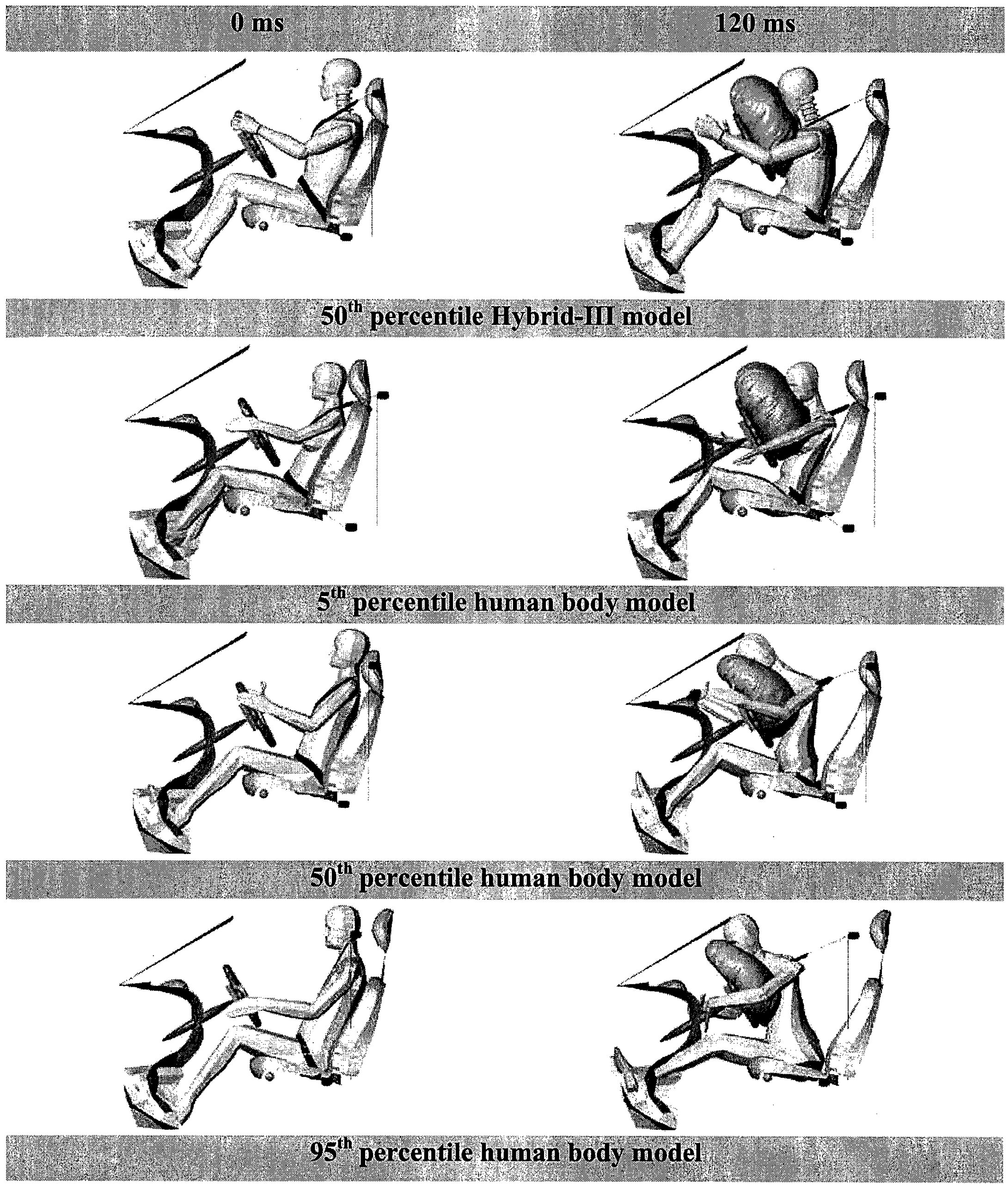


Figure 3. Frames from the animations of the 50th percentile Hybrid-III and 5th, 50th and 95th percentile human body models for the midi-MPV EuroNCAP simulated impacts (baseline model runs).

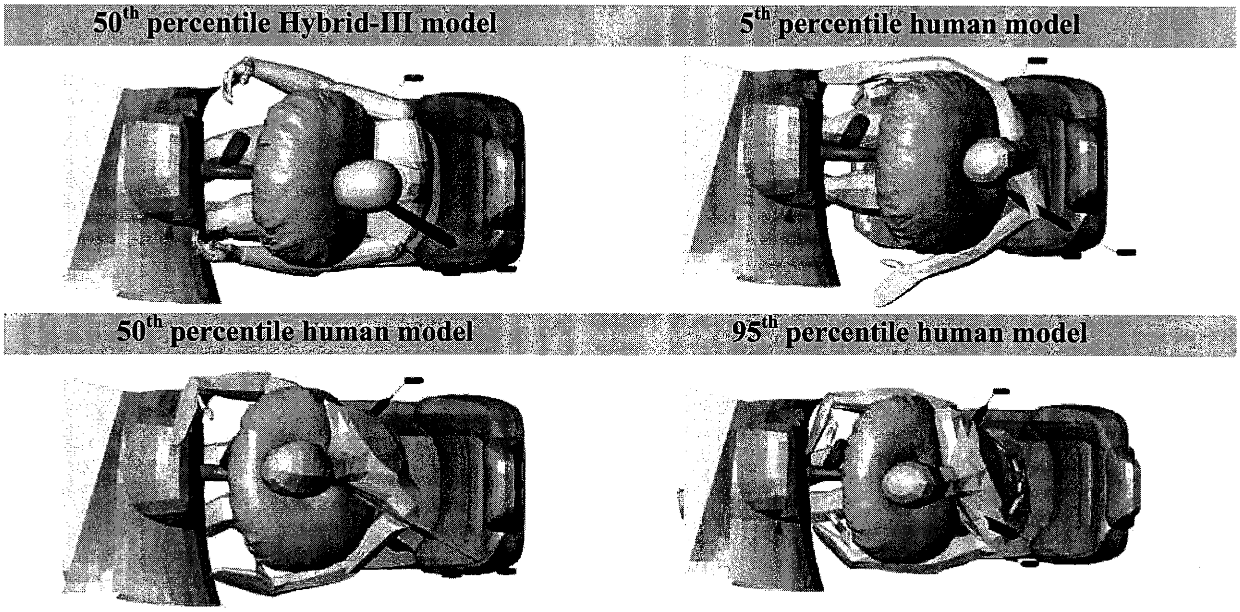


Figure 4. Observed differences in the rotations experienced by the spines of the 50th percentile Hybrid-III and 5th, 50th and 95th percentile human models for the midi-MPV EuroNCAP simulated impacts (baseline model runs).

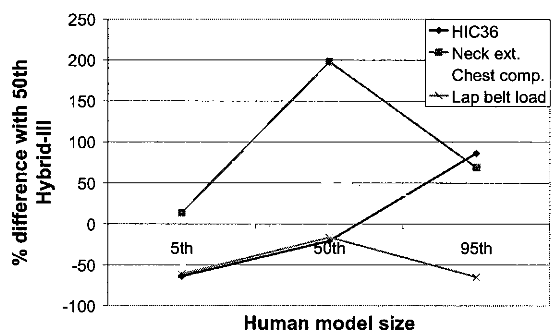


Figure 5. Percentage differences in the injury predictions from the 5th, 50th and 95th percentile human models against those of the 50th percentile Hybrid-III dummy model for a EuroNCAP simulated impact.

<u>Reclined 95th percentile driver -</u> *Occupant kinematics*: In the initial seated posture the shoulders of the reclined 95th percentile human model were behind the upper anchorage leading to a poor fit of the diagonal belt across the chest as characterised by a considerable gap between belt and chest (Figure 6). Similar poor belt fits were observed for reclined front seated passengers in the PRISM '*Passenger Pre-Impact Response Study*' of Morris *et al*, (2005). The head of the reclined model was also initially lower than that of the comparable baseline 95th percentile human model shown in Figure 3. In contrast to the baseline 95th percentile human model, which slides across the seat, the pelvis of the reclined model initially submarined into the seat penetrating it 15mm more than that of the baseline model. The underside of the dummy struck the submarine bar, which led to a high seat contact for the reclined model compared with that of the 95th percentile baseline model response. The pelvis rotated anti-clockwise as viewed in Figure 6, over the lap belt and subsequently the head of the reclined occupant was driven upwards into the roof/windscreen of the compartment. As a consequence of the relatively large amount of initial belt slack the reclined model moved further forward in the seat during the impact and this led to the upper part of the abdomen striking the lower part of the steering wheel possibly increasing the injury risk to the abdomen. Furthermore, there was less vertical rotation of the reclined modelled spine compared with that of the baseline 95th percentile model run. This is evident by comparing the top view of the reclined model in Figure 6 with the comparable image in Figure 4.

Injury predictions: As shown in Figure 7 the HIC, neck extension and lap belt load of the reclined occupant were over 70% greater than the equivalent injury measures predicted by the baseline 95th percentile human model. The lap belt load for the reclined model was 242% greater than that of the baseline 95th percentile model. This was attributed to the greater forward excursion of the reclined model in the seat during the impact. However, the difference in the chest deflection for the baseline and reclined occupant models was less than 4%. Based on these predictions it would appear that reclined occupants experience a greater risk of injury in an impact.

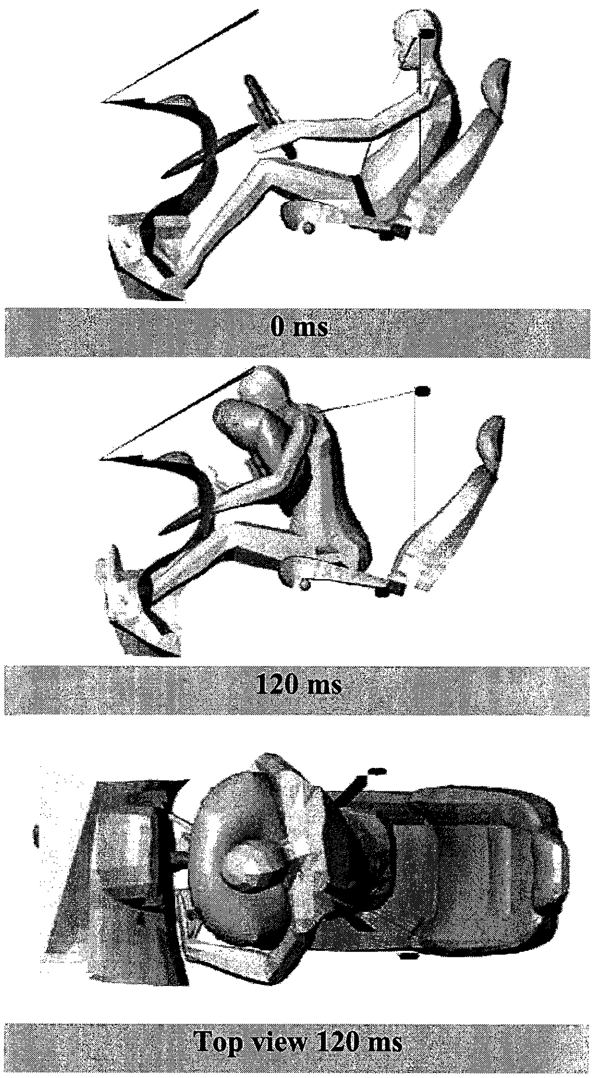


Figure 6. Frames from the model run investigating the influence that a reclined posture has on the predicted injury risk from a 95th percentile human model

<u>**Occupant bracing**</u> - *Occupant kinematics*: The simulated bracing response delayed the forward excursion of the 50th percentile human body model by up to 25ms. Furthermore, the penetration of the braced occupant into the compartment seat was 10mm (25%) more than the seat penetration predicted for the baseline model run with no simulated occupant bracing. No other obvious differences were noticed in the response of the braced and baseline 50th percentile human model responses.

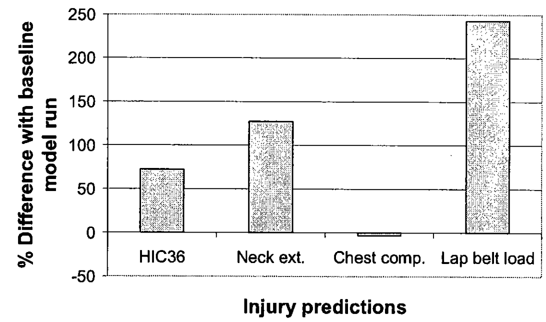


Figure 7. Percentage differences in the injury predictions from the reclined 95th percentile human model against those of the baseline 95th percentile human model.

Injury predictions: All investigated injury predictions from the braced 50th percentile human model were between 5 and 20% greater than those obtained for the baseline 50th percentile human model (Figure 8). It was implied from this set of results that bracing in an impact, which is not considered in the current setup of regulatory and consumer impact tests, appears to increase the injury risk to an occupant.

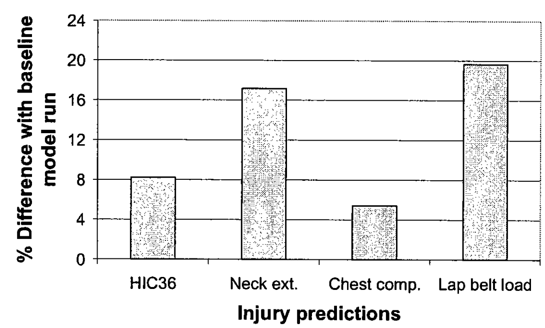


Figure 8. Percentage differences in the injury predictions from the braced 50th percentile human model (1 kN limited arm load) against those of the baseline 50th percentile human model.

<u>**Thoracic fracture**</u> – *Occupant kinematics*: For all three model runs in which thoracic fracture was simulated the abdomen of the 50th percentile human model contacted the lower part of the steering wheel. Based on these predictions it is implied that thoracic fracture could increase the possible injury risk to the abdomen. This could have been anticipated due to the additional belt length added to the restraint system during the simulated impacts. No further differences in the kinematics of the model runs simulating thoracic fracture with those of the baseline model run were observed.

Injury predictions – With simulated thoracic fracture all HIC_{36} predictions were slightly higher than the predicted HIC_{36} from the baseline 50th percentile human model run (less than 5 % difference as shown in Figure 9). Both neck extension and lap belt load were lower for the thoracic fracture model runs by between 3 and 15% and 5 and 23% respectively. Although differences in the chest deflections were less than 5% this set of results was obsolete for this particular investigation as the objective was to investigate the influence that a fracture in the thoracic body region might have on the injury risk to other regions of the body. As such it could be expected for this set of model runs that the chest injury risk for the thoracic fracture model runs was already greater than that for the baseline 50th percentile human model run. The lower predicted belt loads for the model runs imply that there was a reduced injury risk to the abdomen, possibly counteracting the increased injury risk brought about by the contact of the abdomen with the steering wheel as discussed above. Based on these predictions it was not possible to suggest if thoracic fracture would have an increased injury risk to body regions other than the thorax.

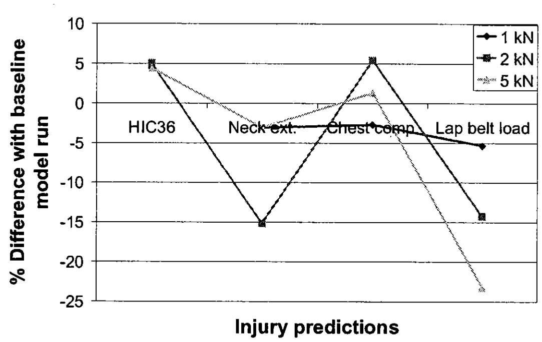


Figure 9. Percentage difference in the injury predictions from the thoracic fracture response model runs with those predicted by the baseline 50th percentile human model run.

Results – Restraint system adaptations for different occupant sizes

The adaptations made to the parameters of the modelled restraint system and the subsequent injury predictions from the occupant models in the parameter model runs were visualised using the 'snake view utility' in ADVISER, as shown in Figure 10. This figure shows how three adaptations made to the setup of the modelled restraint system (black lines) influenced the predicted injuries from the 95th percentile occupant model. The blue line provides the setup and outputs from the 95th percentile occupant model for the baseline model run with no restraint system adaptations. The magnitude of values set for the adapted restraint system parameters is indicated by the black vertical lines in the left hand side of Figure 10 and the magnitude of the occupant model's injury predictions is provided in the red vertical lines on the right hand side of the figure. As can be appreciated, the snake view provides an instant overview of the influence that variations in model inputs have on model predictions. For this investigation the snake views were used to provide an instant indication of the adaptations of the modelled restraint system that provides the lowest overall occupant injury risk. It is indicated from the example of the results obtained for the 95th percentile occupant model shown in Figure 10 that increasing the load limiting level is the dominant parameter in mitigating the overall injury risk for the 95th percentile human model. However, despite the high load limiting force levels and corresponding high belt forces predicted for the 95th human model the chest injury risk is decreased with respect to the baseline simulation.

The predicted ISS for the baseline and best adapted restraint systems for the 50th percentile Hybrid-III and 5th, 50th and 95th percentile human body models is given in Figure 11. The greatest reduction in predicted ISS is achieved for the 95th percentile human model, with a reduction of up to 65% from the baseline situation in which there is no restraint system adaptation for occupant size. A major point contributing to this reduction in predicted ISS was that the best performing adaptation to the restraint system prevented the head of the 95th percentile human model from impacting the roof/windscreen of the compartment (Figure 12). It was found in the PRISM '*Accident Data Study*' that similar roof/windscreen head strikes to those predicted by the baseline model runs do occur. As such it is indicated from the models' predictions in this work that adaptations could be made to the setup of the restraint systems to prevent head strikes with the roof/windscreen.

Predicted ISS for the 50th percentile human model was reduced by approximately 50% and minor reductions in injury risk were achieved for the 5th percentile human model and the 50th percentile Hybrid-III dummy model. The low reduction in the injury risk to the 5th percentile human model was possibly a consequence of the low initial injury risk for this model in the baseline case, as shown in Figure 5. Low reductions for the 50th Hybrid-III dummy model could be expected on account of its exclusive use in assessing the performance of restraint systems in current regulatory and consumer impact tests.

The current parameter adaptation study of the modelled restraint system has investigated a relatively limited (50 in total) set of variations in the set up of the modelled restraint system in order to mitigate injury risk for a variety of occupant sizes. There are additional configurations of the restraint system that could yield greater reductions in the predicted ISS. In this respect the current parameter study provides an improved rather than an optimized restraint system solution for each occupant size. Even so, based on the reduction of predicted ISS for all four scenarios (5th, 50th, 95th percentile human models and 50th Hybrid-III dummy model), it is implied from the models' predictions that if the restraint systems could be adapted to the most optimal setup for the particular occupant, "smart" restraint systems could considerably improve overall occupant safety. The compartment models developed in the PRISM study could support the optimisation of such systems.

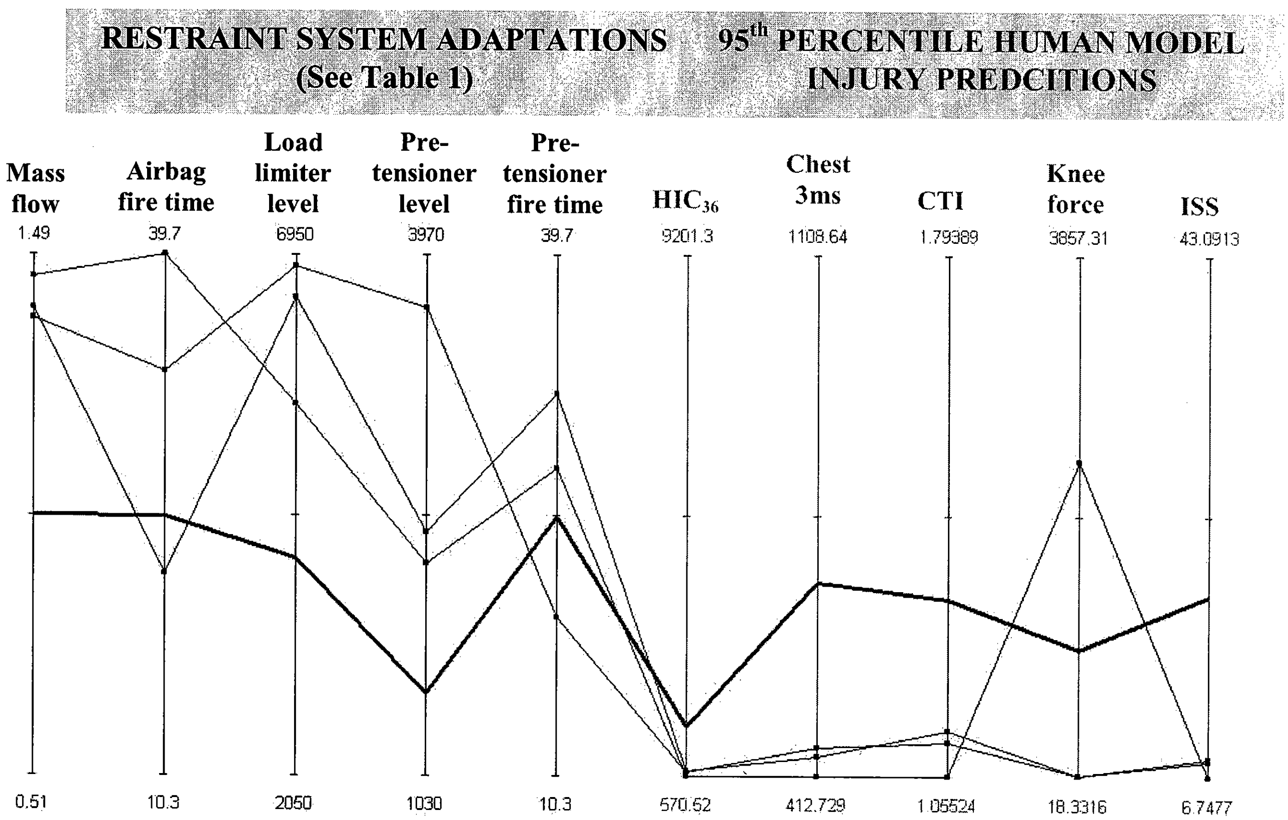


Figure 10. Example results from the restraint system adaptation model runs completed with the 95th percentile human body model. Baseline restraint system parameter values and the 95th percentile human model's injury predictions are indicated by the blue line.

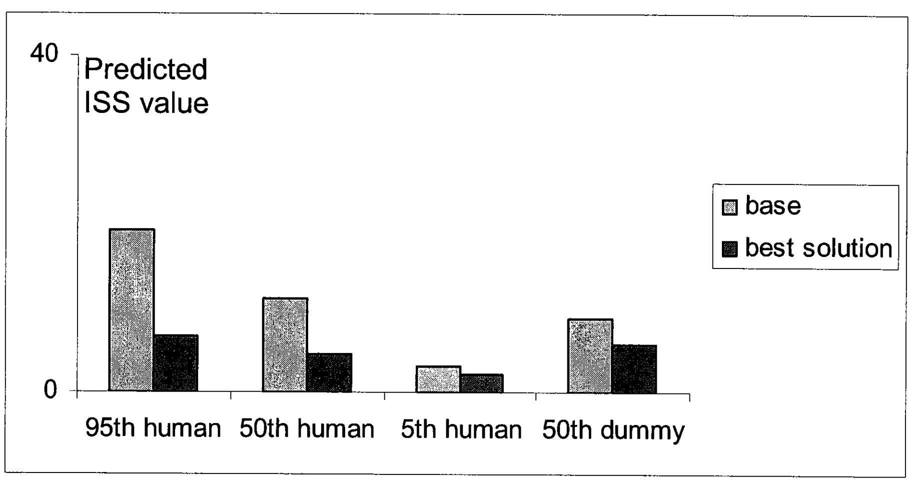


Figure 11. Comparison of the overall injury risks predicted for the baseline simulations and for the best adapted restraint system for each occupant size.

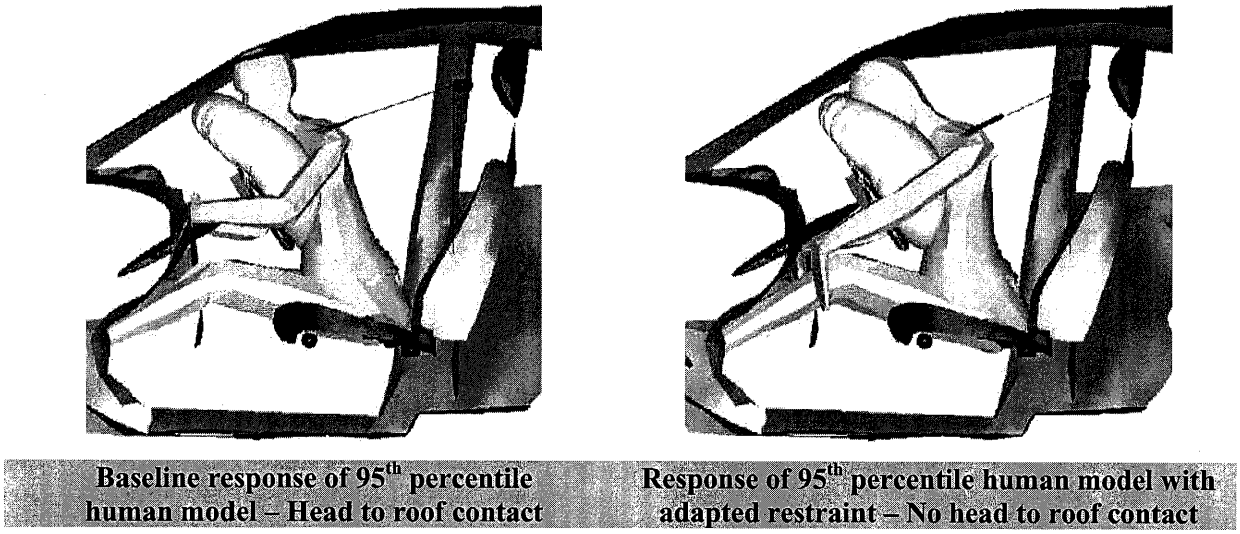


Figure 12. Baseline response and adapted restraint system response of the 95th percentile human model.

DISCUSSION

It is implied from the models' predictions in this work that there are wider circumstances influencing injury risk that are not considered in current regulatory and consumer impact tests and that "smart" alterations of the restraint system could be made that could reduce the injury risk for all vehicle occupants.

With respect to comparisons of the predictions from human and dummy models it has been found that the responses of human models are very different from those of a 50th percentile Hybrid-III dummy model. If this observation is consistent with expected behaviours in real accidents this emphasises the concern that restraints may be optimised for the responses of dummies and not humans. This is supported by the fact that predicted injury values for the 50th and 95th percentile human models in this work were greater than those of a 50th percentile Hybrid-III dummy model. Unexpectedly, the predicted injury risk for the 5th percentile human model was lower than that of the 50th percentile Hybrid-III dummy model despite contrary evidence in the published literature. For instance, McCarthy *et al* (2001) found that greater injury risk is associated with older vehicle occupants, heavier taller males and smaller lighter females. In view of these findings it was proposed by them that "smart" restraint systems would prove most beneficial in protecting these occupant groups. It is anticipated that the low injury predictions for the 5th percentile human model obtained in this work are the result of an ideal initial seat posture for the 5th percentile human model shown in Figure 3. In practice, and evident from the PRISM '*Photographic Study*' (Bingley *et al,* 2005), smaller female occupants are more inclined to lean further forward and therefore increase their injury risk in an impact. This issue will be investigated further in future work within the PRISM project.

Increases in injury risk were also predicted by the models if the reclined position of the seat is increased and the occupant braces in an impact. In addition to the variations in occupant size and differences predicted in the injury risk of human's compared with dummies, these factors would appear to be additional points that could or should be considered in the response of a "smart" restraint system. However, especially in the instance of simulating the braced occupant response, a basic modelling approach has been adopted to represent this behaviour in the model. This effectively delayed the impact of the occupant with the airbag but neglected to consider how additional bracing actions such as muscle tensing affect injury risk. The predicted increased injury risk with occupant bracing found in this study could therefore be an inherent feature of the occupant model or the manner in which bracing was represented in the model. Similar conclusions could be made about the manner in which thoracic fracture was represented in the models. In the predictions from these model runs it was not clear if thoracic fracture would promote an increased injury risk in alternative body regions other than the thorax. It is considered that further modelling work could be completed to investigate in greater detail how these factors influence occupant injury risk.

Similar parameter studies to those presented here have been completed by other researchers investigating the influence that occupant size and mass has on injury risk and how adaptations to the setup of the restraint system could be made to reduce predicted levels of injury risk (Happee *et al,* 1998b, Iyota and Ishikawa, 2003 and Holding *et al,* 2001). Holding *et al* (2001) obtained predicted reductions of up to 41, 18 and 23% in HIC_{36}, chest acceleration and chest compression respectively, by varying seat belt anchor height, pre-tensioner stroke, load limiter maximum force and airbag size and vent area, for a family of Hybrid-III dummy models. They went on to substantiate some of these predicted improvements in restraint system performance in sled tests with 5^{th}, 50^{th} and 95^{th} percentile Hybrid-III dummies with standard and adapted restraint systems. Similar levels of improvement in restraint system performance have been observed in the predictions from the models used in the work described in this paper.

In the earlier modelling studies presented above, the investigators also considered greater variations in occupant size to the conventional 5^{th}, 50^{th} and 95^{th} percentile body proportions considered in this present study. They investigated, in simulated vehicle impacts, the injury risks to occupants with tall and thin and short and squat proportions, and found that the scope of the injury risk problem is greater than that associated with conventional dummy proportions. In the work of Iyota and Ishikawa (2003), it was found that even with adapted restraint systems for 5^{th}, 50^{th} and 95^{th} percentile Hybrid-III dummy models investigations with occupant models having a different body mass index to the conventional body proportions could still experience an elevated injury risk. These findings support the need to optimise the restraint system properties to the individual requirements of the occupant proportions and should not be restricted to standard 5^{th}, 50^{th} and 95^{th} percentile dummy sizes. Furthermore, this links with the important issue that adapted or "smart" restraint systems should not compromise the safety of occupants whose characteristics are different from those on which the restraint system have been adapted for.

In contrast to the previous work discussed above, the PRISM study has so far limited investigations to the injury risk to 5^{th}, 50^{th} and 95^{th} percentile body sizes. However, unlike the previous studies this present work has concentrated on investigating adaptations that could be made to the setup of the restraint system to mitigate the injury risk to various sizes of human rather than dummy occupant models. It has been found, based on model predictions only, that the human response is very different from that of a dummy. Consequently adapted "smart" restraint systems and conventional passive restraint systems should manage the injury risks associated with real occupants and not those of dummies. In the restraint system adaptation study presented here it is important to remember that improvements in restraint system performance were gauged with an overall body injury risk criterion based on a predicted form of ISS. Therefore, in addition to the models' predictions the adapted restraint systems determined in this work are dependent on the applied overall injury risk approach. The setup of the adapted restraint systems for instance could be different from those determined in the work presented here if a different overall injury criterion or different types of predicted injury criteria were used to assess overall injury risk.

In comparison to the Hybrid-III dummy model it was found that the human models used in this study predicted greater chest compression, greater flexibility and stretching in, the lumbar, thoracic and cervical spine, and greater rotation in the spine about the vertical axis, increasing the likelihood of the restrained shoulder rolling out of the belt. These observations match those made by Happee *et al* (2000). Although this overall behaviour subjectively appears more biofidelic than that of the dummy model there are still uncertainties concerning the accuracy with which it predicts the response of real occupants. It is anticipated that the dynamics of the human model are more exaggerated than those of a real human and this should be considered when interpreting the results of this study. One particular concern arising from this work was the unexpected response of the pelvis to rotate over rather than submarine under the lap belt. This appeared to contribute to a considerable amount of bending in the lumbar spine of the human model. It is possible that the positioning of the belt anchorages and low initial position of the lap belt over the abdomen could have accounted for this behaviour. However, an additional feature noticed in the kinematics of the human models was that the lap belt was found to sit forward of the modelled pelvis. This is possibly due to a relatively stiff Hybrid-III pelvis characteristic defined for the human model in the lower pelvic region, as described by Happee *et al* (2000). In the actual impact conditions it is expected that the lower abdomen would deform more than was observed in the human models, to the point where the lap belt would be firmly engaged over the bony structures of the pelvis, such as the iliac wings. Further simulation work would be needed to clarify the significance of this response on the model's behaviour, especially in the region of the pelvis. However, extensive validations of the human model's predictions have been made against volunteer and Post Mortem Human Surrogate test data (Happee *et al* 2000 and 1998a). In this earlier work it was found that the human models do exhibit many comparable biofidelic responses.

CONCLUSIONS

Under the European 5^{th} Framework project PRISM, two numerical studies have been completed using a midi-MPV compartment model that has been developed to investigate the value of "smart" restraint systems in mitigating occupant injury risk. The first of the numerical studies investigated the influence that the following variables have on driver injury risk: occupant size, the reclined position of the seat, the bracing response of the driver and the influence that thoracic fracture has on the injury risk of other body regions. The object behind this numerical study has been to determine the importance of these variables in the operation of "smart" restraint systems to mitigate occupant injury risk. It is necessary to place caution on the interpretations that can be made on the models' predictions, but in consideration of this the general conclusions of this study were as follows:

- A MADYMO compartment model of a generic European midi-MPV with conventional restraint system has been developed.
- Predictions from the compartment model compare well against comparable EuroNCAP injury crash data.
- The human models demonstrate a greater amount of flexibility in the spine and a very different crash response to a 50th percentile Hybrid-III dummy model. This predicted difference in the behaviour of human and dummies may need to be considered in the performance of "smart" restraint systems.
- For simulated EuroNCAP frontal impacts the pelvis's of the 50th and 95th human models rotated over rather than under the modelled lap belt. The pelvis of the 50th percentile Hybrid-III and 5th percentile human body models submarined the lapbelt. This was possibly due to variations in the positioning of the lapbelt across the different occupant models or a factor associated with the modelled stiffness of the pelvis for the human models.
- Predicted injury risks for the 50th and 95th percentile human body models were in general greater than those predicted by a 50th percentile Hybrid-III dummy model for EuroNCAP impact conditions.
- Predicted injury risks for a reclined 95th percentile human model were greater than those for a comparable non-reclined occupant model.
- It was predicted by the model that occupant bracing would increase occupant injury risk.
- There were no obvious indications in the models' predictions that fractures in the thoracic body region would significantly influence the overall injury risk of other body regions.

Overall, it is predicted that "smart" restraint systems should consider in their performance the impact response of humans and not those of dummies. The reclined posture of the occupant and their bracing response would also appear to be additional factors to consider in the performance of a "smart" restraint system.

The second simulation study was performed to assess alterations that could be made to the modelled restraint system to adapt its performance to better protect different occupant sizes. It was concluded from the model's predictions in this study that considerable reductions in occupant injury risk can be achieved if the restraint system is adapted to the responses of different sizes of occupant. In this particular study a 65% reduction in overall predicted injury risk was achieved for the 95th percentile human body. It is proved by this work that the compartment models of the PRISM project could be used to support investigations optimising the performance of "smart" restraint systems to consider a wider variety of accident variables.

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KISS – A universal approach to the development and design of occupant restraint systems

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Abstract

Current passenger cars offer an assemblage of complex systems for the protection of occupants in different accident configurations. The adaptivity of the systems will widen in the future, i. e. the systems will be adapted to offer optimized and increased protection for different occupant classes during serious crash situations. This will lead to an augmentation of system complexity. Only through an intensive application of CAE based methods is one able to a) chose the appropriate system components and b) assess and optimize the interaction of the latter to fulfill the requirements.

The competence of developing and assessing new features is one of the core tasks of car manufacturers. To satisfy this demand, Audi and Volkswagen started the KISS (**k**ey competence **i**ntegrative **s**afety **s**ystems) project. The main goal of KISS is to increase the development and assessment competence of occupant restraint systems throughout the complete development process, which consists of the actual vehicle, the occupants, the restraint systems, sensors, airbag control unit and the algorithm which is implemented to control the deployment of protective measures.

Because KISS kicks in at the very beginning of the development process when essential properties are yet to be defined and boundary conditions are still fluid (e. g. package, system architecture,...), KISS is able to lay the groundwork for an effective and – concerning its complexity – controllable occupant restraint system. Along with conventional car and occupant simulations FEM crash simulations can also be increasingly used for the optimized placement of crash sensors and the computation of sensor signals. Using modern mathematical methods of signal classification, these signals are utilized to generate a first implementation of a crash classifying algorithm. Using stochastical and statistical methods the robustness of a solution can be assessed in a qualified way long before hardware for tests is actually available.

The universal and integrative design of the system is driven by the requirements. Starting with the global request “Protect each occupant as well as possible in each crash situation” one can derive different requirements for the restraint systems, the control unit, the sensor system and the crash algorithm. KISS enables considerable acceleration of the entire development process.

The realisation of new, innovative systems is only possible in close collaboration with system suppliers. A structured approach based e. g. on the V-model starts with a detailed analysis of the requirements to be satisfied. Based on these requirements different solution concepts are created. One of the concepts is finally chosen and implemented. Despite the different focus of car manufacturers and system suppliers in the development process, it is crucial to build up overlapping areas of expertise and competence to jointly develop innovative, robust and cost-optimized solutions.

The following presentation gives a survey of the content, the interaction of the processes and technologies used in the KISS project and their impact on the future role allocation between OEM and system suppliers.

Introduction & approach

Today’s vehicle safety systems are characterised by high levels of functionality and more and more demanding product requirements. In some cases, this leads to very complex systems. For this reason, it is difficult to adapt existing systems to new requirements or to guarantee a sufficient degree of quality from the outset of a new development.
When using traditional, hierarchical and purely deterministic developmental methods, the necessary development requirements are inordinately dependent upon:

- the number of requirements
- the number of functions
- the degree of complexity

This is especially true of vehicle safety. Over the last few years, vehicle functional requirements have increased significantly, both in scope and complexity. And there is no end to this rapid development in sight. On the contrary, it is anticipated that the number of requirements will rise significantly. Passive safety is a particularly good example that can be used to illustrate how functional requirements have increased over the last few years (Figure 1).
A paradigm shift in the approach to product development appears inevitable, without which the dramatic increase in development costs and resources (development effort) cannot be countered.

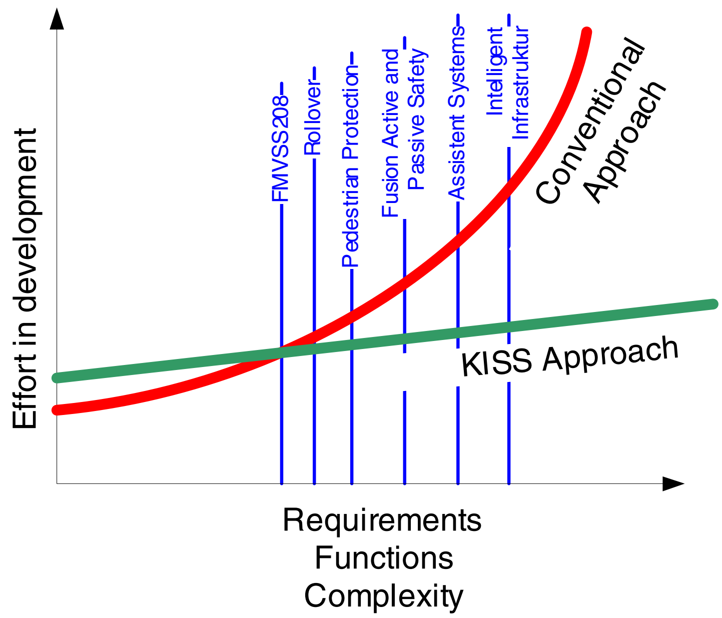

Figure 1: Development effort vs. increasing requirements, functions and complexity.

The solution

As part of the scope of the KISS (**K**ey competence **I**ntegrative **S**afety **S**ystems) project, new technologies are to be introduced to the development process in order to check the disproportionate increase in development effort and secure control over system complexity. This will take place by way of:

- an increased use of process models within the development process for mechanical components and control software, with a view to creating a targeted and requirement-driven approach,
- the application of modern mathematical modelling techniques from the field of multi-variant data analysis and soft computing as a means of containing and maintaining control over complexity, and
- the application of stochastic processes for robustness management and for the handling of uncertain data.
- the rethink of the allocation and understanding of roles between OEM and suppliers.

No one person alone is able to make the breakthrough suggested by the above. Only a targeted, requirement-driven and suitably integrated implementation can produce the desired effect.

Organisation structure and role allocation

When looking at the occupant restraint system from a systematic, global perspective "Intelligent control" should be considered as a separate component. It is of crucial importance since it drives the functional integration of various hardware components (sensors and actuators). This is what we would call a key technology, and the essential element needed to meet current and future requirements.
A logical consequence of this is that the OEM takes on this task as a core competence of global system integrator.
Only the OEM is in the position to implement "intelligent control" calculations and associated mathematical evaluation models within the early concept-led development phase, and thus do justice to its integrative nature. Future requirements cannot be fulfilled efficiently without the active, constructive integration of algorithms and mathematical control models within overall system development. Thus, competence in control logic is a decisive factor in being able to maintain control over the increasingly complex systems of the future.

This need will be intensified by the increasing heterogeneity of electronic hardware and further separation of hardware and software. Open databus systems and increased integration of all different kinds of control systems (active and passive safety) will mean that integrative capabilities will increase in importance.
In particular, topic areas such as sensor fusion, which has been the subject of intense discussion, will not be able realistically to be implemented without such core competences. On the other hand, this will not mean a decline in the importance of the system supplier. Instead, a new kind of partnership is required, characterised by a greater intensity and improved quality. The OEM shall supply concept proposals and requirements to the system supplier in a much more professional and homogenous form, thus improving the basis for fine-tuning and final implementation.

Process models and requirement management

A process-based control of disparate functions and high levels of complexity require new approaches to the development process, which will be driven by software technology.

Over the last years, formal process models have become more established. There are two reasons why. Firstly, because of a need to improve Quality Assurance measures in the development process. Secondly, through the use of synergies - the extensive reuse of similar process models in development processes. Examples of these include the *object-oriented development methods* or the *V-model.*

These process models have a number of variants, which, aside from their detailed attributes, have more or less the same basic structure: first of all, an intensive **requirement analysis** is carried out and a requirement model is created. Based on this model, one or more concepts for the **system blueprint** are developed. The chosen concept is then constructed in a **system development phase** and fed into the concrete **implementation** process.

It is important here that the process begins with a thorough requirements analysis which will then be used to drive development. This may sound like common sense but it is not always applied in practice. In fact, often the exact opposite is true:
For existing systems, new requirements are only implemented incrementally without having carried out a proper requirements analysis and without sufficient examination of the effect on the global requirements complex. Development is driven by the solution which is already in place, avoiding all but the most essential changes. Many innovations stand alone from the global system, on the level of individual components. This means that system development is component-driven, in other words by a detailed technical solution, often without sufficient assessment being carried out of its impact and weighting within the system as a whole.
The above procedures are pragmatic, you may say feasible for simple, well-known systems. When complex systems are involved, the cumulative effect of looking at requirements on an incremental basis is often underestimated or not considered at all. There is then the danger of finding oneself at the end of an ill-conceived trial and error scenario.

Today, where a requirements analysis is carried out at all, it often consists of nothing more than a simplistic, more or less structured collection of requirements in a database or Excel file. Occasionally, a specialised tool (such as DOORS) might be used to collate requirements.
Object-oriented software development technology takes this a stage further by modelling the requirements with UML for example, and generating code (proposals for technical realisation) directly from the requirement models. This enables requirement conflicts to be identified earlier.

A similar requirements analysis can also be carried out for mechatronic systems. Requirement conflicts can be detected and resolved very early on in the development process. This can be achieved by representing the functional requirements of a mechatronic control system's classification module in mathematical form, using concrete examples from the planned behaviour. Multivariate statistical methods, such as cluster analyses, can be used to reveal conflicts between required firing times for certain sensors for example. This also works when explicitly taking into account tolerances and uncertainties.
Requirement management becomes more than filling out checklists. Instead, it is a constructive, engineer-supported development tool that is far more than just an approval criteria applied retrospectively.

Mathematical modelling

The control algorithms are the essence of all "intelligent systems" and are described using mathematic models. By using a suitable mathematical formulation for each requirement, statistical regression can be used to derive the mathematical model for the implementation of the control task: with the proviso that any requirement conflicts are resolved first.

This procedure is universally applicable, and not just limited to the current crash classification. The creation of mathematical models to describe systems cannot only be applied directly to control systems, but also aids the decision-making process during development. It will bring about a similar wave of innovation, as numerical simulation for virtual product development once did in the design of structures.

The required mathematical basis has been fully developed and is readily available. Methods such as

- Multivariate data analysis,
- Statistical regression and prediction models,
- Fuzzy logic,
- Neural networks,
- Machine learning,
- Stochastic validation

will be used on a more broader basis in the future as development tools, and not only by specialists.

The way tasks are created for signal classification can be applied universally, and is also applicable to many other applications. A general classification framework in the middleware of embedded systems will no longer just be a dream. Today, a classification object library could be created allowing the processing of sensor signals to be standardised for simple sensors. The functionality would be then provided by parameterisation alone, while preserving full-scale individualisation of vehicles.

Example of application

The following concrete example is used to illustrate the KISS approach. At its core are the requirements, which drive development. Figure 2 shows the basic structure of the requirements of a restraint system with the scope of passive vehicle safety.

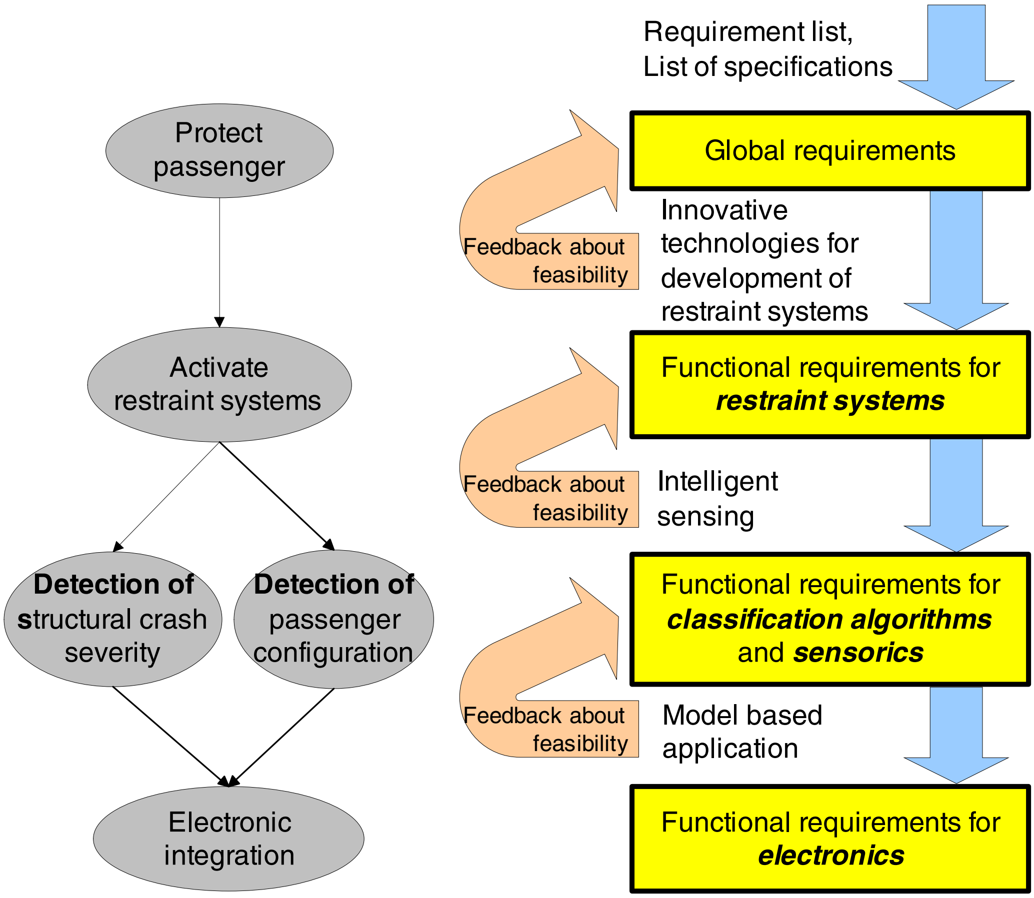

Figure 2: Requirement structure for passive safety

The upper requirement level represents the **general, global requirements**. These determine which crash scenarios vehicle occupants must withstand without serious injury, which legal standards must be met and which market requirements must be taken into account, etc.
Out of these come the technical concepts for the restraint systems: **the functional requirements,** e.g. an adaptive airbag is required to meet certain global requirements, etc.
This must then drive the selected components of the restraint system. Next come the **requirements of the control system,** e.g. that the airbags must be fired at certain, pre-defined times when a crash occurs. In turn, this requires appropriate control electronics to be installed which enable real-time realisation of these classification requirements. Thus, the firing time is a functional requirement of the control algorithm, which follows from technical realisation via a specific airbag!

In KISS up to now, the second layer used to set up the detection algorithms and sensor systems was revised on the basis of the functional requirements of the restraint system. The functional requirements of the restraint systems, such as the requisite trigger times for actuators on the basis of pre-defined sensor signals were represented using examples (crash tests and/or simulations). Using multivariate data analysis, requirement conflicts for firing times can be detected quickly and, above all, on a statistically quantifiable basis, before being fed back into restraint system design. Appropriate

statistical regression methods are then used to derive the mathematic models for signal classification from the models of requirements for restraint system control.
The objective here is to create a universally-applicable framework for a classification algorithm, in which the quasi-automatically generated classification modules can be integrated seamlessly.

In principle, the same methodology can also apply to the level of functional requirements of the restraint system. The lowest requirement level will be represented in future using model-based applications or through the availability of appropriate control unit middleware. In the future, excessive specialised knowledge of embedded programming will no longer be a prerequisite for the application of intelligent control algorithms.

At present, the requirement structure shown in Figure 2 is a reflection of the organisational structure of the car manufacturer. Each requirement level is usually handled by a separate organisational unit. As a result, a great deal of time passes before a response can be received concerning technical feasibility after an additional global requirement has been implemented. This is because all requirement levels must be considered in turn. The new technology in KISS, coupled with a reduction in response times on a sensor systems requirements level, opens up an opportunity to establish a vertical, project-based organisational structure. In the future, this structure will enable the processing of all requirement levels within a very small time frame. Based on this, qualified concept assessments can be submitted.

Integration into the V-Model

At present, the V-model is the standard method used for the development of embedded software in cars. Accordingly, the development steps described above must be adapted to this standard. Figure 3 illustrates the V-model as applied to KISS.

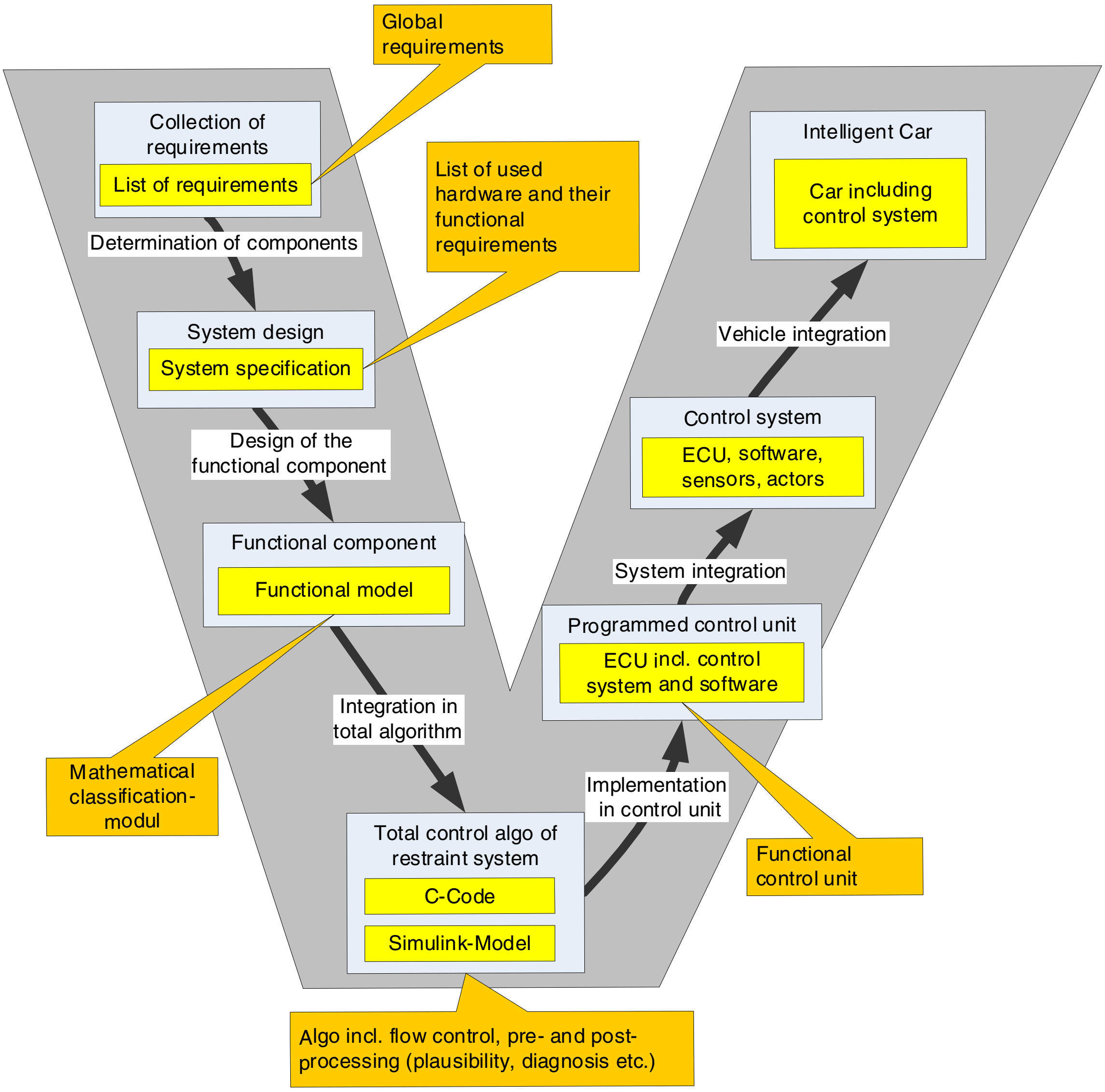

Figure 3: V-Model

First of all, a **system analysis** is carried out in the form of a **requirements analysis** with the resultant **system design** (=concept). This may be used to determine the requirements (using examples of load cases) which actually need to be fulfilled, followed by the number and type of restraint devices to be fitted to the vehicle. This is normally carried out by the appropriate technical department for the development of restraint systems. The result is a list of functional requirements (airbag firing times)

which are represented as concrete examples (test and/or simulation data) depending on the project phase.
Next, the system requirements are converted into the **functional components,** which are used to control the individual actuators. The result here is a mathematical classification module that is generated on a quasi-automated basis, e.g. to control the side airbag deployment or the second level of an frontal airbag. The technical department for restraint systems may also be in charge here. This department applies the methodology to continuously verify the functional feasibility of its firing requirements. The technical department for vehicle structural design can also use this methodology to verify sensor settings. The final implementation model for the functional components can then be fine-tuned by the technical department for algorithm and control logic, for example. This department integrates the functional components within a **global algorithm for the control of restraint systems** and adapts the individual functional components to their overall effect. The global algorithm is created in standardized form as an algorithm model which is independent of final hardware implementation.
The validated global algorithm model serves as a reference and template for the **implementation within the control unit**. Only at this stage is the actual hardware to be used to be considered in greater detail. The system supplier adapts the referential algorithm to his hardware and optimises runtime and memory space requirements accordingly. Correct implementation can be verified using implementation tests with specified input and output behaviours for pre-defined test cases. The system supplier is responsible for integrating the control unit into the overall electronic infrastructure with the associated sensors and actuators. At the end of the process, the vehicle manufacturer will approve and integrate this into the vehicle.

These days, much of the time and effort is concentrated on the right-hand branch of the V-model. A reason for this lies in the technical status of embedded systems, for which software must be programmed in very close proximity to hardware requirements. This means a large adaptation effort is often required even for minimal changes. These days, electronic details play any extremely important role, and in some cases can even influence the system concept. In future, the databus used for sensor communication must not be important for a restraint system. The architecture of the trigger logic should be almost entirely independent of such an electronic configuration.
In future, software and hardware will be to a large extent separable from each other. The operating systems and middleware required here (programming language for embedded systems) are already in development and will be available in the next few years. The right-hand branch of the V-model can for the most part be implemented automatically. This releases the energy required to address the left-hand branch more intensively. This is essential for further development since for the most part the quality of the whole system is already determined in the first two blocks of the V-model. At present, these blocks are given insufficient attention on account of the predominately solution-based and requirement-driven approach currently in existence.

Validation and safeguard strategies

In the future, validation and system safeguarding will assume a more important role than at present.

In the main, this applies to the functional level of mathematical system models used to assure the functionality of control and classification modules. Considering the number and great variety of requirements this task is by no means an easy one. Increasing functionality means it is almost impossible to thoroughly test all combinations in the time available, let alone within a hardware test (Each discrete new function compounds the number of possible system configurations). Stochastic validation methods and probabilistic approaches will be the best tools to assure system functionality.

In addition, the aim here is also to assure the underlying design data, which in future will be principally taken from numerical simulations. In order to prevent problems from arising, these simulation data must be subjected to quality checks. The stochastic nature of the underlying problem (a crash is not deterministic) means that stochastic validation methods are also well suited here.

Formal validation will become more important due to new role models with supplemental/modified process interfaces. A high degree of validation is required to enable conceptual designs/ requirements to be transferred in qualified form.

Summary

As an element of the KISS project, a key design concept has been drawn up for the future development process of intelligent control systems. The following points can be summarized in this regard:

- “Intelligent control” has been identified as a key factor in controlling vehicle safety systems which are likely to increase in complexity in the future. As a result, a greater focus will be placed on taking this into account early on in the development process.
- It will become increasingly important to consider system development on a holistic and integrated basis.
- System modelling using modern mathematical methods represents the underlying core technology. This can be applied directly on a control unit level and also used to aid decision-making processes within development.
- The use of KISS not only means that parts of a classification algorithm are taken on by the OEM, but represents an entire paradigm shift in the whole development process. The resulting benefits come about through a targeted combination of:
    - example-based methods
    - an object-orientated approach
    - use of stochastic methods and other soft computing methods

- The organisational scope for targeted use is provided by software technology with formal approach models, such as object-orientated development methodology or the V-model.
- The development process should always be driven by requirements and not by already available technical solutions.
- A requirement-driven process structure means that development is also driven from the state brought about by the requirements. In general, this is the design of the restraint system and not the electronics.
- This methodology can be integrated seamlessly into the V-model.
- The car manufacturer can concentrate on the left branch of the V-model. In other words, on core themes cost and quality determiners.
- The right branch of the V-model is the remit of the system supplier of the electronic control systems.
- The interface between the vehicle manufacturer and system supplier can be a global standardised algorithm model, which can become the open industry standard. The differentiation on account of function is provided by the functional modules. These can automatically be generated using suitably edited requirement data based on practical examples.
- The result of intensive cooperation between the OEM and system supplier will be an improvement in quality.

Conclusions and outlook

Continuing to use the approaches within KISS will result in the following scenarios for the future:

- The methodology will be extended across the level of requirements made of the restraint system (vertical expansion). In other words, in future this methodology will also be used more intensively in the development of the restraint system itself, not only on the sensor system/algorithm level.
- The methodology will also be applied to other applications, perhaps making use of synergies within sensor evaluation (horizontal expansion and sensor fusion). An example here is the fusion of active and passive safety.
- In the foreseeable future, the right-hand branch of the V-model will become more standardized using better hardware, common operating systems, suitable middleware for embedded systems and the resultant increase in automation. The separation of hardware and software will make it possible to concentrate on the real function of control tasks, of the formulation of the “intelligence” within engineering, without being strongly limited by electronic hardware realisation.
- Generally speaking, existing control tasks are universally applicable. For this reason, the form of the classification module can become the standard, which will be applied universally in the middleware of the software of all control units.

- Driven by requirements, vertical, project-orientated organisational units can realise prototypes of intelligent control systems within a very short period of time.
- The OEM can direct most of its attention to the concept and system design phases within the development process, where quality and cost considerations are decisive.

STRUCTURAL ENERGY ABSORPTION TRENDS IN NCAP CRASHED VEHICLES.

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ABSTRACT

The ANCAP (Australian New Car Assessment Program) have been conducting offset frontal crash tests into a deformable barrier since 1995. During this time the results of the ANCAP tests have shown significant improvements in occupant protection measured via reduction in dummy injury measurements, i.e. HIC, chest ‘g’, etc.

Occupant protection has improved with manufacturers designing structures to minimise the occupant space intrusion with the aim to have the crash energy absorbed by deformation of the frontal vehicle structure. Also new restraint technology has been included along with the vehicle structure designed to optimise the restraint technology.

Previous analyses have questioned whether changes in the vehicle structures and restraint technology have changed the loads either in the occupant compartment or on the front seat belts. The previously analysis of ‘B’ pillar accelerations and also the front seat occupant seat belt loads for frontal crash tests performed by ANCAP from 1995 through to 2003 showed that while the dummy injury measurements have reduced there has not been a corresponding reduction in either ‘B’ pillar accelerations or seat belt loads.

This result was surprising given the occupant gains made through this period. It is possible that the regulatory and consumer crash tests and scoring parameters are such that vehicle engineers find it more efficient to optimise the restraint systems without significantly engineering the crumple zone.

However, the previous study did show small improvements in 'B' pillar decelerations in the small car segment (i.e. kerb weight of up to 1250kg). This study used data from other consumer crash test programs to add to ANCAP data to allow for analysis of a greater number of vehicles. This will be used to identify trends in energy absorption performance in the small car fleet.

The 'A' pillar displacement was used as an indication of load paths and also occupant cell structural integrity. The longitudinal acceleration time traces for driver side ‘B’ pillar will be used to represent the loads on the vehicle structure and correlated with seat belt loads and dummy acceleration measurements. It is intended to determine if crumple zones have been optimised with respect to the restraint system timing.

INTRODUCTION

From 1995 ANCAP included a 40 % offset frontal crash into a deformable barrier in accordance with the test protocols developed by the EEVC in 1993. This test was initially conducted at 60 km/hr, which was the speed for the proposed European regulations.

However, ANCAP increased the crash test speed to 64 km/hr to be consistent with both the US IIHS who also started conducting consumer crash tests at this speed in 1995 and the developing Euro NCAP program.

This study has used the results of 128 passenger vehicles crash tests from both ANCAP and the US IIHS. Unfortunately, Euro NCAP data was not able to be obtained in time to be included in this analysis.

During the time of the offset frontal crash tests conducted by ANCAP (and other NCAP groups) there have been significant improvements in the level of occupant protection in passenger vehicles. This has been shown by the driver dummy injury measurements that have improved from over 1000 HIC and 44 mm of chest deflection to less than 300 HIC and 21 mm of chest deflection.

The benefits of a consumer crash test program has been demonstrated through both the introduction of vehicles with safety technology that exceeds the minimum regulatory requirement and also through international studies showing cars that perform better in crash tests provide better occupant protection than vehicles that perform poorly in crash tests.

The improvements in occupant protection shown in laboratory crash tests have also been experienced in the real world. A study by Farmer [5] in 2004 found "a driver is 74% less likely to die in cars rated good than cars rated poor in car to car head on crash of two cars of similar mass."

Similarly Lie and Tingvall [6] found "cars with three or four stars are approximately 30% safer than cars with two stars."

Studies conducted by Monash University Accident Research Centre [7] concluded that vehicles that performed well in crash tests provided higher levels of safety on Australian roads.

B-PILLAR PEAK ACCELERATIONS

Gradual changes have occurred B-pillar peak deceleration have occurred in NCAP crashed vehicles over the last 12 years. The driver's side B-pillar accelerations are used for an indication of the acceleration experienced by the occupant compartment. The driver's side is chosen because this side impacts the deformable barrier in the offset frontal test, generating higher loads than the passenger's side.

In the offset frontal test a tri-axial accelerometer is mounted on both the driver's and passenger side of the vehicle at the base of the B-pillar near the seat belt anchorage.

For the assessment of B-pillar performance the longitudinal acceleration, Gx, was chosen as this was consistently measured by ANCAP since 1995. Additionally, Gx should give an indication of the performance of the vehicle's structure.

To determine if there was any variation in vehicle structural performance that may result in any significant variation in driver's side B-pillar peak acceleration an analysis of the results was undertaken. Gx was plotted against both year of manufacture of the tested vehicle and also the test mass.

The graph of vehicle test mass vs. Gx, Figure 1, showed a scatter around a line that trended upwards from approximately 30g at 1050kg to approximately 37g at 2050kg.

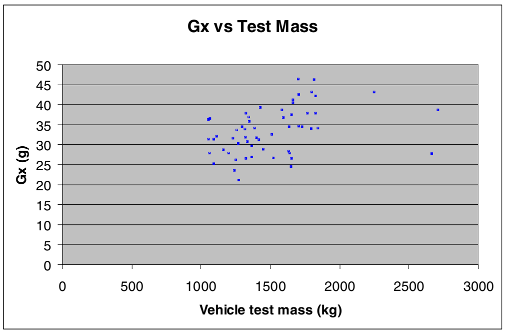

Figure 1. Driver's side Gx verses test mass – all vehicles

Similarly, the plot of YOM against Gx, Figure 2, also showed a small upward trend.

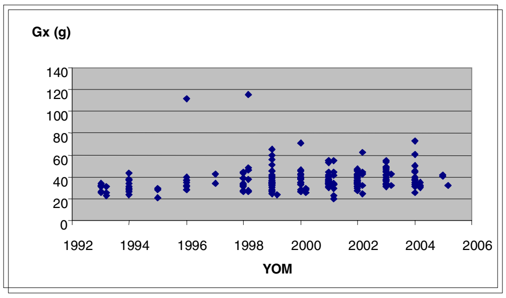

Figure 2. Driver's side Gx verses Year of Manufacture – all vehicles

A regression analysis was conducted with the following results:

- Gx vs. YOM $y = 0.6047x - 1170.9$
- $r^2 = 0.0259$

A review of the high-speed film of some tests indicates that the Gx occurred when the test vehicle bottomed out on the barrier. This is more prevalent with the larger cars.

The analysis conducted did not show any significant change in B-pillar accelerations, or time of maximum acceleration with either YOM or mass of test vehicle.

VEHICLE CATEGORIES

As there was not any significant change due to either year of manufacture or test mass when considering all vehicles, the data was reviewed by vehicle category, i.e. large, medium and small. These are the test categories used by ANCAP and are based on vehicle mass.

Below are the plots of year of manufacture verses Gx for small (Figure 3), medium (Figure 4) and large cars (Figure 5).

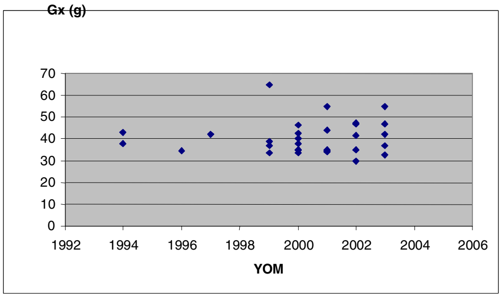

Figure 3. Drivers Gx verses Year of Manufacture - Large Cars

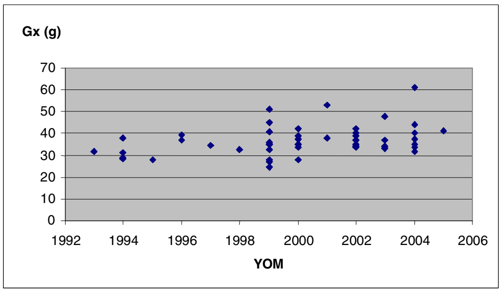

Figure 4. Driver's side Gx Vs Year of Manufacture - Medium Cars

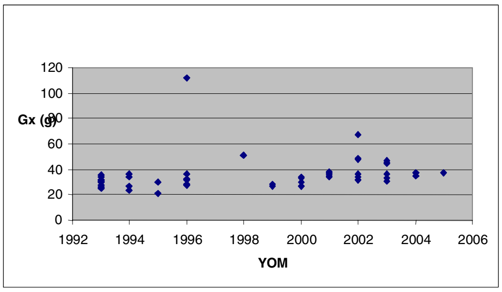

Figure 5. Drivers side Gx Vs Year of Manufacture – Small Cars

Each of these categories showed an increase in maximum Gx with Year of Manufacture. The regression analysis showed the following trends and correlations.

Large cars: $y = 0.2027x - 365.03$
$r^2 = 0.0039$
Medium cars
$y = 0.778x - 1519.5$
$r^2 = 0.1304$

$y = 0.6239x - 1210.8$
$r^2 = 0.0357$

It is likely that the increasing average weight of the vehicles has an effect on these results.

Both the small and medium car segments showed a discernable trend towards increased Gx with later model vehicles.

A-PILLAR DISPLACEMENT

The second part of the paper examines the driver's side A-pillar displacement. Again vehicles from both ANCAP and IIHS tests have been used for this analysis. A total of 128 results were used; 19 large cars, 63 medium cars and 44 small cars.

The A-pillar displacement is used as a measure of structural integrity in vehicles post crash. Vehicle design since the beginning of consumer crash test programs have focused on improving the integrity of the occupant compartments.

Due to lack of data in some tests results from all tests are not able to be used and consequently the number of vehicles analysed in this section will not directly correspond to the number of vehicles analysed in the first part of the paper.

Passenger Cars

The analysis began with considering the A-pillar displacement of all passenger cars against both test mass and year of manufacturer (YOM).

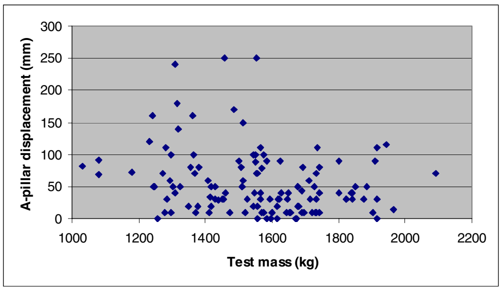

Figure 6 Test mass verses A-pillar displacement for all passenger cars.

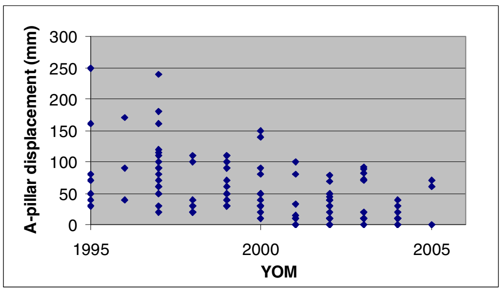

Figure 7 Year of Manufacture vs A-pillar displacement for all passenger cars.

The above graphs show while there is a downward trend with reducing A-pillar displacement with YOM there is no discernable trend between test mass and A-pillar displacement.

A correlation analysis was undertaken with the following results;

- test mass; r^2 = - 0.24
- YOM; r^2 = -0.49

Similar analysis was conducted for large, medium and small passenger cars to consider if these same trends were throughout the range of vehicles tested or if the trend was more prominent in one particular vehicle category.

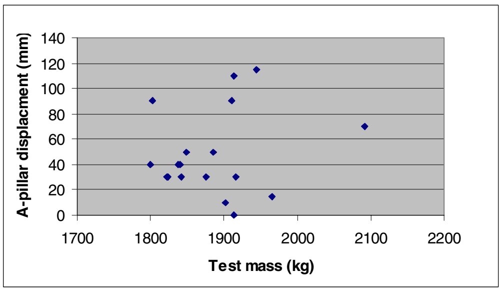

Figure 8 Test mass verses A-pillar displacement for large passenger cars.

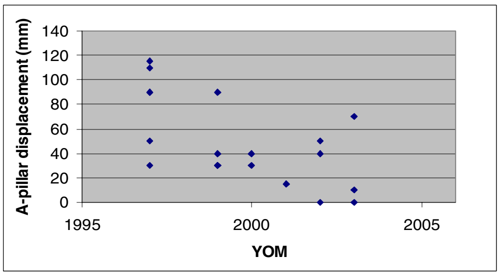

Figure 9 Year of Manufacture verses A-pillar displacement for large passenger cars.

Correlation analysis results;

- test mass; r^2 = 0.17
- YOM; r^2 = -0.61

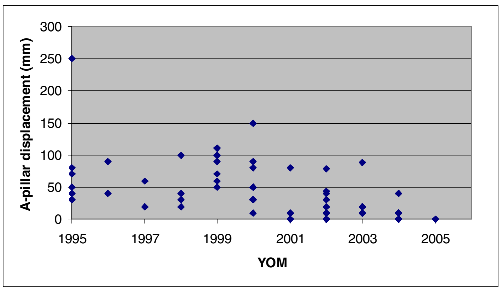

Figure 10 Test mass verses A-pillar displacement for medium passenger cars.

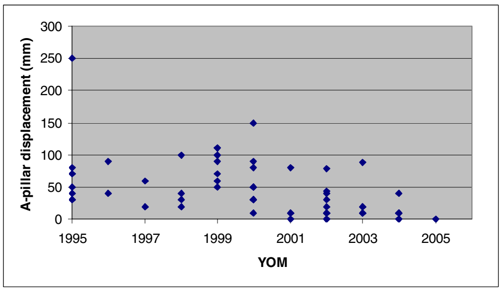

Figure 11 Year of Manufacture verses A-pillar displacement for medium passenger cars.

Correlation analysis results;

- test mass; r^2 = -0.27
- YOM; r^2 = -0.49

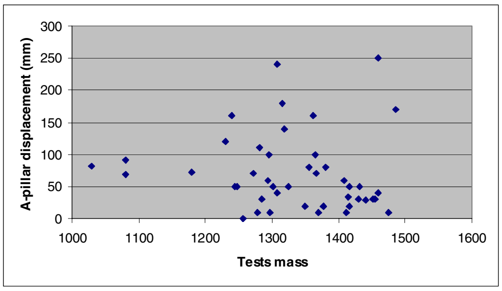

Figure 12 Test mass vs A-pillar displacement for small passenger cars.

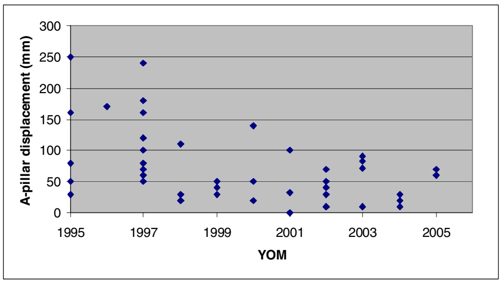

Figure 13 Year of Manufacture vs A-pillar displacement for small passenger cars.

Correlation analysis results;

- test mass; r^2 = -0.10
- YOM; r^2 = -0.48

This analysis showed the trend for a reduction in A-pillar displacement with newer cars, i.e. increasing YOM, was consistent across all vehicle classes.

There were no trends between A-pillar displacement and test mass, either when considering all passenger cars or when considering individual car categories.

Sports Utility Vehicles

A similar analysis was conducted for SUVs results from both ANCAP and IIHS. A total of 69 results were used; 23 large SUVs, 18 medium SUVs and 26 small SUVs.

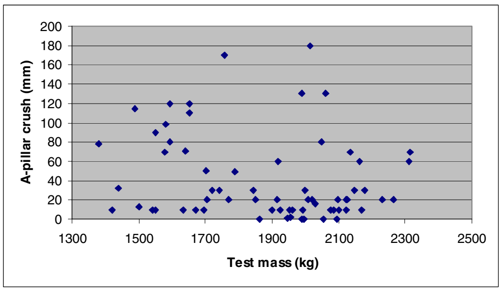

Figure 14 Test mass verses A-pillar displacement for all SUVs.

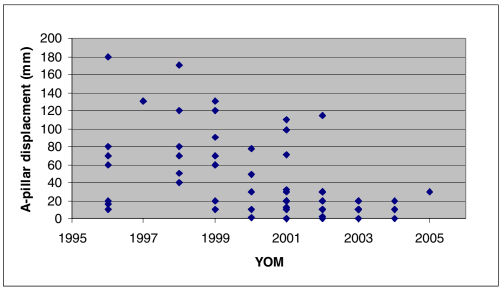

Figure 15 Year of Manufacture verses A-pillar displacement for all SUVs.

Correlation analysis results;

- test mass; $r^2 = -0.21$
- YOM; $r^2 = -0.55$

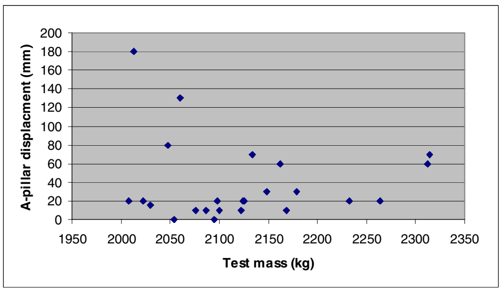

Figure 16 Test mass verses A-pillar displacement for large SUVs.

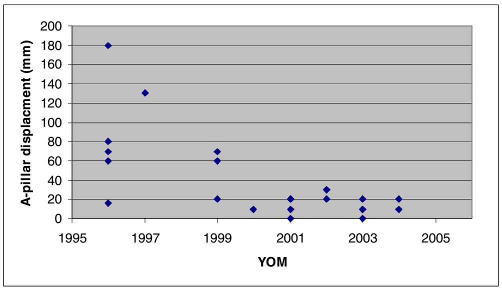

Figure 17 Year of Manufacture verses A-pillar displacement for large SUVs.

Correlation analysis results;

- test mass; $r^2 = -0.07$
- YOM; $r^2 = -0.68$

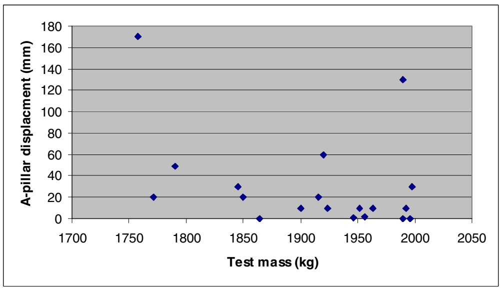

Figure 18 Test mass verses A-pillar displacement for medium SUVs.

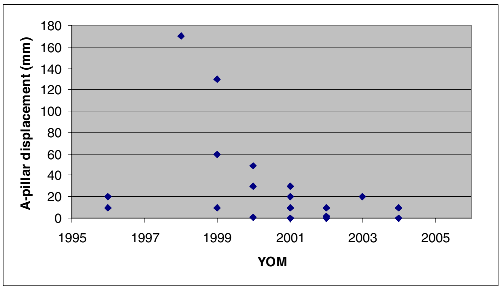

Figure 19 Year of Manufacture verses A-pillar displacement for medium SUVs.

Correlation analysis results;

- test mass; $r^2 = -0.01$
- YOM; $r^2 = -0.39$

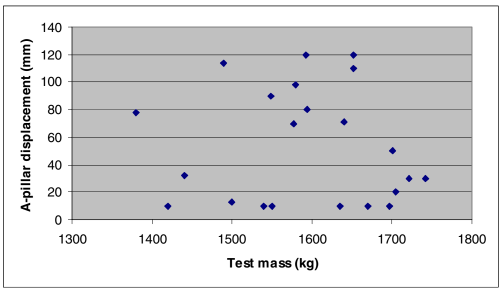

Figure20 Test mass verses A-pillar displacement for small SUVs.

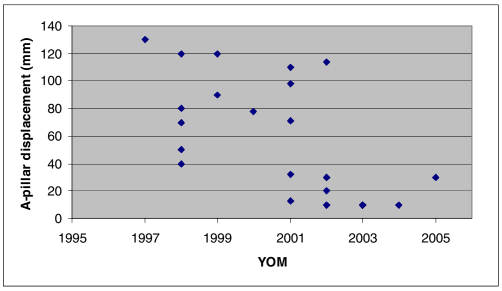

Figure 21 Year of Manufacture verses A-pillar displacement for small SUVs.

Correlation analysis results;

- test mass; $r^2 = -0.08$
- YOM; $r^2 = -0.66$

Similarly to the passenger cars, this analysis showed a trend for a reduction in A-pillar displacement for newer SUVs while test mass did not appear to influence A-pillar displacement.

DISCUSSION

The analysis of peak B-pillar longitudinal acceleration, Gx, showed an upward trend with increased test mass and also for newer vehicles. However, the regression analysis did not show any significant correlation with either YOM or mass of the test vehicle.

The analysis did show that for increasing Gx on the driver's B-pillar a corresponding decrease in A-pillar displacement. An increase in B-pillar deceleration is a good indicator of the deceleration of the vehicle in crash test and gives an indication of the stiffness profile of the vehicle.

The stiffness of the front end of a vehicle is obviously a key aspect of design not the least when a design is considered against the offset crash test. However, optimal performance in an offset crash requires a rigid front end and a strong occupant compartment that effectively absorbs crash forces.

The trend witnessed in the compiled tests indicate that, particularly in the case of small cars, that overall vehicle deceleration may be compensated for by an increased stiffness of the occupant compartments. Essentially the crumple zones are constructed less stiff than the occupant compartments they are designed to protect.

The IIHS have contended that 'manufacturers don't simply stiffen the front ends of their vehicles to perform well in offset tests. Good performance in offset crashes requires strong, or stiff compartments and front ends that effectively absorb crash forces. To achieve this result, the crumple zones need to be less stiff than the compartments' [8]. It may be that we are observing improvements in structural design to optimise for frontal stiffness to achieve desired occupant compartment rigidity.

This observation of increasing vehicle deceleration in parallel with decreasing A-pillar displacement was particularly marked in the small car category. In this case the increase in Gx may be in some way attributed to the stiffness provided to the structure to ensure that the occupant compartments where able to withstand the forces applied by impacts with larger vehicles.

The lack of correlation and variation in both Gx a could be due to limitations of the offset frontal test at 64 km/h. Offset test assesses performance of structure, i.e. how well passenger compartment retains survival space.

The offset test at 64 km/hr may result in vehicles bottoming out on the barrier prior to all the crash energy being absorbed by the frontal vehicle structure. Alternatively, this could indicate there have been only limited changes to the front vehicle structure to manage the crash energy.

This corresponds to research conducted by both the US IIHS and also NHTSA. In their 2001 study, the IIHS found no correlation between stiffness and offset structural performance of vehicles. Similarly, a 1999 NHTSA study on the US NCAP results for light trucks and vans (LTVs) found that during the 14 years of US NCAP frontal crash testing, on average, LTVs have become less stiff.

Additionally, the ANCAP crash tests have shown significant improvements in occupant protection as measured by the test dummies and also through analysis of the vehicle deformation.

The ANCAP crash tests have demonstrated that while the integrity of the vehicle passenger compartment has improved with reduction in intrusion the HIC and chest deflection measures have also reduced.

CONCLUSIONS

This paper reviewed driver side peak longitudinal acceleration and the A-pillar deformations during consumer crash tests over the period between 1993 and 2005.

This analysis showed that the deceleration levels affected on the vehicle as shown by the B-pillar decelerations is increasing. This effect is most significant in the small car segment. The fact that this corresponds also to the most dramatic reduction in A-pillar displacement reduction may indicate a reaction to compatibility issues.

These effects are likely to be still at the lower order of influence on injury outcomes at regulatory and consumer crash test speeds. It seems likely that the occupant restraint systems remain the most significant factor in reducing serious head and chest injury.

However, optimisation of front stiffness profiles and occupant compartment rigidity by vehicle mass categories may have further potential as a design approach.

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CAR DRIVER PROTECTION AT FRONTAL IMPACTS UP TO 80 KM/H (50 MPH)

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ABSTRACT

The structures of modern passenger vehicles are designed to maintain integrity up to an impact velocity of about 64 km/h (40 mph). The occupant protection system is likewise designed to efficiently protect the occupant up to an impact velocity of 64 km/h. However, there are highways with a 90 km/h (56 mph) speed limit without separation of the lanes and many car occupants still die in severe frontal crashes.

To investigate the level of occupant protection at very high impact velocity a full frontal full vehicle rigid wall crash test with a mid size passenger vehicle was carried out. The impact velocity was 80 km/h (50 mph). A 50%-ile Hybrid III crash test dummy was positioned on the driver side. The dummy results show that the possibility of survival of an occupant in that particular vehicle in such a crash was minimal.

With the goal to develop a protection system that in an 80 km/h (50 mph) crash test would result in dummy reading below the FMVSS 208 injury criteria levels a mathematical sled model was developed and a mechanical sled mock-up was set up. The mathematical model was validated by means of results from the mechanical sled tests.

To identify the parameters of the occupant restraint system with the greatest influence on the efficiency of the restraint system factorial analysis was used in which a number of parameters were varied at two levels. The parameters were preloading of seat belt, load limiting of seat belts, gasgenerator output, steering column yield distance and airbag volume.

Using the results from the factorial analysis a mathematical sled simulation and a mechanical sled test were carried out with a restraint system that was designed give reasonable protection to an occupant at an 80 km/h (50 mph) impact. The restraint system consisted of a large volume airbag, a significantly longer ride down distance than what is available in the vehicles today, diagonal and lap belt pretensioning and load limiting. Efficient occupant driver protection in 80 km/h (50 mph) full front rigid wall crash seems to be possible. However, the interior ride down distance needs to be greater than what is available in the vehicles on the market today.

INTRODUCTION

Modern passenger vehicles are being extensively tested for the ability to protect vehicle occupants in the event of a crash. Regulatory as well as rating tests are carried out all over the world. The results from these tests are publicly available and receive great attention. For the consumer the results from these tests are an important factor that influences the choice of vehicle when buying a new passenger vehicle. The impact velocities at which these tests are run have been increasing over time. The rating tests carried out at present in the US and in EUROPE (USNCAP and EUNCAP) are run at impact velocities of 56 km/h (35 mph) and 64 km/h (40 mph). It has even been proposed to run crash tests at 80 km/h impact velocity to evaluate compartment integrity [1].

The structures of modern passenger vehicles are designed to maintain integrity at an impact velocity of 64 km/h (40 mph) and lower. The occupant protection system is likewise designed to protect the occupant up to an impact velocity of about 64 km/h (40 mph). However, there are highways with a 90 km/h (56 mph) speed limit without separation of the lanes and many car occupants still die in severe frontal crashes. In Sweden alone approximately 150 fatalities occurred in frontal collisions in 2003 which is about half of all car occupant fatalities [2].

Crash protection in high-speed barrier crash tests with up to 80 km/h (50 mph) impact velocity was studied in the seventies in the Experimental Safety Vehicle (ESV) program [3]. Since then there seems to be a gap in research efforts in this area. However, recently another study was published in which different driver restraint system configurations were studied in a mathematical model with the goal to achieve interior crash protection at 80 km/h [4]. In the study potential for good driver protection in an 80 km/h frontal crash was shown. The aim of this study was to analyze the theoretical and technical possibilities to design an efficient crash safety system for the driver of a passenger car subjected to fully distributed frontal crashes at 80 km/h (50 mph).

METHODOLOGY

To investigate the level of protection the restraint system of a vehicle offers an occupant at high impact velocity a full frontal rigid wall crash test was performed. The test was run with a mid size passenger vehicle and with an impact velocity of 80 km/h (50 mph). A 50%-ile Hybrid III crash test dummy was positioned in the driver seat according the FMVSS 208 specifications.

To analyze the theoretical and technical potential to design an efficient crash safety system for passenger vehicle occupants in a frontal crash at high impact velocity models were developed. A mathematical sled model and a mechanical sled mock-up were set up based on the geometry of the vehicle used in the crash test. The mathematical model was validated by means of results from the mechanical impact sled test. In order to limit the scope of this study only the interior restraint system was analyzed.

The validated mathematical sled model was used for a parameter sensitivity analysis of the restraint system. A test matrix was created with design of experiment technique (fractional factorial analysis at two levels).

Using the results from the factorial analysis the mathematical model was modified to incorporate a restraint system that was designed to provide the occupant with protection in high impact velocities. This restraint system was also evaluated mechanically by a sled test. The mathematical simulation and mechanical sled test were carried out an impact velocity of 80 km/h (50 mph). The results were compared to the FMVSS 208 injury criteria levels.

Mechanical Full Vehicle Full Frontal Crash Test

In the mechanical crash test carried out a mid size passenger vehicle was impacting at a 0 degree angle full front into a rigid wall. The closing speed was 80 km/h (50 mph). The vehicle was equipped with a standard 3 point belt system and a driver side airbag. The initiation of airbag inflation was done by the existing sensor and triggering system in the vehicle. A 50%-ile Hybrid III crash test dummy was positioned according to FMVSS 208 specification in the driver side of the vehicle (Figure 1). In the dummy, head acceleration, chest acceleration, upper neck force, upper neck moment, chest deflection and femur force were recorded. In addition both lap and shoulder belt forces were recorded. Vehicle acceleration was measured on the tunnel, trunk and the left and right b-pillar.

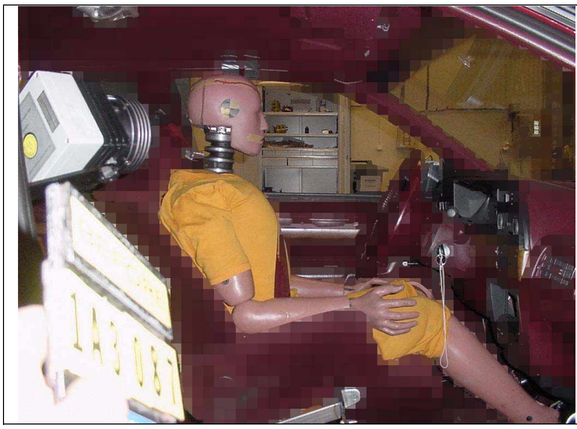

Figure 1. Occupant position in full vehicle crash Test

Development and Validation of Mathematical Model

To design and evaluate a restraint system for occupant protection at high impact velocity a mathematical sled model was developed and a mechanical sled mock-up was set up. The geometry of the occupant compartment in the mathematical model and mechanical sled mock-up was based on the geometry of the occupant compartment of the vehicle tested. The mathematical model was a multi-body dynamics model (MADYMO) that incorporated a 50%-ile HIII-dummy, a windscreen, a ceiling, a seat, a knee bolster, a belt system, an airbag, a steering wheel and a energy absorbing collapsible steering column (Figure 2). The mechanical mock-up of the driver environment was mounted on an impact sled. The mock-up was incorporating a windscreen, ceiling, seat, steering wheel with column, airbag, knee restraints and seat belt (Figure 2).

In the mathematical model and in the mechanical sled test the acceleration from the full frontal rigid barrier crash test at 80 km/h was used. However, the effect of occupant compartment intrusions was not included in the study.

The model was validated by means of results from mechanical sled tests. The predictions and results that were used for validation were head acceleration, chest acceleration, chest deflection, pelvis acceleration, femur force, belt forces, steering column yield distance and airbag pressure.

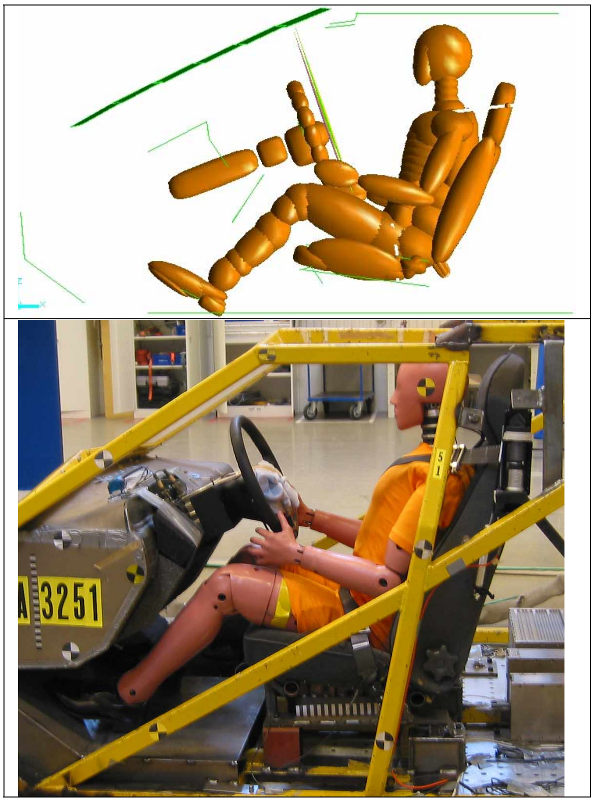

Figure 2. Principal layout of the computer model and the sled test geometry

Design of Experiments (DOE)

In order to limit the number of computer runs and mechanical tests factorial analysis technique was used to identify the restraint system parameters with the greatest effect on the dummy response. A resolution III design was chosen with seven two level variables (Table 1). A resolution III design is a fraction of the full 2^7 factorial (128 runs) namely a 2^{7-4}_{III} design that results in 7 different combinations of the variables to be tested in 8 experiments or as in this study 8 computer runs. The following layout of the test matrix was chosen. Minus sign means low level of the parameter and plus sign means high level (Table 2).

Table 1.
Design of Experiments Matrix

Variable **Run**	A	B	C	D	E	F	G	***Result***
1	-	-	-	+	+	+	-	
2	+	-	-	-	-	+	+	
3	-	+	-	-	+	-	+	
4	+	+	-	+	-	-	-	
5	-	-	+	+	-	-	+	
6	+	-	+	-	+	-	-	
7	-	+	+	-	-	+	-	
8	+	+	+	+	+	+	+	
Design pattern				A B	A C	B C	A B C	

The parameters selected for variation at two levels were airbag volume, gasgenerator output, ventilation area, diagonal belt pretensioning force, diagonal belt load limiting force, lap belt load limiting force and steering column yield force (Table 2). The alteration of the gasgenerator output was achieved by modification of the temperature of the gas.

Table 2.
Design of Experiments Variables

Parameter	-	+
Airbag volume	60 liter	72 liter
Gas generator	Original	Temp x 2
Vent area (cm^2)	1,7 cm^2	7,8 cm^2
Pretensioner force	2 kN	4 kN
Load limiter diagonal belt	5/3 kN	8/5 kN
Load limiter lap belt	3 kN	6 kN
Steering column yield force	5 kN	8 kN

A reduced factorial design always results in confounding patterns where interactions between two or several variables may result in responses that can not be distinguished from the main effects. However in this study the effect of interactions were considered to be of minor importance and have not been further studied.

Mathematical Sled Simulations and Mechanical Sled Test Based on DOE Results

Based on the results from the factorial analysis the mathematical model and sled mock-up were modified with a restraint system that was designed to restrain an occupant at an 80 km/h crash. The driver restraint systems consisted of a three-point seat belt with an upper B-pillar mounted retractor and a dual chamber 72-litre airbag mounted in a state of the art steering wheel. The seat belt system consisted of a dual stage load-limiter with a force level of approximately 5.5 and 3.5 kN. Initially prior to contact between occupant and airbag the load-limiter force was 5.5 kN and after occupant to bag contact the force level was reduced to 3.5 kN. There was no limitation to the spool out due to load limiting. In all tests there were dual pretensioning devices. One pretensioner on the diagonal belt and one on the lap belt. All pretensioners and the airbag were all fired at various times into the crash sequence. The applied pre loading force was approximately 2 kN. The quasi-static elongation of the seat belt webbing was 10% at 10 kN. The airbag mounted in the steering wheel was inflated from a tank with stored gas. The valve of the stored gas tank was opened prior to impact. Therefore inflation of the airbag was initiated before impact. The steering column had a special collapse mechanism to allow for a stroke of maximum 200 mm at predetermined force levels (in the computer model there was no restriction to the stroke). The deformable element consisted of aluminum honeycomb. The yield force of the steering column was, based on the results from the factorial analysis, set at a force level of 7 kN. Two load cells were installed to register the yield force. A reinforced standard seat was used in all tests. As string potentiometer was used to register the yield distance of the steering column. A steel plate was built in under the seat cushion in order to avoid excessive seat cushion deformation and seat chassis deformation during testing. The seat was positioned in the mid position with a 26° seat back angle. The knee bolsters consisted of energy absorbing polypropylene (density 40 kg/m^3).

RESULTS

Results Mechanical Full Vehicle Barrier Test

For the vehicle acceleration measurements the tunnel acceleration was less than 30 g until 35 ms into the crash. At 35 ms the acceleration increases rapidly to 55 g (Figure 3). Thereafter the acceleration decreases slowly until 0 which was reached at approximately 120 ms. Significant deformation of the vehicle was observed. A global dynamic deformation of the vehicle of 1,06 m was obtained. In addition there was intrusion of the firewall into the vehicle.

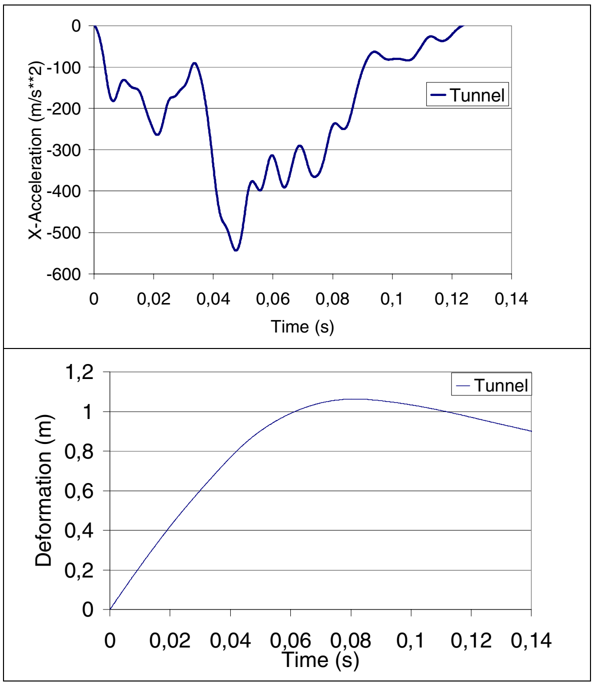

Figure 3. Vehicle acceleration and deformation

For the steering wheel there was significant displacement (Figure 4). The steering wheel intruded into the vehicle and moved upwards. In addition the wheel rotated from the initial 25 degrees to a horizontal position. The rotation started at 50 ms and at 70 ms into the crash the horizontal angle for the wheel was reached.

Due to the translation and rotation of the steering wheel the occupant was not protected by the airbag. The airbag was trapped under the chin of the occupant and the chin was pushed upwards. In addition deployment of the airbag was observed to be initiated after about 15 ms. Such rather late deployment resulted in that the pressure in the bag was not at a sufficient level to protect the occupant when the airbag was reached by the head of the occupant.

Figure 4. Steering wheel, airbag and occupant at 70 ms (computer graphics for enhanced visualization)

For the vehicle occupant all injury measures but chest deflection and femur left force were greater than the FMVSS 208 injury criteria levels (Figure 5 and 6) (Appendix A) [3]. HIC_{15} was 352% greater than the FMVSS 208 injury criteria level.

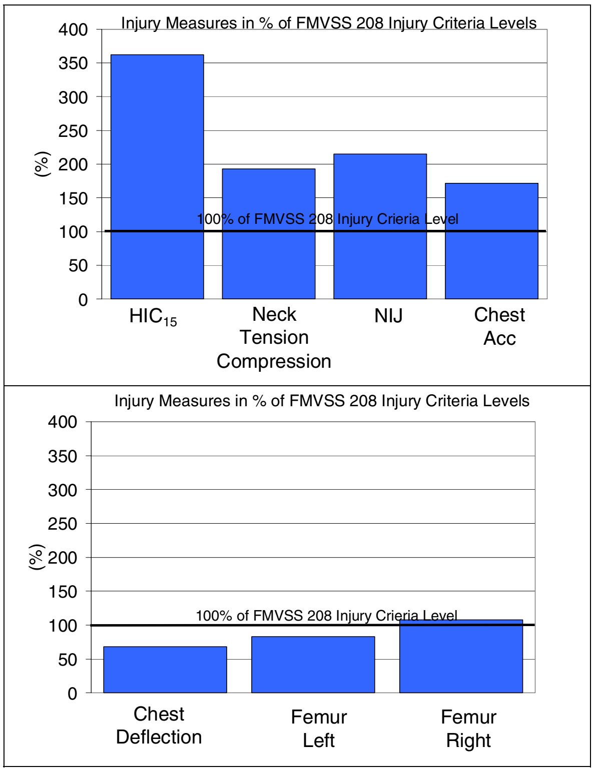

Figure 5. Injury reading in full vehicle crash test

Results Development and Validation of Mathematical Model

The mathematical model was validated by means of results from the mechanical sled tests. Generally good agreement between predictions from the model and results from the sled test was obtained.

In addition to validation at an impact velocity of 80 km/h (50 mph) the model was validated for an impact velocity of 56 km/h (35 mph).

Results Design of Experiments

In the factorial analysis it was found that the greatest effect on head acceleration was from the steering column yield force with the higher force level increasing head acceleration with 184 m/s^2 (Figure 6). This leads to the conclusion the force level in the energy absorbing mechanism is an important parameter influencing head acceleration. However, all runs with a low force level were associated with a column stroke between 230-400 mm. Since it was considered that such a stroke would be extremely difficult to realize the higher force level of 7 kN was selected to be realized in the sled tests. This force level produced strokes between 61-160 mm. The higher load limiting level in the lap belt had an effect of 84 m/s^2 in reducing the head acceleration. The lower level of force in the load limiter in the lap belt had the highest effect on the chest acceleration and reduced it with 76 m/s^2 (Figure 7). It had the second largest effect on chest deflection with a reduction of 4,5 mm. Then largest effect on chest deflection had the load limiting force in the diagonal belt with the higher force level increasing chest deflection with 7,5 mm (Figure 8). The second largest effect on chest acceleration had the load limiting force level in the diagonal belt with the higher force level increasing the chest acceleration with 72 m/s^2. The higher column force had an effect of 41m/s^2 and increased the chest acceleration but had only a minor effect on the chest deflection with an increase of 2 mm. The larger air bag decreased chest acceleration with an effect of 41 m/s^2. Taking all this information into account further computer analysis was made to design a restraint configuration that would result in dummy injury values below FMVSS 208 injury criteria levels.

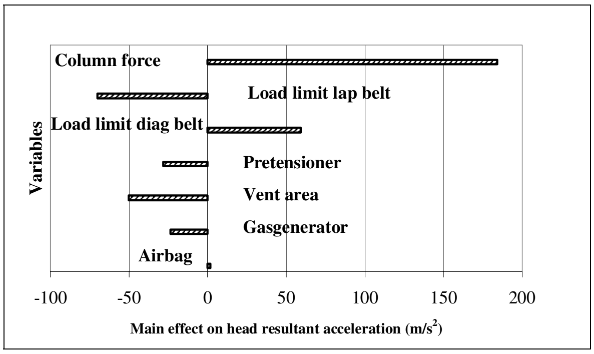

Figure 6. Effect on head resultant acceleration

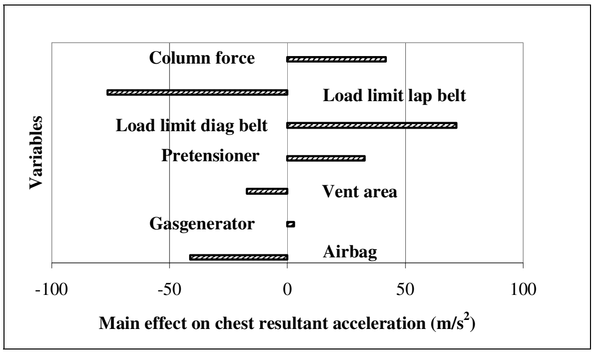

Figure 7. Effect on chest resultant acceleration

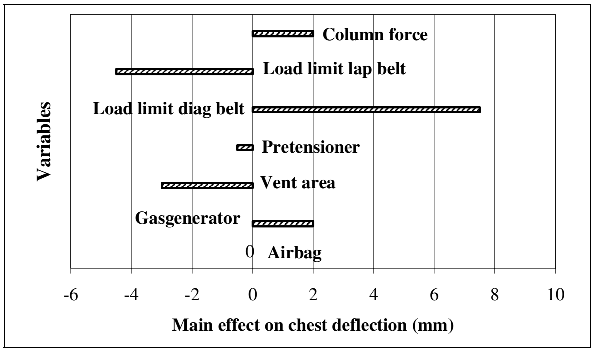

Figure 8. Effect on chest deflection

Results Mathematical Sled Simulations and Mechanical Sled Tests Based on DOE Results

The restraint system of the mathematical model was modified based on the results from the DOE to efficiently restrain a driver at an 80 km/h crash (Figure 9).

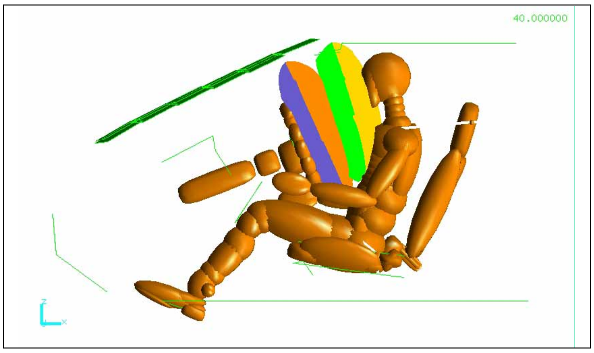

Figure 9. Mathematical model occupant kinematics at 40 ms

In the simulation with a restraint system designed to protect an occupant at 80 km/h (50 mph) the injury readings predicted from the model were all below the FMVSS 208 injury criteria levels (Figure 10). HIC_{15}, chest acceleration, chest deflection, femur right force and femur left force were all significantly lower than the FMVSS 208 injury criteria levels. In addition, steering column yield distance was 195 mm.

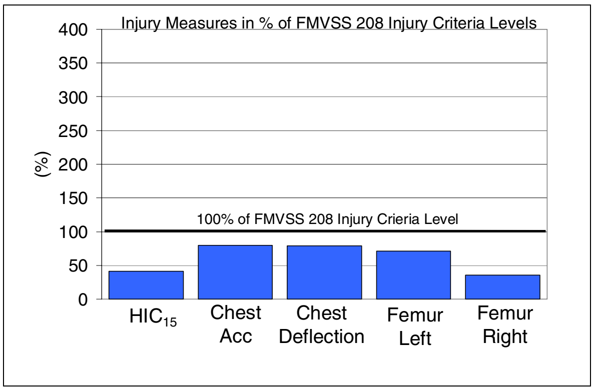

Figure 10. Injury readings in mathematical sled model

The restraint system in the mechanical sled test mock-up was also modified in the same way as was done in the mathematical model (Figure 11).

Figure 11. Mechanical sled test occupant kinematics at 40 ms

In the results from the corresponding mechanical sled tests that was mimicing the mathematical model not all injury measures were below the FMVSS 208 injury criteria levels (Figure 12). HIC_{15} and chest acceleration were somewhat above the injury criteria levels while neck tension-compression, NIJ, chest deflection, femur left force and femur right force were significantly lower than the injury criteria levels. In addition, steering column yield distance was 156 mm.

One of the reasons for the differences between the mathematical model predictions and sled test results can be that the kinematics of the airbag differed between the mathematical analysis and the mechanical test (Figure 9 and 11).

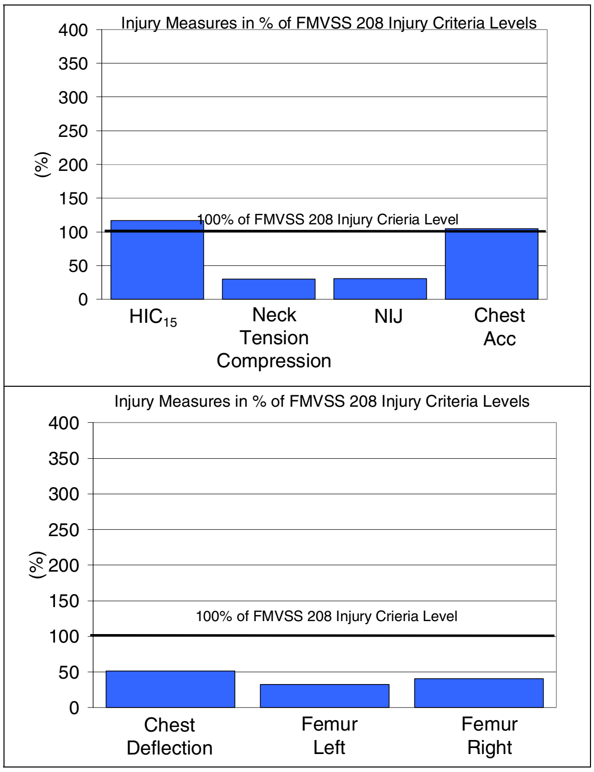

Figure 12. Injury readings in mechanical sled test

DISCUSSION

In the 80 km/h full vehicle full front crash test most occupant injury readings were above the FMVSS 208 injury criteria levels. Therefore the chance for survival of an occupant in such a crash is minimal. There were extremely high occupant injury values measured for the head, neck and chest of the occupant. The intrusion of the firewall and the intrusion of the steering wheel were likely to contribute to the high injury measures. The high neck forces were likely to be caused by the steering wheel being trapped under the chin of the occupant and the inflating bag pushing the chin upwards.

For an occupant protection system to protect the occupant at such high impact velocity the system has to be adapted to such high impact velocities. To evaluate the theoretical and mechanical potential to adapt an occupant restraint system for such high impact velocities mathematical modeling and mechanical sled testing were used. Both the compartment geometry of the mathematical occupant model and the mechanical sled mock-up were based on the compartment geometry of the vehicle tested. However intrusion of the firewall and steering wheel was not included in the study since it was assumed that the intrusion can be eliminated through design modifications of the vehicle structure.

A number of parameters which possibly influence the performance of an occupant restraint system in a crash test were studied. From the analysis of these results valuable insights were given that will be used in future work. However other parameters with possible influence on the occupant response should also be studied. The restriction on the occupant's forward displacement due to the geometry of the occupant compartment especially the upper windshield frame was not addressed. However the test at 80 km/h showed "reasonable" occupant kinematics. It is, however, obvious that the forward displacement of the occupant must be controlled in order to avoid a head contact with the windshield frame. Such a contact can result in high HIC numbers and neck loads. There are three major load carrying systems directly controlling the ride down of the dummy's thorax namely the load limiting belt, the airbag and the collapse mechanism in the steering column. The phasing-in of the functions of these systems is of importance, especially for the chest deflection, and should be further explored.

The results from the study show that with proper design of an adaptive restraint system efficient occupant protection can be achieved at both high and very high impact velocities. However, in the proposed protection system the ride down distance of the occupant was greater than what is available in the vehicles on the market today. In addition there was a very early coupling between the occupant and the vehicle through the airbag. The airbag was inflated from a tank with stored gas. A fast opening valve was controlling the flow from the tank to the airbag. Due to the slow evacuation of the tank the valve was opened prior to impact. Therefore inflation of the airbag was initiated before impact. However, it needs to be evaluated if the proposed airbag system in an 80 km/h crash can be fired after initial contact or if the airbag has to be fired prior to impact.

The goal was to define an occupant protection system that in crash testing in high velocity with an occupant would result in injury measures below the FMVSS 208 injury criteria levels. The results form the mathematical model indicated that such a system can be developed. However, in the mechanical test carried out not all results were below the FMVSS 208 injury criteria levels. One reason can be the difference in airbag kinematics between the simulation and the mechanical test. However, this need to be studied in more detail.

In addition a restraint system designed to protect the occupant at very high impact velocities can be too stiff for the occupant at low impact velocities. In addition it can be too stiff for the elderly population with lower tolerance limits. However, with proper tuning of an adaptive restraint system (belt and bag) good protection can be achieved in both high and low impact velocities.

The analysis was made with a specific crash pulse obtained from crash testing of a conventional mid-sized car. As it is well known that the crash pulse has an effect on the dummy response it is recommended to try different crash pulses and study their effect on the dummy response.

The basic configuration of the tested restraint system was advanced. However, belt force limiting devices with other characteristics and a more sophisticated energy absorbing seat structure should be tried.

CONCLUSION

- Efficient driver protection at frontal impacts up to 80 km/h appears to be reachable.

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[4] Carter, Robert L. 1972 “Passive Protection at 50 miles per hour”. NHTSA. DOT HS 810, 1972

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APPENDIX A: FMVSS 208 INJURY CRITERIA LEVELS

HIC_{15}	700
NIJ	1
Chest Acceleration	60 g
Chest Deflection	63 mm
Femur Force	10000 N

AN EXTENDABLE AND RETRACTABLE BUMPER

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Paper No. 05-0144

ABSTRACT

An extendable and retractable bumper (E/R bumper) is presented in this paper. The E/R bumper is intended to automatically extend in situations in which there is a high risk of frontal impact to prepare the vehicle for crash and retract when the risk subsides. A functional demonstration vehicle and two experimental vehicles were built with the E/R bumper. Analytical and nonlinear finite element models were used to aid in the design of these vehicles, and to predict their crash performance in full, offset and oblique impact tests. While the functional demonstration vehicle was used to study its control and operation sequences, the experimental vehicles were crashed in a 56*kph* rigid barrier impact test and a 64*kph* 40% Offset Deformable Barrier impact test. These crash tests, together with nonlinear finite element analysis, showed that the additional crush space realized by extending the bumper could reduce the severity of the crash pulse and the amount of structural intrusion to the vehicle compartment.

INTRODUCTION

The structures and interiors of modern motor vehicles are designed to prepare for a crash full time although crashes are relatively rare events. Full time readiness for a crash has imposed stringent restrictions on the styling, design and utility of motor vehicles. With the advancement in sensing technologies, a new class of safety features, called crash preparation features, has shown great potential in relieving the design restrictions. "Crash preparation" is the timely reconfiguration of a vehicle's structure and interior to the crash-ready state before an imminent crash. If the threat of a crash subsides, the vehicle reverts to its normal driving state, i.e., a "less" crash-ready state. Crash preparation can offer the needed crash protection while allowing new styling, design and utility previously not possible due to the needs for crash protection.

A conceptual crash preparation feature, called the extendable and retractable knee bolster (E/R knee bolster), was previously presented in [1]. The E/R knee bolster is intended to automatically extend in situations in which there is a high risk of frontal impact to help prepare the vehicle for crash and retract when the risk subsides.

In this paper, another conceptual crash preparation feature, called extendable and retractable bumper (E/R bumper)[2], is presented. The E/R bumper is normally in the stowed position. When a high-risk of frontal impact crash is detected, the bumper extends to provide additional crush space. Recall that in a frontal impact crash accident, the kinetic energy of a motor vehicle is rapidly converted into work by plastic deformation of vehicle structures. During this energy conversion process, the vehicle is decelerated in a relatively short time and distance. The stopping distance, which is a function of the available crush space and the crush efficiency of the front-end of a vehicle, is a good crash severity indicator. For vehicles involved in similar crash impact conditions, elementary physics ensures that those with less crush space and lower crush efficiency will have shorter stopping distances, higher average deceleration, and hence, more severe crash outcomes.

As motor vehicles have become more compact to meet the ever-stringent fuel efficiency requirements, the available crush space of motor vehicles has been involuntarily reduced. The E/R bumper is the only known safety feature that could provide the desired crush space only when a need appears. The additional crush space would allow the extended bumper structure to absorb additional crash energy to reduce the severity of the crash. The bumper automatically retracts when the risk subsides. In this paper the proof of concept of the E/R bumper and its potential benefits are discussed in detail.

MAIN ENABLING COMPONENTS

The E/R Bumper consists of a pre-crash sensing system, a pair of actuator, self-locking mechanism and energy absorption element assemblies, and a bumper and its fascia. Of these, the main enabling components are presented in what follows.

Pre-Crash Sensing System

The extension of the E/R bumper is designed to be automatically triggered by a detect signal from a pre-crash sensing system. The long-range radar sensor with a 100*m* plus range has been ruled out for this option, since its narrow radar beam has limitations when an object is closer than 7*m*. A short-range sensor with a 3*m* range has been ruled out for a rather different reason. While the short-range radar can work reliably when the object is close, it provides a very short actuation time budget for the E/R bumper. Figure 1 depicts the theoretical relationship among the range, closing rate and actuation time budget of a pre-crash sensing system. Note that a constant closing rate between the striking and the struck objects is assumed here to represent the worse case scenarios. We see that for a collision event with a 3 m range and 144*kph* closing rate the actuation time budget is only about 80*msec*. This presents a problem since this would require impractical high power actuators and energy sources.

To provide a reasonable actuation time budget, we selected a sensor system with a range between the short and long ranges. Specifically, from Fig. 1, we selected a sensor with a range of 20*m*, which could provide more than 500*msec* for an actuation time budget before a collision, if the closing rate is equal to or lower than 144*kph*, for the E/R bumper. In the event of a false detect or a crash that was not sufficiently severe so as to damage the bumper system, retraction of the E/R bumper could be programmed for an even slower rate.

Other vehicle sensors could also be used to extend the E/R bumper in select high collision risk scenarios in which detection may have not yet been registered by the pre-crash sensor. Among these could be the activation of the ABS braking system, operation at a speed in excess of a preset limit such as 128*kph*, or the manual selection of a precautionary mode by the vehicle driver.

Actuators

To extend and retract the bumper, reversible actuators are required for the E/R bumper. A wide range of reversible actuators, including electrical motors, solenoids, pneumatic cylinders, etc., could be used. However, linear actuators using rotary electric motors are attractive candidates for this application because of their flexibility of packaging and operation, their ready availability as off-the-shelf technologies, and the considerable experience with them in power seat applications. Two specific types were considered for the prototypes to be developed, those involving motor driven ball screws and those involving motor driven lead screws. Motor driven lead screws were selected as the drive units for the E/R bumper, because of their low cost.

Energy Absorption Elements

There are many different means[3] that can be used for energy absorption applications. Of these, the crushing structure tube was selected for the E/R bumper due to its high energy density. The required force to crush a tube can be estimated with the following empirical equation:

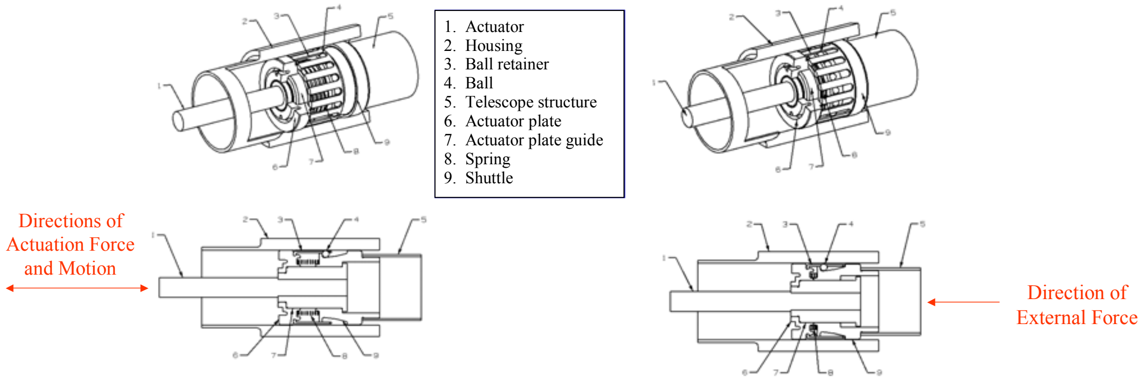
$$F_{tube} = 2\sigma_{ut}\left(\frac{4t}{d}\right)^{1.7}\left(\frac{\pi d^2}{4}\right) \qquad (1).$$

where σ_{ut} is the ultimate strength of the tube material, t is the thickness of the tube wall, and d is the diameter of the tube.

Figure 1. Relationship of range, closing rate and actuation time budget.

Self-Locking Mechanism

A mechanism that can provide self-locking functions is desired for the E/R bumper. This mechanism needs to be responsive only to impacts on the front surface of the bumper, and not to the normal operation of the extension and retraction actions of its actuator. An impact on the front surface of the bumper must activate the self-locking function of the mechanism and then allow the unit to withhold the violent impact force. Another desired function of the mechanism is that it must be able to self-lock the bumper at any position and at any time to provide resistant force in instances in which there is an incomplete actuation before an impact. A patented self-locking telescoping mechanism[2,4], which possesses all these functions, was chosen for the E/R bumper.



(a) Extension mode and retraction mode **(b) Self-locking/energy absorption mode**

Figure 2. Three operation modes of the self-locking telescoping mechanism.

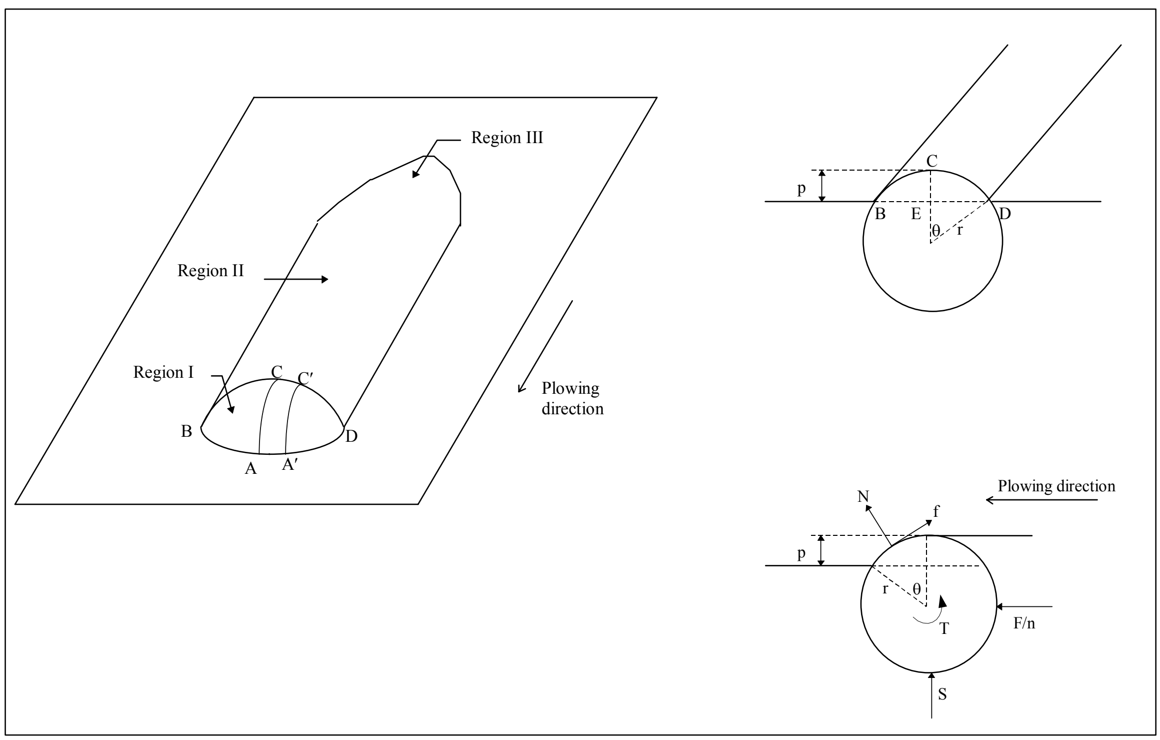


Figure 3. The mechanics model for estimating the locking force.

As shown in Fig. 2, the self-locking telescoping mechanism is composed of a stationary outer tube, an inner tube telescoped into the outer tube having a cone-shaped ramp at the inboard end and a bracket for attaching the bumper at the outboard end, and a plurality of metal balls between the cone-shaped ramp and the outer tube. The self-locking telescoping mechanism further includes an actuator rod, a driver which translates the actuator in the collapse direction and in an opposite expansion direction corresponding to an increase in the length of the telescoping mechanism, and a tubular retainer on the actuator rod having a plurality of closed-ended slots around respective ones of the metal balls. During the extension action, all of the metal balls will stay in the ends of the slots due to their inertia. This essentially prevents the balls from becoming wedged between the cone-shaped ramp and the outer tube. During the retraction action, all of the metal balls will again stay in the ends of the slots. The only difference in this case is that they are confined by the tubular retainer but not by their inertia.

In the self-locking mode, the metal balls become wedged between the cone-shaped ramp and the outer tube when the inner tube is thrust into the outer tube under a substantial load on the front surface of the bumper, such as the crash impact force, thereby locking the inner and outer tubes together and rendering the telescoping mechanism structurally rigid in the collapse direction. A previously developed mechanics model [1] could be used to analytically estimate the locking force. As shown in Fig. 3, a balance of internal work and external work of all the balls gives the following relationship for the plowing force, i.e., the locking force, F,

$$F = \frac{2n\sigma_0 t\left[t\theta + r(\theta - \sin\theta)\right]}{g(\theta,\mu)} \quad (2).$$

where n is the number of balls, σ_0 is the yield stress of the tube material, t is the thickness of the outer tube wall, r is the common radius of the balls, μ is the coefficient of friction between ball and tube, and

$$g(\theta,\mu) = 1 - \frac{1}{\cos\frac{\theta}{2} + \frac{1}{\mu}\sin\frac{\theta}{2}} \quad (3).$$

Self-locking mechanisms could be designed and built using Eqs. (2), and (3).

Subassembly of actuator, self-locking and EA mechanism

Figure 4 shows an assembly drawing of the self-locking telescoping mechanism with a motor drive and lead screw, and a tubular energy absorption element. Observe its a rather compact design, which will allow it be fitted inside of a mid-rail structure to save packaging space.

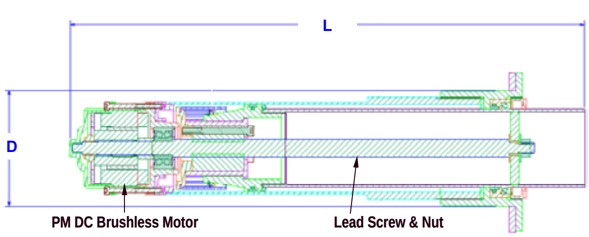


Figure 4. Assembly drawing of a self-locking telescoping mechanism with a motor and lead screw, and an EA element.

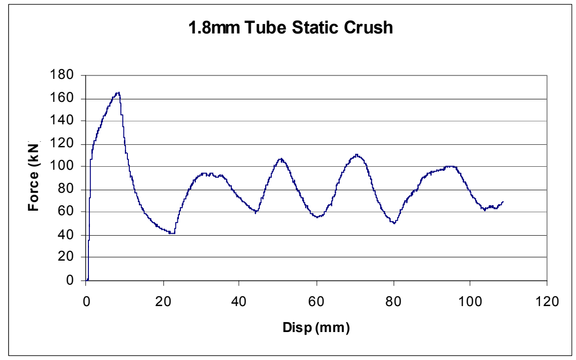


Figure 5. Drop tower test result of the energy absorption element.

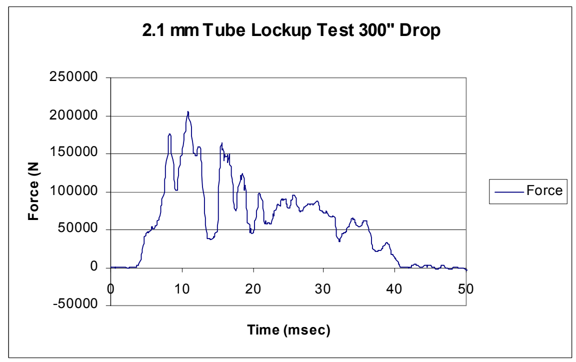


Figure 6. Drop tower test result of the self-locking telescoping mechanism.

DEMONSTRATION VEHICLE

Design Analysis

To demonstrate the extension, retraction and self-locking modes of the E/R bumper concept, a 2001 Aztek was chosen as the functional demonstration vehicle. An E/R bumper with two energy absorption elements, each with an 80*kN* crushing capacity and 100*mm* crushable length, was designed using Eq. (1) to provide a 10% additional energy absorption capacity to the 1800*kg* Aztek in a 48*kph* full barrier impact test.

A drop tower crush test was conducted to verify the design. Figure 5 shows that as intended the average crush force of the energy absorption element is indeed about 80*kN* each. The very same test also provided the minimal self-locking force requirement for the self-locking mechanism (observe the high peak force of 165*kN* required for initiating the crush).

Factoring in a safety margin, we have selected 250*kN* as the design locking force for the self-locking mechanism. Equations (2) and (3) were used in aiding the design of the self-locking mechanism. Another drop tower test was conducted to verify the design. The force versus time trace from the drop tower test is shown in Fig. 6. We see that the mechanism has successfully taken 200*kN* impact force punishment from the moving mass of the drop tower without any failure. Although the peak load of this test was 50*kN* lower than the self-locking mechanism's design load, 250*kN*, we chose not to repeat the test, since the result was within the safety margin of the design.

Figure 7. Main components of the E/R bumper assembly and their relative assembling relationship.

Figure 8. A partially assembled E/R bumper mounted at the end of the mid-rail.

Subassembly and Packaging

The preferred approach is to design the E/R bumper during the initial vehicle design so that they could be seamlessly integrated for aesthetics and optimal performance. For the modified Aztek, we took a less desirable add-on design approach due to obvious reasons. Figure 7 depicts the main components of the E/R bumper assembly and their relative assembling relationship. Notice that the energy absorption elements are in the extended position for viewing purposes. Figure 8 shows a partially assembled E/R bumper mounted at the end of the mid-rail (again the energy absorption elements are in their extended position for easy viewing). The actuator and self-locking mechanism units are not visible because they are packaged inside the mid-rail. Note that this mounting arrangement is only one of many possible mounting arrangements[5].

Figures 9 and 10 show the Aztek with a fully installed E/R bumper without and with the pre-crash sensing system, respectively. The sensing system consists of two 24-GHz radar sensors, which are packaged behind the front fascia of the vehicle. Note that the bumper fascia was removed for visual purpose.

Figure 9. The modified Aztek with a fully installed E/R bumper, but without the pre-crash sensing system.

Figure 10. The modified Aztek with a fully installed E/R bumper and the pre-crash sensing system.

Figure 11. The modified and unmodified Aztek.

(a) Retracted **(b) Extended**

Figure 12. Front-end changes enabled by the E/R bumper.

In Figure 11, observe the similarities between the unmodified Aztek on the right and a second Aztek on the left equipped with an E/R bumper. That is, when the E/R bumper is fully retracted, it appears identical to the bumper on the unmodified Aztek. Figure 12 contains photographs of the modified vehicle with the bumper in its fully retracted and fully extended positions.

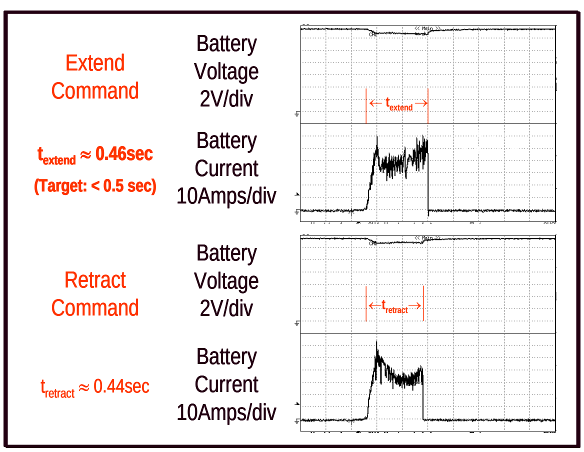


Figure 13. Measured voltages and currents of the E/R bumper.

Actuation Time Verification

Recall that the energy absorption elements of the E/R bumper for the Aztek demonstration were designed to provide 100*mm* extra crush, and that the actuation time budget is 500*msec*. To meet the 100*mm* crush requirement, the E/R bumper was actually designed with a 160*mm* extendable and retractable stroke. The additional stroke is required to accommodate the stacking of the crushed materials. The extension and retraction operations of the E/R bumper were verified using the demonstration Aztek. Figure 13 verifies that the E/R bumper can extend and retract within the 500*msec* actuation time budget.

EXPERIMENTALVEHICLES

To further study the feasibility and potential benefits of the E/R bumper, another E/R bumper prototype was designed and built using the same methods described in the above. It was designed for two identical experimental vehicles, namely A and B. Since these vehicles are lighter than the Aztek, their E/R bumper consists of two smaller energy absorption elements with 60*kN* crush capacity energy absorption elements with 120*mm* crushable length. These experimental vehicles were crashed in a 56*kph* rigid barrier NCAP test and a 64*kph* 40%, Offset Deformable Barrier (ODB) impact test, individually. Figures 14 and 15 show these vehicles with their bumper extended in the test cell before the tests.

Figure 14. NCAP test setup for the experimental vehicle A.

Figure 15. 64*kph* 40% ODB test setup for the experimental vehicle B.

NCAP Test Performance

Nonlinear finite element models were created to predict the crash performance of these experimental vehicles. Figures 16 and 17 depict the predicted crash sequence of the experimental vehicle A with the E/R bumper and its energy absorption elements during the first 30*msec* of the NCAP test event. The simulation predicts that the E/R bumper will be axially crushed as intended. The parts later extracted from the actual test, shown in Fig. 18, verified this prediction. The simulations further predict that adding the E/R bumper to experimental vehicle A has reduced the average deceleration of the vehicle by 9% (from 20.3*G* to 18.6*G*) and the toe-pan intrusion by 40*mm*. Figure 19 shows the comparison of the simulated vehicle velocity time history plots for the vehicle with and without the E/R bumper. Indeed, we see that the vehicle with the E/R bumper rendered a much softer crash pulse than without it.

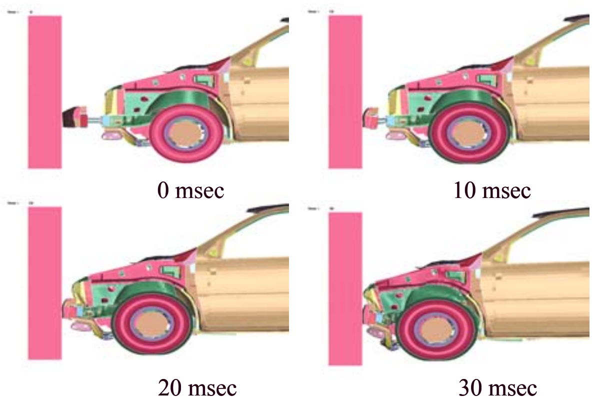


Figure 16. Simulation of the NCAP Test.

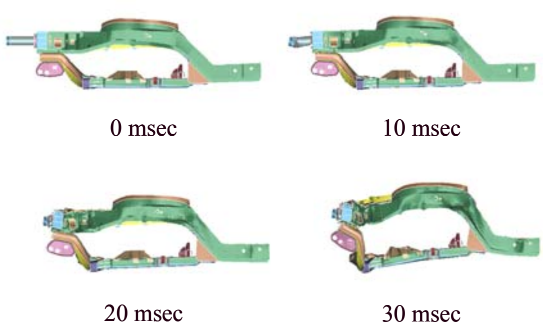


Figure 17. Simulated NCAP test: crush sequence of the energy absorption elements.

Figure 18. NCAP test: Axially crushed energy absorption elements.

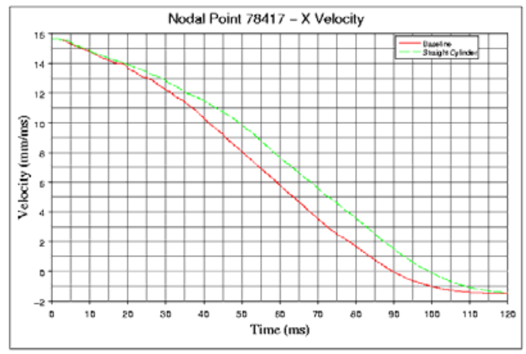


Figure 19. Comparison of the simulated vehicle velocity time history plots with and without the E/R bumper.

64*kph*, 40% ODB Test Performance

The simulation of the experimental vehicle B in a 64*kph* 40% Offset Deformable Barrier test is shown in Fig. 20. The simulation predicts that the offset barrier load will bend the bumper beam at near its 40% offset mark. This, in turn, causes the impact-side energy absorption element of the E/R bumper to buckle prematurely and the non-impact side energy absorption element to be pulled inward by the bending motion of the bumper beam. The parts extracted from the actual test, shown in Fig. 21, verified this prediction. Observe the similarity of the buckled energy absorption element from the test and simulation (see Fig. 22). The simulation also identified the main benefit of the E/R bumper for the ODB tests - the reduction in vehicle compartment intrusion. As shown in Fig. 23, toe-pan intrusion decreased by as much as 100*mm* for the vehicle with the E/R bumper.

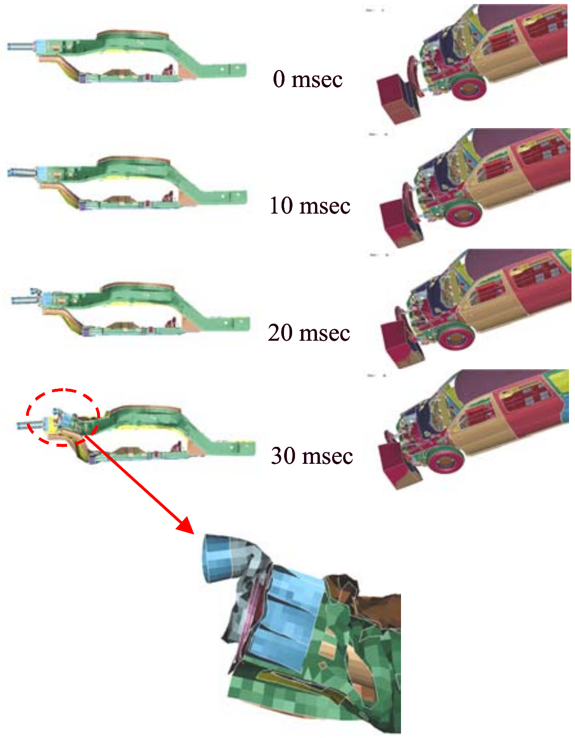


Figure 20. Simulation of the 64*kph* 40% ODB test.

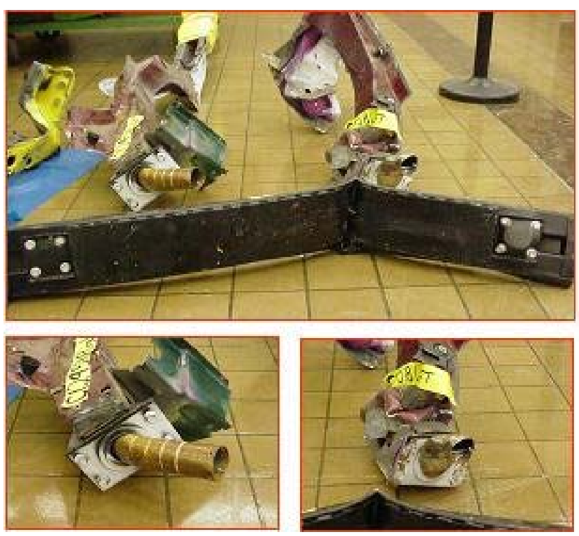


Figure 21. 64*kph* 40% ODB test: Prematurely bent bumper beam and buckled/pulled energy absorption elements.

(a) Simulated **(b) Tested**

Figure 22. 64*kph* 40% ODB test: Comparison of buckled energy absorption element from the test and simulation.

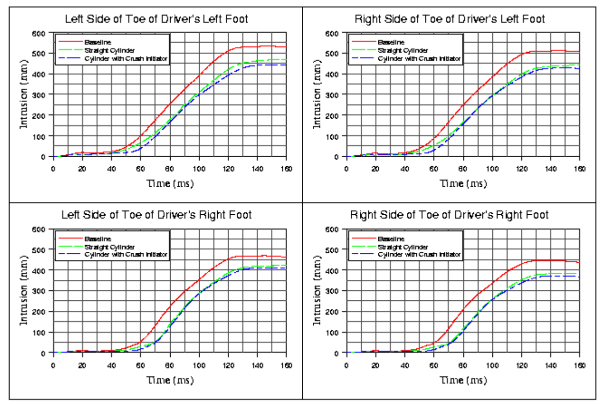


Figure 23. Simulated results of the 64*kph* 40% ODB test: Toe-pan intrusions.

48*kph* Oblique Rigid Barrier Impact Test

No physical test was planned for the 48*kph* 30^0 rigid barrier impact test. However, we used the experimental vehicle model to simulate this load case. The benefits identified from the simulation include: reduction of toe-pan intrusion by 50*mm*, yawing reduction of 145*mm*, and pitching reduction of 62*mm.*

CONCLUSIONS

A crash preparation feature, the extendable and retractable bumper, has been studied with analytical methods, nonlinear finite element analysis, experiments and demonstration vehicles. The study shows that the E/R bumper can provide additional crush space in an at-risk situation of frontal impact to prepare the vehicle for a subsequent crash and retract when that risk subsides. The study further shows that the additional crush space realized by extending the bumper can reduce the severity of the crash pulse and the amount of structural intrusion to the vehicle compartment. Other potential benefits of the E/R bumper include improving compatibility in car-to-truck crashes and enabling short, front overhang styling. However, no attempt was made to assess manufacturability, mass implications, market interest, or the reliability of the pre-crash sensing technology in this study. Further developments to address all safety requirements, including real-world crash events, are necessary before implementing this feature in a production vehicle.

ACKNOWLEDGMENTS

The author would like to thank the many individuals who, as team members, made key contributions to the successful execution of the E/R bumper project. Team members, in alphabetical order, were Osman Altan, Alan Browne, Ching-Shan Cheng, Don Daniels, Gary Jones, Bahram Khalighi, Ian Lau, Joe McCleary, Chandra Namuduri, Larry Peruski, Ken Shoemaker, Jian Tu, Scott Webb, William E. Thomas, and Frank Wood. The author would also like to thank Mark Neal for reviewing this paper and for his useful suggestions.

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REAR SEAT OCCUPANT PROTECTION IN FRONTAL CRASHES

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ABSTRACT

Though a significant body of literature exists on the safety performance and effectiveness of various types of front seat occupant restraint systems, there is a paucity of data on the performance of rear seat occupant restraint systems. A research program was initiated to better understand rear seat restraint performance. Research included examining real world data using National Automotive Sampling System/Crashworthiness Data System (NASS/CDS) and Fatality Analysis Reporting System (FARS) as well as conducting full frontal vehicle crashes into rigid barriers with dummies restrained in rear seats. Child dummies (Hybrid III 6 year-old) and adult dummies (Hybrid III 5th percentile female and 50th percentile male) were used for this purpose. The dummies were placed in rear outboard seats with lap/shoulder belts as well as in the center seating position where the lap/shoulder belts were integrated to the seat.

A double-paired comparison study using FARS data files suggested that while occupants younger than 50 years of age benefit from sitting in rear seats in frontal crashes, restrained adult occupants older than 50 years are significantly better off in the front seats than the rear seats. The most injured body region for restrained children in rear seats is the head while that for restrained adults is the thorax. The major injury source for restrained occupants, not in child safety seats, is the seat belts while that for unrestrained occupants is the front seat back. The injury measures of restrained adult dummies in rear seats in frontal crash tests were generally higher than those of dummies of the same size in the driver and front passenger seat. The seat backs of integrated rear seats experienced excessive forward rotation in frontal crash tests, thereby causing the dummy's head to hit the console or front seatback, resulting in high head and neck injury measures. The field and vehicle crash test data indicate that rear seat restraints could be further optimized to mitigate injury in frontal crashes for older rear seat occupants.

INTRODUCTION

While the dynamic performance of front seat lap/shoulder belts is evaluated in dynamic crash tests in FMVSS No. 208 - Occupant Crash Protection, the performance of rear seat belts and seats are only evaluated in static tests as per FMVSS No. 209 - Seat Belt Assemblies, and FMVSS No. 210 - Seat Belt Anchorages. Prior to 1989, only lap belts were required in rear outboard seating positions. Rear seat outboard lap/shoulder belts were first required in passenger cars after December, 1989 and in convertible passenger cars, light trucks, vans and sport utility vehicles after September, 1991. Pursuant to Anton's Law passed by Congress in 2002, NHTSA published a final rule in December 2004, requiring lap and shoulder belt assembly for each designated rear seating position in a passenger motor vehicle with a gross vehicle weight rating of 10,000 pounds or less.

Evans (1987) conducted a double-paired comparison analysis of the FARS data files and estimated an 18±9 percent effectiveness of rear seat lap belts and 41±4 percent effectiveness of front passenger seat lap/shoulder belts in mitigating fatalities. Dalmotas (1987) examined the Canadian accident database, TRIAD, and found similar effectiveness of lap and lap/shoulder belts in rear seating positions as Evans (1987) using the FARS databases. Padmanaban (1992) examined the FARS database and state accident data and found no appreciative difference between the safety performance of lap belt and lap/shoulder belts in the rear seats.

Morgan (1999) found that the change from lap to lap/shoulder belts has significantly enhanced rear seat occupant protection in frontal crashes with rear seat lap/shoulder belts being 25 percent more effective than lap belts alone in reducing fatalities. Morgan also noted that rear outboard seat belt use rate is significantly lower than front outboard seat belt use, and the use rate is 7-10 percentage points higher with laps/shoulder belts than with lap belts alone.

More recently, Paranteau and Viano (2003) examined field data of rear seat adult occupant injuries and found that for lap-shoulder belted rear seat occupants in frontal crashes, thoracic injuries from the seatbelt are by far the dominant injury type. For unbelted rear seat occupants, the extremities and head are injured by the B-pillar, seatback and other interior surfaces. The authors found the risk of serious injury for rear seat occupants in lap belts to be the same as those in lap/shoulder belts. Paranteau noted that possible improvements in rear seat occupant protection include load limiting belts, pretensioners, improved belt geometry, and energy absorption padding to the front seat back.

Smith and Cummings (2004) examined NASS-CDS data files for the years 1993-2000 and estimated that the rear seat passenger position may reduce the risk of death in a motor vehicle crash by about 39% and reduce the risk of death or serious injury in a crash by 33%, compared to the front seat passenger position.

While research has been conducted on comparing the effectiveness of lap/shoulder belts and lap belts in rear seats as well as comparing the risk of injury and death for occupants in front and rear seats, there is a paucity of data on the effectiveness of rear seat lap/shoulder belt restraints with respect to front seats restraints in frontal crashes. This paper examines the NASS-CDS and FARS databases to examine the effectiveness of rear seats in mitigating fatality and injury in frontal crashes compared to that of the front seats for different age occupants. The real world data was compared to the observations from vehicle crash tests.

REAL WORLD DATA

ANALYSIS OF FARS DATABASES

The Fatality Analysis Reporting System (FARS) data files for the years 1993-2003 were analyzed. Only frontal crashes (no rollovers) of passenger cars and LTVs of model years later than 1991 were considered.

A double-paired comparison study was conducted according to the procedure developed by Evans (1987) to determine the risk of death of outboard rear seat occupants relative to that of the front seat passenger. The driver in these crashes was considered the control group. This method of double paired comparison uses two groups of fatal crashes. The first group consists of fatal crashes where a driver and front outboard seat passenger are present and at least one of them was killed. The second group consists of fatal crashes where a driver and a rear outboard seat passenger are present and at least one of them was killed. Each of these groups is further subdivided into different age categories of the passenger and the restraint status of the driver and passenger: restrained driver and passenger, unrestrained driver and passenger. Effectiveness was estimated separately for the presence and absence of passenger side air bag.

Children younger than 5 years old who are properly restrained in child safety seats or booster seats are considered restrained. Unrestrained children include those with misuse of child restraint systems and belt systems. All other restrained occupants in front and rear seats are with lap/shoulder belts.

As an example of the double-paired comparison procedure, consider the category of restrained driver and passenger. For a given age category of the passenger, if F_1 is the number of driver fatalities and F_2 is the number of front passenger fatalities in the first group, and F_3 is the number of driver fatalities and F_4 is the number of rear passenger fatalities in the second group, then the effectiveness of rear seat restraints compared to those of the front seat for that age category of the passenger is given by Equation 1.

$$\boldsymbol{E} = 100 \times (1 - \frac{\boldsymbol{F}_4 / \boldsymbol{F}_3}{\boldsymbol{F}_2 / \boldsymbol{F}_1}) \qquad (1)$$

Significance testing (at 95 percent confidence level) of the effectiveness estimates was conducted using the chi-square test. The error ranges in the estimates was computed according to Evans (1987) as shown in Equations 2 and 3.

$$\sigma = \sqrt{0.01 + 1/\boldsymbol{F}1 + 1/\boldsymbol{F}2 + 1/\boldsymbol{F}3 + 1/\boldsymbol{F}4}$$

$$\boldsymbol{E}_{lower} = 100 \times [1 - \boldsymbol{e}^{Ln(1-E/100)+\sigma}] \qquad (2)$$

$$\boldsymbol{E}_{upper} = 100 \times [1 - \boldsymbol{e}^{Ln(1-E/100)-\sigma}] \qquad (3)$$

Appendix C presents the FARS data used in the double-paired comparison study. Figures 1 and 2 present the effectiveness of rear outboard seats relative to the front outboard passenger seats with and without frontal air bag for restrained and unrestrained occupants. When the error bars in the effectiveness estimates (also presented in Figures 1 and 2) do not pass through zero, it implies that the effectiveness estimate is significant.

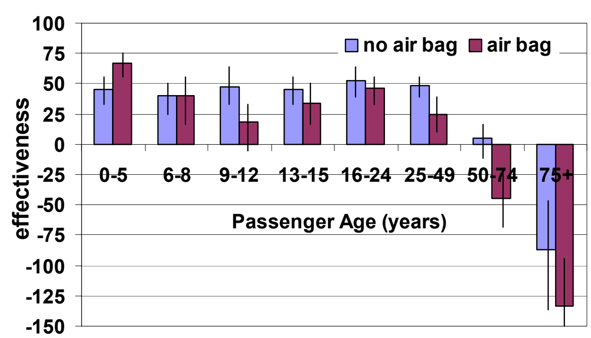

Figure 1. Effectiveness of outboard rear seats compared to front outboard passenger seats with and without front passenger air bag in mitigating fatalities for restrained occupants.

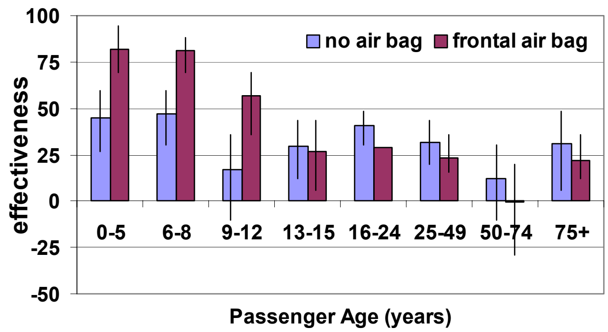

Figure 2. Effectiveness of outboard rear seats compared to front outboard passenger seats with and without front passenger air bag in mitigating fatalities for unrestrained occupants.

The FARS double-paired comparison study suggests that while the rear seats are significantly effective in mitigating fatalities for occupants younger than 50 years old (restrained and unrestrained), they demonstrate significantly reduced effectiveness (130 % reduction in effectiveness) compared to front seats for restrained occupants older than 50 years of age. In general, rear seats are significantly effective compared to front seats in frontal crashes for unrestrained occupants of all ages.

Rear seat effectiveness is increased by the presence of front passenger air bag for children 5 years old and younger restrained in child safety seats. However, the effectiveness of rear seats is reduced by the presence of passenger air bag for restrained occupants older than 8 years of age. The presence of passenger air bag reduces the effectiveness of rear seats for restrained occupants older than 50 years. This suggests the added benefits of air bags to older occupants.

The presence of front passenger air bag increases the effectiveness of rear seats in mitigating fatalities for unrestrained children 12 years old and younger suggesting the harmful effects of air bag deployment for unrestrained children. For unrestrained occupants older than 12 years of age, the presence of front passenger air bag reduces the effectiveness of the rear seat suggesting the benefits of air bag for unrestrained occupants in this age group.

ANALYSIS OF NASS-CDS DATABASES

The NASS-CDS data files were examined to get a better understanding of the injuries sustained by rear seat occupants. The NASS-CDS data files for the years 1993 to 2003 were analyzed. Only frontal crashes of passenger cars and LTVs of model years later than 1991 with no rollovers were examined. The data presented in this section are weighted by weighting factors in NASS/CDS to represent national estimates of towaway crashes.

The risk of AIS 2+ or AIS 3+ injury for a restraint condition is estimated as the ratio of the number of AIS 2+ or AIS 3+ injured occupants in the specified restraint condition to the total number of occupants in that restraint condition. The risk of injury to rear seat occupants and the distribution and source of injury was examined as a function of age, and restraint status.

Ninety percent of rear seat occupants are in the second row seat with 78 percent in outboard seats and 18 percent in center seats. Sixty-four percent of outboard rear seat occupants involved in frontal crashes are belted and among these restrained rear seat occupants, 64 percent are 12 years old and younger and 78 percent weigh less than 160 lbs.

Among children 0-3 years, 75 percent are in child safety seats, 4 percent are in belts, and 21 percent unrestrained. Among children 4-8 years in age, 7 percent are in child safety seats, 43 percent are in belts, and 50 percent are unrestrained.

The risk of injury and the distribution of injury was estimated only for outboard front and rear seat passengers. Children 5 years of age and younger were considered restrained if they were properly restrained in child safety seats. Occupants older than 5 years of age were considered restrained if they were restrained by lab shoulder belts.

While the risk of moderate to fatal injuries among restrained front seat occupants in frontal crashes is 5.2 percent, the risk for restrained rear seat occupants is only 1.6 percent. Though children 12 years and younger constitute 64 percent of rear seat occupants, they only represent 32 percent of the MAIS 2+ injured rear seat occupants and 26 percent of the fatally injured rear seat occupants.

Figures 3 and 4 present the risk of AIS 2+ and AIS 3+ injuries as a function of occupant age, for restrained and unrestrained passengers in rear outboard seating positions.

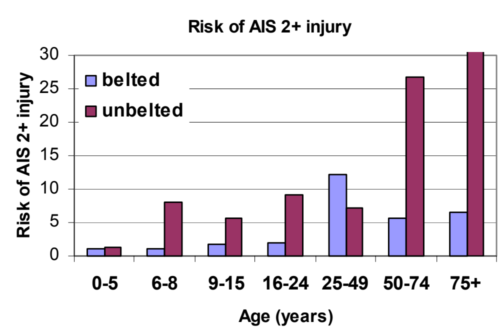

Figure 3. Risk of AIS 2+ injury for belted and unbelted passengers in rear outboard seats

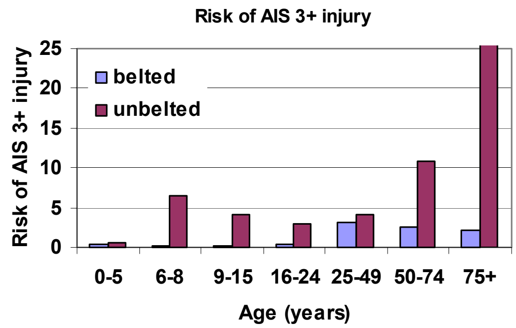

Figure 4. Risk of AIS 3+ injury for belted and unbelted passengers in rear outboard seats.

While the average risk of AIS 2+ and AIS 3+ injury is relatively low for restrained rear seat occupants, the risk of injury is higher for older occupants than younger ones.

Figures 5 and 6 present the distribution of AIS 2+ and AIS 3+ injuries to different body regions for restrained passengers in rear outboard seats as a function of occupant age. While the head is the dominant AIS 2+ and AIS 3+ injured body region among restrained children, the thorax is the dominant injured body region among adults.

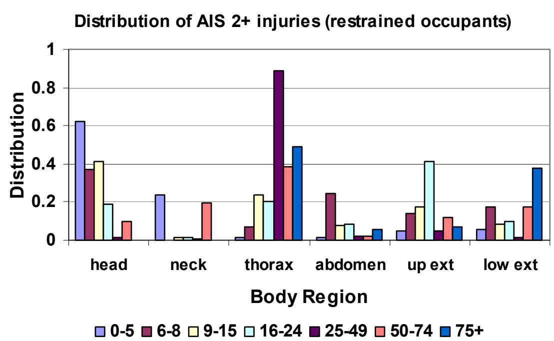

Figure 5. Distribution of AIS 2+ injuries to different body regions for restrained rear seat occupants as a function of their age.

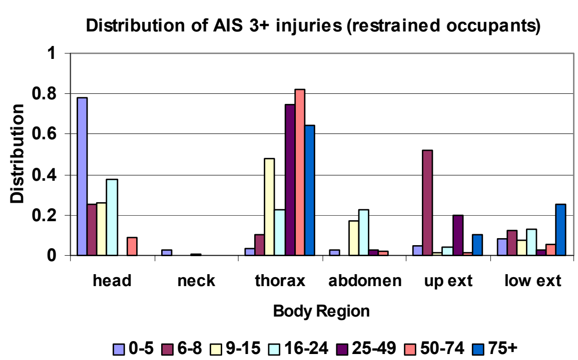

Figure 6. Distribution of AIS 3+ injuries to different body regions for restrained rear seat occupants as a function of their age.

The source of MAIS 2+ injury to restrained and unrestrained children (in child safety restraints) and restrained adults was examined. The data suggests that impact with the front seatback is the major source of head injury among unrestrained children in rear seats while the seat belt is the major source of thoracic and abdominal injury to restrained adult rear seat occupants. For children in child safety seats, the major sources of injury are the left and right interior vehicle surfaces and exterior surface.

With this understanding of the real world data, vehicle crash test data with occupants in the rear seats was examined. The injury measures of the dummies in the rear seats were compared to those in the front seats and the relative injury potential was compared to that observed in the real world.

VEHICLE CRASH TESTS

Full frontal rigid barrier vehicle crash tests were conducted at 48, and 56 km/h with adult Hybrid III dummies (Hybrid III 50th percentile male dummy - HIII 50M and Hybrid III 5th percentile adult female dummy - HIII 5F) in the front outboard seats and child (Hybrid III 6 year-old child dummy-HIII 6C) and adult Hybrid III dummies in rear outboard seats. Adult HIII and child dummies were also positioned in rear center seats of some vehicles where lap/shoulder belts were integrated to the seat (rear center integrated seats). The FMVSS No. 208 specified seating procedure was used to seat the dummies in the driver and front passenger seats. All vehicles were equipped with driver and front passenger air bags and the dummies in the front and rear seats were restrained by lap/shoulder belts. The HIII 6C dummies in the rear seats were in booster seats and used the available lap/shoulder belts. Appendix A presents a list of vehicle crash tests and the dummies used in the front and rear seats.

The computation of injury measures and the corresponding threshold values are in accordance with that specified in the FMVSS No. 208 Advanced Air Bag rule (65 FR 30680). The Nij intercepts and independent axial force limits for the adult dummies correspond to those specified for "in position" condition (Table 1). The neck tension and compression limits for the HIII 6C dummy are the "in position" limits specified by Mertz and Irwin (2003). In order to compare the injury potential indicated by various dummies used in these crash tests, the injury measures for each dummy were normalized by their respective injury threshold levels in Table 1.

Table 1. Injury threshold levels used to normalize dummy injury measures.

Injury Criteria	HIII 50 M	HIII 5F	HIII 6C
HIC15	700	700	700
Nij	1	1	1
Neck tension	4170	2620	1890
Neck Compression	4000	2520	1820
Chest Accel.	60	60	60
Chest Defl. (mm)	63	52	40

Figure 7 presents the normalized average HIC15 values for front and rear seat dummies in 48 and 56 km/h full frontal rigid barrier crash tests. In 48 km/h crashes, the average normalized HIC15 of the driver is 0.27±0.13 and that of the front seat passenger is 0.32±0.15 while the average normalized HIC15 of rear seat outboard passengers is 0.78±0.3 and that for occupants in center rear integrated seats is 0.84±0.29. The normalized HIC15 values for dummies in rear outboard seats as well as in rear integrated seats are significantly higher than those of the driver and the front seat passenger (95% confidence) in 48 ad 56 km/h crash tests.

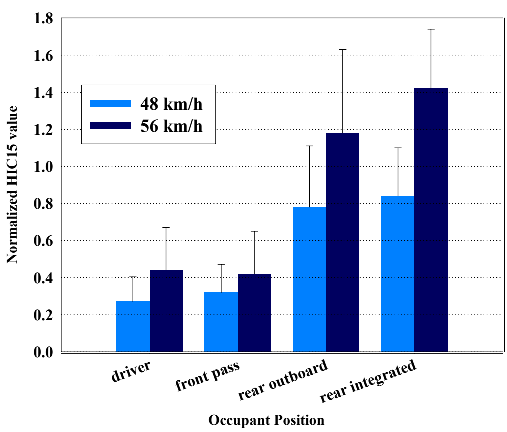

Figure 7. Average normalized HIC15 values of dummies in the front and rear seats in 48 and 56 km/h full frontal rigid barrier crash tests.

Table 2 presents the percentage of dummies in the driver, front passenger, and rear outboard seating positions in 48 km/h and 56 km/h full frontal rigid barrier crashes that exceeded the injury threshold levels of the various injury criteria in Table 1. The HIC15 values were in excess of the threshold limits for 23% of the rear seat dummies in 48 km/h crash tests and 36% of the rear seat occupants in 56 km/h crash tests while all the drivers and front seat passengers in 48 and 56 km/h tests had HIC15 values within the threshold level of 700.

Table 2. Percentage of dummies in the driver, front passenger, and rear outboard seating positions with injury measures in excess of the threshold levels.

Injury criteria	driver	front pass	rear outboard	rear integrated
48 km/h				
HIC15	0%	0%	23%	50%
Neck Ten	0%	0%	35%	25%
Nij	12%	0%	27%	0%
chest Ax	8%	4%	4%	0%
Chest Defl	8%	0%	19%	25%
56 km/h				
HIC15	0%	4%	36%	50%
Neck Ten	0%	0%	100%	50%
Nij	5%	0%	71%	50%
chest Ax	5%	4%	21%	25%
Chest Defl	0%	0%	7%	0%

The average neck tension for dummies in rear outboard seats was also significantly higher than that of dummies in front seats (Figure 8) in 48 and 56 km/h frontal crashes. The neck tension exceeded the allowable limit for all the dummies in rear outboard seats and 50 percent of the dummies in rear integrated seats in the 56 km/h crash tests. The average Nij values for dummies in rear outboard seats and rear integrated seats were also higher than the average Nij of dummies in front seats however, this difference was not significant.

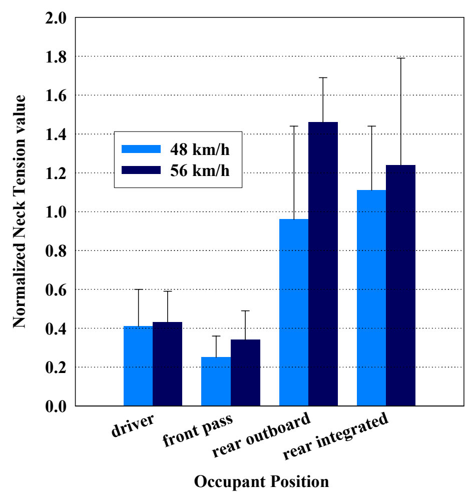

Figure 8. Average normalized neck tension values of dummies in front and rear seats in 48 and 56 km/h full frontal rigid barrier crash tests.

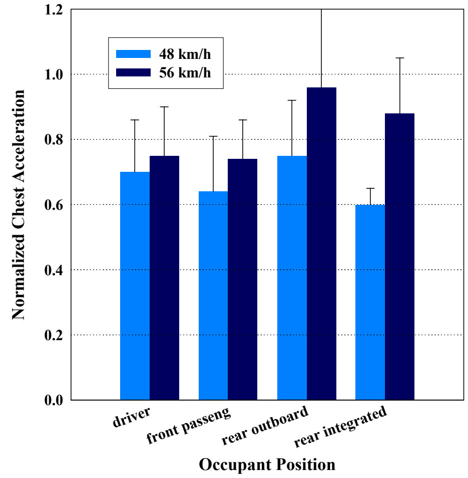

Figure 9. Average normalized chest acceleration of dummies in front and rear seats in 48 and 56 km/h full frontal rigid barrier crash tests.

While chest acceleration, and chest deflection were slightly higher for rear seat occupants than for front seat occupants, the difference was not significant (Figures 9-10). Chest acceleration and chest deflection measures for rear seat occupants exceeded the allowable values less frequently than the head and neck injury measures.

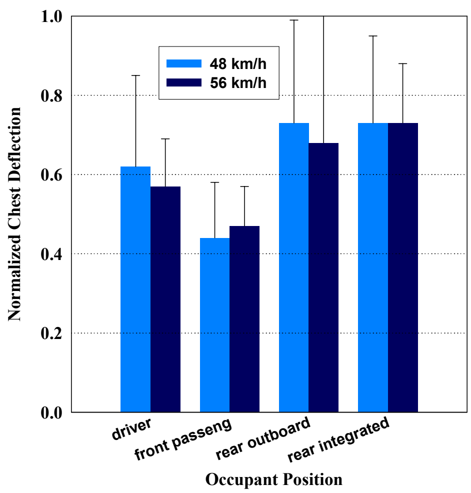

Figure 10. Average normalized chest deflection of dummies in front and rear seats in 48 and 56 km/h full frontal rigid barrier crash tests.

In most of these vehicle crash tests, adult dummies were used in the front seats while HIII 6C dummies were used in the rear seats. The higher normalized injury measures of the dummies in rear seats compared to those in front seats in these crash tests may be related to the different dummies used in the rear and front seats as well as the differences in the injury assessment values used to normalize the injury measures.

In order to compare the performance of rear seats and front seats in frontal crashes without the confounding effect of differences in dummies, only those tests were considered where the same size dummies were in the front and rear seats. Appendix B presents the test data of 5 full frontal rigid barrier 56 km/h crash tests with restrained HIII 5F dummies in the driver, front passenger, and rear outboard seating positions and 5 full frontal rigid barrier 48 km/h crash tests with unrestrained HIII 50M dummies in the driver and front passenger seats and restrained HIII 50M dummy in rear outboard seat.

Figure 11 presents HIC15 for the HIII 5F dummies in the driver, front passenger, and rear outboard seating positions in the 5 fontal crashes (Appendix B). The HIC15 values of the rear outboard HIII 5F dummy are higher than those of the HIII 5F driver and front seat passenger in all the five crashes and are higher than the allowable limit of 700 in two out of five 56 km/h frontal crash tests.

Figure 12 presents the HIC15 values for the unrestrained HIII 50M dummies in the driver and front passenger seats, and the restrained HIII 50M in rear outboard seat in 48 km/h frontal crashes (Appendix B). The restrained HIII 50M in the rear seat has higher HIC 15 measures than the unrestrained HIII 50M in the driver and front passenger seats in all the crash tests except that with the Liberty. The HIC15 of the HIII 50M dummy in the rear seat is lower than the allowable limit in all the five crash tests at 48 km/h.

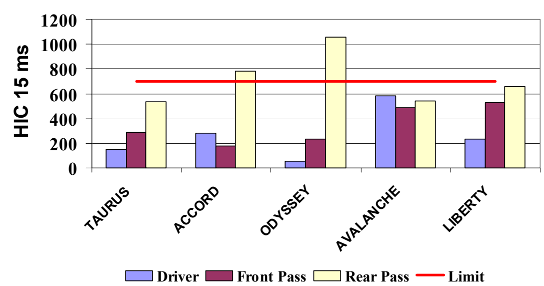

Figure 11. HIC15 for the HIII 5F dummy in the driver, right front passenger, and rear outboard seats in full frontal rigid barrier vehicle crash tests with 2004 model year vehicles at 56 km/h.

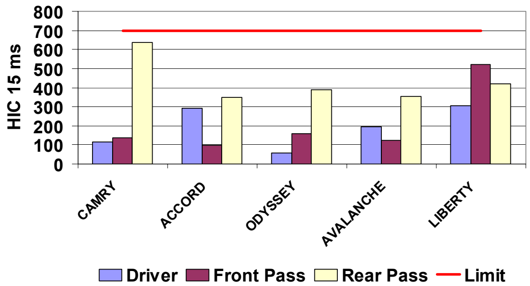

Figure 12. HIC15 for the HIII 50M dummy in the driver, right front passenger, and rear outboard seats in full frontal rigid barrier vehicle crash tests with 2004 model year vehicles at 48 km/h.

The neck tension of the HIII 5F in the rear seat exceeded the allowable limit of 2620 N in the crash test of the Honda Accord and the Honda Odyssey. The Nij of the HIII 5F in the rear seat also exceeded 1.0 in the crash test of the Odyssey and Avalanche. The chest injury measures of the HIII 5F dummy in the rear seat were within the allowable limits in all the tests. All the injury measures of the HIII 50M rear seat passenger were within the prescribed injury limits in the five crash tests. All the injury measures of the HIII 50M and HIII 5F in the driver and front seat positions in all the crash tests were within allowable limits.

The average ratio of HIC15, chest acceleration, chest deflection, neck tension, and Nij of the HIII 5F dummy in the rear outboard seat with respect to that of the HIII 5F driver and that of the HIII 5F front seat passenger in full frontal 56 km/h rigid barrier crashes of five 2004 vehicles is presented in Figure 13. The average ratio of the injury measures of the restrained HIII 50M dummy in rear outboard seats with respect to that of the unrestrained HIII 50M driver and front seat passenger in full frontal 48 km/h rigid barrier crashes of five 2004 vehicles is presented in Figure 14.

The ratio of head and neck injury measures are greater than 1.0 in tests with the HIII 5F and the HIII 50M dummies. The head and neck injury measures for rear seat occupants are significantly greater (95 percent confidence) than those of the driver and front passenger in tests with the HIII 50M and the HIII 5F dummies. This suggests an increased injury potential to the head and neck for an average restrained adult and small female in rear seats compared to that of an average unrestrained adult and a restrained small female in the front seats, respectively. Since the risk of injury to front seat occupants in frontal crashes is greater for the unrestrained condition than the restrained, the test data suggests that the injury potential for the average restrained adult in the front seat is also likely to be lower than that in rear seats.

The chest acceleration injury measures are not significantly different for the rear and front seat occupants (driver and front passenger) in tests with the HIII 5F as well as the HIII 50M dummy. While the chest deflection of the rear seat passenger and driver are not significantly different, the chest deflection of the rear seat passenger is significantly greater (at a 95 percent confidence) than that of the front seat passenger in tests with the HIII 50M and the HIII 5F dummies.

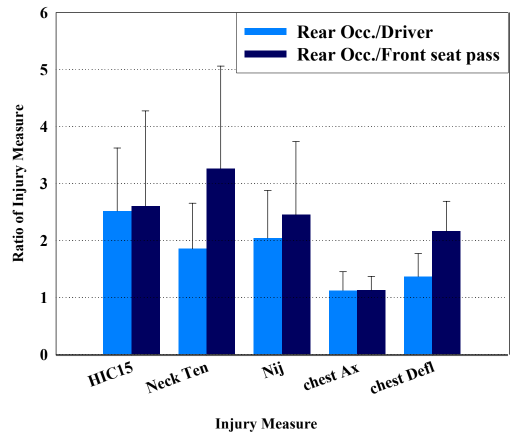

Figure 13. Average ratio of injury measures of restrained HIII 5F dummy in the rear seat to that of the restrained HIII 5F driver and front seat passenger in five 56 km/h full frontal rigid barrier crash tests.

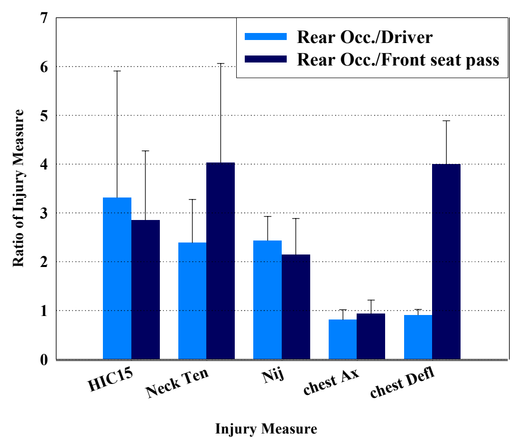

Figure 14. Average ratio of injury measures of restrained HIII 50M dummy in the rear seat to that of the unrestrained HIII 50M driver and front seat passenger in five 48 km/h full frontal rigid barrier crash tests.

CENTER REAR INTEGRATED SEAT PERFORMANCE

Integrated seats are seats where the seat belt assemblies are attached to the seat. Such seats have the potential of providing better belt fit to their occupants and the potential of preventing full or partial ejection in rollover and rear crashes. While integrated front seats are subjected to a dynamic crash test, rear integrated seats have to only meet the static test requirements specified in FMVSS No. 210 and 207. Ten 48 and 56 km/h frontal rigid barrier crash tests with HIII 50M, HIII 5F, and HIII 6C dummies in rear integrated center seats demonstrated that the seat back of integrated seats experiences excessive forward rotation due to inertial loading of the occupant resulting in the dummy head contacting the front seat back, the front console or its own knees. This generally results in high head and neck injury measures as is indicated in Figures 7 and 8. The forward rotation of the seatback results in less belt loading on the thorax, which results in lower chest acceleration and deflection (Figures 9 and 10).

DISCUSSION

A comparison of fatality rates among front and rear seat passengers suggests that although rear seat belts are effective in reducing death and serious injury (Morgan, 1999), their effectiveness compared to that of the front seat restraints in mitigating fatalities and serious injury depends on the age of the occupant. The data suggests that restrained occupants younger than 50 years benefit from sitting in rear seats in frontal crashes. However, restrained occupants older than 50 years of age have significantly improved protection in frontal crashes when seated in the front seat than in the rear outboard seats. Unrestrained occupants of all ages benefit from sitting in rear seats than front seats in frontal crashes.

The presence of a frontal air bag reduces the protection level of front seats for children 5 years old and younger who are restrained in child safety seats and for unrestrained children 12 years old and younger. This highlights the importance of having children 12 years old and younger sit in rear seats, as per NHTSA's recommendation. The presence of a frontal air bag improves the protection level of front seats for occupants older than 12 years of age.

Smith and Cummings (2004) demonstrated that in frontal crashes, the risk of injury to rear seat occupants is lower than that of front seat occupants. However, Smith did not examine this relative injury risk as a function of age. Though 64 percent of restrained rear seat occupants are younger than 12 years of age, they only represent 32 percent of the MAIS 2+ injured and 26 percent of the fatally injured rear seat occupants. This suggests that the overall reduced risk of injury and fatality to rear seat occupants may be related to the large representation of young occupants in rear seats.

The risk of AIS 2+ and AIS 3+ injury to restrained and unrestrained rear outboard seat occupants increases with occupant age. In addition, while the most injured body region for children is the head, the thorax is the most injured body region among adults and is significantly more prominent among older occupants. A major source of AIS 3+ chest and abdomen injuries for restrained rear seat occupants is the seat belt. These findings suggest that restraint systems of rear seats could be further optimized to afford better protection to the older population.

The head and neck injury measures of restrained adult dummies in the rear seat of 2004 model year vehicles tested were significantly higher than those of restrained and unrestrained adult dummies in the front seats. This suggests that the advanced restraint systems of the front seats in these newer vehicle models make the front seat position more effective than the rear seating position for adult occupants in reducing serious to fatal injuries.

The significantly higher chest deflection of the HIII 5F and HIII 50M dummies in rear seats compared to that of the corresponding dummy in the front passenger seat may be related to the fact that since there is more space available in the front passenger seat position, the air bag alone and the combination of air bag and belt restraints can be optimally designed to allow the occupant to take advantage of the ride down.

While field data indicates chest injuries to be the dominant injured body region among adult rear seat occupants in frontal crashes, the crash test data suggests a greater risk of head and neck injuries than chest injuries among restrained adult rear seat occupants. The differences in crash test data from real world data may be related to the prescribed injury threshold levels and differences in interaction of the dummy with the restraint system compared to human adults in rear seats.

Full frontal rigid barrier crash tests at 48 and 56 km/h with adult occupants in center rear integrated seats resulted in excessive rotation of the seatback thereby causing the dummy head to contact the front seatback, console, or its own knees, resulting in high head and neck injury measures. Neither rear nor center seat positions are required to be tested dynamically in FMVSS No. 208. The integrated restraints are evaluated statically in FMVSS Nos. 207 and 210. These crash test results, though very limited, suggest that the static test requirements of FMVSS Nos. 207 and 210 may not be sufficient to optimize the protection to occupants in these seating positions in severe frontal crashes. However, much more work is necessary to understand how the regulatory requirements might be altered.

Research efforts have been made in improving rear seat restraint systems. Haberi et al. (1987) presented the development of an ergonomic rear safety belt system used in the European BMW 7 series models that ensured improvements in use rate as well as in occupant protection. The restraint system is characterized by reversed shoulder belt geometry – the upper mounting points are inboard and the diagonal shoulder belt angle across the torso is in the opposite direction of what is customary. Haberi conducted full frontal vehicle crash tests to demonstrate that the forward location of the outboard buckle improves the belt fit and reduces the likelihood of submarining, making the pelvic restraint more effective in head-on collisions.

Zellmer et al. (1998) examined the feasibility and the protective effect of belt pretensioners and load limiters in the rear seats using MADYMO simulations and sled testing. The study showed that optimized belt systems significantly reduce thoracic loading on the rear seat occupant. More recently, Kawaguchi (2003) proposed the concept of optimal belt load control system to afford protection to all size occupants through MADYMO simulations.

The field data as well as the frontal crash test data indicate a need for improvement in frontal crash protection for older rear seat occupants. Advanced restraint systems in rear seats have the potential of improving frontal crash protection for rear seat occupants of all ages, and in particular for the elderly.

CONCLUSIONS

This paper presents the analysis of real world crash databases and crash test data to compare the effectiveness of rear seat restraints to those of the front seats. The findings from this study are as follows:

1. While occupants younger than 50 years of age benefit from sitting in rear seats in frontal crashes, the front seats offer significantly improved protection compared to rear seats in frontal crashes to restrained adults 50 years and older.
2. The most injured body region for restrained children in rear seats is the head while that for adults is the chest.
3. The main source of chest and abdominal injuries for restrained adult occupants in rear seats is their interaction with the seat belts. The major source of injury among unrestrained occupants is contact with the front seat back.
4. Protection of occupants in rear integrated seats may be optimized further by designing seat backs such that they do not experience forward rotation in a moderate to severe frontal crash sufficient to allow injurious contact with the vehicle interior.
5. Rear seat restraints may offer improved protection to occupants of all ages, and in particular, to the elderly, if they are optimized to dynamic crash conditions.

FUTURE RESEARCH

NHTSA is continuing its research program to better understand rear seat and rear integrated seat performance. The NHTSA Special Crash Investigations and CIREN programs will be conducting detailed examination of select crashes involving rear seat occupants with serious to fatal injuries. Different size dummies in rear seats will be added in frontal crash tests to continue evaluation of the dynamic performance of rear seats and rear integrated seats. Numerical simulations will be conducted to determine the feasibility of advanced restraint systems and improved restraint geometry in rear seats to improve rear seat occupant protection.

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APPENDIX A

Table A-1. Full Frontal Rigid Barrier Crash Test – Driver and Front Outboard Passenger

				Driver							Passenger					
TSTNO	Test Speed (km/h)	Make	Model	Model Year	HIII adult dummy size	15 ms HIC	Neck Tension (N)	Max Nij	Chest Ax (gs)	Chest Defl (mm)	HIII adult dummy size	15 ms HIC	Neck Tension (N)	Max Nij	Chest Ax (gs)	Chest Defl (mm)
3783	48	DODGE	GRAND CARAV	2001	5	190.2	1850.7	1.83	67.1	57.5	5	486.2	725.9	0.82	61.5	16.8
3784	48	FORD	ESCAPE	2001	5	134.3	1441.7	1.23	50.3	58.7	5	120.2	511.3	0.68	37.9	10.8
3796	48	FORD	F150 PICKUP	2001	5	136.8	645.9	0.29	34.8	29.0	5	111.1	443.3	0.31	41.7	10.3
4237	56	NISSAN	FRONTIER	2002	50	414.8	1965.0	0.31	45.5	37.7	50	329.3	802.9	0.24	41.8	29.3
4252	56	DODGE	DAKOTA	2002	50	653.9	3135.7	0.56	58.7	48.3	50	256.0	2040.7	0.65	41.0	26.2
4416	56	CHEVROLET	TRAILBLAZER	2002	5	617.2	1638.7	0.55	73.8	44.2	5	793.0	1955.8	0.75	67.4	36.7
4417	56	JEEP	LIBERTY	2002	5	244.8	1742.0	0.60	47.5	29.0	5	192.0	1470.7	0.85	41.7	23.2
4463	57	HONDA	ODYSSEY	2003	50	204.4	1273.2	0.19	41.4	32.4	50	237.1	836.2	0.18	37.1	27.1
4472	56	CHEVROLET	SILVERADO	2003	50	523.0	1957.2	0.33	44.8		50	629.0	2305.4	0.52	49.0	
4483	57	MERCEDES	E320	2003	50	288.2	1006.1	0.23	48.7	34.9	50	216.2	719.2	0.34	48.5	36.1
4486	57	TOYOTA	AVALON	2003	50	383.1	1196.4	0.27	43.0	26.2	50	340.6	1002.2	0.40	39.6	32.8
4487	56	SATURN	ION	2003	50	238.5	813.9	0.26	42.3		50	152.5	1078.3	0.20	35.9	
4493	56	VOLVO	XC 90	2003	50	419.1	1669.5	0.47	49.7	31.7	50	231.7	1676.9	0.38	58.0	35.7
4512	48	CHEVROLET	TRAILBLAZER	2002	5	144.9	1768.8	0.55	64.7	40.9	5	366.4	1682.2	0.70	58.9	38.4
4546	56	TOYOTA	4RUNNER	2003	50	466.8	1494.5	0.28	46.5		50	315.2	1121.3	0.23	45.3	
4549	56	CHEVROLET	TAHOE	2003	50	0.0	1751.0	0.35	52.6	28.6	50	433.3	2171.9	0.46	52.0	34.4
4671	48	BUICK	RENDEZVOUS	2003	50	327.2	1326.6	0.27	47.3	32.4	50	307.0	629.7	0.35	42.0	30.5
4672	48	DODGE	CARAVAN	2003	5	347.8	1352.8	0.48	42.2	24.2	5	292.4	520.9	0.44	41.6	23.7
4673	48	BUICK	RENDEZVOUS	2003	5	357.8	1875.9	0.79	39.9	23.2	5	325.2	756.1	0.44	40.4	25.8
4674	48	HONDA	CRV	2003	50	93.5	1002.0	0.26	36.3	26.2	50	101.8	876.3	0.18	35.1	22.8
4675	48	CHEVROLET	TRAILBLAZER	2003	50	237.1	1767.8	0.36	49.2	39.8	50	291.4	1807.3	0.52	46.2	34.8
4676	48	VOLKSWAGEN	PASSAT	2003	50	179.3	1296.8	0.25	36.3	32.5	50	157.1	1053.2	0.19	33.0	27.3
4681	56	NISSAN	MAXIMA	2002	5	344.3	1968.1	1.23	38.6	29.1	5	409.7	898.7	0.50	40.0	24.1
4682	56	HONDA	CIVIC	2002	5	108.0	1348.0	0.76	41.4	28.1	5	180.5	742.4	0.53	40.1	25.1
4683	56	HONDA	ACCORD	2002	5	69.7	1217.7	0.73	49.8	40.9	5	361.0	670.2	0.60	43.4	20.9
4686	48	HONDA	ACCORD	2003	5	159.1	1908.5	0.92	33.3	22.1	5	224.8	400.4	0.25	35.5	21.0
4687	48	VOLVO	V70	2003	5	120.8	1144.3	0.49	41.9	32.6	5	199.3	535.8	0.43	44.1	28.4
4689	48	ACURA	1.7 EL	2003	5	123.2	1612.9	0.95	37.5	25.4	5	133.7	467.8	0.45	33.2	20.8
4690	48	FORD	EXPLORER	2003	5	396.1	1965.3	1.14	53.7	35.6	5	387.4	714.2	0.53	44.2	29.1
4698	48	TOYOTA	MATRIX	2003	50	110.5	779.9	0.15	32.5	21.6	50	59.3	601.6	0.25	30.9	19.9
4701	56	VOLVO	XC 90	2004	50	288.1	1413.2	0.39	41.7	40.1	50	169.9	1702.1	0.25	48.3	
4776	57	FORD	TAURUS	2004	50	316.6	1284.6	0.30	43.0	27.7	50	146.9	1253.4	0.28	41.9	22.0
4780	48	DODGE	CARAVAN	2003	50	289.4	875.7	0.34	49.8	46.5	50	348.9	818.0	0.22	8.1	31.0
5092	56	VOLVO	S40	2004	50	185.0	1278.8	0.38	47.2	38.7	50	143.4	1070.8	0.21	43.5	31.0
5117	57	SUBARU	OUTBACK	2005	50	238.7	1067.7	0.23	38.9	28.6	50	178.6	911.9	0.17	44.0	29.7
5143	56	FORD	TAURUS	2004	5	166.0	1433.8	0.44	37.5	29.1	5	289.9	409.7	0.28	42.0	19.1
5144	56	HONDA	ODYSSEY	2004	5	56.8	917.6	0.43	32.4	24.4	5	233.2	918.9	0.49	38.1	14.5
5145	57	HONDA	ACCORD	2004	5	279.9	914.9	0.30	32.1	26.0	5	181.5	738.0	0.22	38.3	28.8
5164	48	MITSUBISHI	GALANT	2004	50	149.7	1240.7	0.29	39.7		50	182.0	1256.0	0.26	33.7	
5166	48	SUZUKI	SWIFT	2004	50	128.4	1228.8	0.26	36.6		50	185.4	1534.2	0.29	32.2	
5167	48	NISSAN	MAXIMA	2004	50	113.8	999.2	0.22	39.0		50	276.3	852.9	0.24	35.0	
5168	48	HONDA	ELEMENT	2004	50	110.8	1302.2	0.29	34.0		50	215.0	1344.6	0.31	35.1	
5173	48	MERCEDES	C230	2004	50	186.2	1085.6	0.24	46.3		50	214.5	808.3	0.21	40.7	
5174	48	HYUNDAI	TIBURON	2004	50	96.4	671.8	0.17	33.4		50	107.0	963.0	0.24	44.0	
5182	48	CHRYSLER	CONCORDE	2004	50	316.6	1295.5	0.33	43.4		50	128.5	1029.7	0.20	35.2	
5191	48	CHEVROLET	MALIBU	2004	50	172.8	1205.1	0.29	33.0		50	135.9	1113.6	0.32	34.6	
5203	47	TOYOTA	SIENNA	2004	5	126.7	1201.5	0.44	34.5		50	230.7	666.1	0.38	29.7	

Note: **HIII Dummy Size: 50**: Hybrid III 50th percentile male dummy; **5**: HIII 5th percentile female dummy,

Table A-2. Full Frontal Rigid Barrier Crash Test Data – Rear Seat Occupant

TSTNO	Test Speed (km/h)	Make	Model	Model Year	occ. seat positon	HIII dummy size	15 ms HIC	Neck Tension (N)	Max Nij	Chest Ax (gs)	Chest Defl (mm)
Rear Outboard Seats											
3783	48	DODGE	GRAND CARAVAN	2001	3	6C	759.3	376.3	0.30	52.7	29.0
3784	48	FORD	ESCAPE	2001	3	6C	762.7	608.4	0.24	69.3	39.7
3796	48	FORD	F150 PICKUP	2001	4	6C	425.2	530.2	0.20	40.8	26.0
4252	56	DODGE	DAKOTA	2002	3	6C	476.8	2031.4	1.15	55.9	0.0
4463	57	HONDA	ODYSSEY	2003	4	6C	593.9	2230.0	0.89	39.0	0.0
4472	56	CHEVROLET	SILVERADO	2003	4	6C	0.0	2680.5	1.36	0.0	0.0
4483	57	MERCEDES	E320	2003	4	6C	724.2	2626.4	1.16	57.7	1.3
4486	57	TOYOTA	AVALON	2003	4	6C	887.4	2911.7	0.98	54.4	23.6
4487	56	SATURN	ION	2003	4	6C	0.0	2760.4	1.01	0.0	0.0
4493	56	VOLVO	XC 90	2003	4	6C	0.0	2954.1	1.27	53.7	38.1
4546	56	TOYOTA	4RUNNER	2003	4	6C	0.0	3504.3	1.42	0.0	0.0
4549	56	CHEVROLET	TAHOE	2003	4	6C	0.0	2487.0	1.03	36.8	25.5
4671	48	BUICK	RENDEZVOUS	2003	4	6C	730.0	3335.1	1.41	0.0	34.7
4672	48	DODGE	CARAVAN	2003	3	6C	481.8	2176.7	0.95	0.0	19.7
4682	56	HONDA	CIVIC	2002	4	6C	607.1	2339.2	0.85	0.0	40.8
4686	48	HONDA	ACCORD	2003	3	6C	416.3	1420.6	0.68	0.0	22.8
4687	48	VOLVO	V70	2003	3	6C	465.3	1500.7	0.56	0.0	40.8
4687	48	VOLVO	V70	2003	4	6C	319.4	1817.7	0.63	0.0	43.9
4689	48	ACURA	1.7 EL	2003	3	6C	684.0	2247.0	0.91	0.0	38.3
4689	48	ACURA	1.7 EL	2003	4	6C	665.3	2308.2	1.04	0.0	34.1
4690	48	FORD	EXPLORER	2003	4	6C	527.4	3413.8	1.43	0.0	43.8
4698	48	TOYOTA	MATRIX	2003	4	6C	545.8	2150.8	0.75	0.0	34.1
4701	56	VOLVO	XC 90	2004	4	6C	824.5	2628.1	0.99	88.3	36.2
4776	57	FORD	TAURUS	2004	4	6C	1020.7	2799.6	1.13	57.6	18.6
4780	48	DODGE	CARAVAN	2003	3	6C	1051.9	2741.3	1.32	0.0	42.9
5092	56	VOLVO	S40	2004	4	6C	0.0	3084.0	1.80	60.3	0.0
5117	57	SUBARU	OUTBACK	2005	4	6C	1477.8	3527.0	1.41	73.6	32.8
5143	56	FORD	TAURUS	2004	3	5	536.0	2378.3	0.89	42.0	32.8
5144	56	HONDA	ODYSSEY	2004	3	5	1057.0	3354.0	1.17	52.8	37.2
5145	56	HONDA	ACCORD	2004	3	5	783.0	2774.0	0.94	48.6	47.1
5164	48	MITSUBISHI	GALANT	2004	4	5	515.0		0.96	45.6	32.8
5167	48	NISSAN	MAXIMA	2004	4	5	270.0		0.70	47.4	35.9
5168	48	HONDA	ELEMENT	2004	3	5	642.0		0.96	41.3	33.7
5173	48	MERCEDES	C-230	2004	4	5	663.0		0.98	48.9	36.0
5174	48	HYUNDAI	TIBURON	2004	4	5	483.0		0.76	43.5	34.0
5182	48	CHRYSLER	CONCORDE	2004	3	5	373.0		0.87	46.3	38.0
5191	48	CHEVROLET	MALIBU	2004	3	5	343.0		0.72	51.7	34.6
5203	48	TOYOTA	SIENNA	2004	4	5	396.0		0.71	36.8	28.8
Seatbelts Integrated to Seat											
4416	56	CHEVROLET	TRAILBLAZER	2002	6	50	552.6	3170.5	0.65	41.4	44.6
4417	56	JEEP	LIBERTY	2002	6	50	684.0	3221.6	0.62	47.2	36.4
4493	56	VOLVO	XC 90	2003	6	6C	1411.9	3371.2	1.32	65.2	27.9
4512	48	CHEVROLET	TRAILBLAZER	2002	6	50	354.4	3688.4	0.70	32.8	65.8
4690	48	FORD	EXPLORER	2003	6	6C	795.0	2491.8	0.97	0.0	28.0
4701	56	VOLVO	XC 90	2004	6	6C	1324.5	3128.3	1.27	56.7	37.5
5166	48	SUSUKI	SWIFT	2004		5	480.0		0.84	38.6	32.1
5203	48	TOYOTA	SIENNA	2004	3	5	725.0		0.44	36.6	28.7

Note: **Occupant Seat Position: Position 3**: Right rear seat; **Position 4:** Left rear seat; **Position 6:** Rear center seat. **HIII Dummy Size: 50**: Hybrid III 50th percentile male dummy; **5**: HIII 5th percentile female dummy, **6C**: HIII 6 year-old child dummy.

APPENDIX B

Full frontal rigid barrier crash tests with the same size dummy in the front and rear seats

Table B-1. Full frontal rigid barrier crash test at 56 km/h with restrained HIII 5F dummies in the driver and front outboard seats and restrained HIII 5F dummy in the rear outboard seat.

				HIC15			Neck Tension (N)			Nij			Chest Accel. (gs)			Chest Defl (mm)		
tstno	Make	Model	Year	driver	Front Pass	Rear Pass	driver	Front Pass	Rear Pass	driver	Front Pass	Rear Pass	driver	Front Pass	Rear Pass	driver	Front Pass	Rear Pass
5143	FORD	TAURUS	2004	152.2	289.9	533.8	1433.8	409.7	2378.3	0.44	0.28	0.89	37.5	42.0	42.0	29.1	19.1	32.8
5145	HONDA	ACCORD	2004	279.9	181.5	780.8	914.9	738.0	2774.6	0.30	0.22	0.94	32.1	38.3	48.6	26.0	28.8	47.2
5144	HONDA	ODYSSEY	2004	56.8	233.2	1052.6	917.6	918.9	3354.0	0.43	0.49	1.17	32.4	38.1	52.8	24.4	14.5	37.2
5210	CHEVROLET	AVALANCHE	2004	579.5	483.9	540.5	1727.7	1770.2	2220.6	0.74	1.03	1.32	58.6	53.6	41.5	44.4	14.9	42.2
5211	JEEP	LIBERTY	2004	232.4	527.1	659.0	1755.3	1369.4	2519.5	0.79	0.78	0.92	44.8	42.8	51.2	31.1	24.2	49.2

Table B-2. Full frontal rigid barrier crash test at 48 km/h with unrestrained HIII 50M dummies in the driver and front outboard seats and restrained HIII 50M dummy in the rear outboard seat.

				HIC15			Neck Tension (N)			Nij			Chest Accel. (gs)			Chest Defl (mm)		
tstno	Make	Model	Year	driver	Front Pass	Rear Pass	driver	Front Pass	Rear Pass	driver	Front Pass	Rear Pass	driver	Front Pass	Rear Pass	driver	Front Pass	Rear Pass
5216	TOYOTA	CAMRY	2004	116.51	138.12	637.57	1650.1	559.52	3517.28	0.343	0.36	0.94	52.79	41.051	ND	33.06	14.74	ND
5215	HONDA	ACCORD	2004	293.57	97.394	348.5	1383.2	615.36	2374.12	0.256	0.272	0.792	58.06	35.039	37.86	54.52	11.36	55.81
5212	HONDA	ODYSSEY	2004	57.742	160.58	388.42	1371.7	415.94	2446.94	0.297	0.29	0.702	41.99	39.293	43.74	48.24	9.782	38.6
5213	CHEVROLET	AVALANCHE	2004	193.3	124.29	355.5	1599.2	1632.3	3876.41	0.321	0.357	0.598	44.2	35.926	ND	47.51	8.951	ND
5158	JEEP	LIBERTY	2004	306.74	523.21	419.56	604.53	1342.5	2352.12	0.298	0.578	0.632	54.83	66.593	41.24	41.62	12.03	37.77

APPENDIX C

FARS data (1993-2003) of frontal crashes (excluding rollovers) involving passenger cars or LTVs of model years later than 1991 that were used in the double-paired comparison study.

Restrained Occupants

	Front Passenger Seat Occupants				Rear Seat Occupants	
	Belted and no air bag		Belt+ Air Bag		Belted	
age group	Driver F1	RF Pass F2	Driver F1	RF Pass F2	Driver F3	rear Pass F4
0-5	95	93	25	41	428	230
6-8	90	82	44	40	219	120
9-12	91	72	81	41	200	83
13-15	145	94	96	52	140	50
16-24	625	572	506	403	257	111
25-49	697	852	569	478	190	121
50-74	644	997	623	635	139	205
75+	308	723	290	545	37	162

Unrestrained Occupants

	Front Passenger Seat Occupants				Rear Seat Occupants	
	No Belt and no air bag		No Belt+ Air Bag		No Belt	
age group	Driver F1	RF Pass F2	Driver F1	RF Pass F2	Driver F3	rear Pass F4
0-5	48	65	11	46	72	54
6-8	59	49	17	40	113	50
9-12	71	35	19	18	117	48
13-15	123	101	58	46	160	93
16-24	823	926	523	490	622	413
25-49	753	903	368	394	287	236
50-74	239	354	111	144	50	65
75+	92	211	54	109	24	38

REAR SEATED OCCUPANT SAFETY IN FRONTAL IMPACTS

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ABSTRACT

Rear seating systems are still being used in military vehicles as well as in some civilian 4 Wheel Drive (4WD) vehicles. Very limited research work is available in regards to the safety of a rear facing seated occupants in a frontal impact crash. This paper describes a new energy absorbing rearward facing seating system which can be used in a 4WD vehicle to attenuate the deceleration forces in a frontal impact. A series of dynamic sled tests on prototype seats were conducted. A 50% male Hybrid III dummy was used for the sled tests. Both the dummy and the seat were subjected to a 49km/h speed change where the forward crash deceleration was 22 g's over duration of 100 ms with the seat and dummy positioned backwards. A MADYMO model was then developed and calibrated against the sled test data.

In the calibration process attention was focussed on the head and chest decelerations in the forward direction as well as on the maximum energy absorbed by the prototype seat. Once the model was calibrated it was then used to simulate the same frontal crash conditions where a 95% male and a 5% female Hybrid III dummy respectively were seated in the prototype seat.

The prototype seat, the sled test results, the simulation models and resulting decelerations and injury outcomes are described in the paper. This study showed that by using an energy absorbing seating system, the crash deceleration can be effectively attenuated and occupant injuries significantly reduced in comparison to conventional seating systems.

INTRODUCTION

The Australian Army is equipped with Perentie 4x4 vehicles which are based on the Land Rover 110. One of the variants used is a Regional Forces Surveillance Vehicle (RFSV). The RFSV has a crew of three personnel; two occupants sit in the front of the vehicle and are provided with three point lap sash seatbelts. The third crew member sits in a rear facing seat and is provided with a lap belt as the photographs show in Figure 1. As a result of developments undertaken initially by Project TRANSAFE and subsequently Project OVERLANDER to improve the occupant safety systems, the restraints where changed to a harness. The rear facing seat was moved further rearwards to accommodate equipment storage. Previously the rear facing seat back was constrained in a forward collision by its proximity to the cross bracing of the Roll Over Protective Structure.

Figure 1. Photos of Regional Forces Surveillance Vehicle (RFSV)

The placement of the rear facing seat rearwards resulted in an analysis of the seat and alternatives. The rear facing seat and commercially available alternative rear facing seats were subjected to a 20g acceleration pulse using a Hybrid III 50% adult male Anthropomorphic Test Dummy (ATD) to measure occupant decelerations.

The rear facing seat and commercially available alternative rear facing seats failed to prevent injurious loading. A soldier proof robust tapered energy attenuator was then designed to accommodate both a 5% adult female and a 95% adult male which could be positioned between the rear of the seat and the Roll Over Protective Structure. This was done so as to investigate the seat's crashworthiness for a range of possible occupants.

TESTS ON REAR FACING SEATS

In order to determine the dynamic performance of the RFSV rear facing seat, a series of dynamic sled tests on prototype seats were conducted as shown in Figures 2 to 5 [reference 1, 2].

Figure 2. Pre Test S010165 (ISRI reclining seat)

Figure 3. Post Test S010165

The first series of tests were carried out on a rigid seat. Figures 2 and 3 show the pre and post test S101165, an ISRI reclining seat without an energy absorber. The seat incorporated a reclining system (operated by means of a spring-loaded self-locking release mechanism) which was reclined to produce a seat back angle of approximately 76°. This seat was tested in conjunction with a backrest stopper mounted onto the test rig's bulkhead. The stopper was designed to limit the amount of deformation of the seat back.

The second series of tests were carried out on modified seats where the seat back was supported by an energy absorber as shown in Figures 4 and 5. The backrest stopper was removed and replaced by an energy absorber. The head restraint incorporated a mild steel plate three millimetres thick within the seat's foam padding.

The test method was based on the dynamic test requirements of Australian Design Rule 68/00 "Occupant protection in buses" [reference 3]. The Hybrid III test dummy, although designed for frontal impact, was used to assess the seat strength, the occupant restraint system and injury protection provided.

Figure 4: Pre test S010287 (old ISRI seat)

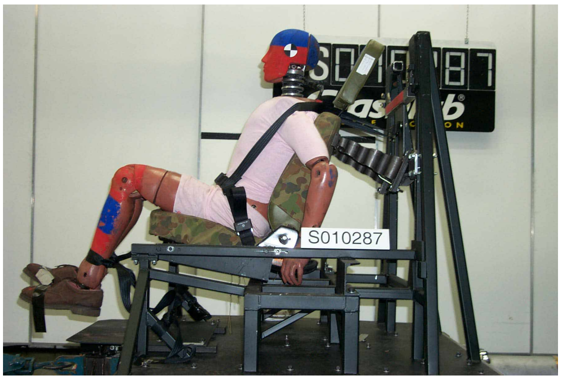

Figure 5: Post test S010287

The test rig used for all tests was fabricated from square tubular steel to position the test seats on the sled. The rig incorporated attachment fittings for the seat (by means of designated attachment frames to enable different mounting configurations), anchorage points for the occupant restraint system, bulkhead and floor. A foot support section mounted to the rig's floor was raised by approximately 30 mm to enable the test dummy's feet to be placed flat on the floor.

The energy absorber was mounted to the test rig's bulkhead directly behind the seat back at an angle of approximately 67° to the vertical and was required to absorb the loads during impact [see figure 4]. The system consisted of two tapered mild steel sections approximately 300mm long, incorporating a series of folds as shown in Figure 6. The taper was 30mm wide directly behind the test seat and 90 mm wide at the bulkhead mount giving a 30:90 configuration. A static compression test was carried out in the laboratory and its load-deflection curve is presented in Figure 7.

Figure 6. Photo of the energy absorber

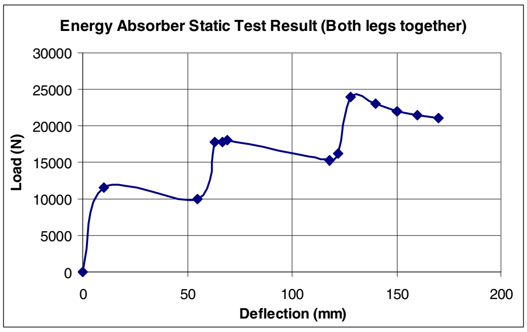

Figure 7. Energy absorber load deflection test curve

Figures 1 and 3 show the test setup. A Hybrid III test dummy was positioned in the test seat and the system subjected to the dynamic impact pulse shown in Figure 8. Australian design Rule 68/00 "Occupant Protection in buses" Clause 7.4 requires a velocity change of not less than 49 km/h and a forward deceleration of at least 20 g's (196 m/s^2) to be achieved within 30 ms.

The occupant restraint system used with the seats was a four point harness system. The harness is comprised of two shoulder belts each incorporating an emergency locking retractor (ELR) that is mounted to the rig's bulkhead directly behind the seat. The shoulder belts were joined to a manually adjusted lap belt mounted to the seat.

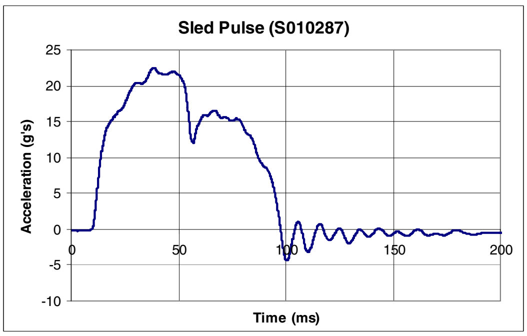

Figure 8: Sled deceleration pulse used for test S010287

The test results of the Hybrid III acceleration measurements are summarised in Table 1. It should be pointed out that any injury severity parameter for the Hybrid III was not calculated for the test because the Hybrid III test dummy has validated bio-mechanical responses for frontal impacts only.

Table 1: Hybrid III acceleration measurements

	S010165	S010287
Head (g's) - x	455	56
- y	9	2
- z	97	37
Resultant (max)	465	58
Chest (g's) - x	68	43
- y	7	3
- z	19	8
Resultant (3ms max)	66	39
Energy Absorber deformation (mm)	N/A	33

The high speed film of test S010165 shows the dummy sliding back into the seat towards the direction of impact, where it began to load the seat back approximately 25 ms after impact. The gradual loading of the seat back resulted in impact with the backrest stopper at approximately 50ms, which in turn loaded the chest substantially throughout the event. A 3ms resultant chest acceleration of 66 g's was measured. The head restraint contacted the upper section of the bulkhead at approximately 55ms where it started to deform. At approximately 65 ms the back of the head contacted the upper half of the head restraint as a result of neck extension resulting from the impact event. Compression of the head restraint's padding cushioned the impact between the head and upper section of the bulkhead producing a maximum resultant acceleration of 465 g at around 72 ms.

For test S010287, the high speed film shows the dummy sliding back into the seat towards the direction of impact. The dummy then started to load the seat back at approximately 30ms followed by loading of the energy absorber at approximately 35 ms. The energy absorber appeared to undergo loading for a further 35 ms with the deformation being reasonably uniform on both sides. The back of the head contacted the centre of the head restraint at approximately 45 ms after impact. The foam padding then began to compress. The impact of the back of the head with the head restraint gave a maximum resultant head acceleration of 58 g's at around 56 ms. A 3 ms resultant chest acceleration of 39 g's at 51 ms was also noted.

Test results clearly show a significant improvement when test S010287 is compared to test S010165 in term of occupant response. It proved that by incorporating an energy absorber into a rear facing seating system, occupant safety can be dramatically improved.

OCUPANT DYNAMIC SIMULATION

It has long been recognised that computer simulation can be an effective and relatively low cost tool to analyse design alternatives or to carry out detailed parametric studies of the crashworthiness performance of a mechanical system [4-9]. The use of suitable computer models to assist in the development of prototypes or to improve a particular design can also reduce the amount of costly physical testing.

The main objective of this project was to develop a capability to simulate occupant dynamics in a rear facing seat under a frontal impact situation. These simulations can then be utilised to determine peak occupant decelerations and injury values for different dummy sizes, providing information for seat design.

The MADYMO computer package was chosen to simulate the occupant dynamics [ref. 10-13]. In this study, a 50% male Hybrid III dummy was used to simulate and develop the energy absorbing seating system.

MADYMO Model

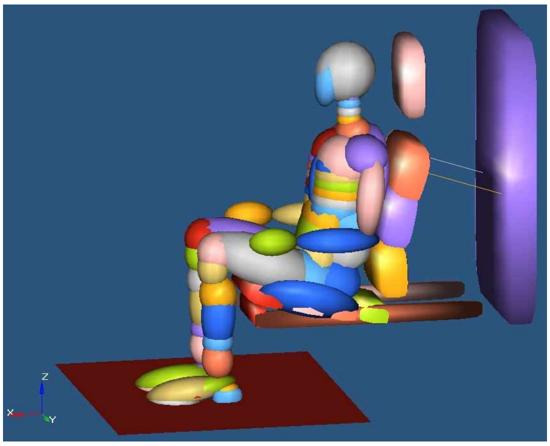

Figure 9. MADYMO Model setup

In constructing the MADYMO model, the seat/rig geometry, occupant properties (segment geometry, inertial properties, and joint properties), and occupant/seat contact interaction properties had to be specified. The belt restraint system was not modelled because it had little influence on the occupant dynamic behaviour for this particular application.

Seat/rig Model. The seat setup shown in Figure 9 was modelled as a multi-body system, consisting of a seat base, seat back and head rest. The seat was constrained to the rig's rail by using the point-restraint feature. The floor was modelled as a plane.

Energy Absorber Model. Maxwell spring elements were used to model the energy absorber with an initial length of 300 mm. The stiffness values from the laboratory test presented in Figure 6 were incorporated into the model.

Occupant Model. The occupant properties were based on the Hybrid III anthropomorphic crash dummy. The MADYMO library contains a standard data set which characterises the dynamic behaviour of the Hybrid III dummy in a frontal crash, but can also be used for such rearward simulation. A rearward impact dummy (RID) is not available as yet. Geometric, inertial and joint properties were obtained from various measurement data, including static and pendulum tests (refs 10-11). The dummy was positioned in the same way as in the test setup shown in Figure 4.

Occupant/Seat & Rig Interaction. By representing body segments and seat/rig components as ellipsoids and planes, the MADYMO algorithm models the interactions for ellipsoid-ellipsoid and plane-ellipsoid contacts according to the contact parameters specified by the user, which include stiffness, hysteresis and friction.

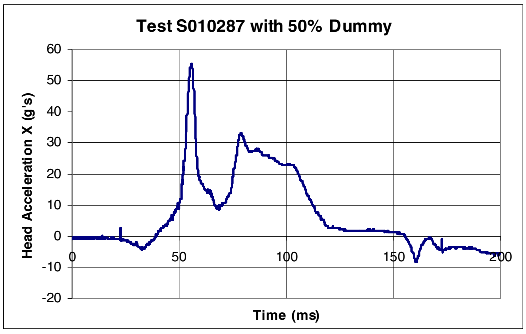

Figure 10. Head frontal (x) acceleration

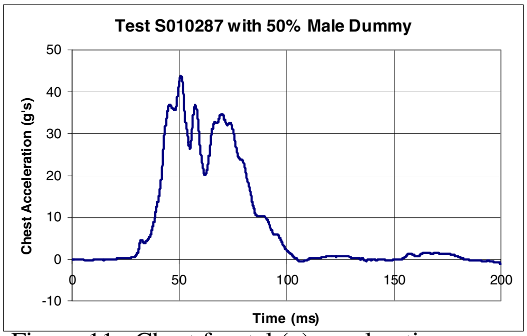

Figure 11. Chest frontal (x) acceleration

Model Validation. Once the MADYMO model was developed, it was then calibrated against the crash test S010287 described in the last section. In the calibration process attention was focussed on the head and chest acceleration in the axial direction and maximum compression of the energy absorber. In particular, head and chest acceleration in the axial direction [Figures 10 and 11] from the test were used as the benchmark in the calibration process. The simulation results obtained for both occupant head acceleration (Figure 12) and chest acceleration (Figure 13) matched the test results with satisfactory accuracy. The peak acceleration and the energy absorber deformation are a very good match to the test measurements as shown in Table 2.

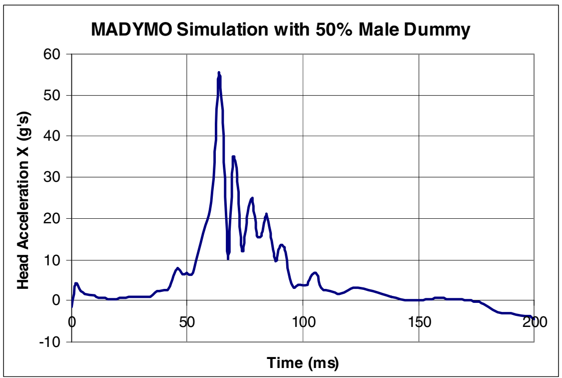

Figure 12. Head frontal (x) acceleration from MADYMO simulation

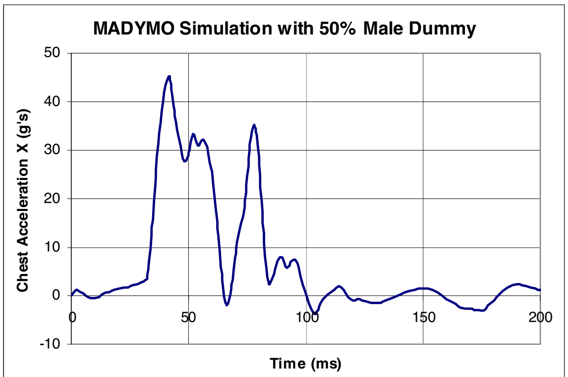

Figure 13. Chest frontal (x) acceleration from MADYMO simulation

Table 2: Hybrid III acceleration measurements

	Test S010287	MADYMO Simulation
Head (g's) - x	56	55
Chest (g's) - x	43	45
Energy Absorber deformation (mm)	33	33

SIMULATON RESULTS

A total of three impact simulations were performed. These consisted of three different sizes of occupants including a 50% male dummy, a small 5% female hybrid III dummy and a large 95% male hybrid III dummy. All three dummies were placed in the same seating position and subjected to the same crash pulse. Tables 3 and 4 list the predicted responses for the different size occupants. Table 5 summarises the deformation of the energy absorber.

Table 3. Peak Occupant Acceleration Results

Dummy Type	Head Resultant Acceleration (g)	Chest Resultant Acceleration (g)
50% Male	62	47
95% Male	57	56
5% Female	92	51

Table 4. Occupant Injury Results

Dummy Type	Head Injury Criterion (HIC)	Upper thorax 3ms maximum (g's)
50% Male	232	42.4
95% Male	239	38.3
5% Female	324	48.6

Table 5. Energy absorber deformation.

Dummy Type	Energy Absorber deformation (mm)
50% Male	33
95% Male	43
5% Female	11

50% male occupant impact. During dynamic simulation the occupant slid back into the seat towards the direction of impact. It commenced to load the seat back at approximately 30 ms, followed by loading of the energy absorber at approximately 35 ms (Figure 14). The seat was continually loaded up until approximately 110 ms when the dummy started to slide off. The back of the head contacted the centre of the head restraint at approximately 50 ms after impact. The impact of the back of the head with the head restraint gave a maximum resultant head acceleration of 62 g's at 64 ms (Figure 15). The maximum resultant chest acceleration was 47 g's (Figure 16). The corresponding HIC was 232 (Table 4). The computed 3-ms chest acceleration was 42 g's. The impact resulted in the energy absorber system deforming 33 mm.

95% large male occupant impact. The kinematics of the large size occupant is similar to that of the 50% dummy, except the dummy loaded more into the seat. The dummy commenced to load the seat back at approximately 30ms followed by loading of the energy absorber at approximately

35 ms (Figure 14). The seat was continually loaded until approximately 130 ms when the dummy started to slide off. The maximum resultant head and chest acceleration computed were 57 g's and 56 g, respectively (Figures 17&18). The calculated HIC was 239 (Table 4). The computed 3-ms chest acceleration was 38 g's. It was predicted the energy absorber would deform 43 mm when subject to the impact load.

5% small female occupant impact. As expected, the small female occupant loaded into the seat much more lightly than the male occupants, although its dynamic response to the same crash pulse was similar to that of the large male occupants. However, the injuries calculated were the largest among the three for the small female ATD. The HIC was 324 and 3-ms chest acceleration was 49 g's. Figure 19 and 20 show the head and chest responses for the simulated crash. The deformation of the energy absorber was only 11 mm.

Overall, by using the energy absorbing seating system, the occupant peak acceleration for all three occupant sizes is much lower than that when a conventional seating system is used (Table 1). Occupant injuries are small to moderate.

CONCLUSIONS

A MADYMO model was developed and validated for a rear facing seat in frontal crashes. Three simulations were performed based on a 50% average male Hybrid III dummy, a 95% large male dummy and a 5% small female dummy to cover the range of occupant sizes. Occupant safety has been assessed through simulations.

The results of the simulations showed that by using an energy absorbing seating system, crash deceleration can be effectively attenuated and occupant injuries significantly reduced in comparison to conventional seating systems.

In future, physical crash tests will still be required as the final certification method for approval of a particular crashworthy mechanical system. However during the development process the application of computer simulation methods as presented in this paper show that it is possible to reduce development costs.

ACKNOWLEDGEMENTS

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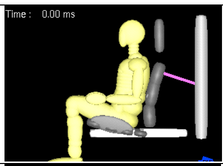
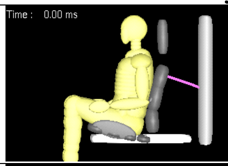
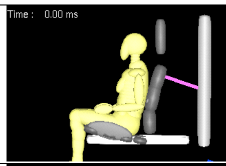
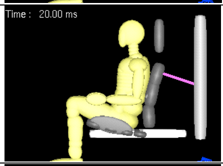
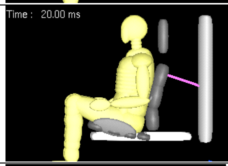
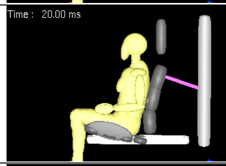
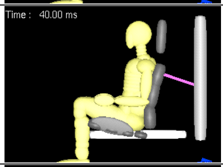
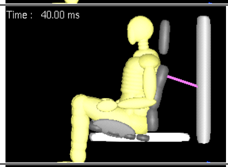
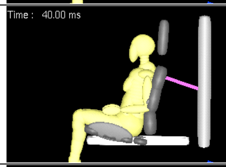
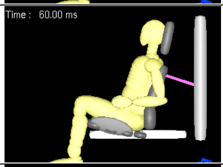
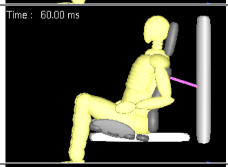
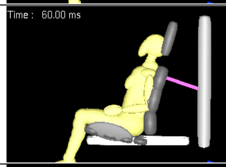
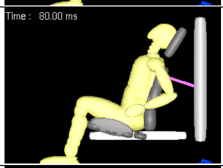
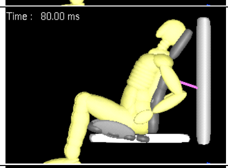
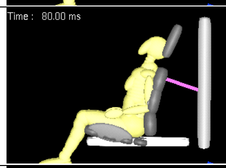
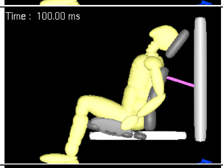
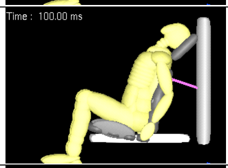
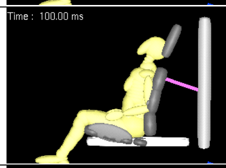
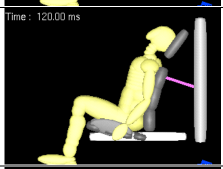
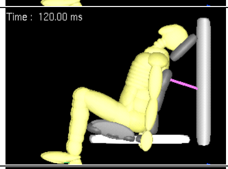
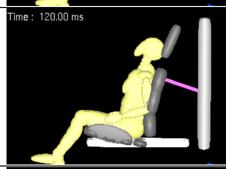
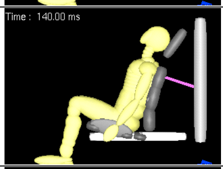
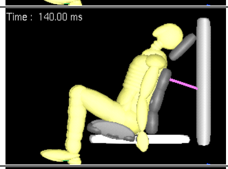
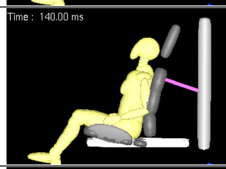
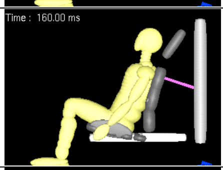
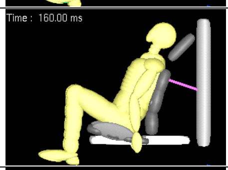
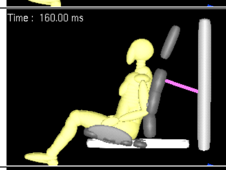
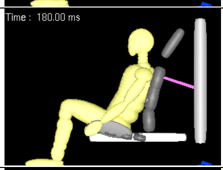
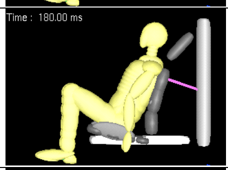
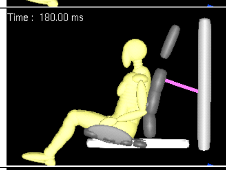
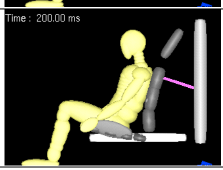
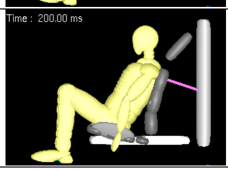
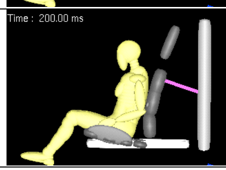
Time (ms)	50% male dummy	95% male dummy	5% female dummy
00			
20			
40			
60			
80			
100			
120			
140			
160			
180			
200			

Figure 14: Dummy Kinematics during impact

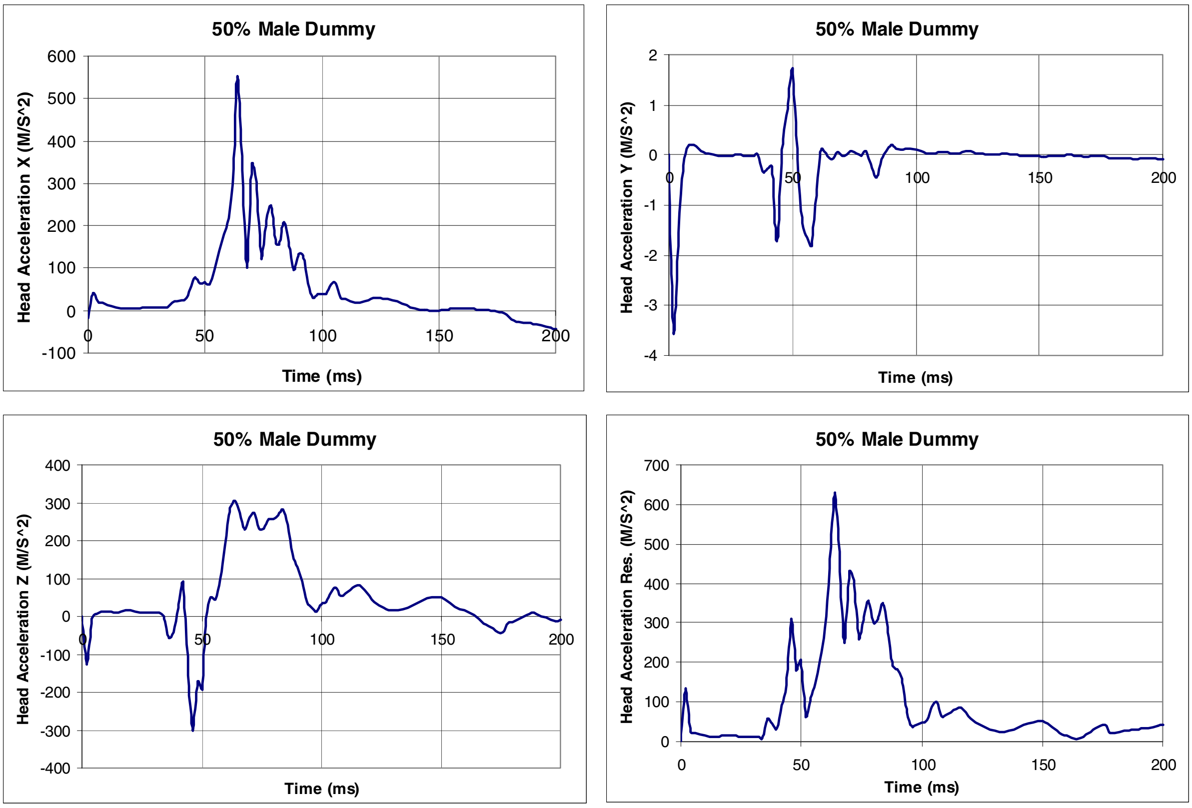


Figure 15. Head acceleration plot for 50% male dummy from computer simulation

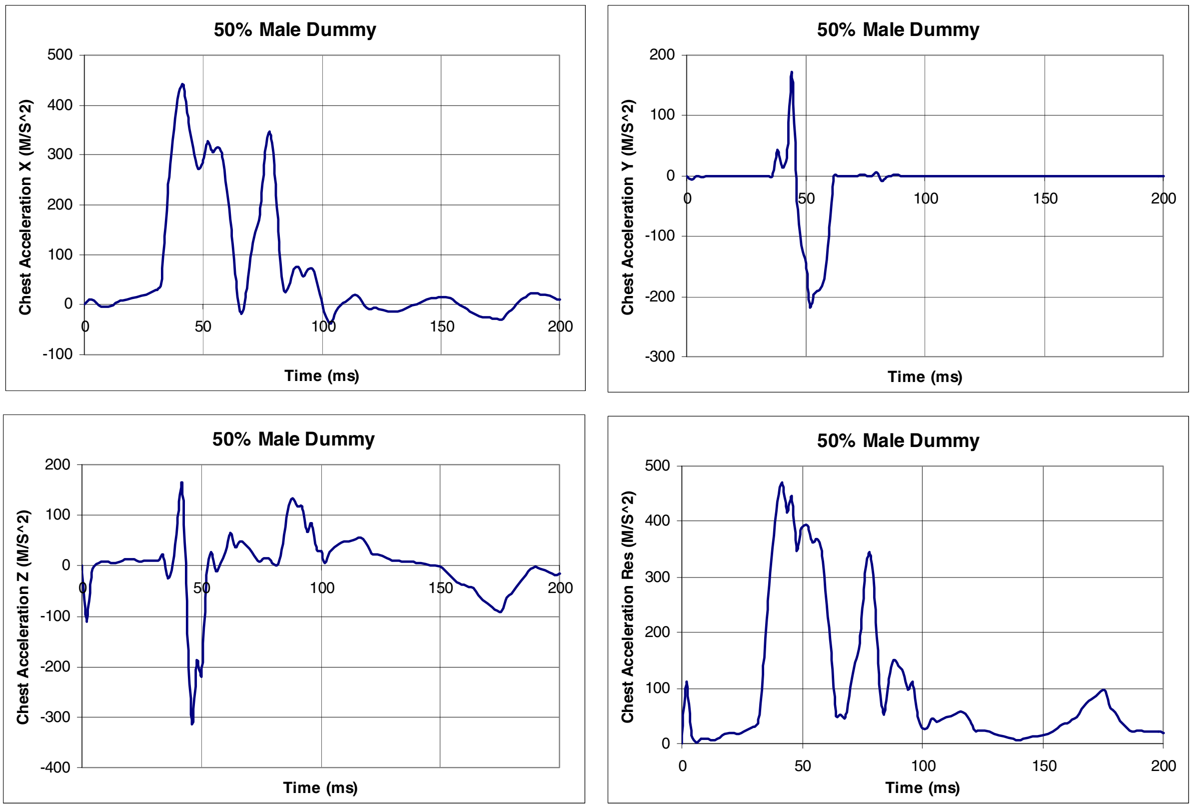


Figure 16. Chest acceleration plot for 50% male dummy from computer simulation

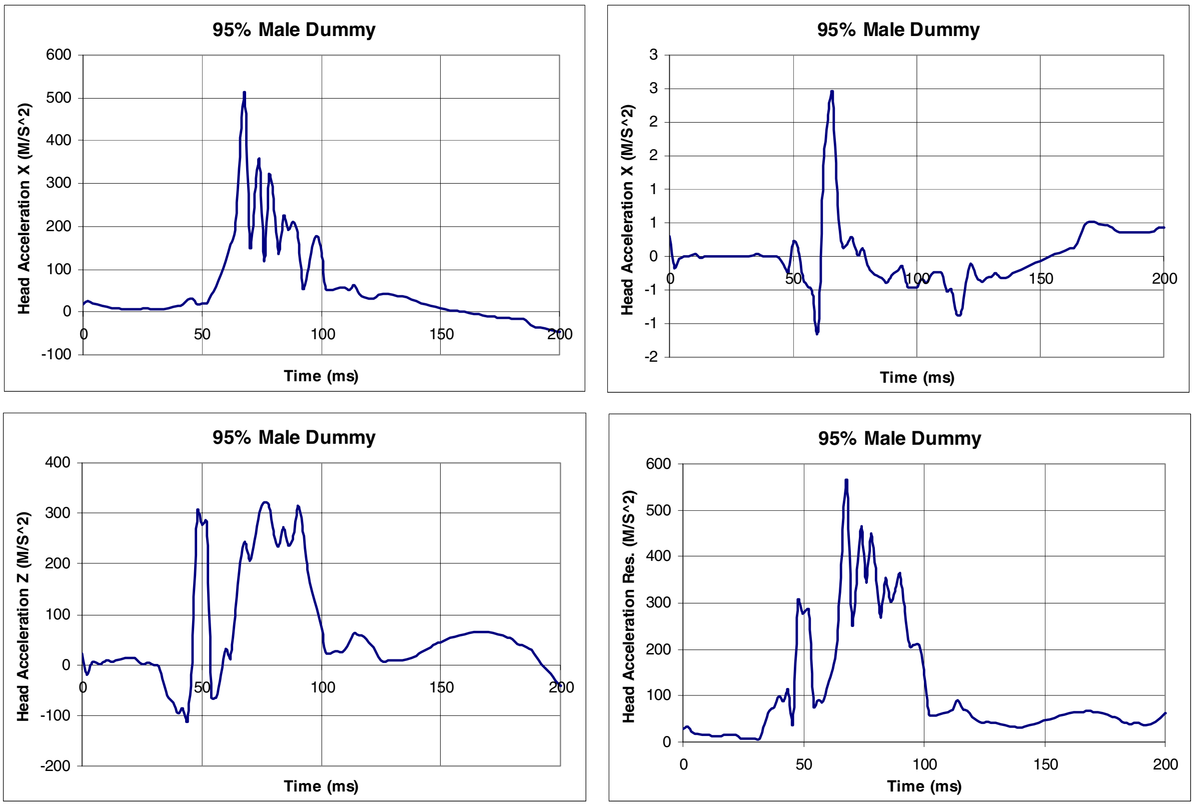


Figure 17. Head acceleration plot for 95% male dummy from computer simulation

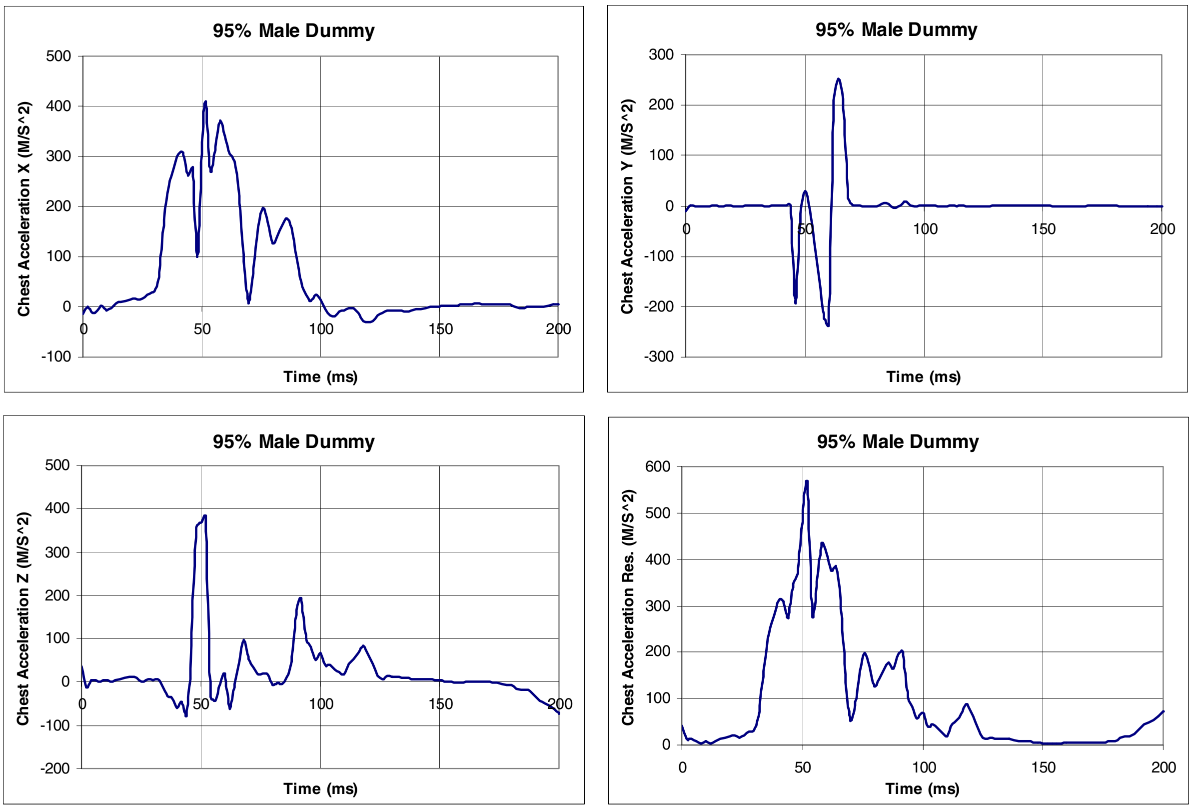


Figure 18. Chest acceleration plot for 95% male dummy from computer simulation

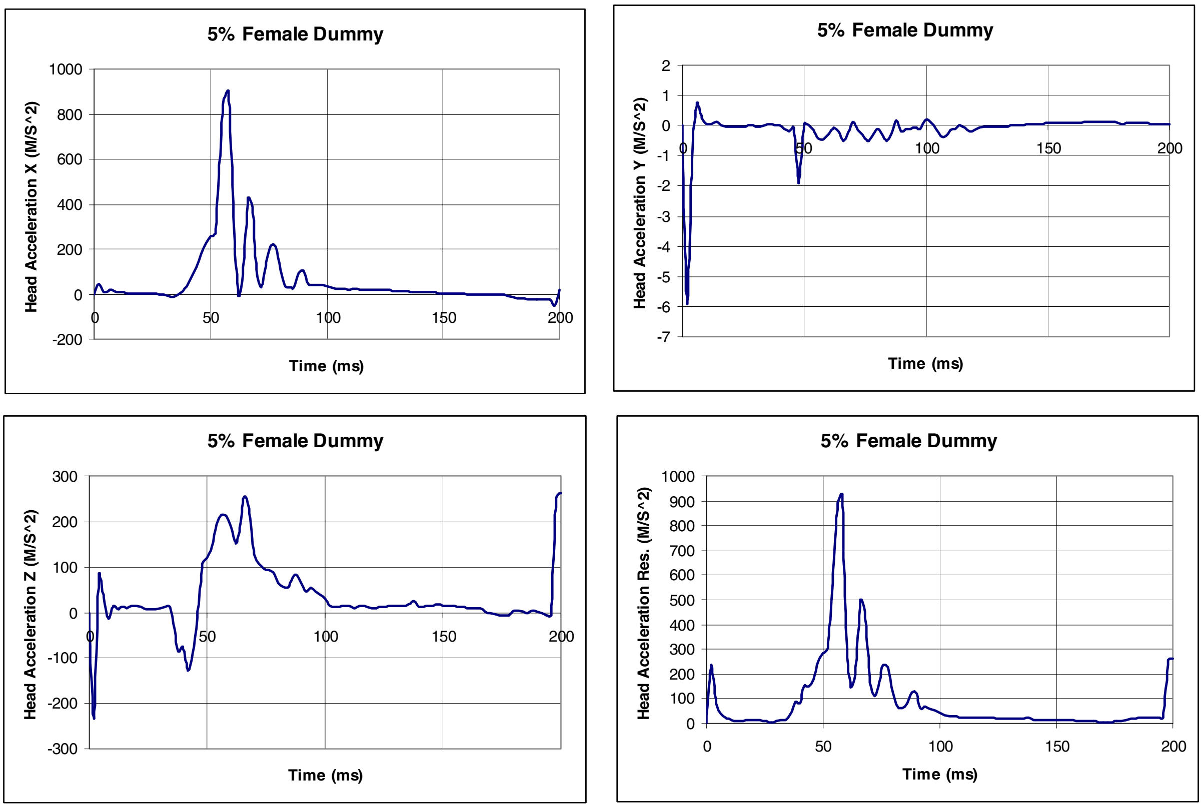


Figure 19. Head acceleration plot for 5% female dummy from computer simulation

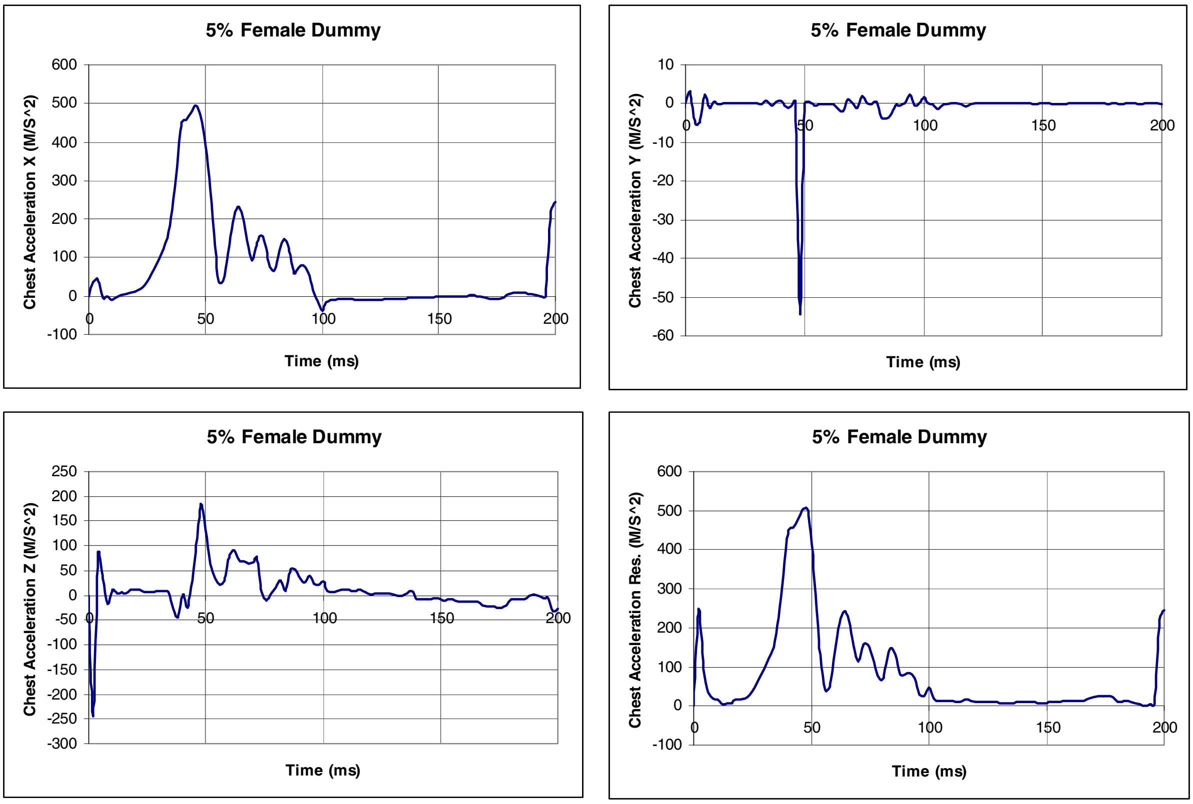


Figure 20. Chest acceleration plot for 5% female dummy from computer simulation

THE INFLUENCE OF VEHICLE DESIGN ON INJURY RISK TO SERIOUSLY INJURED CASUALTIES AND RESCUE PERSONNEL.

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Hereford and Worcester Fire and Rescue Service[2].
West Midlands Fire Service[3]. United Kingdom
ID #: 05-0244

ABSTRACT

Seriously injured casualties in traffic collisions are frequently extricated from their vehicles by fire rescue services. This is achieved by employing space creation techniques to create apertures to provide access to casualties for the administration of medical assistance and to facilitate extrication of the casualty.

Data relating to a sample of 235 passenger car crashes was analyzed to identify the characteristics of such crashes. The data were selected on the basis of a geographical area for which a sample of the occupant extrication data from the Fire Service in that area was also available.

Analysis showed that there was a significant likelihood of rescue service involvement in crashes with an occupant with MAIS ≥ 3 injury severity.

Rescue service intervention was significantly more likely to occur when the occupants had received an injury of AIS ≥ 2 severity to the head, face or upper/lower limb body regions. Steering wheel intrusion, pedal disruption and front passenger compartment intrusion were also seen to significantly influence the need for rescue service intervention. In side impacts, only compartment side intrusion was found to be significantly present when rescue service intervention took place.

Fire service data are being analyzed to identify time intervals for extrication of casualties. It is perceived that these will increase due to the influence of modern vehicle design features such cable routing, pyrotechnic device location and non deployment of

Secondary Safety features. The study also discusses the influence of such features on the likelihood of increased injury risk to the casualty and rescue personnel.

1. INTRODUCTION.

Entrapment of occupants in motor vehicles following a Road Traffic Collision (RTC) is a frequent occurrence in a modern industrialized society. Rescue Services are called to the scene of such incidents that present a unique and challenging environment in which those individuals work.

Often there is an extremely short time frame during which the entrapped occupant has to be medically assessed, stabilised and freed from their damaged vehicle in order to be conveyed to hospital appropriately.

The potentially hazardous nature of the rescue operation adds a further complication to this scenario, as crews are required to conform to Health and Safety legislation and work as safely as possible.

It would appear that little has been published on the subject of inadvertent deployment of airbags during a rescue operation following a Road Traffic Collision. Some authors have identified the Post-Crash phenomena as the final part of an event comprising three major facets: accident causation, injury causation and post-crash circumstances.[1]

The post-crash phenomena has been described as, “an event which occurs after (a collision) and is not related to the cause of the collision or impact induced injuries, but which can result an increase of the injuries incurred or the possibility of additional injury”[1].

Other studies describe the process of gaining access to entrapped individuals in order for a medic to evaluate their medical status and then describe a second phase of the rescue employing extrication to release them.[2] Much research thus far has studied the incidence of fuel leakage, vehicle fires or water submersion as an additional factor in such scenarios.

Crawford[3] refers to the frequency of rescues at Road Traffic Collisions annually performed by the British

Fire Service; some 7500 in number. This compares to 4300 rescues from fires and 1000 rescues from other dangerous situations.

Purswell and Hoag[4] describe vehicles in the context of their escape worthiness and have performed tests analysing Vehicle, Passenger and Environmental characteristics and Vehicle/Passenger Condition in relation to the extrication process.

It would appear that few studies have been undertaken that investigate the length of entrapment time for occupants following a Road Traffic Collision or to establish the potential for inadvertently firing a Supplementary Restraint System Device as a consequence of the rescue operation.

Therefore a study was undertaken to investigate these issues and to attempt to quantify the extent to which rescue crews need to be aware of such occurrences to ensure safe working practices at the scene of a Road Traffic Collision.

2. METHODOLOGY

The data used in this analysis form part of a study into vehicle crash performance and occupant injury undertaken between the years 1998 and 2002 in Great Britain. The data form part of the Co-operative Crash Injury Study (CCIS) database which is maintained by the Transport Research Laboratory and is sponsored by a consortium of Motor Vehicle Manufacturers and the UK Department of Environment, Transport and Regions (DETR). The database only includes passenger cars, which were less than 7 years old at the time of the crash and were towed away to a garage or a vehicle dismantler. A more comprehensive overview of the CCIS study can be found in references [7&8].

The CCIS study requires a stratified sampling criterion to be applied for the crashes to be selected for further investigation. Some 80% of serious and fatal and some 10 – 15% slight injury crashes according to the UK Government's classification are investigated. The resulting sample is biased towards more serious injuries. Some 900 crashes were investigated annually.

Details of injuries are obtained from the Accident and Emergency departments in the region and H. M. Coroners' office. Each injury is rated on the six point Abbreviated Injury Scale (AIS)[9]

The CCIS database also contains some unique factors, such as delta – V.[10] Delta – V, for example, permits analysis of occupant injuries by crash severity.

The following criteria were used to select the data for the study:

- Vehicles: The struck vehicle had to be a passenger car aged less than 7 years old at the time of the crash.
- Severity: Only tow-away crashes are included.
- Occupant: All passenger casualties are included.
- Seat belts: Only drivers wearing a three point manual restraint system were included.
- Injury: The casualty sustained a serious or a fatal injury according to the Department for Transport classification.
- Crash location: Only collisions which occurred in the West Mercia region of UK are included.

These selection criteria resulted in a sample of 235 passenger car casualties.

Additional separate set of data was obtained form the Hereford & Worcester fire brigade. The data relates to collisions which occurred between the years 1998 to 2002 in the West Mercia region of the UK

The following 2 criteria were used to select the data for this study:

- Only collisions which occurred in the same geographical are included.
- Only collisions in which the casualty was trapped and needed extrication are included.

3. HAZARDS PRESENTED TO RESCUE CREWS

Quite often, casualties are trapped within the vehicle following a collision. Entrapment can occur due to one or more of several reasons; door jamming, obstruction of the door way, seat belt jamming, intrusion of the passenger compartment leading to entrapment of casualty body parts, injuries requiring stabilisation which would entail enlarging the access area into the vehicle and other factors.

As the design of passenger vehicles evolves and becomes more complex, new hazards are presented to crews attending the scene of Road Traffic Accidents. The use of new lubrication fluids to make production processes more efficient and the introduction of Liquid Petroleum Gas as an alternative fuel source are just two examples of how new potential hazards have presented themselves by either contamination or explosive risk.

Recent studies have shown that entrapment due to door jamming alone accounts for 25% in European cars[5]. Some 50% to 70% of the casualties suffer serious to fatal injuries. The injuries are mainly AIS ≥ 2 severities. The majority of these injuries are internal and skeletal, located to the head, face, neck, thorax, abdomen and spine body regions[6]
These casualties require immediate medical attention. This increases the urgency to gain access to the casualty and it is the Fire Service rescue teams who are responsible for providing access and extrication facilities to the casualty. It is imperative that this increased urgency does not put either the rescuers or occupants in further danger.

In doing so the rescue team has to be aware of the potential risks and guard their own safety while carrying out the operation and also ensure that there is no adding risk to the casualty at the same time.

The increasing presence of airbags in passenger cars adds to the risk of injury to both the rescues team and the casualty. The risk is mainly posed by undeployed airbags which may deploy as a during the rescue operation.

However, as a function of the rescue operation and particularly the space creation techniques, i.e. cutting into the vehicle structure utilised by the Fire Service, the accidental activation of Supplementary Restraint Systems (SRS) presents arguably the greatest risk.

Despite the frequency of occupant entrapment in modern vehicles fitted with multiple SRS devices, the amount of research into this developing phenomenon appears to be somewhat limited. At the time of publication, little appears to be known about the frequency of such events although undoubtedly there have been injuries caused to occupants and rescue personnel by inadvertent deployments.

It is for this reason that this study has been undertaken to investigate the issues relevant to the safe working of rescue crews at road traffic collisions and in the future to quantify the scale of the problem as it exists now and how potentially it could become more significant in the future with the increase of new vehicles on the road fitted with multiple SRS devices.

To that end, the Fire Service is developing new procedures to ensure the risk is minimized. Part of the problem appears to be the lack of information available to Rescue teams at the incident scene relevant to the varying discharge times of airbag capacitors (potentially in some cases up to 30 minutes post crash) which may provide the activation source for undeployed airbags and the positioning of pyrotechnic firing devices which may cause injury should they be transected by a cutting tool.

This paper will investigate the incidence of entrapment using selected data from the West Mercia Police region of the United Kingdom collected by the Co-operative Crash Injury Study (CCIS) and the nature of the Entrapment from analysed data supplied by Hereford and Worcester Fire and Rescue Service for the same geographical area.

4. FIRE AND RESCUE ATTENDANCE AT AN INCIDENT INVOLVING ROAD TRAFFIC COLLISION

In general terms, when a road traffic collision occurs and all three rescue services attend the role of each service is broken down into the following areas of responsibility:

The Police are responsible for closing off the scene and redirecting the traffic flow around it -or for more serious incidents will close a carriageway completely and divert traffic around the incident using alternative routes. The scene should also be “sealed” to ensure preservation of evidence.
The Ambulance Service has responsibility for the well being of the casualties at the scene and will lead any activity based on casualty care or handling. Ultimately, they will have the greatest influence of the three Services on how long a casualty can be trapped for with reference to the casualty status. They will make the decision as to whether the casualty requires rapid extrication (due to the nature of their injuries) or whether the casualty can be stabilised more effectively within the vehicle while the Fire Service utilise space creation techniques to facilitate the extrication process more effectively.

Therefore the Fire Service is responsible for the management of the Health and Safety issues that arise as a consequence of the nature of and difficulties presented by the scene and the joint Rescue operation. They will protect the Incident scene and will assist the Ambulance in the extrication of the entrapped casualties.

This paper utilises data from Hereford and Worcester Fire and Rescue Service, therefore it would seem apposite to outline the activities of that organisation in the extrication process at a typical Road Traffic Collision. It should be stressed that the following is an overview of a typical approach the Fire Service would adopt, but this may vary to encompass dynamic and unique nature of individual Road Traffic Collisions.

5. THE PROCESS OF EXTRICATION

Once a Fire and Rescue appliance has been mobilised to a Road Traffic Collision, the crew on board will have a clear understanding of the individual tasks required of them. There will be a basic plan of action agreed before arrival at the scene that will have the flexibility to adapt to the resources that may or may not be available when the crew attends.

For example if the Fire Appliance arrives before an Ambulance, at least one crew member will be detailed to administer basic First Aid to any casualty in need of it, a task that will be taken over by the Ambulance when they attend. If, as is often the case, the Ambulance arrives first then the Fire Crew member will be able to assist with another predetermined task.

5.1 Approach

As the Fire Appliance approaches the scene and visual contact is made, the appliance will slow down and proceed with caution. There are two main reasons for this: firstly, it is possible that there are “walking wounded” vehicle occupants who are in a dazed and unsteady condition who maybe behaving in an unpredictable manner, around the outer extremities of the scene. Secondly, a slow approach over the last hundred metres towards the scene will allow the Officer in Charge of the appliance time to make his initial assessment of the incident and to formulate a Plan of Action and a Dynamic Risk Assessment, to ensure the safety of the crew and other individuals within the scene itself.

5.2 Sectorising

It’s at this point, with the scene clearly in view that the Officer in Charge will divide the incident into Sectors to facilitate an efficient Command and Control structure. Typically in a two vehicle RTC one vehicle will be referred to as Sector One, the second as Sector Two. This allows oncoming crews to fit into the rescue operation with minimal disruption and focuses the efforts of individual teams to dedicated tasks.

5.3 Scene Safety

The Fire Appliance adopts a “fend off” position as it comes to rest in close proximity to the incident. This means that the driver will park diagonally across the carriageway, protecting the scene if the traffic lanes around it are still “live”. The equipment lockers containing the RTC Extrication equipment are found on the front nearside of the Appliance and thus as the crew get to work at the scene they are automatically shielded from other moving vehicles/hazards.

5.4 Vehicle Stabilisation

The first step in the Extrication process is to stabilise the scene and the vehicles involved. Initially, the crew will get a charged hose reel and a Carbon Dioxide Fire Extinguisher off the Pump as a precaution, so that if for some reason a damage vehicle catches fire, a prompt reaction will extinguish the flames and prevent the incident becoming more serious.

Given that a paramedic crew is already attending to an entrapped occupant, the Fire Crew will immediately stabilise the vehicle before any further Extrication work is done. This means preventing the vehicle from moving forwards or back and taking it off its suspension thus giving rescuers a stable platform to work on. This is achieved by “Blocking and Chocking” the vehicle with wedges and blocks on all four corners and wedging under each tyre to ensure stability, assuming that vehicle is still upright on all four wheels. In terms of Extrication the Fire Service consider there are three main scenarios – that where the vehicle is on its wheels, that were it is on its side and that when it is on its roof. Each scenario requires some form of Blocking and Chocking to achieve vehicle stability.

As this work is in progress the Officer in Charge of the Appliance will be liaising with the medics to decide upon which course of action to take in the extrication process. This will depend upon the severity and nature of the occupant’s injuries and which of the three scenarios, mentioned above, the vehicle is in. A decision at this stage may include spending more time at the scene to stabilise a casualty who is not in a life threatening condition or to perform a rapid extrication, if the casualty is in urgent need of more specialised care (i.e. surgery).

5.5 Glass Management
Whichever decision is taken the vehicles glazing is removed to make the cutting and space creation techniques utilised easier and safer, with the casualties being protected during this process by either plastic sheeting or a thin teardrop shaped shield.

5.6 Cutting and Space Creation Techniques
At this stage Fire crews are now ready to start the process of cutting and using space creation free entrapped occupants. This process is now beginning to present a significant problem potentially to Fire Crews if they are working on newer vehicles that are fitted with numerous passive SRS devices.

It has been noted that there have been incidences of SRS being inadvertently activated through rescue operations, despite a vehicle's power supply being isolated for a considerable amount of time prior to the accidental activation. (See appendix 1). It would appear that cutting through the wiring between the ECU and the device (that may typically run through an 'A', 'B' or 'C' pillar for a Side Impact Airbag or an Inflatable Tubular Structure) could potentially cause a short circuit in the system and result in an inadvertent activation.

Some Brigades in the United Kingdom are devising strategies to combat this problem. Often the protective plastic facia cladding within the vehicle interior is being removed to expose wiring for the supplementary restraints, gas generators for the cant rail inflatable structures or the pyrotechnic firing assemblies fitted in the 'B' Pillars of some vehicles to activate the pretensioning devices of the seatbelts. Inevitably, this will lengthen extrication times as the crews work to remove these facia.

In most cases if the vehicles on its wheels, as rescue teams go to work, the roof will be removed to allow the medics easier access to their charges. This will usually be facilitated by use of dedicated hydraulic cutting equipment (widely known as the "Jaws of Life). In some instances however, some Rescue Crews are now being instructed to remove the internal plastic facia from the internal surfaces of the 'A', 'B' and 'C' pillars to expose pyrotechnic firing devices, SRS gas generators and associated wiring, thus allowing the crews to avoid (wherever possible) cutting through these items. Inevitably, this necessary process will extend entrapment times for the occupants.

Once the roof has been removed, other techniques and tools can be employed to create space within the vehicle to release trapped occupants and allow medics to get spinal boards into the vehicle and adjacent to the casualties to ensure their safe removal from it. Spreading tools or hydraulic rams (the latter powerful enough to move vehicle bulkheads away from an entrapped occupant) are utilised in this process, as are pedal cutters and reciprocating saws if required. This part of the extrication is arguably the point at which the rescue crews and medics need to work absolutely in unison and adopt a "casualty centred" approach.

6. CASE STUDY: INADVERTENT FIRING OF SRS SYSTEM FOLLOWING RTC.

Following a recent road traffic collision incident attended by Appliances from both South Yorkshire and Nottinghamshire Fire and Rescue Services an inadvertent firing took place as a consequence of rescue operations.

An Alfa Romeo 147 (2003 registration) was involved in a front offside collision with a Mitsubishi Gallant. During the initial impact both the driver and passenger airbags on the Alfa Romeo activated and the vehicle had come to rest on its offside.

Whilst undertaking a roof fold down on this vehicle the rear `C` post airbags activated as hydraulic tools were in operation making a final (2nd) release cut in this post. This was some 30 minutes into the extrication - post impact, the ignition keys had been removed from the vehicle and both the `A` and `B` posts had already been cut.

ENTRAPMENT

The data from the CCIS database was interrogated to identify the entrapment status of the 235 casualties available in this analysis.

ENTRAPMENT

There were 129 casualties who were trapped and required extrication from the vehicle. This amounts to over half of the sample.

Table 1: Sample Size

	No Rescue	Rescue	Total
Number of Incidents	84	90	174
Number of Casualties	106	129	235

The injury distribution of the 235 casualties is shown in Table 2. It is observed that casualties who are trapped suffered more severe injuries.

Table 2: Injury Distribution of Casualties in Sample.

MAIS	Rescue Damage			
	No Rescue		Rescue	
	Number	Percentage	Number	Percentage
0	1	1	3	2
1	21	20	12	9
2	48	45	28	22
3	19	18	29	22
4	8	7	24	19
5	4	4	20	16
6	3	3	11	8
9	2	2	2	2
Total	106	100	119	100

7. EXTRICATION

It is seen from Table 3 that persons trapped are significantly more likely to require to be extricated from the vehicle. Some 86% of the casualties who were trapped required to be extricated from the vehicle compared to 45% of the casualties who were not trapped.

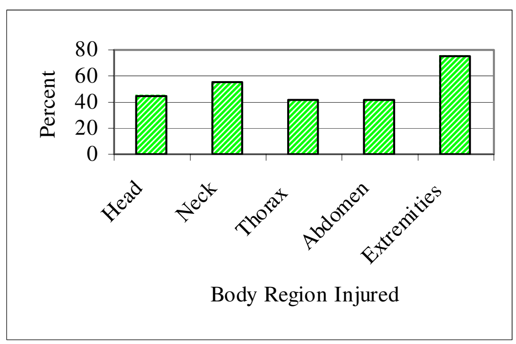
Most of the casualties requiring extrication are likely to have received severe injuries. In fact, nearly three quarters (72%) of the casualties received an injury of MAIS≥3.The distribution of body regions suffering

Table 3: Extrication Status

Entrapment Status	Extrication Required			
	No		Yes	
	N	%	Nr	%
No	98	55.4	8	13.8
Yes	79	44.6	50	86.2
Total	177	100%	58	100%

injuries of AIS ≥ 2 severity are shown in Fig 1. It is seen that three quarters of the casualties received an injury to the extremities. However these injuries are not of a life threatening nature since they are of AIS ≤ 3 severities. The concern is for casualties with injuries to the head, thorax and abdomen body regions. Injuries to these body regions include life threatening injuries. Therefore safe and speedy access to these casualties is paramount. In attempting to affect extrication of these casualties, the rescue personal have to consider the presence of undeployed restraints. The inadvertent deployment of such restraints can be hazardous to both the rescue personnel and the casualty. Such risk is likely to increase with the development and installation of more restraints. This is likely to increase casualty entrapment and entrapment times as greater care will be needed to effect extrication.

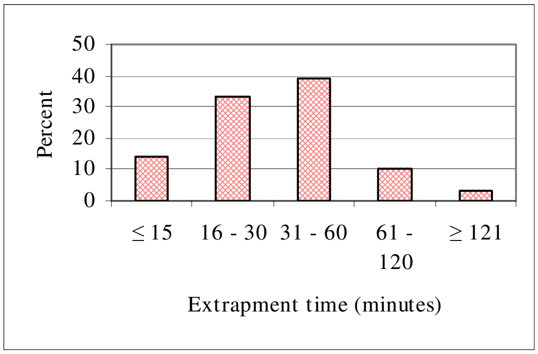
Fig 1: Body Regions Injured



7.1Entrapment Times
The distribution of entrapment times is shown in Fig2. It is observed that nearly 38% of the casualties are trapped in the vehicle for up to an hour. Some 33% of the casualties are trapped for 30 minutes and only about 14% of the casualties are trapped for less than 15 minutes. This would suggest that there is a potential risk posed by undeployed restraints to the

majority of the casualties for up to an hour, since it is known that SRS systems can stay live for up to that time.

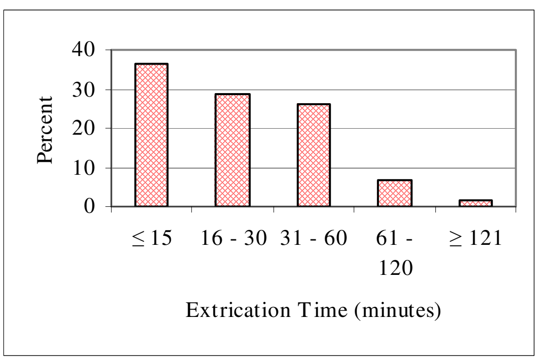
Fig 2: Entrapment Time



7.2 Extrication Times

Rescue personnel are also exposed to a similar risk whilst carrying out extrication procedures. The distribution of extrication times is shown in Fig 3. Some 37% of the extrications are completed within 15 minutes, whilst a further 28% are completed within 30 minutes. A quarter of the Extrications are completed within one hour. Therefore, a large majority of the rescue personnel are also exposed to this risk.

Fig 3: Extrication Times



CONCLUSIONS

Firm conclusions cannot be drawn from this limited study. However, the study shows that there is a potential risk of injury to the casualty and rescue teams with the increasing use of Supplementary Restraints.

A more in depth study currently being carried out will help to establish firm findings.

ACKNOWLEDGEMENT

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Further information on CCIS can be found at http://www.ukccis.org

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