Proceedings of IMECE2002
ASME International Mechanical Engineering Congress & Exposition
November 17–22, 2002, New Orleans, Louisiana

IMECE2002-33517

STUDY OF SEAT SYSTEM PERFORMANCE RELATED TO INJURY OF REAR SEATED CHILDREN & INFANTS IN REAR IMPACTS

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ABSTRACT

Since 1996 the NHTSA has warned of the airbag deployment injury risk to front seated children and infants, during frontal impact, and they have recommended that children be placed in the rear seating areas of motor vehicles. However, during most rear impacts the adult occupied front seats will collapse into the rear occupant area and, as such, pose another potentially serious injury risk to the rear seated children and infants who are located on rear seats that are not likely to collapse. Also, in the case of higher speed rear impacts, intrusion of the occupant compartment may cause the child to be shoved forward into the rearward collapsing front seat occupant thereby increasing impact forces to the trapped child. This study summarizes the results of more than a dozen actual accident cases involving over 2-dozen rear-seated children, where 7 children received fatal injuries, and the others received injuries ranging from severely disabling to minor injury. Types of injuries include, among others: crushed skulls and brain damage; ruptured hearts; broken and bruised legs; and death by post-crash fires when the children became entrapped behind collapsed front seat systems. Several rear-impact crash tests, utilizing sled-bucks and vehicle-to-vehicle tests, are used to examine the effects of front seat strength and various types of child restraint systems, such as booster seats and child restraint seats (both forward and rearward facing), in relation to injury potential of rear seated children and infants. The tests utilized sedan and minivan type vehicles that were subjected to speed changes ranging from about 20 to 50 kph (12 to 30 mph), with an average G level per speed change of about 9 to 15. The results indicate that children and infants seated behind a collapsing driver seat, even in low severity rear impacts of less than 25 kph, encounter a high risk of serious or fatal injury, whether or not rear intrusion takes place. Children seated in other rear seat positions away from significant front seat collapse, such as behind the stronger "belt-integrated" types of front seats or rearward but in between occupied collapsing front seat positions, are less likely to be as seriously injured.

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INTRODUCTION

Airbag induced serious and fatal injuries to front seated infants and children has resulted in government recommendations which suggest, among other things, the placement of children into the rear seat area of motor vehicles [1]. However, during a rear impact most conventional automotive front seats occupied by adults will collapse into the rear seat area. This exposes the rear seated child to other risks of injuries such as: fractured legs; abdominal injuries; thoracic injuries; skull fractures; brain damage; and entrapment which hinders extrication in the case of post crash hazards such as fire. In addition, occupants in the collapsing seats also experience hazardous conditions due to contact with the rear seated passengers, or the rear compartment structures, and possible ejection, even if belted, when the front seat collapses rearward [2,3,4,5,6,7]. Rearward load strength tests run on a wide variety of commercially available automotive front seat systems, such as the single or dual sided recliner types and the stronger belt integrated types, demonstrate a wide range of occupant load resistance. The most common type of automotive front seat system is the single sided recliner type, and these seats typically collapse rearward after only reaching a horizontal load resistance of about 3220 Newtons when tested with a "torso" body block device that spreads the loads over the seatback in a manner similar to that of an actual occupant [6]. When tested dynamically with an average size male surrogate (80 kg), these types of seats will only reach threshold velocities of about 20 kilometers per hour, or about 6 G' s of dynamic load, before fully collapsing rearward into the rear seat area. The above threshold velocity and peak G value are below average rear impact vehicle crash measures.

On the other end of the spectrum, the belt integrated seat systems reach load levels as high as 20,300 Newtons [6]. These stronger types of seat systems can provide support and retain the front seated occupants from collapsing fully rearward at peak G load levels well beyond the majority of most rear impact crashes, and as such can provide protection to both the front seated occupants as well as the infants or children seated behind the front seated occupants. Thus the stronger seat systems, like the belt integrated designs, offer the potential to significantly reduce the previously cited injury risks to rear seated children and infants.

Proponents of the conventional collapsing seat systems, however, suggest that yielding or collapse of the front seat during rear impact reduces injury to the front seated occupant [8,9], and that the stronger belt integrated types of seat systems may cause whiplash type injuries. Regardless of whether or not a collapsing seat reduces injury to front seated occupants during a rear impact, the concept of placing children in the rear seat area, where the seats generally do not collapse, and then allowing the front seated occupants to collapse directly into the rear seat area presents a dangerous situation to those occupants seated behind the collapsing adult occupied front seats.

In order to more fully understand the ramifications of this contradiction of allowing a front seat to collapse during rear impact so as to mitigate injuries to front seated occupants, while at the same time allowing that collapsing seat and its occupant to infringe on the occupant space of children and infants seated behind, a number of actual accident cases were studied and compared with statistical information, as well as the results of controlled vehicle and sled buck tests. In most of the accident cases reviewed, the injured children were located in the second row, directly behind the driver, or the right front passenger, who was seated in a conventional collapsing seat. In some cases there were also children or adult occupants seated in a third row of seats, such as is commonly found in a family minivan type of vehicle.

In these cases the children, or adults, were located directly in front of the crash impact and crush intrusion zone, but generally away from the effects of rearward collapsing occupied front seats. These latter cases enabled a qualitative comparison, within a given accident, of the injury potential resulting from front seat failure versus the situation of no front seat failure when the occupants are subjected to the same level of accident severity. Finally, as noted above, several vehicle and sled buck tests were conducted with child and infant surrogates seated behind collapsing, and non collapsing seat systems, while using various types of the restraint systems for the children, such as: forward and rearward facing child restraint seats; booster seats; and 3 point restraints.

FIELD ACCIDENT CASES

More than a dozen rear impact accident cases, involving rear seated children and infants who were injured as result of occupied front seat collapse, are reviewed below. These cases were primarily 2 vehicle accidents with no rollover. In some instances, the impacted vehicle did have minor front-end contact with other vehicles or roadside obstacles. These cases are broken down into two groups. The first group, series "A", deals with rear impacts that resulted in speed changes from about 20 kph to 35 kph on the impacted case vehicle. This group includes accidents that would generally be considered as "minor" to "just above-average" in rear impact severity. The second group is designated as series "B" and deals with speed changes beyond 35 kph, up to approximately 50 kph, on the impacted vehicle. The Table 1 provides a summary of the key data of the series "A" cases and, likewise, Table 2 provides a summary of the key data for the series "B" cases. Each table identifies information related to the following categories: Vehicle Type (i.e. MV = minivan, SUV = sport utility vehicle, SD4 = sedan 4 door, etc.); Front Seat Occupant Information (i.e. seat location, gender, age and weight); and, Rear Seat Occupant Information (i.e. seat location, gender, age, weight, type of restraint used, and injury severity group level).

For simplicity, the basic Abbreviated Injury Scale (AIS) levels were grouped into three groups where: Injury Group 1 (IG – 1) includes AIS levels 0, 1, and 2 (i.e. no injury, minor injury, and moderate injury); Injury Group 2 (IG – 2) includes AIS levels 3,4, and 5 (i.e. serious injury, severe injury, and critical injury); and Injury Group 3 (IG – 3) which designates fatal injuries. With regard to seat location, values of 1, 2,and 3 represent the driver seat position, center front seat position, and the right front seat position, respectively. Likewise locations for the second row of seats would be designated as positions 4,5, and 6,with position 4 starting from the left side of the vehicle. Positions for the third row seats, if pertinent, would be designated as 7,8,and 9, with position 7 starting from the left side of the vehicle.

As noted earlier, some of the field accident cases dealing with children injured from front seat collapse, included other children or adult occupants seated in a third row of seats adjacent to the impact zone, but away from the influence of collapsing occupied front seats. The last three cases listed in Table 1 (Series "A") include such situations. These cases offer the potential to qualitatively study the difference between the hazards to children seated behind collapsing occupied front seats versus being seated directly adjacent to the impact and intrusion area but not subjected to the effects of occupied front seat collapse. In most cases the forward facing children, and infants, seated directly behind occupied collapsing front seats, received severe head and chest injuries as a result of being struck by the head of the front seat occupant or the upper area of the collapsing seat back and headrest of the collapsing front seat. Fractured legs also often occurred due to the impact of the collapsed occupied seat, which normally rotates rearward onto the child's legs. In the case of infants in rearward facing child restraint seats, the infants usually suffered severe head injuries when the collapsing occupied front seat rotated rearward on top of the child restraint seat and trapped or crushed the skull of the infant. This crushing type of head injury is not necessarily an acceleration type of injury, and as such the severity of the injury is therefore not always quantifiable with the more common Head Injury Criteria (HIC).

TABLE 1: Summary of Series "A" Field Accident Rear Impact Cases (20 to 35kph)

Case No.	Veh. Type	Delta Vel. (kph)	Front Occupant Data: Seat; Gender &; Wt.			Rear Occupant Data: Seat; Gender &; Wt.; Restnt; Injury				
			Pos.	Age	(kg)	Pos.	Age	(kg)	Type	Group
1A	MV	23	1	F- 35y	125kg	4	F- 4y	21kg	LS	IG-2 (Head injury)
2A	SD4	35	1	F- 37y	62kg	4	M- 9y	30kg	LS	IG-1
			3	M-38y	86kg	6	F- 5y	23kg	LS	IG-3 (Fatal Chest)
3A	SD4	33	1	F- 17y	75kg	4	F- 44y	90kg	LS	IG-1
			3	M-34y	75kg	6	F- 6 wk	6kg	RCRS	IG-2 (Head Injury)
4A	SD4	33	1	M-35y	73kg	4	F- 3y	21kg	LS	IG-2 (Head Injury)
			3	F- 33y	73kg	6	M-10y	37kg	LS	IG-1
5A	MV	30	1	F- 30y	102kg	4	F- 4y	18kg	LS	IG-2 (Head Injury)
						6	F- 8y	34kg	NA	IG-1
						9	M-2y	14kg	FCRS	IG-1
6A	MV	33	1	M-42y	98kg	4	F- 3y	13kg	LS+B	IG-2 (Head Injury)
			3	F- 37y	61kg	7	F- 13y	NA	LS	IG-1
						9	M-12y	NA	LS	IG-1
7A	MV	27	1	M-58y	98kg	4	F- 24y	82kg	LS	IG-1
			3	M-52y	83kg	6	M- 8 mo	11kg	FCRS	IG-3 (Fatal Head)
						7	F- 54y	61kg	LS	IG-1
						9	F- 51Y	93kg	LS	IG-1

Abbreviations for restraint types include: LS = lap & shoulder belt; B = booster; FCRS = forward facing child restraint seat; RCRS = rear facing child restraint seat; and NA = not available. A brief description of the events surrounding each of the cases listed in Tables 1 is given below.

Series "A" Field Accident Cases (20 kph to 35kph Speed Change)

Seven cases are summarized in Table 1 dealing with the series "A" accidents involving speed changes up to 35 kph. The Case 1A subject vehicle was a 1996 Dodge Caravan minivan that was occupied by one adult driver and a 4-year-old child seated directly behind the driver. The subject vehicle was struck in the rear by 1999 Plymouth Voyager minivan with a primary direction of force of approximately 6:00 and a change in velocity of about 20 to 24 kph. Post impact evidence indicated that the driver seat had collapsed toward the rear seat area. The driver was a 35-year-old female who was using the available 3-point restraints and did not sustain any significant injury. She was approximately 168 cm tall and weighed approximately 125 kg. Seated behind the driver, in the left outboard captains chair (i.e. position 4) was a 4-year-old female child weighing approximately 21 kg, with a seated height of 61 cm (standing height of approximately 112 cm), and restrained with the available 3-point restraints for her seat position. During the impact the driver seat and driver rotated rearward, and the driver's head extended over the seat back and headrest, impacted into the child's head. As result of this impact the child received a permanently disabling head injury.

Case 2A involved a 1994 Buick Skylark 4 door sedan occupied by two adults and two children. The subject vehicle was struck in the rear by 1979 Ford F-250 pickup truck with a primary direction of force of approximately 6:00 and a change in speed of approximately 35 kph. The seat backs of both the female driver (approximately 62 kg and 157.5 cm tall) and the right front male passenger (approximately 86 kg and 180 cm tall) collapsed rearward during the accident. Both front seat adults were utilizing the available 3-point restraints and suffered no injuries. Seated behind the driver, who was shorter and lighter than the right front seat occupant, was a lap belted 9-year-old male (approximately 30 kg weight) who received only relatively minor injuries. Seated behind the right front adult occupied seat was a 5-year-old female weighing approximately 23 kg, with a standing height of 112 cm. She was utilizing the available lap belt restraint. She sustained a bloody nose and no other obvious external injuries. However, internally, this 5-year-old female passenger experienced a lacerated heart that resulted in her death. Interestingly, she had no rib fractures, skull fractures, pneumothorax, or hemothorax.

Case 3A involved a stationary 1990 Oldsmobile Cutlass Ciera 4 door sedan that was struck in the rear by a 2000 Ford GT convertible traveling at a speed just under 66 kph. The impact was colinear, with the striking vehicle offset slightly (i.e. a few inches) to the right of center of the Ciera. The subject vehicle contained three adult occupants and a six-week-old female infant weighing just under 6 kg. The infant was located in the right rear seat position, restrained in a rearward facing child restraint seat (RCRS). Next to the infant, in the left rear position, was a restrained 44-year-old female adult who weighed approximately 90 kg. The restrained driver of the vehicle was a 17-year-old female weighing approximately 75 kg. Seated in the right front position (i.e. position 3), just in front of the infant restrained in the rearward facing infant seat, was a restrained 34-year-old male passenger weighing approximately 75 kg. As a result of the impact by the Ford vehicle, the Ciera vehicle experienced a change in velocity of just under 33 kph, and both occupied front seats deformed rearward into the rear occupant area. The three adults' received only minor injuries however the infant sustained severe crushing head injuries.

The Case 4A involved in 1993 Nissan Sentra 4 door sedan occupied by two adults and two children. The subject vehicle was struck in the rear by a 1977 Chevrolet pickup truck, with a primary direction of force of approximately 7:00, which resulted in a change in velocity of approximately 33 kph for the Nissan. Both the driver and right front passenger seat backs collapsed rearward during the accident and were found on top of the two rear seat occupants. The restrained driver of the vehicle was a 35-year-old male who was approximately 183 cm tall and weighed about 73 kg. His injuries included a complaint of pain on the left side of the head, left arm and shoulder. He sustained no permanent debilitating injuries. Occupying the right front position was a restrained 33-year-old female who was approximately 165 cm tall and weighed about 73 kg. Her injuries included complaints of neck and shoulder pain, and pain in the left groin area. The occupant seated in the left rear position behind the driver was a three-year-old female, restrained by a lap and shoulder belt; she weighed approximately 20.5 kg and had a seated height of just under 69 cm. Her injuries included a contusion to the left side of the forehead, a 4 cm laceration to the left frontal and parietal scalp area, a non displaced skull fracture extending horizontally from the frontal area posteriorly, fractures of the lateral wall of the left orbit, bi-frontal skull fractures, bi-frontal lobe hematoma, subarachnoid hemorrhage, and was unconscious and comatose. Seated in the right rear position was a 10-year-old male who was approximately 145 cm tall and weighed 36.8 kg. This youngster had a seated height of 79.4 cm and was restrained with a lap and shoulder belt. He received no significant injuries other than glass puncture wounds in the posterior part of the head in the occipital and vertex region, but later had some complaints of headaches and dizziness.

Case 5A involved in 1991 Plymouth Voyager minivan occupied by one adult and three children. The subject vehicle was struck in the rear by 1995 Mitsubishi Mirage with a primary direction of force of approximate 6:00 and a change in velocity of approximately 30 kilometers per hour. The driver seat back collapsed rearward during the accident and impacted the occupant seated behind her. The restrained driver of the vehicle was a 30-year-old female who was approximately 170 cm tall and weighed about 102 kg. She sustained minor bruises as a result of the accident. Seated in position No. 4, directly behind the driver, was a 4-year-old female who was approximately 91 cm tall and weighed about 18.2 kg. The 4-year-old was using the available 3-point restraint. She sustained severe head injury as a result of impact from the front seat occupant. Her injuries included swelling of the left parieto-occipital temporal scalp, diffuse cerebral edema, hemorrhagic contusion of the midbrain and left parietal -- frontal occipital regions, multiple linear skull fractures of the right and left frontal bone and superior bilateral parietal bones, left frontal subdural hematoma and right frontal epidural hematoma. Adjacent to the 4-year-old female, occupying the outboard position No. 6, was an 8 year-old female who was about 129.5 cm tall and weighed 34 kg. She was uninjured as a result of the accident. It is unknown if she was restrained or not. Finally, seated in the right rear most outboard position (i.e. position 9) was a two-year-old male who was 91.4 cm tall, weighed 13.6 kg, and was restrained in a forward facing child safety seat. This child was uninjured even though it was located adjacent to the region of impact and intrusion. The seat in front of this child did not collapse rearward, in part due to the low weight of the 8-year-old female (34 kg) seated in position 6.

The Case 6A involved a 2001 Dodge Grand Caravan minivan that was struck in the rear by a large tractor-trailer, causing a change in speed of approximately 33 kilometers per hour to the minivan. Two adults in the front captains chairs, and three children in the remaining two rows of seats, occupied the minivan. The restrained 42-year-old male driver of the vehicle weighed approximately 97.5 kg and was about 183 cm tall. The right front passenger was a 37-year-old female, who was also restrained and weighed approximately 61 kg. Seated directly behind the driver, on a "OEM" built-in booster seat, was a fully restrained three-year-old female weighing approximately 12.7 kg. The remaining two children were seated in the third row bench seat located directly in front of the region of impact and intrusion. The child in the left side position of the rear bench seat (i.e. position 7) was a restrained 13-year-old female. The child in the right side position of the rear bench seat (i.e. position 9) was a restrained 12-year-old male. The only occupant seriously injured in this accident was the three-year-old female who received a serious head injury when the driver seat collapsed onto her and she was struck by the head of the driver who rotated rearward into her occupant space. All the other occupants, including the children seated directly adjacent to the area of impact and intrusion, received only minor injuries such as stiff necks and minor bruises. As in the previous case, the rear most seated children did not experience any effects of front seat collapse since the seats in front of them were either empty or only occupied by the lightweight 3 year-old child.

Finally, Case 7A involves a 1998 Dodge Grand Caravan minivan occupied by five adults and an 8-month-old male infant who weighed approximately 10.5 kg and was about 69 cm tall. The subject vehicle was struck by a 1969 Ford F-100 pickup truck traveling at about 53 kph. The impact of the pickup truck was colinear, but offset approximately 11 inches to the left of the minivan, and caused a speed change of approximately 27 kph to the minivan. All occupants in the vehicle were restrained. The 8-month-old male infant was restrained in a forward facing child seat that was securely mounted to the position 6 captain seat located directly behind the right front seat. A restrained 52-year-old male who weighed 83.4 kg and was 188 cm tall occupied the right front seat. The driver was a 58-year-old male weighing 97.7 kg and was 193 cm tall. Seated to the left of the infant, in position 4, was a 24-year-old restrained female who weighed 81.8 kg and was 170 cm tall. On the left side of the third row bench seat (i.e. position 7) was a 54-year-old female weighing 61.4 kg and 169 cm tall. On the right side of the third row bench seat was a 51-year-old female weighing 93 kg and standing 168 cm tall. During the impact both front seats collapsed rearward into positions 4 and 6. The infant in position 6 received fatal head injuries when he was struck by the head of the right front occupant who collapsed back and rotated rearward into the child's position. The adult occupant adjacent to the infant, located in position 4, received only minor injuries. Of the 2 occupants located in the third row bench seat, only the right side occupant received minor injuries due to the intrusion and crush from the rear impact. Both front seat occupants and the remaining third row occupant received minor or no injuries.

TABLE 2: Summary of Series "B" Field Accident Rear Impact Cases (36 to 50kph)

Case No.	Veh. Type	Delta Vel. (kph)	Front Occupant Data: Seat Pos.	Front Gender & Age	Front Wt. (kg)	Rear Occupant Data: Seat Pos.	Rear Gender & Age	Rear Wt. (kg)	Restnt Type	Injury Group
1B	SUV	43	1	M- 34y	93kg	5	M- 6y	23kg	LS	IG-1
			3	F - 32y	61kg	6	M- 2.5y	16kg	LS	IG-3 (Fatal Head)
2B	SD4	42	1	M- 22y	75kg	4	F- 22y	NA	LS	IG-1
			3	M- 20y	77kg	5	F- 20y	NA	LS	IG-1
						6	M- 3Y	13kg	FCRS	IG-3 (Fatal Head)
3B	SD4	47	1	F- 21y	61kg	4	M- 1.5y	10kg	FCRS	IG-2 (Head Injury)
			3	M-18y	91kg	5	F- 2.5y	12kg	FCRS	IG-3 (Fatal Head)
						6	M- 1.5y	14kg	FCRS	IG-2 (Head Injury)
4B	MV	46	1	F- 36y	60kg	4	F- 1y	10kg	FCRS	IG-1
			3	M-35y	108kg	6	M- 4y	19kg	LS	IG-2 (head Injury)
5B	MV	37	1	M-37y	95kg	4	M- 3y	18kg	LS	IG-2 (Head Injury)
			3	M- 7y	34kg	6	F- 37y	61kg	LS	IG-1
6B	SD4	50	1	M-26y	73kg	4	M-6 mo	13kg	RCRS	IG-2 (Head Injury)
			3	F- NA	63kg	6	M- 2y	NA	LS	IG-1
7B	SUV	50	1	M-44y	NA	4	M- 7y	NA	NA	IG-3 (Fatal Burn)
			3	F- 40y	NA	5a	F- 6y	NA	NA	IG-3 (Fatal Burn)
						5b	F- 6y	NA	NA	IG-2 (Eject Burn)
						6	M- 8y	NA	NA	IG-2 (Eject Burn)

A brief description of the events surrounding each of the cases listed in Table 2 is given below.

Series "B" Field Accident Cases (36kph to 50kph Speed Changes)

As with the series "A" cases, 7 accidents are summarized in the series "B" group. The first case, Case 1B, involved a 1995 Jeep Grand Cherokee occupied by two adults and two children. The vehicle was stopped for a traffic light when it was struck in the rear by 1994 Isuzu pickup truck. The impact by the pickup truck caused a change in velocity of approximately 43 kph on the subject vehicle. The principal direction of force was approximately 6:00 o'clock. The 34 year-old restrained male driver (approximately 93 kg and 180 cm tall) and the 32 year-old restrained right front seat female occupant (approximately 61 kg and 173 cm tall) were uninjured as result of the incident. Both front seatbacks collapsed rearward into the rear seat area where the two children were seated. In the center rear position was a 6-year-old male (approximately 23 kg) who was utilizing the available lap belt and was uninjured as result of the incident. Seated in the right rear outboard seat position (i.e. position 6), directly behind the right front seat occupant, was a 2 1/2-year-old male (approximately 16 kg) who was also restrained and stood approximately 109 cm tall, with a seated height of about 56 cm. As a result of the rearward collapse of the right front seat adult directly into the area of the 2 1/2-year-old male, this child sustained a large laceration to the forehead (approximately 1.5 cm) and was fatally injured. He received a linear fracture through the right fronto-parietal occipital regions with a free segment in the right frontal region that was depressed 1 to 2 mm. There was also associated soft tissue swelling in this area. In addition, there was evidence of subarachnoid blood in the supracellar cisterns and a one cm shift of the brain from right to left. The autopsy revealed the skull fracture to be a complex fracture extending for approximately 21 cm, from the right frontal bone, through the right temporal bone, to the right occipital bone. There were also areas of contused brain in the right fronto-parietal area.

The second case in this series, Case 2B, involved a 1993 Saturn SL2 4 door vehicle that was struck in the rear by 1986 Mitsubishi Montaro. The rear impact by the Montaro was colinear but offset slightly to the right side of the Saturn and caused a speed change of approximately 42 kph to the subject Saturn vehicle. The Saturn was occupied by four adults (all in their early 20s) and a three-year-old male child. All occupants in the subject vehicle were restrained. The three-year-old child was seated in a forward facing child restraint seat that was securely mounted in the right rear (i.e. position 6) location. The child weighed 12.7 kg and was 101.6 cm tall. The male driver and male right front passenger weighed approximately 75 kg. Both front seats collapsed rearward as result of the impact. Intrusion on the right rear area caused the child seat to be moved forward approximately 20 to 25 cm toward the rearward collapsing occupied front seat. The three-year-old male child received fatal head injuries. The autopsy reports indicated that the blunt impact to the head caused subdural hemorrhage, as well as cerebral cortical contusions, and diffuse cerebral edema. The driver received only minor whiplash injuries. The right front occupant was rendered unconscious as result of head contact with the child seated behind. The injuries to the right front passenger were not permanent and included a sprained ankle. Seated in the other rear seat positions (i.e. position 4 and position 5) were two adult females. Both of the rear seated females sitting adjacent to the fatally injured three-year-old child received only minor head and back pain type of injuries. The center rear female had evidence of minor head injury and confusion shortly after the accident. She also had contusions on her left arm, left calf, and a bump on the back of her head. She also swallowed some glass, which resulted in a scratched throat, and some cuts in her mouth. The left rear female experience scratches and a whiplash type injury.

Case 3B involved a 1985 Dodge 4 door K-car that was rear and by a 1994 Ford crewcab pickup pulling a horse trailer with a horse. The impact by the pickup caused a speed change of approximately 47 kph to the subject vehicle. The subject vehicle had two adult occupants in the front bench seat, and three children in the rear seat. All three rear seated children were restrained in forward facing child seats. The restrained 21-year-old female driver of the vehicle weighed approximately 61 kg and stood about 160 cm tall. The restrained 18-year-old right front male occupant weighed approximately 91 kg and was also about 160 cm tall. As a result of the impact, the front bench seat collapsed rearward and struck all three rear seated children. The 1 1/2 year-old left rear seated male child weighed 10 kg. This child received a serious head injury. The child in the middle rear position was a 2 1/2 year-old female weighing about 12 kg. This child received a fatal head injury. The child in the right rear seat position was a 1 1/2-year-old male weighing 14.5 kg. This child received a serious head injury. In addition this child also experienced fractures of the upper and lower left leg. As in the previous case, the rear seat area of this vehicle also experienced intrusion of approximately 20 to 25 cm.

In the Case 4B, a 1996 Ford Taurus (GL), 4 door, was struck in the rear by a 1999 Ford Expedition SUV type vehicle traveling at about 45 mph. Principal direction of force was approximately 6:00 o'clock and resulted in a speed change of about 46 kph to the subject Taurus vehicle. The subject vehicle contained four occupants; two adult occupants in the front seats and two children in the rear seat directly behind the front seat adult occupants. The restrained 36-year-old female driver of the vehicle weighed approximately 60 kg and stood 160 cm tall. The restrained 35-year-old male occupant in the right front seat weighed approximately 108 kg and was about 180 cm tall. As a result of the impact both adult occupied front seats collapsed rearward into the rear seat area where the two children were located. The four-year-old male child, seated in the right rear position, weighed approximately 19 kg and was restrained by the available lap and shoulder restraint system. This child was approximately 109 cm tall and received a serious head injury when the heavier right front occupant collapsed rearward into the child. The other child in the left rear seat was a one-year-old female who was secured in a forward facing child restraint seat. This child weighed approximately 10 kg and received only minor injuries from the much lighter driver who collapsed rearward with less force than the right front occupant. Unlike the previous two cases, there was no noticeable intrusion into the rear seat area of the subject vehicle.

The Case 5B involved a 1988 Ford Aerostar minivan that was rear impacted by a 1971 Lincoln Continental vehicle. The subject vehicle experienced a speed change of approximately 37 kph as result of the impact. The restrained male driver of the vehicle weighed approximately 95 kg and was about 186 cm tall. In the right front seat was a restrained young male child weighing approximately 34 kg. Seated behind the driver in the left rear, mid row position, was a three-year-old male weighing approximately 18 kg and utilizing the available 3-point restraint system. Seated next to this child in the right rear, mid row position, was a 37-year-old female occupant weighing approximately 61 kg. As result of the impact, the driver seat occupied by the heavy male occupant collapsed rearward allowing the head of the driver to strike the head of the child seated behind. As result of this impact from the rearward collapsing driver, the left rear child sustained a severe head injury which included right occipital and temporal comminuted skull fractures, intracranial hemorrhage, left occipital bleeding, basilar skull fracture, and right frontal skull fractures that emanated rearward toward the comminuted occipital fractures. The right front seat occupied by the lightweight child did not collapse rearward. Except for the left rear position three-year-old passenger, all other occupants received virtually no injury.

In Case 6B a 1987 Plymouth Horizon 4 door hatchback was rear ended by a 1990 Ford Taurus. The impact caused a change in speed of approximately 50 kph to the Plymouth Horizon. A male driver and an adult female right front passenger occupied the vehicle front seats. The 26-year-old restrained male driver of the vehicle weighed approximately 73 kg and was 168 cm tall. The restrained right front female occupant weighed approximately 63 kg and was also 168 cm tall. Seated in a forward facing child restraint seat, in the right rear position was a restrained 2-year-old male. Next to him, in the left rear seat position, was a five and 1/2 months old male infant who was restrained in a rearward facing infant seat. As a result of the rear impact, the 1987 Plymouth Horizon vehicle was accelerated forward such that the occupied front seats collapsed and moved rearward toward the rear-seated children. In addition, the trunk cargo was crushed forward causing the rear seat back latch to give way and allowed the rear seat back to also encroach into the rear seat area and shoved both of the rear seated children forward into the collapsing front seats and occupants. This intrusion also rotated the rear seat cushion upward such that the rearward facing infant restraint seat rotated upward at the rear such that the front edge of the infant seat was rotated downward relative to its initial position with the driver seat in front. Due to the combined intrusion into the rear seat occupant area, from both the collapse of the heavier occupied driver front seat and the forward intrusion of cargo from the rear, the 5 1/2 months old infant became trapped in his infant seat, between both the front collapsing driver seat, and rotated infant seat, and received a serious life-threatening head-brain injury. Externally, the infant only demonstrated a small bruise to the left forehead area. Internally however, CT scan's showed a massive left sided subdural hematoma with massive left hemisphere brain edema. Neither of the front seat adult occupants was injured in the crash. The right rear seated 2-year-old child, who was seated behind the lighter front seat occupant, also was not injured.

Finally, Case 7B involved a stationary 1992 Chevrolet S-10 Blazer 4 door vehicle that was rear ended by a 1995 Ford F-150 4x4 pickup truck. The impacting vehicle struck with the right front into the left rear of the subject vehicle. The rear impact caused a speed change of approximately 50 kph to the subject vehicle. The subject vehicle was occupied by two adults in the front seats (a 44-year-old male driver and a 40-year-old right front female passenger) and four children in the bench seat located behind the front seats. Restraint usage was unknown due to the severe post crash circumstances of the vehicle and the injury of the occupants. Located behind the driver, from left to right, were a 7-year-old male child and a six-year-old female. Located to their right, directly behind the right front seat occupant, were a six-year-old female and an 8-year-old male child. As a result of the impact, the driver seat collapsed rearward onto the two children seated behind the heavier occupied front seat, and trapped these two children. The right front seat, occupied by the lighter of the two adult occupants, did not collapse as far rearward and the two children located behind that seat did not become trapped by the seat. During the post impact trajectory movement of the subject vehicle, the vehicle burst into flames prior to coming to rest. The driver and the two children trapped behind him burned to death. The lighter right front passenger, and two children seated behind her, where both ejected during the post impact yawing trajectory and received severe burns over approximately 80 percent of their bodies.

PROBABILITY OF REAR OCCUPANT INJURY RELATED TO FRONT SEAT PERFORMANCE

Friedman and his co-authors studied and reported on the "Effects of Front Seat Performance Failure on Rear Seat Occupant Injuries in Rear Impacts". The results were partially reported in a 1999 L.A. Times News article [1] and later in a more complete form [7]. This study reviewed several cases from the National Accident Sampling System Crashworthiness Data System (NASS-CDS) for the years 1988 to 1997. This study examined tow away rear end crashes of light body vehicle styles where there was an occupant in the front seat forward of a rear seated occupant. No rollovers were considered. Injury outcomes were separated into groups of AIS 0 to 2 and compared with those into groups of AIS 3 to 6. The effects of age, intrusion, vehicle type, performance of the seat forward of the rear seat occupant, rear seat performance and restraint usage were considered in the study. A total of 404 occupant records, representing 249,714 occupants, were used in the analysis. Most of the cases selected represented rear seat occupants sitting directly behind front seats, as opposed to a third row seated occupant sitting behind a second row occupant, such as was the situation of the last three cases of Table 1. When considering cases in the crash severity range of 6.7 – 11.2 m/s, the Friedman study found that the probability of serious injury increased by a factor almost 25 to 1 when the occupied front seat had a performance failure versus no performance failure. Also, it was found by Friedman that in the more severe range of speed change (i.e. 42 to 75 kph) other factors, such as major amounts of intrusion, may have masked the influence of the seat performance failure. However, in the range of impact series considered in this current study (i.e. up to 50 kph) the field accident data seems to be consistent with the findings of the Friedman study indicating the likelihood of increased serious injury for rear seated occupants seated behind occupied front seats with performance failure or collapse into the rear occupant space. In order to further quantitatively examine the rear seat hazards posed by collapsing occupied front seats on rear seated occupants, such as children and infants, a series of vehicle and sled buck tests were run where, in several cases, side by side comparisons were made of injury potential to children and infants seated behind weak collapsing front seats versus the stronger belt integrated types of seat systems. The data from these tests is provided in the following section.

EXPERIMENTAL STUDY OF SEAT SYSTEM PERFORMANCE RELATED TO REAR OCCUPANT INJURY HAZARDS

Five rear impact experimental tests are reviewed below. The first three tests involved a sled-buck arrangement that utilized the entire vehicle body of a popular late model minivan so as to examine issues dealing with several of the low severity impact cases of Series "A". The remaining two tests utilized a vehicle-to-vehicle and a rear-moving barrier impact test to study issues dealing with higher impact severity.

<u>Sled-Buck Test Series Test-1</u>

During the sled-buck dynamic tests the entire front and rear compartment areas of the vehicle were included on the sled-buck arrangement so as to more properly evaluate the benefits of seat designs within real world geometric constraints of the occupant compartment interior, and floor attachment structures. In addition, a restrained child surrogate weighing 21kg, and having a seated height of 61 cm, was placed in the left-rear seat position (i.e. position 4) directly behind the driver to simulate the size of the child in Case 1A. The front seat surrogates for these sled-buck tests were restrained Hybrid III male surrogates ballasted up to about 125 kg to simulate the size of the driver in the Case 1A. The original right front weak collapsing "OEM" seat was replaced with a much stronger 1996 Sebring belt-integrated seat. Also, the Hybrid III driver surrogate, seated in the collapsing "OEM" seat design, had a standing "pedestrian" type pelvis so as to more closely replicate the kinematics of a human subject when rotating reward during the front seat collapse. Figure 1 illustrates the surrogate pre-test positions described above for the first sled-buck test. In these tests the driver seat was positioned rearward as per the location indicated by the actual driver of Case 1A. The stronger right front replacement seat was matched in position with the "OEM" driver seat.

Figure 1. Surrogate Pre-test Setup for Sled-Buck Test 1

The sled-buck systems were towed rearward into a crushable honeycomb barrier that simulated the low severity of the Case 1 A. The severity of the sled-buck crash pulses were chosen by analysis, and vehicle testing, to be related to the actual impact cases. This allowed for comparison of the surrogate responses with the injuries actually sustained by the front-seated occupants, and the rear seated children and infants, involved in the real world accident situations described in the case studies. The stronger right front seat also allowed for side-by-side comparison of what would have likely been the occupant injury outcome had the stronger seat been available. Previously conducted "torso body-block" quasi-static seat tests indicated that the 1996 "OEM" collapsing driver seat could only reach a maximum horizontal load resistance of about 3,070 Newtons, where as the much stronger 1996 Sebring "belt-integrated" seat reached a maximum horizontal load resistance of approximately 14,670 Newtons [5,6]. Figure 2 illustrates the typical "torso body-block" quasi-static test set-up used to evaluate seat strength. Figure 3 illustrates a typical crushable honeycomb impact barrier used in the sled-buck test series.

During these tests the sled-buck arrangement was towed rearward at a speed of approximately 20 kph into the crushable barrier. With the rebound, a horizontal change in velocity of about 23kph was reached along with an average peak G level of about 9 G's indicated by the steepest slope of the "Velocity Change" curve. Figure 4 illustrates the longitudinal (i.e. X-direction) "G" load curve for this sled-buck series.

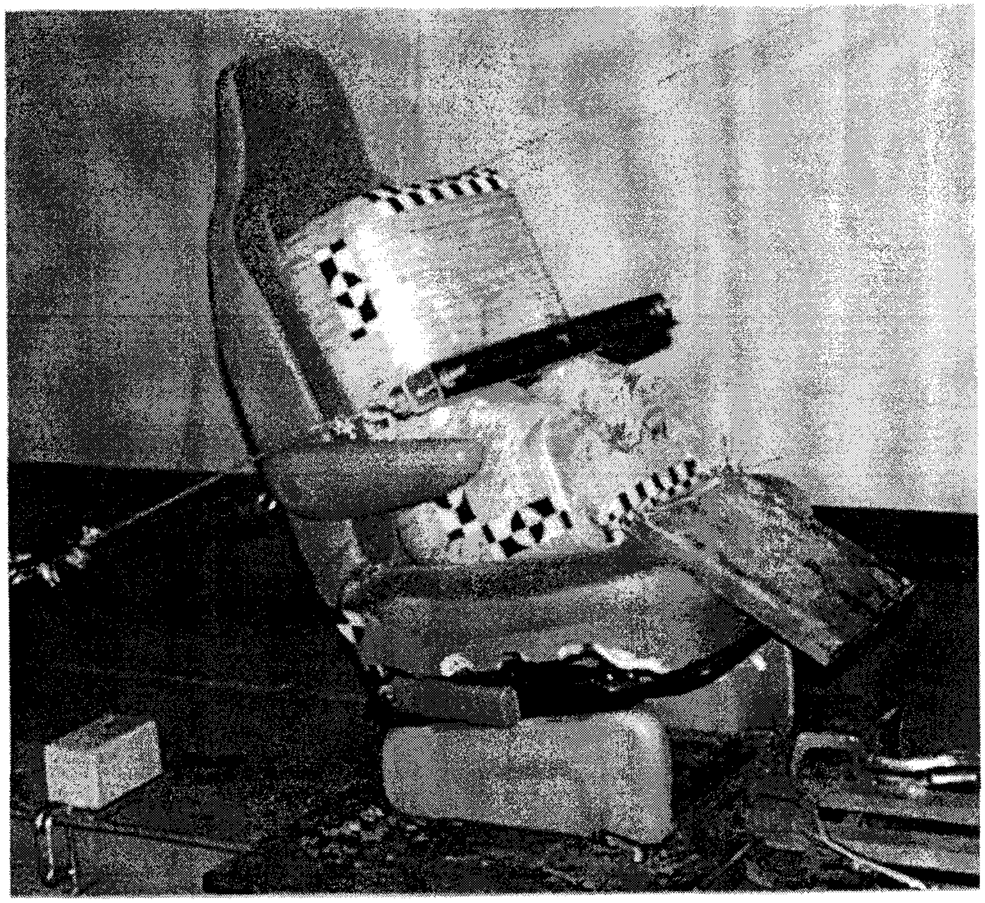


Figure 2. Quasi-static "Torso Body-Block" Seat Strength Test Set-Up

During this first test, the 125kg surrogate in the weaker "OEM" driver seat collapsed rearward such that the head of the driver surrogate struck the head of the child surrogate seated directly behind the driver seat. Figure 5 is a photograph taken at about 150 ms into the crash event and this shows the head-to-head contact of the driver head with the child's head. Figure 6 shows the post-test positions of the surrogates. Figure 7 shows a closer view of the rear seated child surrogate showing the "yellow" and "blue" chalk transfers from the head of the front dummy imprinted on the face of the child, and it's legs, due to the front seat collapse.

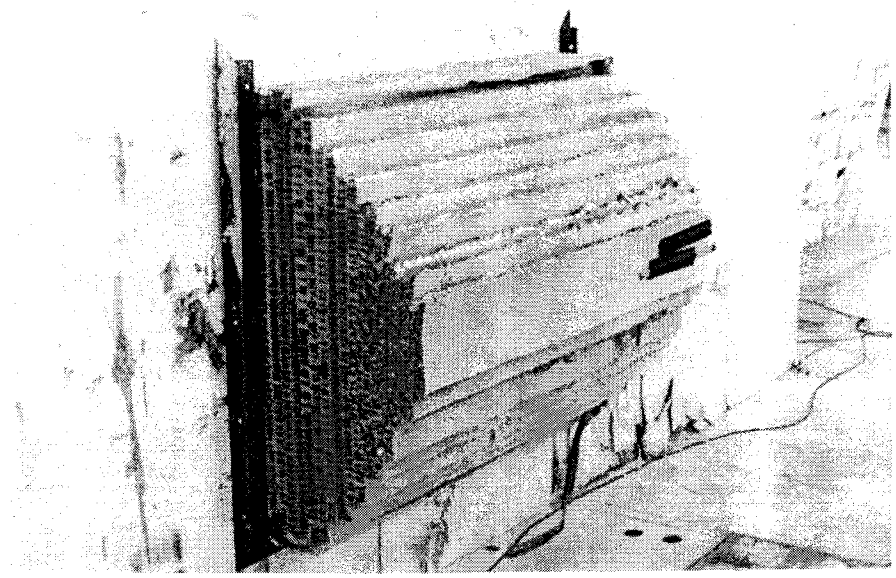


Figure 3. Crushed Honeycomb Barrier Used to Provide Case 1A Crash Pulse

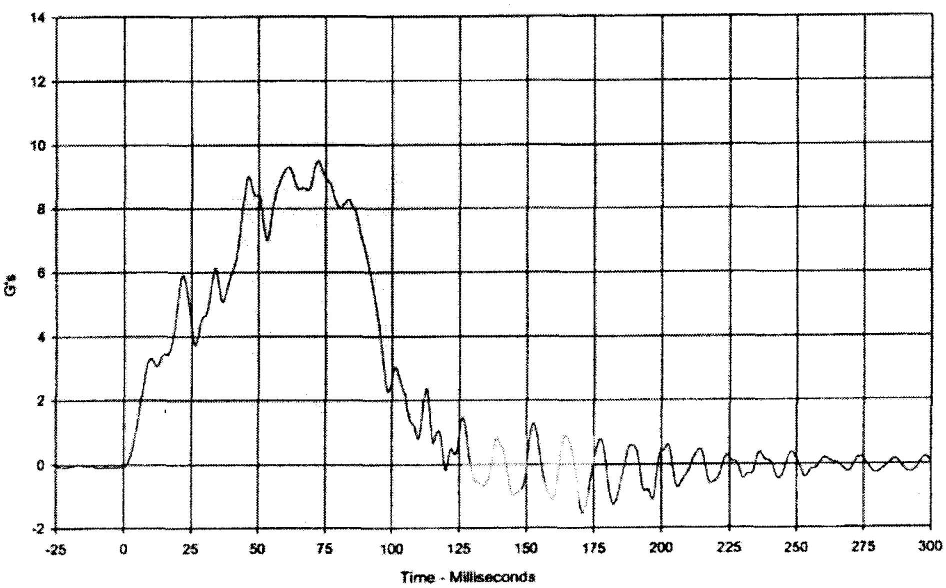


Figure 4. Typical Minivan Longitudinal Crash Pulse for 23 kph Speed Change

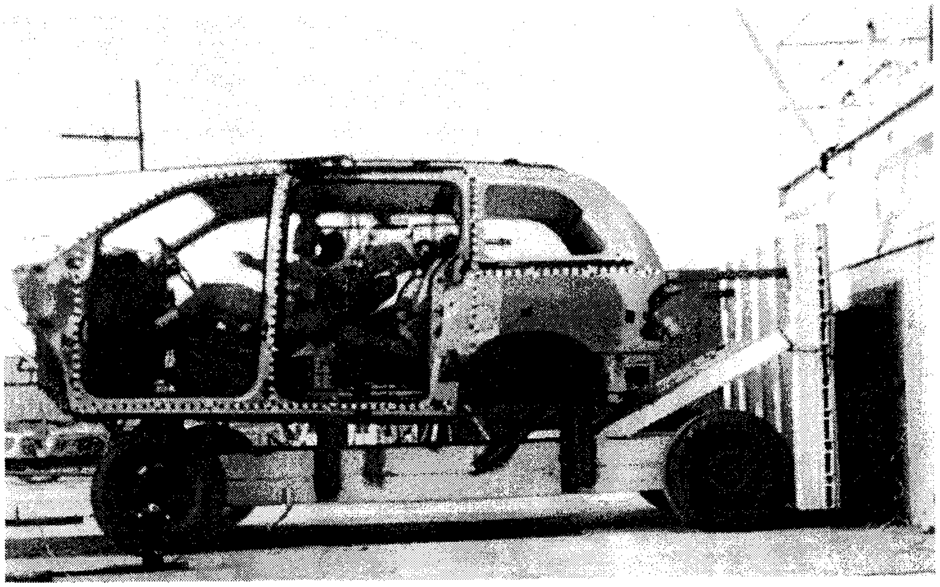


Figure 5. Occupant Response at 150 ms into Test 1 of Sled-buck Series

Figure 6. Post Test Surrogate Positions for Test 1 Set-up

Figure 7. Close Up Showing Head Strike and Leg Impact Chalk Marks on Rear Child

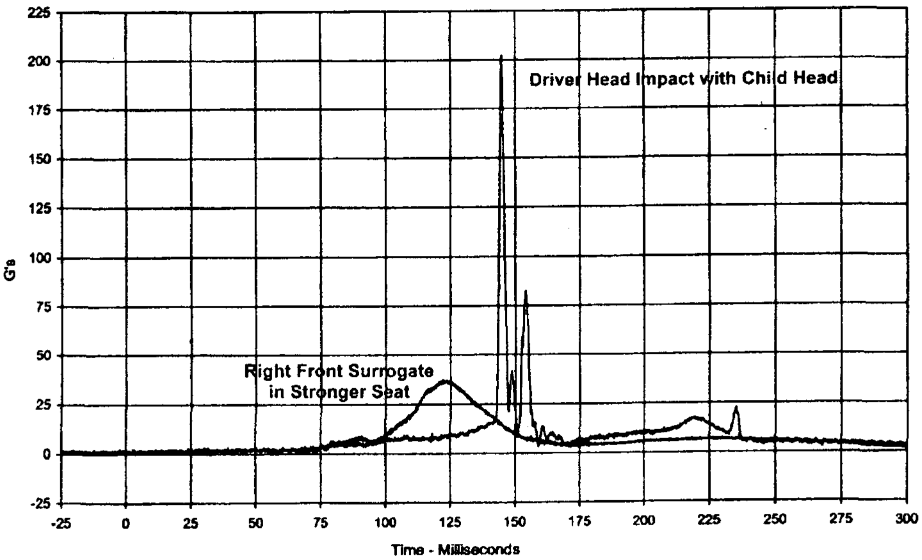


Figure 8. Head Impact of Driver (Weak Seat) vs. Right Front Surrogate (Strong Seat)

Contrary to the collapse of the driver surrogate, the 125 kg surrogate in the stronger right front seat stayed in place and not only would not have struck a child seated behind, but received much lower head loads as indicated by the comparison data shown in Figure 8. Obviously, the 200 G head impact loads experienced by the driver would be equal but opposite to the loads experienced by the rear seated child of case 1A, who did indeed suffer a severe and permanently disabling head injury.

Sled-Buck Test Series Test-2

This test is a repeat of the test 1 with the exception that the 21 kg child Surrogate seated behind the driver seat is now placed on a "Booster" child seat that raises the body of the child about 10 cm. The impact forces in this test are the same as those in the test 1 of this series with virtually identical peak G levels and speed changes. The front seat adult surrogates are the same size and type as those of test 1 and are seated in undamaged replacement seats similar, with one exception, to those used in test 1 (i.e. weak collapsing driver seat and much stronger "belt-integrated" right front seat). Figure 9 illustrates the pre test configuration for this test with the "Booster" child seat.

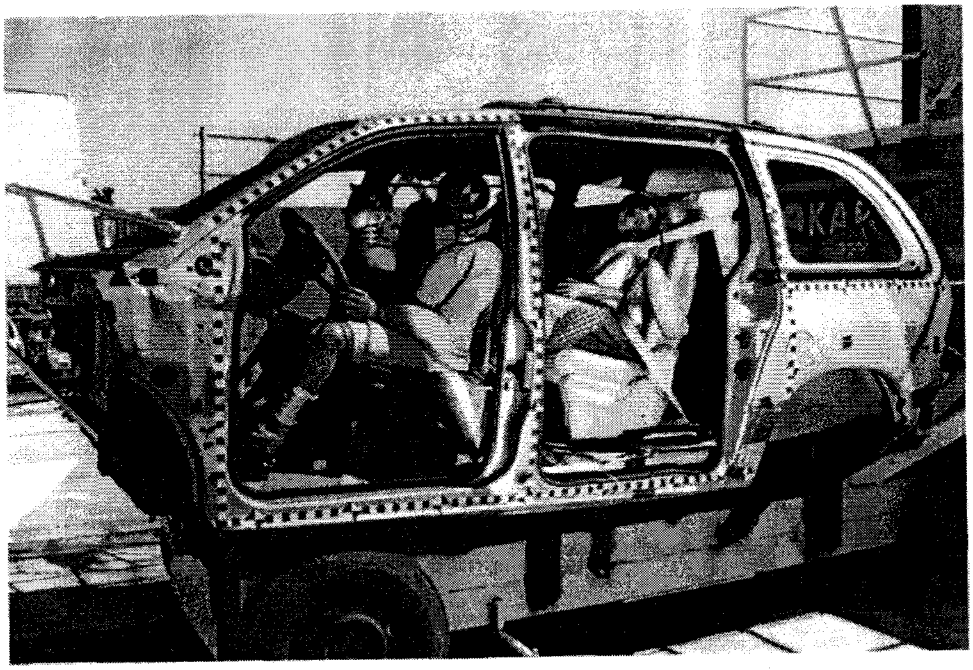


Figure 9. Sled-Buck Test 2 Pre-Test Set-up with Rear Child in a Booster Seat

Figure 10 however, illustrates that the right front "belt-integrated" seat was really only a simple modification of the weaker "OEM" collapsing seat, where a ALR lap belt was mounted diagonally behind the right front seatback up to the "D" ring. This simple retrofit type "mod" increased the weaker "OEM" strength from about 3,067 Newtons to over 13,500 Newtons, which is comparable to the 1996 Sebring "belt-integrated" seat used in test 1 of this study. As in the previous test, the front seat surrogates of test 2 weighed 125 kg. The only major exception was that the rear seated child dummy located behind the weaker front seat was now placed more vertically upright due to the child "Booster" seat.

Figure 10. Strengthened Weak "OEM" Right Front Seat for Test 2

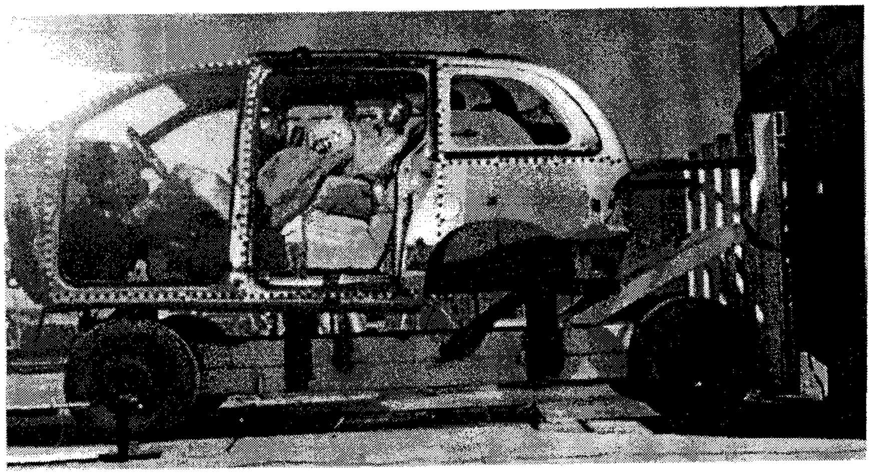


Figure 11. Test 2 Occupant Response at 150 ms with Child "Booster" Seat

The effect of raising the rear seated child on the "Booster" seat in this test 2 caused the collapsing front seat driver occupant to strike into the legs and torso area of the child, rather than into the head, as was the situation in the case 1 test. Figure 11 is a photograph taken at about 150 ms into the test 2 crash event and this shows the leg and torso contact on the rear seated child by the collapsing driver surrogate and front seat. While this situation does not appear to be as serious as the head impacts of test 1, there is the potential hazard of striking the child in the chest (rather than the head) with enough force to cause a fatal injury such as a ruptured heart, which occurred to the rear seated 5 year-old female in the Case 2A.

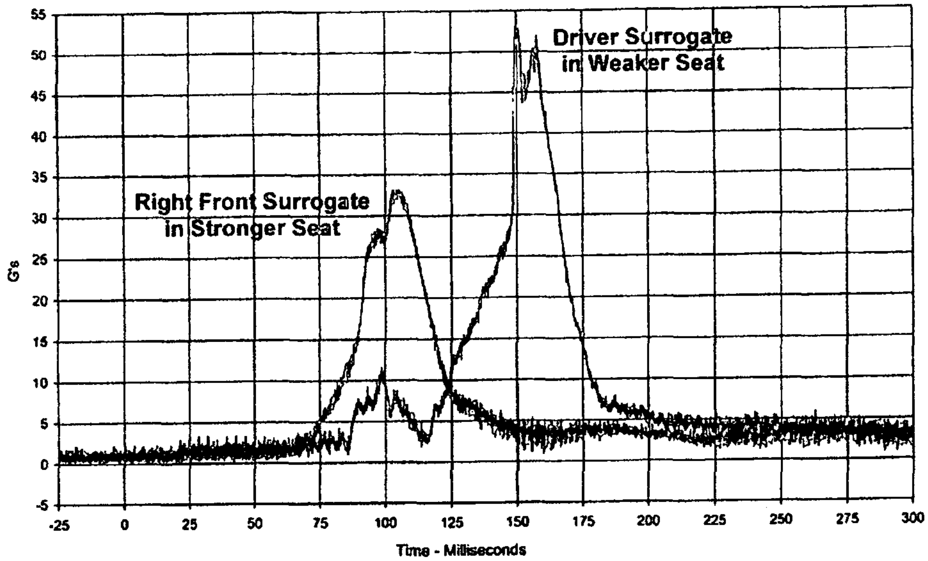


Figure 12. Test 2 Comparison of Head Response for Front Seat Surrogates

Also, as in test 1, the stronger right front seat surrogate would not have intruded into the rear-seated child's occupant space. In addition, although lower than in test 1, the surrogate in the weaker collapsing front seat tends to experience higher head and neck loads than the surrogate in the stronger front right front seat. Figure 12 illustrates the "head resultants" for the test 2.

Sled-Buck Test Series Test 3

The previous two tests demonstrated the dangers of possible leg, chest and, or, head injury to rear seated children when adult occupied seats directly in front of them collapse rearward during even low level rear impacts. Obviously, if the front occupied seats are likely to collapse rearward, and it is required that the child or infant be placed in the rear seat area, then the safer position for a child would seem to be centered between the two collapsing front seats. In the case of a typical minivan with a two passenger mid-bench seat, this would involve placing the child in a number 5 position that is not located directly behind either front seat, but rather just slightly right of center. While this may seem to be a safe position for the child, it is possible that a front seat occupant could be leaning "out-of-position" (OOP) inward toward the center of the vehicle. It has been suggested by proponents of the conventional collapsing seat systems that stronger seats could be dangerous to an "out-of-position" front occupant because they may experience whiplash injury during a rear impact due to the greater rearward resistance of the stronger seat, as contrasted to the lower rearward load resistance of the more common weaker front seats [8]. If indeed the OOP occupant orientation is a real issue, then this OOP occupant orientation should also be tested and evaluated with respect to the weaker collapsing seats to determine what hazards may exist under that situation for both the occupant of that seat and children seated rearward.

Test 3 examines the OOP occupant issue as it relates to an adult occupant seated in a conventional "OEM" weaker collapsing front seat and a rear-seated child located in a safer position, not directly behind the collapsing seat. In this test, both front seats are conventional "OEM" collapsing types. The child surrogate and the front seat adult surrogates are the same size as in the previous tests. In this test however, the child surrogate has been placed toward the center position between the two front seats, and the right front adult surrogate is leaning slightly inboard OOP, toward the center of the vehicle, at about an 11degree angle. Figure 13 illustrates the surrogate set-up for test 3.

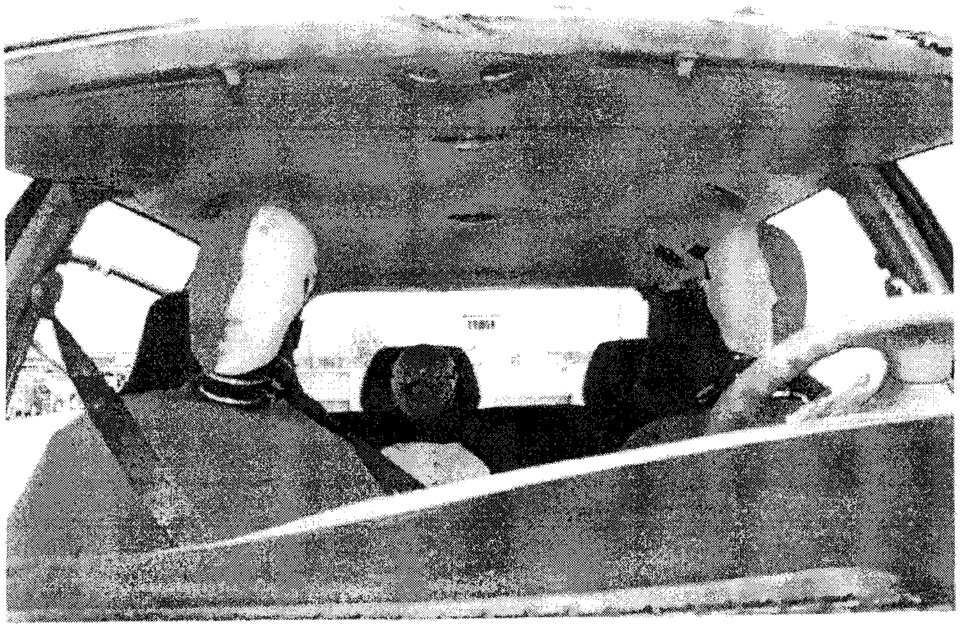


Figure 13. RF (OOP) Surrogate & Child in Pre-test Setup of Sled-Buck Test 3

As a result of the "inboard" leaning OOP orientation of the right front surrogate in the collapsing seat, the more centered rear seated child was struck in the right chest and shoulder, and also received a glancing blow to the side of the head, from the impact of the head of the rearward collapsing right front OOP occupant. This is shown in Figure 14 by the yellow chalk transfer marks on the chest, shoulder, and side of head of the child surrogate. The driver dummy, which was also seated in a collapsing type "OEM" seat, also collapsed rearward into the empty position 4 of the rear mid-bench seat. Neither of the front seat surrogates received injurious head or neck loads from impact with the child dummy or the empty rear seat position. Most importantly, however, as noted by the yellow chalk marks imprinted from the head of the right front OOP surrogate collapsing onto the rear seated child, even center rear seat positions are not likely to be safe for children and infants if the front seat occupants are leaning "out-of-position" and the front seats tend to collapse rearward, especially at rear impact severity levels as low as in this case (i.e.23 kph speed change and 9 G loads).

Figure 14. Collapsing Seat OOP Dummy Head Chalk Marks on Rear Seated Child

Vehicle-to-Vehicle Crash Test with Infant in Forward Facing Child Seat

The following vehicle-to-vehicle crash test deals with three main topics: 1. Demonstration of hazards to rear seated infants restrained in forward-facing child restraint seats (FCRS), which are mounted behind occupied collapsing front seats; 2. Comparison of the hazards of item 1 with the impact response of rear-most seated occupants, including children, located in the last bench seat of a minivan directly adjacent to the rear impact and crush intrusion zone, but away from any significant front seat collapse hazards; and 3. Side-by-side comparison of the response of front seated surrogates in collapsing seats versus the stronger "belt-integrated" type seats, but with the headrests located below the base of the heads so as to induce "out-of-position" (OOP) loads on surrogates seated in both the strong and the weaker collapsing types of seats, while subjected to identical impact severity.

In this test a stationary late model minivan vehicle, identical to the body style used in the previous sled-buck series, is rear impacted by a half-ton pickup truck traveling at 54 kph. The centerline of the impacting vehicle is aligned with, but offset by about 28 cm to the left of, the minivan centerline. Figure 15 illustrates both vehicles just prior to impact. Figure 16 shows the crash pulse experienced by the impacted minivan. This pulse is very similar the crash pulse simulated by the crushable barrier used in the previous sled-buck test series.

Figure 15. Vehicle-to-Vehicle Test Set-up Just Prior to Impact

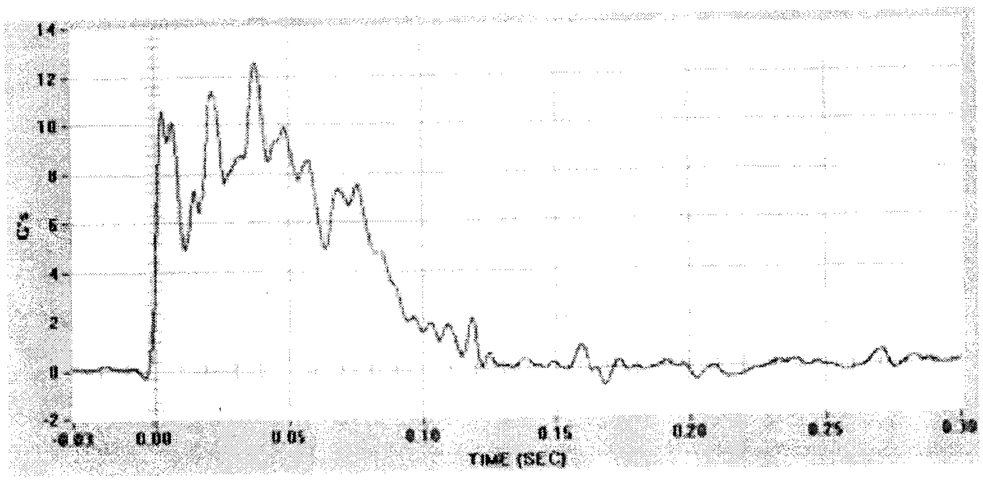
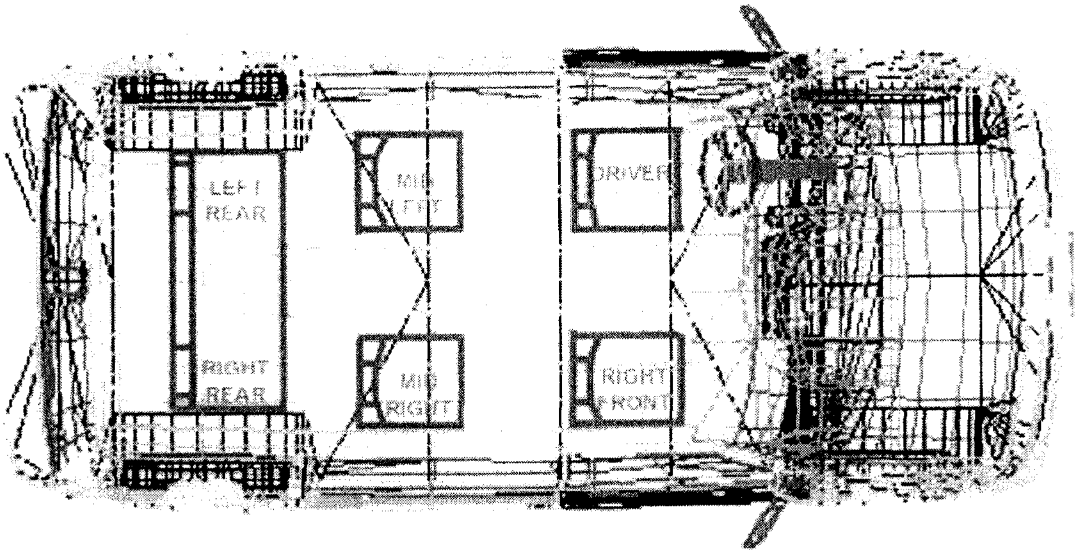


Figure 16. Stationary Minivan Longitudinal Crash Pulse from 54 kph Impact by PU

In this test, the minivan experienced a longitudinal change in speed of 27.7 kph with an average "G" level of about 9 G's. Five instrumented surrogates, and one uninstrumented surrogate, were placed in the out-board seating positions for this test. Table 3 outlines the types of surrogates and seats for each position.

TABLE 3. VEHICLE-TO-VEHICLE SURROGATE & MINIVAN SEAT DATA



DRIVER SEAT: STRONGER 1996 CHRYSLER SEBRING "BELT-INTEGRATED" SEAT @ 20 deg ANGLE Replacing WEAKER 1998 "OEM" COLLAPSING SEAT

DRIVER: HYBRID III 50%tile MALE (w Seated Pelvis) BALLASTED TO 87.3 kg & SEATED with HEAD to ROOF CLEARANCE MATCHING 6' 1" MALE

RT FRT SEAT: STANDARD "OEM" COLLAPSING SEAT PLACED FULL REAR (matching the position of the replaced driver seat) @ 16 deg SB ANG.

DUMMY: SAME AS DRIVER SURROGATE (except for Standing Pelvis)

MID LFT SEAT: STANDARD LEFT SIDE 1998 "OEM" REMOVABLE CAPTAIN CHAIR

DUMMY: 71 kg SIDE IMPACT DUMMY (non-instrumented) FOR BALLAST

MID RHT SEAT: STANDARD RIGHT SIDE 1998 "OEM" REMOVABLE CAPTAIN CHAIR

DUMMY: 6 Month CRABI BALLASTED TO 10 kg In a CENTURY "ACCEL SE" Child SEAT Mounted Forward Facing to the MID RHT CAPTAIN CHAIR

REAR BENCH: STANDARD REMOVABLE 3-PASSENGER REAR BENCH SEAT

LEFT : HYBRID III 5^{TH}%tile FEMALE @ 51.8 kg
RIGHT: 6-YEAR-OLD CHILD SURROGATE (20 kg) with 51.8 Floor Weight

NOTE: Headrests Full Down on Each Front Seat & All Surrogates Fully Restrained

The front seat contained restrained and instrumented (i.e. head, neck, and chest) Hybrid III males ballasted to 87.3 kg. Both were seated upright on a pad so that the "head-to-roof" clearance matched that of a 185.5 cm tall male. A stronger 1996 Sebring "belt-integrated" seat replaced the "OEM" weaker driver seat. The right front seat was the standard minivan "OEM" collapsing type seat. The dummy in the weaker right front seat had a "pedestrian" standing pelvis (rather than the standard molded "seated" pelvis) so as to more realistically replicate the kinematics of a human when this seat (i.e. right front) collapsed rearward. The headrests of both front seats were placed in the lowest positions so as to allow for the study of alleged "whiplash" dangers to "out-of-position" (OOP) occupants seated in strong seats. This side-by-side arrangement of strong and weak seats, with the tops of the headrest set below the base of the head, enabled a quantitative comparison of surrogate head and neck response for the same level of impact severity with two distinctly different levels of seat strength (i.e. 3,070 Newtons vs. 14,670 Newtons). Figure 17 shows the front seat headrest positions for this test. All other headrests of (i.e. rear seats) were adjusted properly upward.

Figure 17. Lowered Front Seat Headrests In Vehicle-to-Vehicle Test

The mid-row seats were each standard "OEM" captain seats located in the outboard positions 4 and 6. Seated on the left-mid seat was an uninstrumented side impact surrogate weighing 71 kg. Seated on the right side of this row, behind the weaker right front seat, was a 6 month-old CRABI surrogate ballasted to 10 kg. The CRABI was instrumented with tri-axial head and chest accelerometers. The CRABI was restrained in a "forward-facing" child restraint seat that was in turn secured to the right-mid seat as shown in Figure 18. Figure 19 shows a restrained 5^{th} percentile Hybrid III female, and a 6-year old, in the rear bench seat.

Figure 18. Mid-Left Adult Surrogate and Mid-Right Forward Facing Infant Surrogate

Figure 19. Rear Bench 6-Year-Old (right rear) & LR 5th Percentile Female Hybrid III

Figure 20 is a film clip, taken from the hi-speed films at 156 ms, for the passenger side view which shows the right front surrogate, in the weaker "OEM" seat, collapsing into the head and chest of the infant seated behind. Figure 21 shows the head and chest impact accelerations imparted to the infant behind the collapsing seat.

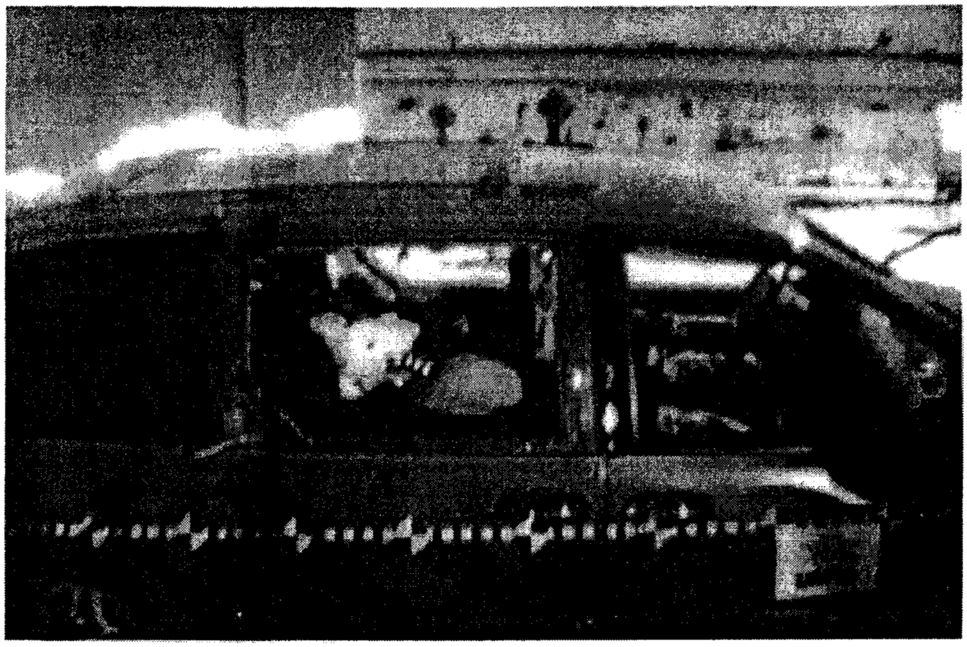


Figure 20. Head & Chest Impact to the Infant at 156 ms Into the Crash

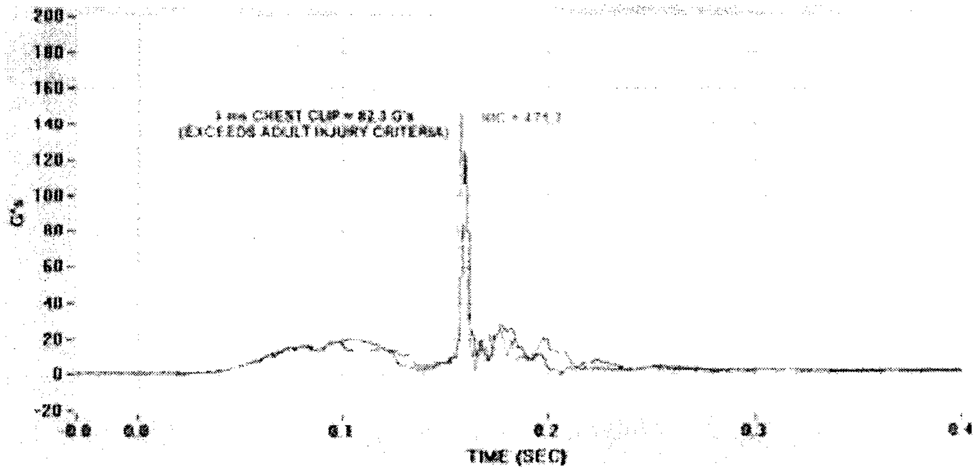


Figure 21. Mid-right Infant Head (red) and Chest (blue) Impact Accelerations

As shown by the results in Figure 21, the impact to the head and chest of the infant was of sufficient severity to likely cause serious, or even fatal, injury to the infant.

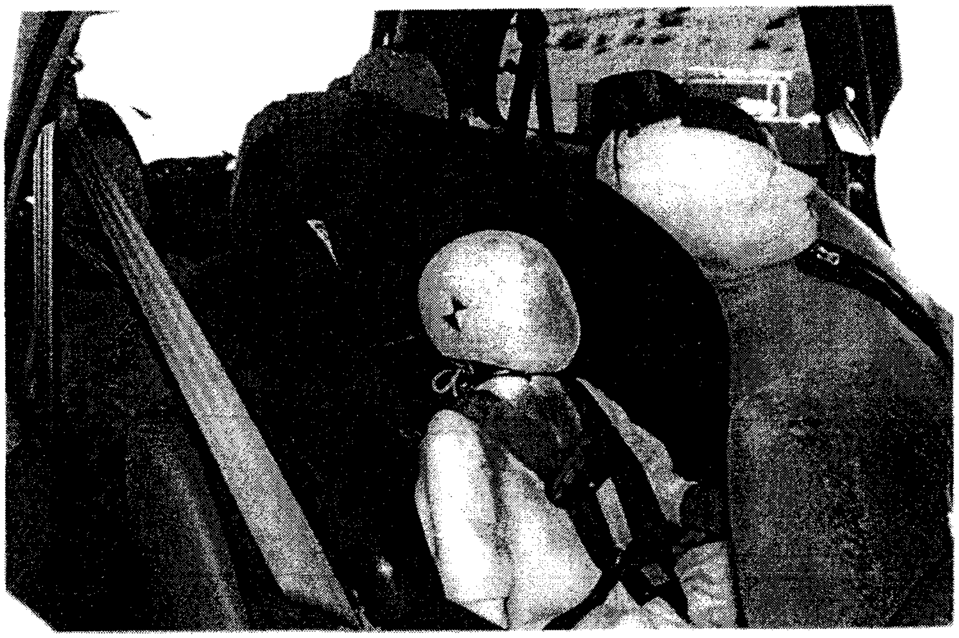


Figure 22. Post Test View of Infant with Chalk Transfer from RF Head Impact

On the other hand, none of the remaining instrumented surrogates in the vehicle reached injurious load levels. For instance, Figure 23 illustrates a comparison of the resultant head accelerations for both of the adult front seat occupants with headrests in lowered positions.

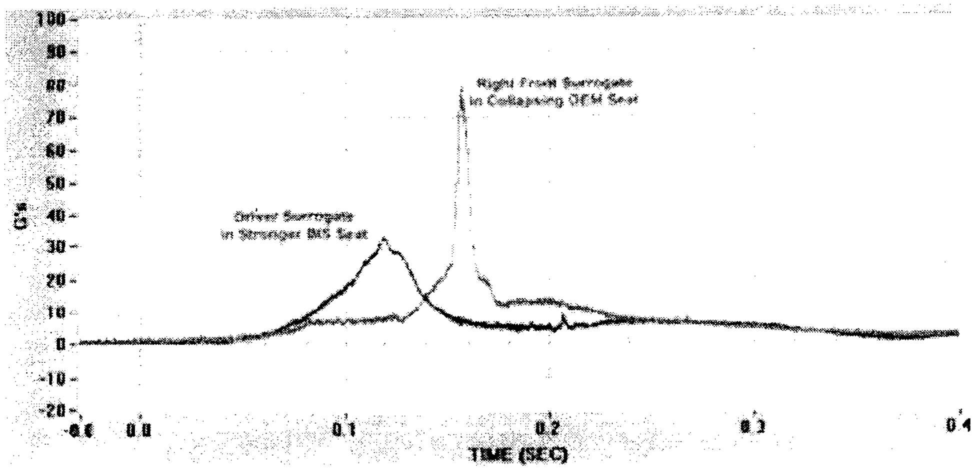


Figure 23. Comparison of Head Accelerations for Driver (blue) & RF Surrogate (red)

Likewise, Figure 24 illustrates the neck torque loads for the extension and flexion modes on these surrogates. Figure 25 provides a comparison of the axial neck loads for both front occupants. The data does not indicate any likelihood of serious head or neck injury to either front seat occupant, regardless of the fact that the headrests were purposely set in low positions exposing the heads and necks to "extension" type whiplash environments. Even the rear bench seated occupants located in the crush-impact and intrusion zone did not receive injurious loadings. A summary of the occupant load and injury data for the front occupants (i.e. 50 percentile Males ballasted to 87.3 kg), the mid-right seat infant (i.e. CRABI surrogate in a forward facing infant seat) and the left-rear bench seat occupant (i.e. 5th percentile female) is contained in Table 4. The 6-year-old dummy in the right rear bench seat was only instrumented with uniaxial (X-axis) accelerometers in the head and chest, which recorded maximum loads of only 25 to 33 G's at about 98 ms. Neither load indicated injury to this child.

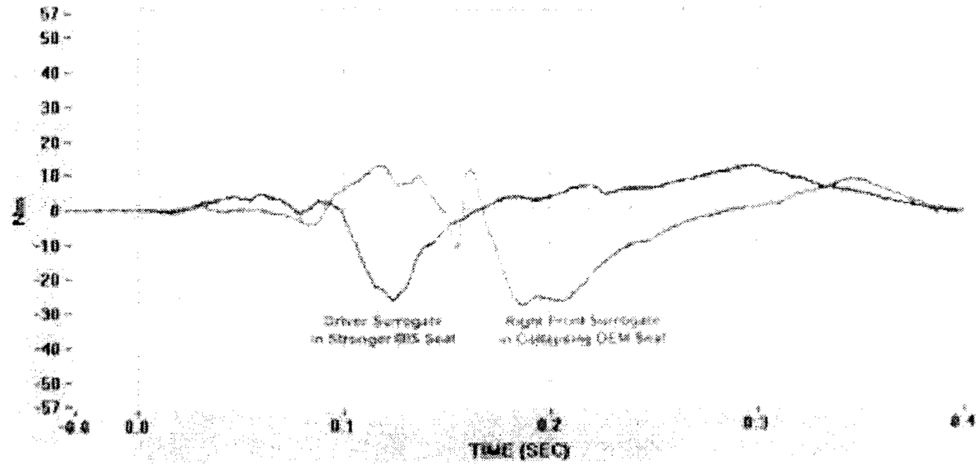


Figure 24. Comparison of Neck Torques for Driver (blue) & Right Front Surrogate (red)

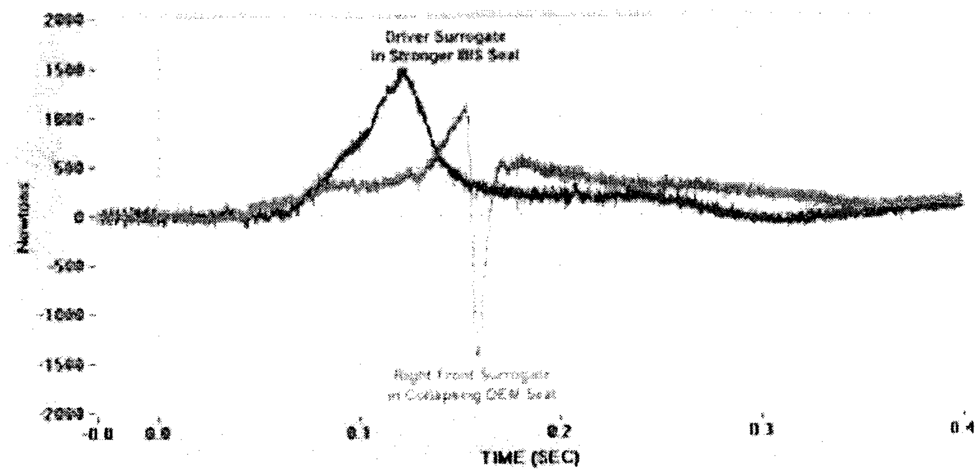


Figure 25. Comparison of Neck Axial Loads for Driver (blue) & RF Surrogate (red)

Table 4. Side-by-Side Comparison of Head, Neck, & Chest Loads for Instrumented Surrogates in the Front & Rear (i.e. mid-row & rear bench) Seats of Veh-to-Veh Test

Veh.-to-Veh. 98 Minivan Hit by Pickup	Front Bucket Seats		Rear Seats (Middle Row & Rear Bench)	
	Driver (87.3 kg) Position 1	RF Pass. (87.3 kg) Position 3	Mid-Right (10.0 kg) Position 6	Left-Rear (51.8 kg) Position 7
SEAT TYPES (Max Load - N)	96 Sebring BIS (14,670)	98 Minivan OEM (3,070)	Captain Chair OEM + FCRS (3,070)	Rear Bench OEM (NA)
Fz (N) NECK COMPRESSION	-141.7	-1,457.0	NA	-171.7
Fz (N) NECK TENSION	1,504.3	1,160.0	NA	1,887.1
My (Nm) NECK EXTENSION	-26.5	-27.9	NA	-26.4
My (Nm) NECK FLEXION	12.1	12.8	NA	15.2
PEAK "G" HEAD	32.7	79.0	148.4	49.3
(HIC) HEAD INJURY	110.1	222.9	471.2	149.6
PEAK "G" CHEST	16.3	12.0	125.5	14.9
3 Ms CLIP CHEST	16.2	10.9	82.3	14.8
Nij Combined Load Neck Injury Criteria	$N_{TE} = 0.618$ (At 120 ms)	$N_{CE} = 0.405$ (At 157 ms)	NA	$N_{TE} = 0.735$ (At 132 ms)

It is interesting to note that the vertical clearance from the "top of the head" to the "top of the lowered headrests" for both front-seated surrogates was 16.3 cm, plus or minus 0.5 cm. Also, the horizontal space from the back of the head to the headrest was 6.6 cm, plus or minus 0.8 cm. In effect, both front seat surrogates were "out-of-position" (OOP) with respect to the headrests since their heads were exposed above the headrests and lacked support for rear impact loads. In spite of the lack of support from the headrests, the "Combined Load" neck injury criteria data for both front-seated surrogates (i.e. driver in stronger seat and right front in collapsing seat) indicates that neither surrogate would likely have experienced whiplash injury. Also, the left rear bench seated female surrogate, whose headrest was properly adjusted upward, was positioned to receive headrest support to the head and neck (as shown by Figure 19.) and she experienced slightly higher, but *non-injurious*, "*Tension-Extension*" combined neck loads than did the front seat surrogates who were purposely set OOP with respect to their headrests.

Rear Moving Barrier to Vehicle Crash Test with Infants in Rear Facing Child Seats

In this test a non-deformable 1813 kg rear moving barrier, traveling at 50.3 kph, is impacted into the rear end of a stationary 1521 kg four-door sedan. Figure 26 shows this test arrangement before impact. The front seats of the sedan contained two restrained Hybrid III male surrogates, each weighing 79 kg. The surrogate in the driver seat contained the standard "seated pelvis" while the right front surrogate had an "articulating" type of pelvis. Both of the front seat surrogates were seated in "Original-Equipment-Manufactured" (OEM) type collapsing front seats. Seated behind each of the front seats were 6-month infant CRABI surrogates weighing 8.2 kg and restrained in rearward facing child restraint seats (RCRS) that were in turn each belted to the rear bench seat. The right rear CRABI was restrained in an Evenflo child seat. The left rear CRABI was restrained in a more robust infant seat that had larger side wings and was placed a little more upright than the Evenflo seat. Figure 27 illustrates the pretest arrangement for the back seat set-up of rear facing infants. Note that the left rear infant, in the more robust infant seat, is angled slightly more upright than the right rear infant. The right rear infant had a chest angle of 45 degrees from horizontal versus 50 degrees for the left rear infant chest angle. Also note that the heads of the surrogates were coated with chalk so as to identify any infant head contact within the rear compartment.

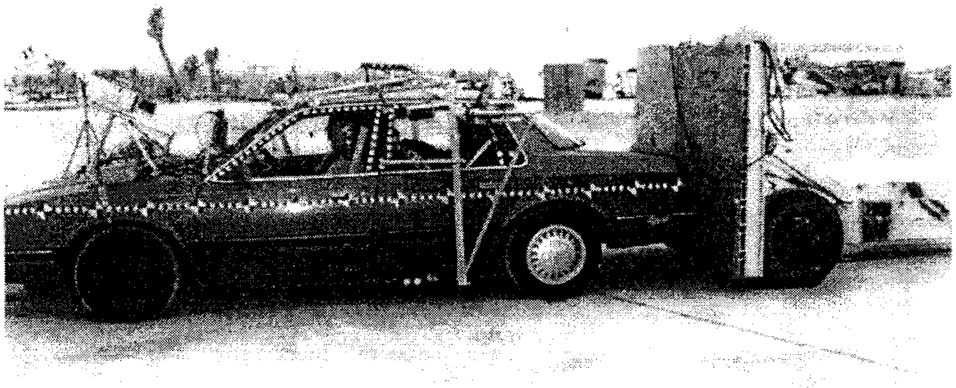


Figure 26. Pre-Test Setup for 50 kph Rear Moving Barrier Test with Infants in RCRS

As a result of the barrier impact the target vehicle experienced a 32.2-kph longitudinal speed change and an average peak acceleration of 10 G's over the steepest slope of the speed change. The shape of the target vehicle acceleration curve was very similar to those shown in Figures 4 and 16 for the previous tests. During the impact the adult occupied front seats collapsed rearward into the rear facing infant seats. In the case of the right rear infant, the infant seat buckled and folded like a "clam shell" allowing the infant in this seat to make contact with the rear seatback and the back of the right front seat headrest. Red chalk transfer from the head of the right rear infant can be observed in these areas as shown by the Figure 28.

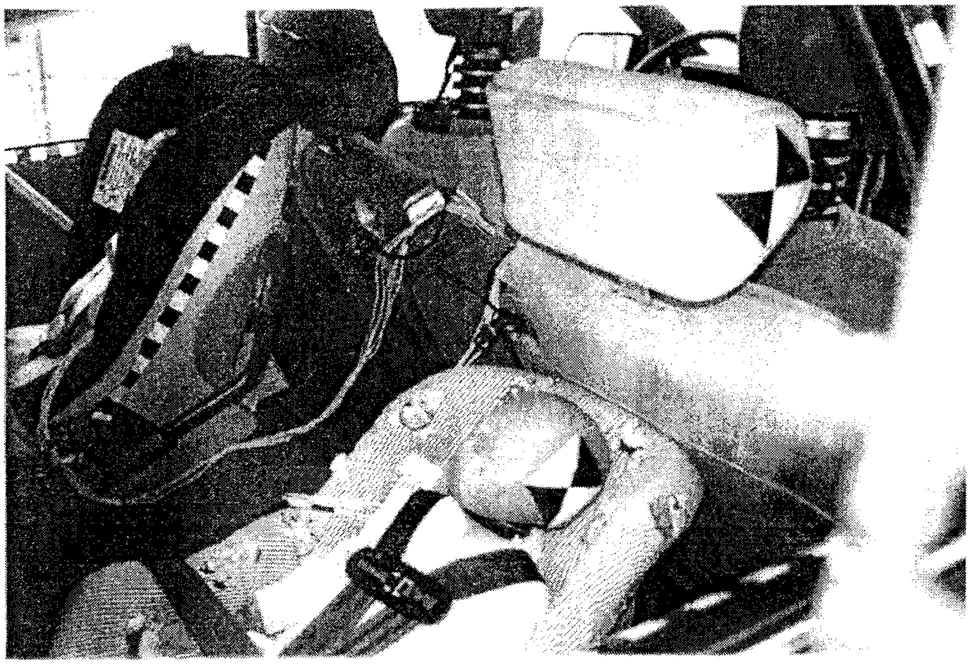


Figure 27. Pre-Test Orientations of Left and Right Rear Facing Infants in Child Seats

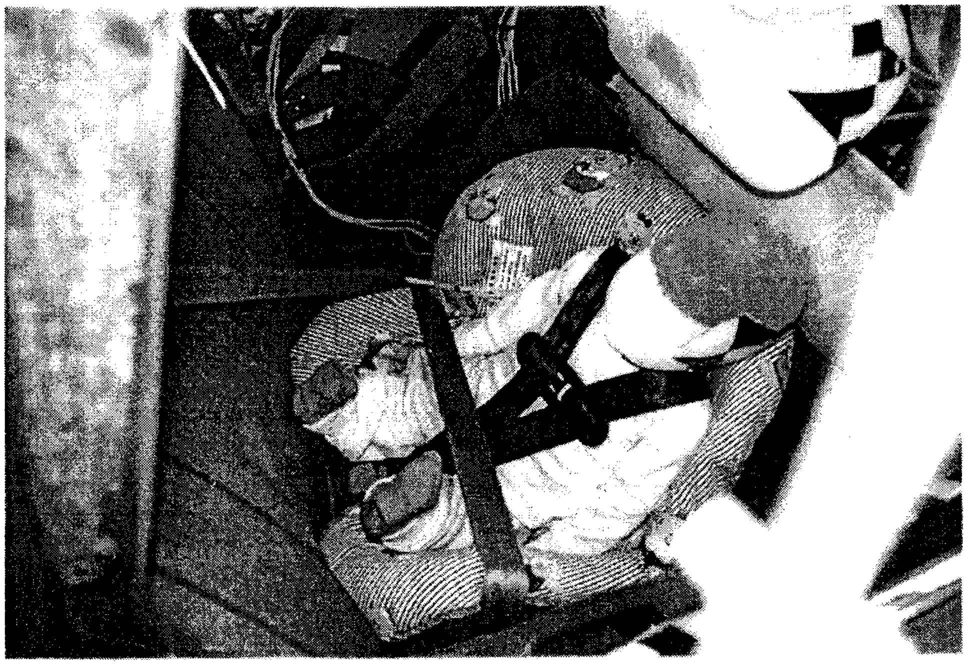


Figure 28. Post-Test RR Infant Head "Red" Chalk Marks on Rear Seat & OEM Headrest

Comparison of Figures 27 and 28 shows that the right rear infant seat has been "buckled" or "folded" by the compression of the collapsing front seat and occupant. This loss of structural integrity of the infant seat, coupled with the multiple head strikes of that infant on the rear seatback and the back of the front seat headrest, illustrates the potential head impact hazards for infants in rear facing infant seats when the occupied front seat collapses into the rear occupant area and the infant seat integrity is compromised.

Similarly, Figure 29 shows that the more robust left rear infant seat has also been rotated more upright (i.e. placing the child in a more vertical or standing position), and shoved toward the rear seatback, due to the collapse of the "OEM" driver seat and occupant. In this situation however, the more "robust" infant seat maintained its' integrity and prevented the head of the left rear infant from impacting with either the back of the collapsed front seat or the rear seatback, as was the case with the adjacent infant (i.e. right rear infant in the "buckled" infant seat). Also note that the top edge of the hard plastic child seat is now above the top of the collapsed front driver seat headrest. Although neither of the front seat occupants in this test experienced injurious load levels to the head, it is possible that the front occupant (even if they are not leaning left or right OOP in the collapsing seat) could forcefully strike the back of their head on the hard plastic edge of the child seat that has been rotated more upright and above the edge of the front seat headrest.

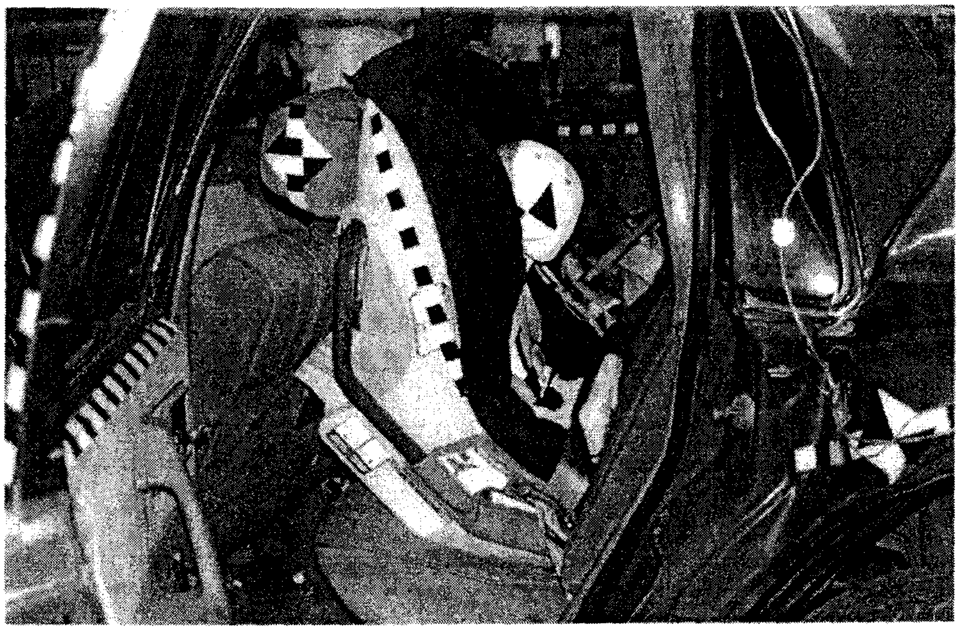


Figure 29. Post Impact Orientation of LR Infant Due to Front Seat Collapse

Figure 30 illustrates a comparison of the horizontal head impact accelerations for the rear infants in this case. Obviously, even though the loads did not indicate head impact injury levels, the infants in these situations (i.e. infants in Rear facing Child Restraint Seats (RCRS) located directly behind collapsing front occupants and seats) are exposed to the potential for serious crushing types of head injury as was found to be an injury in field accident Cases 3A and 6B.

Conversely, the infant in the "robust" and more upright left rear infant seat experienced higher chest loads than those of the right rear infant. These chest loads reached just over 50 G's and could have led to injury. Table 5 provides a summary of the head and chest loads for this test.

Table 5. Side-by-Side Comparison of Head & Chest Loads for Instrumented Surrogates in the Front & Rear Seats of RMB Test

RMB TEST: 4-door Sedan hit by 50 kph RMB	Front Bucket Seats		Rear Bench Seat	
	Driver (79.1 kg) Position 1	RF Pass. (79.1 kg) Position 3	Left-Rear (8.2 kg) Position 4	Right-Rear (8.2 kg) Position 6
SEAT TYPES (Max Load - N)	4-dr Sedan OEM (2,625)	4-dr Sedan OEM (2,625)	Rear Bench OEM + RCRS (NA)	Rear Bench OEM + RCRS (NA)
PEAK "G" HEAD	45.7	18.8	26.9	40.8
(HIC) HEAD INJURY	184.0	32.3	59.2	98.8
PEAK "G" CHEST	28.9	13.6	56.7	40.8
3 Ms CLIP CHEST	26.2	13.0	52.0	39.7

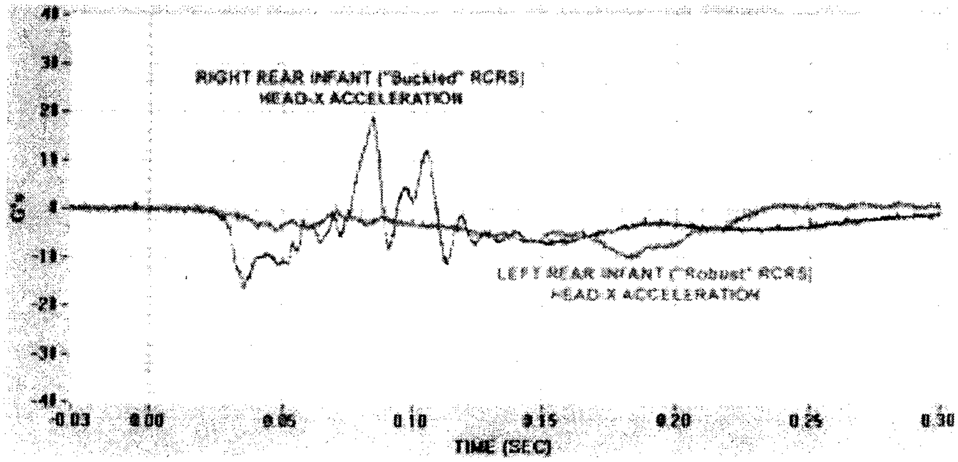


Figure 30. Head-X Response for Infants in the "Buckled" (blue) vs. "Robust" (red) CRS

CONCLUSIONS

The results of the various tests reported in this study, coupled with the statistical findings of Friedman and the various case studies reviewed, indicate that allowing a front occupied seat to collapse into the rear occupant space during rear impact is a hazardous situation for rear seated infants and children who are located behind the collapsing front seat, regardless of the type of child restraint employed. Although it has been suggested that a collapsing front seat is beneficial in mitigating injury to the front occupant during rear impact, it should be clear that the occupants and children seated directly behind the collapsing seats are at risk of being seriously injured, even in low severity impacts such as Case 1A. In the minivan cases studied where rear seated occupants were located directly ahead of the area of impact and intrusion, but without intrusion from any occupied front seat collapse (i.e. Cases 5A, 6A and 7A), these occupants were not seriously injured. In fact the only seriously injured occupants in these cases were the children in the mid-row seats that were located directly behind an occupied collapsing seat. This result was confirmed in the vehicle-to-vehicle test. The sled-buck tests, and the rear moving barrier test, also demonstrated the injury risk to various sizes of rear-seated children, and infants, from the collapsing seat hazard during low levels of impact. One would expect that placing a child in a rear seat position located between the front seats would alleviate the collapsing seat hazard. However, as the third sled-buck test showed, an out-of-position (OOP) front occupant seated in a collapsing front seat could compromise the safety benefits to children in the rear location between the front seats. In several instances it was shown that the stronger front seat designs, like the belt integrated types, could provide better protection to both the front and rear occupants, even when the headrests were in less than optimum positions exposing the head and neck of the front seated occupant to OOP environments that have been suggested as reasons for not employing stronger seats [8,9]. One other collapsing seat hazard that has been cited in the past [2] deals with entrapment and loss of egress capabilities that could result in death due to post crash hazards such as fire. Case 7B gives a real world example of this hazard. The hazards become even greater when the rear-seated children are subjected to both intrusions from the rear as well as the collapse of the front-seated occupant into the rear area. The stronger "belt-integrated" seats alleviate part of this problem. Also, based on the results of the vehicle-to-vehicle test, as well as Cases 5A, 6A and 7A, those occupants seated directly adjacent to the impact crush and intrusion do not seem to be as severely injured as the child subjected to front seat collapse. Thus, based upon the results of this study, it is concluded that stronger front seats, such as the "belt-integrated" types, will improve protection to rear seated children, regardless of the child restraint type or seat position, and, if properly designed with good headrests, will also provide improved protection to the front seat occupant as well.

ACKNOWLEDGEMENTS

The authors express their appreciation to Frank Richardson, Jerry Kratzke, and the members of the technical staff at KARKO Engineering for their assistance in conducting the crash tests. The authors also express appreciation to Pete Baray, Charles Dickerson and Ambrose Hubbard for their assistance in conducting the quasi-static seat tests, as well as with the dynamic tests.

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