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Field Accident Evaluations and Experimental Study of Seat Back Performance Relative to Rear-Impact Occupant Protection

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ABSTRACT

This study examines in some detail 23 actual rear-impact cases dealing with front seat collapse and compares the findings with similar results from 23 Canadian cases. In addition, seat tests and car-to-car crash tests are utilized to examine the potential hazards and/or benefits of collapsing versus non-collapsing seat systems. Evaluation of the above 46 cases indicates that an extremely high rate of rearward ejection occurs to restrained front-seat occupants subjected to rear impact. The majority of those ejected experienced serious to fatal injuries, either from contact in the rear or outside of the vehicle, when seated in collapsing seats. These results are contrary to some earlier published data and, as such, recommendations are made which could help improve data collection methods so as to better evaluate the issues associated with rear-impact seat strength.

INTRODUCTION

Interest in determining the adequacy of automotive seat back strength for providing occupant protection during rear-end collisions has been renewed in recent years [Saczalski, 1989]. A sparsity of objective field accident data complicates assessment of key issues which, for the most part, seem to partition into two groups: one advocating stronger and less yielding front seat systems, and the other suggesting that the current designs of collapsing front seats are able to absorb sufficient energy so as to minimize harmful loads applied to the occupants during rear impacts.

In this paper, several actual accident cases are reviewed in some detail with major focus on occupant kinematics, kinetics, resulting injuries, locations of impact, and, in some cases, the amounts of energy absorbed during the collision by collapsing seat structures. Experiments on exemplar production seat systems were conducted to determine amounts of possible resistance or energy attenuation provided by the seat structure. In addition, rear-impact, car-to-car experiments, utilizing instrumented anthropometric test devices, were reviewed and compared with the results of a car-to-car crash test which contained both a non-yielding seat and a standard collapsing seat structure, each occupied by an instrumented fiftieth percentile male surrogate. One of the primary objectives of the latter test was to gain insight into the potential hazards of both seat design approaches (i.e., collapsing seats versus stronger, less yielding seat structures).

With respect to the actual accident cases reviewed and discussed in this paper, 23 cases deal with real-world accidents evaluated by the authors, and another 23 cases represent the results of a recent Canadian study on real-world accidents involving seat back failures, examined on behalf of Transport Canada [Marriner, 1990]. Evaluation of the field accident data from the above-cited 46 real-world cases, which focused primarily on the effects of automotive seat structure in rear impacts, indicates that an extremely high rate of partial or total ejection (approximately 50%) occurs to restrained front-seat occupants subjected to rear impact. Furthermore, the majority of the ejected occupants experienced serious to fatal injuries, either from contact in the rear or outside of the vehicle after rearward ejection, and in virtually all cases the occupants were seated in standard collapsing seat systems. These results are contrary to some earlier published data [Data Link, 1990] and analysis [James, 1991; Warner, 1991] which relied upon the National Accident Sampling System (NASS) data base and concluded that, among other things, restraint usage, combined with collapsing seats in rear impacts, has a substantial injury-reducing effect. These conclusions are similar to those presented by Strother in an earlier paper on this subject [Strother, 1987]. For whatever the reason, even though it was publicly available at about the same time as the Data Link study, the Canadian data has not been reviewed or cited in some of the earlier mentioned technical articles dealing with issues of automotive seat strength in rear impacts. As such, one of the objectives of the current paper is to present the Canadian data, along with the previously unpublished data relating to the 23 real-world cases examined by the authors, so as to provide a more complete data base for other automotive engineers and researchers interested in better understanding the hazards and/or benefits associated with each of the two basic schools of thought relating to seat design for rear-impact occupant protection.

There are several potential hazards suggested by the opponents of each of the two basic approaches suggested for rear-impact occupant protection. With respect to collapsing seat structures (which seems to be the "norm" for most current automotive systems), opponents suggest at least six classes of potentially hazardous situations which can occur when a seat back collapses in an uncontrolled manner and these include: (1) loss of vehicle control by a driver when the seat back collapses rearward in an uncontrolled manner during a rear impact; (2) reduced effectiveness of the restraint system when the collapsed seat back allows a front-seat occupant to rotate and slide rearward from under the lap belt during a rear impact, thus enabling potential injurious contact with rear seat objects and passengers; (3) ejection of occupants who have slid out from beneath their lap and shoulder harness system when the seat back easily collapses rearward in an uncontrolled manner from rear impact and allows the passenger to be tossed around unconstrained during the subsequent motions of the vehicle which could experience other impacts, and/or roll-over after the initial impact, since the driver has usually lost control of the vehicle due to the rearward collapse of his or her body; (4) injury to rear-seat passengers who are likely to be struck by the violent rearward motion of the front seat occupant collapsing into the rear seat passenger area where the rear seats do not collapse rearward in a rear impact; (5) reduction or loss of egress capabilities of rear-seat passengers whose bodies are likely to be trapped under the plastically deformed and collapsed front seat backs of occupied seats during rear impact (This situation is especially dangerous in the event of post-crash fires); and (6) injury to fully restrained front-seat passengers during a frontal impact when the seat back easily collapses from the rear loading of a lap belted or unrestrained rear-seat passenger (or heavy object) which can greatly enhance the loading on the thorax, spine, and abdomen of the restrained but compressed front-seat passenger.

With regard to non-collapsing seat structures, opponents suggest at least four classes of potentially hazardous situations and these include: (1) severe hyperextension neck injury to out-of-position occupants (i.e., someone leaning around the edge of the stronger seat back with their head and neck away from the headrest); (2) ramping of unbelted occupants up the seat back and into the roof structure with the potential for injurious compressive neck loads; (3) rebound and possible ejection of unbelted occupants who elastically load-up the stronger seat back structure and then may rebound forward into the windshield and dashboard area; and (4) injury to unrestrained or "lap belted" only rear-seat passengers who, in the event of a frontal impact, can move forward violently into the rear of the stronger non-collapsing seat structure in front.

To be sure, all of the above potentially hazardous situations can possibly occur and, as such, they must be considered in the final analysis as to which seat design approach is best for providing optimum protection to occupants subjected to rear impact, as well as frontal. Thus, another objective of this paper is to address the above-identified potential hazards through the use of the more recently available real-world data, and car-to-car tests with instrumented surrogates, so as to provide additional insight into the weakness or strength of each approach. Historically, much data has already been presented on the merits of stronger seat systems by researchers such as Severy [Severy, 1958; Severy, 1967] and more recently on the merits of collapsing-seat structures by researchers at Collision Safety Engineering [Strother, 1987]. In the following sections, a brief overview of some historically relevant aspects of the seat strength issue is presented along with some data on human tolerance to longitudinal loadings.

SEATS, RESTRAINTS AND WHOLE BODY HUMAN TOLERANCE

Investigations reported by Colonial John P. Stapp [Stapp, 1955] indicate that for spineward (chest-to-back direction) loadings, such as those which may occur in frontal impact, the whole body human tolerance limit is approximately 45 G's for a time duration of about 100 milliseconds, with the body fully restrained in a 7.6 centimeter-wide shoulder harness, lapbelt with thigh straps, and a chest belt. These tolerance limits decrease with longer time durations and may be increased with time durations much shorter than 100 milliseconds.

With respect to rear impact or sternumward (back to sternum direction) loading, it can be expected that the full length overall body support of a non-yielding seat back and headrest should offer an even greater degree of restraint than that of the localized harness system used in the frontal impact by Stapp. In fact, the maximum recorded human tolerance limit for sternumward loading, without permanent injury, in a non-yielding full-length seat, was measured as 83 G's with the time duration of 0.04 seconds and a load on-set rate of 3800 G's per second [Beeding and Mosely, 1960]. Although no permanent injury was suffered by the volunteer in the above test, the subject did experience shock and required on-the-scene medical treatment, thus suggesting that the human tolerance limit for sternumward loading is somewhere between the 83 G and 45 G level. The research by Carr [Carr, 1975] presents an excellent data summary of rear-impact human tolerance and lists data source references.

For the most part, the above G-levels are well above the vehicle deceleration levels experienced in most frontal and rear barrier automotive collisions and suggests that if the head, neck and upper torso are fully supported by a strong seat back and headrest, the occupant should be able to survive moderate rear impacts without experiencing serious injury. The early research by Severy and others, dating back into the 1950 time frame, seemed to confirm the above through investigation of the effects of production seats versus stronger seats and headrests as a potential means for reducing harmful loadings and motions to rear-impacted vehicle occupants. A review of some of this early work was presented in the 1987 paper of Strother and James [Strother, 1987]. A more complete review and update of the research dealing with the issues of seat strength is provided in the Shaw critique of the Strother article [Shaw, 1990].

Briefly summarized, in 1967 as a result of the research conducted with car-to-car crash tests, and the testing performed on the Liberty Mutual Safety car, Severy recommended that seats be designed to withstand 30 G loadings when loaded by an occupant during rear impact [Severy, 1967]. In 1968, as a result of his research, Severy recommended torque resisting levels of 1808 N-m (16,000 inch-pounds) to 3728 N-m (33,000 inch-pounds) about the "H" point with a seat back height of 72 cm. (28 inches) [Severy, 1968]. In 1969, Severy recommended that the seat back should also sustain a torque of 11,298 N-m (100,000 inch-pounds) in the rearward direction without exceeding a 10° deflection in that direction [Severy, 1969]. In contrast to the above, the Federal Motor Vehicle Safety Standard (FMVSS) 207 for seat back strength and torque requirements, adopted in 1971, is only 373 N-m (3,300 inch-pounds).

Numerous other researchers made recommendations for stronger seats, less yielding seats, and dynamic testing during the years following the adoption of the FMVSS 207 requirement but as yet the requirement has not changed from the 373 N-m level.

In 1974, Nash filed a petition with the National Highway Traffic Safety Administration (NHTSA) to include passive occupant crash protection in impacts from the rear of the vehicle [Nash, 1974]. This petition recommended amendments to FMVSS 208 (dynamic frontal impact) and 207 that would have mandated dynamic rear-impact tests compatible with the test requirements of FMVSS 301-75 (vehicle fuel systems dynamic test). These recommended tests were to be conducted with anthropomorphic test devices at each designated seating position. Recommended performance criteria included: ". . . Rearward flexion of the neck shall not rotate rearward through an angle of more than 45 degrees . . . . No part of the seats or head restraints shall become disengaged from their mountings or attachments nor shall any part of the seat or head restraint be distorted so that the anthropomorphic test devices would leave their designated seating positions or have contact with other than laterally adjacent test devices."

During this same time period of the early to mid-1970's, several manufacturers applied for and received patents dealing with methods for making seats stronger and less yielding. For instance, the Ford Motor Company received a patent in 1973 for a "Safety Seat with a Safety Belt, in Particular for Motor Vehicles" [Giese, 1973]. Also, in 1974, Muncharu Urai of Japan filed for and received a patent for a "Seat Mounting Device for Vehicle" which attached a portion of the seat back to the roof of the vehicle for the purpose of "increasing the seat's holding force, to alleviate the shock imparted to the human body in the event of a collision accident" [Urai, 1975]. Figure 1, shown below, illustrates the patent drawing for the Ford Safety Seat with a Safety Belt. Ford also applied for and received a patent in 1973 for an "Energy Absorbing Seat Back" [Glance, 1973]. In this patent, the upper portion of the seat back was designed to have a predetermined torsional resistance, with a controlled rate, to thereby control the deceleration of a rear occupant impacting the front seat during a frontal collision.

In the 1970 time frame, there was also considerable on-going American, European and Japanese automobile industry research which demonstrated through the U.S. Government Research Safety Vehicle (RSV) program and the Experimental Safety Vehicle (ESV) program that stronger, less yielding seats with energy absorbing foam pads could provide much improved occupant protection in all modes of impact, including the rear-impact direction (currently, several automotive racing organizations require non-collapsing seat systems).

Also, in 1974, the NHTSA published a proposed rulemaking to strengthen the seat strength standard (FMVSS 207) and the headrest standard (FMVSS 202) by combining the two requirements into a single rule, and then imposing dynamic crash test requirements on the overall "rear impact restraint system" that would incorporate these components [Federal Register, 1974]. These requirements would have been similar to those in FMVSS 301, which sets test criteria to determine fuel system integrity in rear-end crashes. For various reasons, however, in April 1979, NHTSA terminated the 1974 rulemaking and replaced it with a regulatory plan for overall "significant upgrading" of occupant protection in all directions, including rear, side, front and rollover, and including "new comprehensive standards ... developed in terms of injury levels that occur" in dynamic crashes in all four modes [NHTSA Five Year Plan, 1979]. Ultimately, the 1979 regulatory plan, which would have upgraded seat "restraint" performance in "crash exposures representative of the real world," was abandoned by the Reagan Administration in 1981.

In spite of the research of the 1960's and 1970's which suggested improved safety to occupants in stronger seat systems, there has been, with a few exceptions, rather sparse activity on the part of NHTSA and the industry as to research and development of safer seat systems. Two exceptions are the BMW 850 rigidized seat with integrated restraints [Habrel, 1989] and the Mercedes Benz 500 SL sports car with a rigidized seat and integrated restraint [Mercedes Benz, 1989]. The theoretical and experimental results presented by Habrel regarding the BMW 850 rigidized seat design demonstrates that the stronger seat systems allow for attachment of the belt shoulder harness restraints to the seat and seat back system with concomitant lower HIC, chest G loads, and shoulder belt loads than those likely to be incurred with current belt restraint configurations mounted to the vehicle structure.

The above paper by Habrel also points out that the stiffer seat frame with the seat-integrated belt system (SBS) offers "demonstrably lower loads on the occupants in the event of side collisions and increases the occupant protection effect in the event of a rear-end collision for those occupying the front seats, as well as those in the rear of the car." Habrel also notes that, "Since the SBS seat back deforms only slightly, driver and front passenger are held reliably in their seats, and there is no risk for the rear-seat passengers being trapped behind the front-seat backs; and the good belt wraparound effect of the SBS system -- improves protection in roll-over accidents." He also notes that, "The occupant is held in his seat more effectively, with the risk of contact injuries, particularly as a result of head contact with parts of the roof frame, being further reduced." The results presented in this paper suggest that this BMW seat system can withstand torque values as high as about 5,650 N-m (50,000 inch-pounds). Figure 2 illustrates the BMW 850 rigidized seat [IIHS Status Report, 1989] along side of the Cox Safety Seat tested by Severy in the late 1960 time period [Severy, 1967].

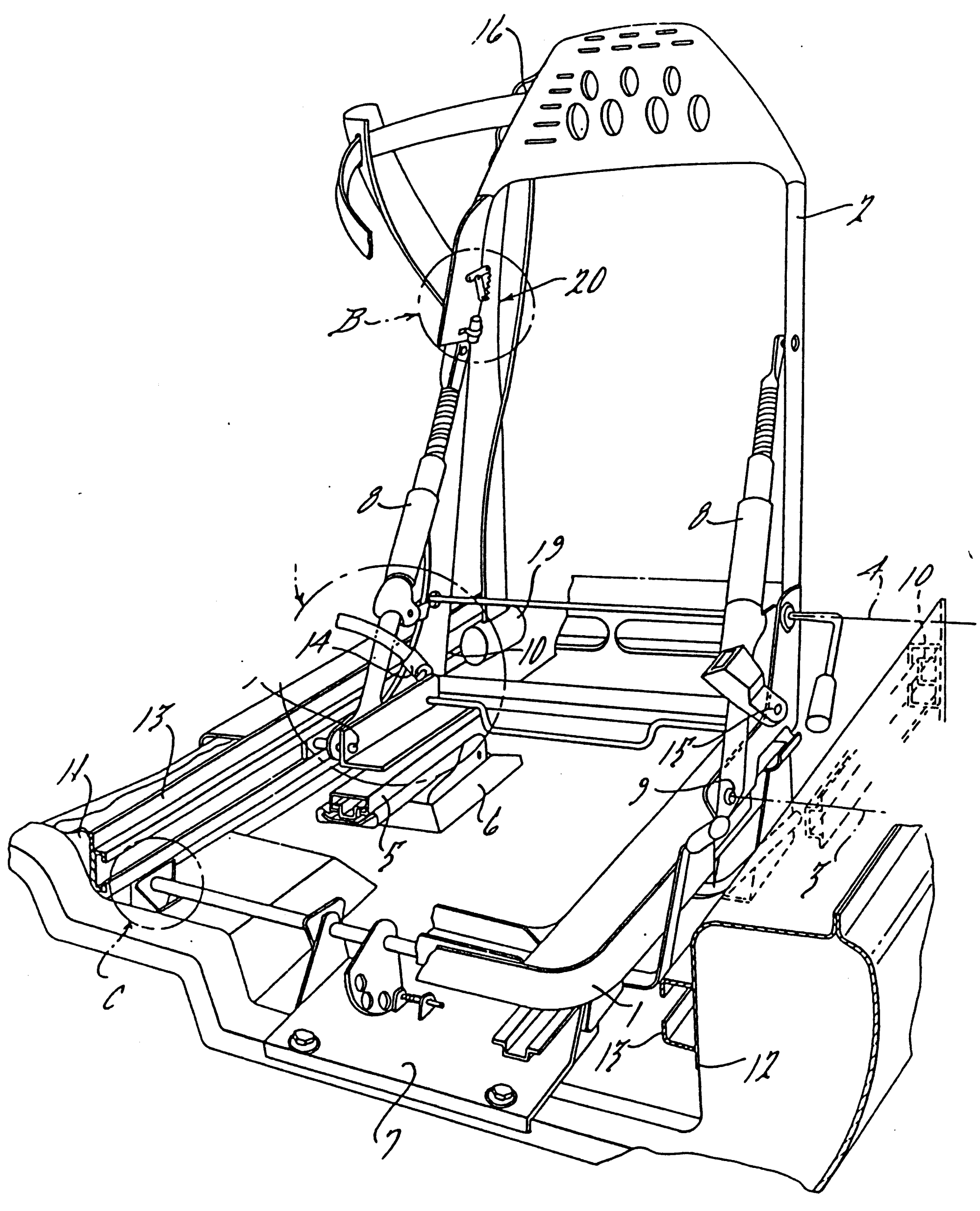
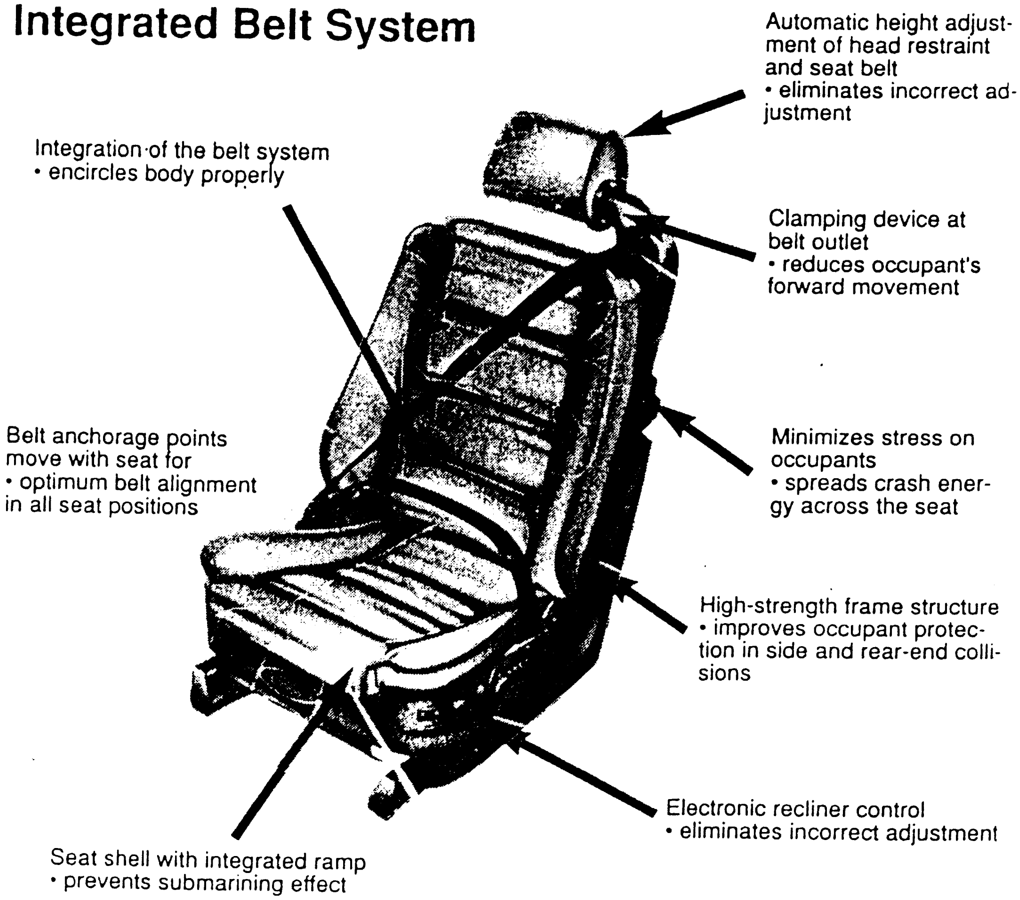
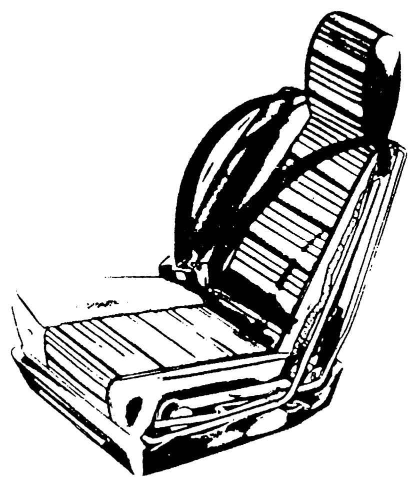


Figure 1 - Ford Safety Seat Patent Drawing [Giese, 1973]

Safety Features of the Seat Integrated Belt System





COX SAFETY SEAT (1963)

Figure 2 - BMW Seat with Seat Integrated Belt System [IIHS, 1989], [Strothers, 1987].

All in all, however, as reported by Severy and others, there has been little change in the load carrying capability of automotive seat systems between the 1940's and the late 1980's [Severy, 1976; Strother, 1987]. The above factors (i.e., early research indicating improved protection to occupants in stronger seats but relatively little change in seat strength since the 1940's, etc.) coupled with the authors' experiences gathered during investigation of injuries sustained by restrained occupants in real-world rear impacts, and the conflicting data resulting from studies relying on the NASS data base to establish effectiveness of restraints with collapsing seats in rear impacts, prompted the collaboration which led to the field accident analysis set forth in the following sections of this paper.

BELT EFFECTIVENESS BASED ON FIELD DATA

As noted previously, a Canadian field accident study of 23 accidents was conducted to look at accidents involving seat back collapse. Briefly summarized, the case studies represent a wide range of incidents which include failures of seat backs during normal driving or everyday use to failures during crash impact situations. A summary of each case describing the circumstances is contained in Appendix A. Table 1 summarizes key data from the Canadian study which identifies occupant positions, injury severity, occurrence of seat back failure, occurrence of ejection, restraint use, and contribution of seat back failure to the resultant injuries. It is interesting to note that the seat back failures take place in a wide variety of ways which include failures such as floorpan and seat structure distortion, failure of recliner mechanisms, seat track separation and seat frame distortion.

Forty-one occupants were involved in the 23 Canadian case studies and front seat back collapse occurred in at least one of the front occupant positions in each case. In 3 of the cases seat back collapse occurred to drivers during normal occupant loading (i.e., driver reaches for wallet while stopped in a line at a drive-through restaurant, etc.). Fortunately, in all 3 cases there was only one minor injury and all 3 drivers were able to regain control of their vehicles.

Of the remaining 20 cases, there were 28 front seat occupants who experienced some form of seat back collapse or failure, and of these, 20 occupants were identified as being positively restrained. However, nearly 50 percent of those 20 restrained occupants in collapsing seats (9 out of 20) were either partially or totally ejected through the rear area of the vehicle. In addition, over half of those ejected received fatal or major injuries. With respect to the restrained front seat occupants not ejected (11 out of 20) from collapsing front seats, only 18 percent (2 out of 11) received fatal injuries.

Seven of the 28 front seat occupants in collapsing seat systems were unrestrained, and in one other instance it was unknown if the restraint was used or not used. With respect to this group, 86 percent (6 out of 7) were partially or totally ejected with fatal injuries being received by 83% (5 of 6) of those ejected.
With respect to the general effect of seat back failure on passenger ejection, the Canadian summary notes that eleven of the 23 cases examined resulted in one or more of the passengers being ejected from the vehicle (4 occupants were partially ejected), and in 14 cases of the 23 "the occupant was forced out of the seat in a rearward direction because the seat was unable to withstand the force exerted on it by the occupant." The Canadian study concludes that, "In all cases the ejection would probably have been avoided if the seat back remained upright when loaded by the occupant during the ejection."

As a result of these rearward direction loadings of front seat occupants, there were also 3 cases (cases 9, 19 and 23) where the rear seat passenger seated behind the occupant in the collapsing front seat received injuries due to the failure of the seat back in front of them. In 2 of these 3 cases, the rear seat occupants were fatally injured. One of the fatalities occurred to a seven week old infant (case 9) where the headrest detached from the collapsing seat in front and struck the infant. This case appears to illustrate one of the hazards anticipated by Nash in his 1974 NHTSA petition which requested that "no part of the seats or headrests shall become disengaged from their mountings or attachments..." [Nash, 1974]. All total, 60 percent of the rear seat passengers (3 out of 5) were injured when seated behind a front seat passenger with a collapsing seat. All of these Canadian results suggest a much higher percentage of injuries due to rear contact than the 2.8 percent reported in the Data Link study for only unrestrained cases [Data Link, 1989].

Similar results are found from the 23 author researched field accidents summarized in Table 2 and Appendix B. Fifty-three occupants were involved in these 23 case studies and front seat back collapse occurred in at least one of the front occupant positions in each case. There were 36 occupants in collapsing front seats and of these, 19 were identified as being positively restrained. In this case, 58 percent of the 19 restrained occupants in collapsing seats (11 out of 19) were either partially or totally ejected from their restrained front seat positions, through or into the rear of the vehicle. Of those ejected 73 percent (8 out of 11) received moderate to fatal injuries. With respect to the restrained front seat occupants not ejected in this phase of the study (8 out of 19), only 12 percent (1 out of 8) received major injury.

As in the Canadian study, there were seven unrestrained occupants seated in collapsing front seat systems and 10 instances where it was unknown if the restraint was used or not used. With respect to this group of 7 unrestrained front seat occupants, 57 percent (4 out of 7) were partially ejected and, of these, 75 percent (3 out of 4) received major injury. In virtually all of the above cases of front seat occupants occupying collapsing seats it was determined that the collapse of the seat contributed to the injuries received. In addition, it was also found that in at least 3 of the author investigated cases (cases 7, 8, and 14) there was a loss

Table 1 - Summary of Canadian Field Accident Study

Case Vehicle	Occupant Position	Injury Severity	Seat Back Failure	Ejected	Restraint Used	Contribution to Injury
1	Driver	MINOR	YES	YES	YES	YES
	RF	MINOR	YES	NO	YES	YES
	LR	MINOR	YES	YES	NO	YES
2	Driver	MINOR	NO	NO	YES	N/A
	RF	MINOR	YES	PARTLY	YES	Unknown
3	Driver	NONE	NO	NO	YES	N/A
	RF	FATAL	YES	YES	NO	YES
4	Driver	MAJOR	YES	YES	YES	YES
	RF	MINOR	NO	NO	YES	N/A
5	Driver	MINOR	YES	NO	YES	Unknown
6	Driver	MINOR	YES	NO	YES	YES
	RR	Unknown	NO	YES	YES	N/A
7	Driver	MINOR	YES	NO	YES	YES
	RF	MINOR	YES	NO	YES	YES
8	Driver	FATAL	YES	YES	YES	YES
9	Driver	MINOR	YES	YES	NO	YES
	RF	MINOR	YES	NO	NO	Unknown
	LR	FATAL	NO	NO	YES	YES*
10	Driver	FATAL	YES	YES	NO	YES
11	Driver	MINOR	YES	YES	Unknown	YES
12	Driver	MAJOR	YES	YES	YES	YES
	RF	FATAL	YES	YES	NO	Unknown
	RF	MINOR	YES	YES	NO	Unknown
13	Driver	FATAL	YES	YES	YES	YES
	RF	MINOR	NO	NO	YES	N/A
14**	Driver	NONE	YES	NO	Unknown	N/A
	LR	NONE	NO	NO	Unknown	N/A
15	Driver	MINOR	YES	NO	YES	YES
16	Driver	MINOR	YES	PARTLY	YES	YES
17	Driver	MINOR	YES	NO	YES	YES
18**	Driver	Unknown	YES	NO	Unknown	Unknown
19	Driver	MINOR	YES	NO	YES	YES
	RF	MINOR	YES	NO	YES	YES
	RR	MINOR	NO	NO	YES	YES*
20**	Driver	MINOR	YES	NO	Unknown	YES
21	Driver	FATAL	YES	YES	NO	YES
22	Driver	FATAL	PARTLY	YES	YES	YES
	RF	FATAL	YES	NO	YES	Unknown
23	Driver	FATAL	PARTLY	YES	YES	YES
	RF	FATAL	YES	NO	YES	Unknown
	RR	FATAL	NO	NO	NO	YES*

* The passenger was injured due to the failure of a seatback in front of them.

** Vehicle stationary or moving when failure of recliner mechanism occurred without acceleration loads.

Table 2 - Summary of Author Researched Field Accident Study

Case Vehicle	Occupant Position	Injury Severity	Seat Back Failure	Ejected	Restraint Used	Contribution to Injury	Loss of Control
1	DR (1)	MINOR	NO	NO	UNKNOWN	NO	NO
	RF (3)	MAJOR	YES	PARTIAL	UNKNOWN	YES	
2	DR (1)	MAJOR	YES	NO	NO	POSSIBLE	NO
	RF (3)	MAJOR	YES	NO	NO	POSSIBLE	
	REAR (?)	MAJOR	UNKNOWN	NO	NO	POSSIBLE	
	REAR (?)	MAJOR	UNKNOWN	NO	NO	POSSIBLE	
3	DR (1)	MINOR	YES	PARTIAL	YES	YES	NO
	RF (3)	MINOR	YES	PARTIAL	YES	YES	
	LR (4)	MAJOR	NO	NO	YES	YES	
	RR (6)	MINOR	NO	NO	YES	YES	
4	DR (1)	MODERATE	YES	YES	YES	POSSIBLE	POSSIBLE
5	DR (1)	MINOR	YES	NO	YES	NO	NO
	RF (3)	MINOR	YES	NO	YES	NO	
	RR (6)	MAJOR	NO	NO	YES	NO	
6	DR (1)	MAJOR	PARTIAL	NO	YES	POSSIBLE	NO
	RF (3)	MINOR	PARTIAL	NO	YES	POSSIBLE	
	RR (6)	MINOR	NO	NO	YES	NO	
7	DR (1)	MAJOR	YES	PARTIAL	YES	YES	YES
8	DR (1)	MAJOR	YES	PARTIAL	UNKNOWN	YES	YES
	RF (3)	MINOR	NO	NO	UNKNOWN	NO	
9	DR (1)	MINOR	YES	NO	UNKNOWN	UNKNOWN	NO
	LR (4)	FATAL	NO	NO	UNKNOWN	YES	
10	DR (1)	MAJOR	YES	NO	UNKNOWN	YES	NO
11	DR (1)	FATAL	YES	YES	YES	YES	NO
	RF (3)	MINOR	YES	PARTIAL	YES	POSSIBLY	
12	DR (1)	MAJOR	YES	NO	YES	YES	NO
	RF (3)	MINOR	YES	NO	YES	UNKNOWN	
13	DR (1)	MAJOR	YES	PARTIAL	YES	YES	NO
	RF (3)	FATAL	YES	PARTIAL	YES	YES	
	LR (4)	MINOR	YES	NO	YES	YES	
	REAR (7)	NONE	NO	NO	UNKNOWN	N/A	
14	DR (1)	FATAL	YES	NO	Unknown	YES	YES
	RF (3)	FATAL	YES	NO	Unknown	YES	
	LR (4)	FATAL	NO	NO	Unknown	YES	
	CR (5)	FATAL	NO	NO	Unknown	YES	
	RR (6)	FATAL	NO	NO	Unknown	YES	
15	RF (3)	MAJOR	YES	PARTIAL	YES	YES	NO
	DR (1)	MINOR	NO	NO	YES	YES	
16	DR (1)	MAJOR	YES	NO	NO	YES	NO
17	DR (1)	MAJOR	YES	PARTIAL	NO	YES	NO
	RF (3)	MINOR	YES	PARTIAL	NO	YES	
18	DR (1)	MAJOR	YES	PARTIAL	NO	YES	NO
19	DR (1)	MAJOR	YES	NO	Unknown	YES	NO
	RF (3)	FATAL	YES	NO	Unknown	YES	
	LR (4)	MODERATE	NO	NO	Unknown	YES	
	RR (6)	MINOR	NO	NO	Unknown	YES	
20	DR (1)	MINOR	PARTIAL	NO	YES	Unknown	NO
	RF (3)	MAJOR	YES	YES	YES	YES	
21	DR (1)	MINOR	PARTIAL	NO	YES	Unknown	NO
	RF (3)	MAJOR	YES	YES	YES	YES	
22	DR (1)	MAJOR	YES	PARTIAL	NO	YES	NO
23	DR (1)	MINOR	YES	NO	Unknown	YES	NO
	RF (3)	MAJOR	YES	YES	Unknown	YES	

of vehicle control with subsequent injury resulting from the collapse of the driver's seat. Tables 3 and 4 summarize the combined results comparing ejection data for restrained and unrestrained occupants seated in collapsing front seat systems.

Overall, the above results relating to ejection show that there is a lower incidence of ejection if the occupants of a collapsing seat system are restrained. Thus, as was indicated by the Data Link study [Data Link, 1989], there is a certain amount of effectiveness or benefit from wearing a restraint during seat back collapse. However, as also shown by the 5 cases of front seat occupants in non-collapsing seats of this study (cases 3 and 13 of Table 1, and cases 1, 8 and 19 of Table 2) there was a 100 percent retention rate of the occupants - independent of restraint use. This data indicates that, although restraints may have some effect in the case of a collapsing seat system, the non-collapsing seat system clearly provides a much more effective restraint than that of the belts with collapsing seats. The above conclusion seems to be corroborated in the Data Link study when one observes the results for harm versus occupant belt use rates comparing car rear end impact to all car impacts, as shown in Table A-27 of the Data Link study [Data Link, 1989]. This data is summarized below in Table 5.

Table 3 - Ejection Data for Belted Front Seat Occupants *

	Canadian Data	Author Data	Total
Ejected	9	11	20
Not Ejected	11	8	19
Total	20	19	39

*Occupants in collapsing front seats

Table 4 - Ejection Data for Unbelted Front Seat Occupants *

	Canadian Data	Author Data	Total
Ejected	6	4	10
Not Ejected	1	3	4
Total	7	7	14

*Occupants in collapsing front seats

Table 5 - Harm Versus Belt Use [Data Link, 1989]

	Car Rear End Impacts			All Car Impacts		
Occ. Belt Use	Distribution of Harm	Distribution of Occupants	Harm per Occupant	Distribution of Harm	Distribution of Occupants	Harm per Occupant
No	73.4	70.1	1.0	88.6	71.6	1.2
Yes	22.6	29.9	0.9	11.4	28.4	0.4
All	100.0	100.0	1.0	100.0	100.0	1.0

The above data shows that there is only about a 10 percent reduction in harm for rear end impacts when belts are used versus almost 70 percent reduction in harm for all car impacts in crash modes such as front, side and rear.

Further evidence of the safety benefits associated with non-collapsing seats versus collapsing seats is shown by the four cases of this study in which there were two front seat occupants in a vehicle where one seat back failed and the other did not fail (cases 3, 4 and 13 of Table 1, and case 15 of Table 2). In all 4 cases, the occupant in the failed seat suffered major or fatal injuries, even though 3 of the 4 seriously injured persons in the collapsing seats were belted, while those occupants in the non-collapsing seats received only minor or no injuries at all. While the evidence seems to clearly support the benefits of non-collapsing seats, there was one case (case 4 of Table 2) in which a collapsing seat appeared to save the driver's life when the intrusion of a tractor trailer vehicle would most likely have caused fatal injuries if the driver had remained upright in a non-collapsing seat. Instead, the driver received survivable injuries.

As in the Canadian study, the author investigated cases also show a much higher incidence of injuries associated with contact in the rear of the vehicle than the 2.8 percent figure reported in Table 13 of the Data Link study [Data Link, 1989].

One possible reason for some of the differences in the findings of the Data Link study and the current studies reported in this paper may be related to the data collection methods used to obtain NASS data which served as the basis for the Data Link analysis. In particular, the NASS data does not specifically seek out, or attempt to evaluate quantitatively, the often subtle damage in the rear of vehicles, which may be masked beneath the soft foam of seat back cushions and provide evidence of injuries due to contact of front seat occupants deposited in the rear of the vehicle by the collapsing front seats.

An example of how injury contact regions may be masked and need quantitative evaluation, often times through testing of exemplar structures, is given by the first case study in the following section.

SELECTED CASE STUDIES OF REAR IMPACT

Two rear impact accident cases are reviewed in this section of the paper, with focus on occupant kinematics, kinetics, resulting injuries, locations of impact and the amount of energy absorbed by the collapsing seats during the collision.

Case Study I - A comparison of the effects between collapsing and non-collapsing seats in rear impact is illustrated in this first case study. In addition, this case also demonstrates the value of quantitative testing to establish if certain subtle structural damage patterns, often hidden beneath soft foam coverings of rear cushions, are likely to be caused by body contact with forces sufficient to cause the injuries received.

For this case, a 1985 Ford Tempo 4 door sedan was slowing when it was struck in the rear by a tractor trailer vehicle. The target vehicle was being driven by a small adult female (approximately 5th percentile) and the right front passenger seat was occupied by an average adult male (approximately 50 percentile). Both subjects of the target vehicle were belted (3 point lap and shoulder belt) and were slowing their vehicle because a vehicle in front was in the process of making a left-hand turn. Impact between the tractor trailer vehicle and the target vehicle was essentially collinear. After the initial rear end impact, the target vehicle was shoved forward into the left turning vehicle which produced a small amount of damage to each vehicle.

Analysis of the damage to the vehicles indicated a change in velocity of about 30 km/hr (18 mph) to the target vehicle during the rear impact. The driver seat exhibited little damage but the right front passenger seat was broken loose from the seat tracks and deformed rearward. The driver received no serous injuries. The right front passenger; however, was found in the collapsed seat with a compressive neck load.

A survey of NHTSA crash test data revealed a FMVSS 301 rearend crash test on an essentially identical vehicle which by chance also had a 5th percentile female surrogate and 50 percentile male surrogate seated in the front seats, although in opposite positions to those of the actual occupants involved in the crash [Garn, 1983].

The rear end crush of both the accident target vehicle and the NHTSA test vehicle, as illustrated by figure 3, was almost identical. The final rest positions of the surrogates in the test vehicle were essentially the same as the rest positions of the actual occupants, with the heavier subject laying back in the collapsed seat and the lighter subject seated almost upright. Only the smaller (lighter) surrogate was apparently instrumented in the NHTSA test and the recorded loads indicated low non-injury producing acceleration levels and head injury criteria (HIC) as was the case with the small driver of the actual case vehicle. The test report also noted, however, that even though the larger (heavier) surrogate produced significantly more residual deformation in the driver seat of this test, there was no apparent contact of the dummy with the vehicle interior based upon post-test visual inspection.

Similarly, at first glance, the interior of the accident vehicle also showed no apparent contact damage. In light of the compressive load to the neck of the heavier occupant in the collapsed seat, however, it was clear that some action or reaction source must have provided a contact surface with sufficient resistance to allow the neck to be loaded compressively by the torso as the seat collapsed rearward. Removal of the rear seat back cushion revealed what appeared to be a small embossment below the forward edge of the package tray sheet metal structure just behind the head of the seriously injured right front passenger.

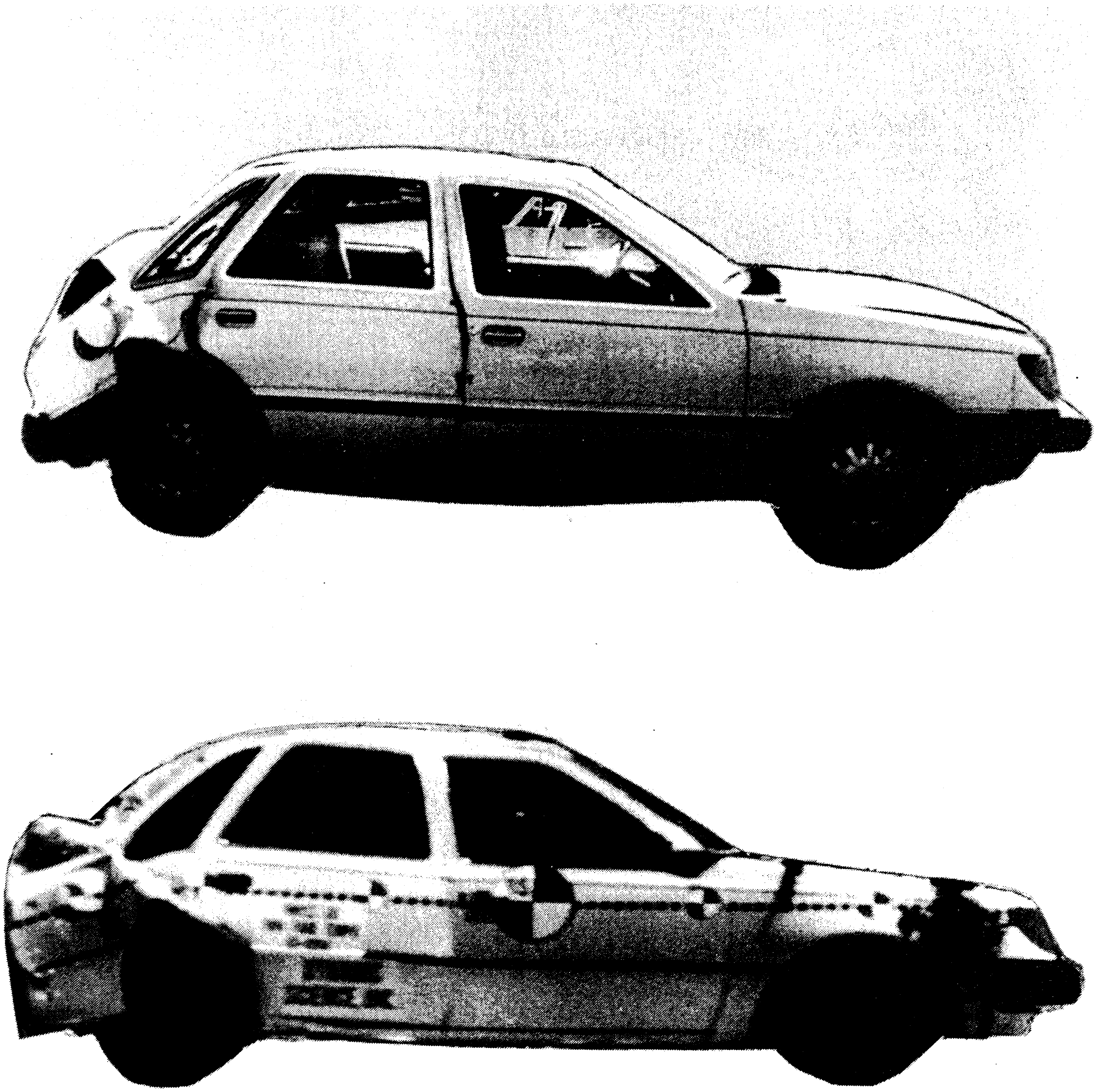


Figure 3 - Accident and NHTSA Test Vehicle Damage

In order to determine if the embossment found was caused by a force of the magnitude and direction necessary to be consistent with loads generated by someone sliding rearward from beneath the restraint when the seat back collapses, an exemplar rear clip was purchased and a simulated head push test was conducted. Figure 4 illustrates the structural test set-up to duplicate subtle damage and establish load levels on an exemplar clip. The results of the test confirmed that the load levels necessary to duplicate the damage would also have been large enough to cause the serious neck injury received by the heavier front passenger.

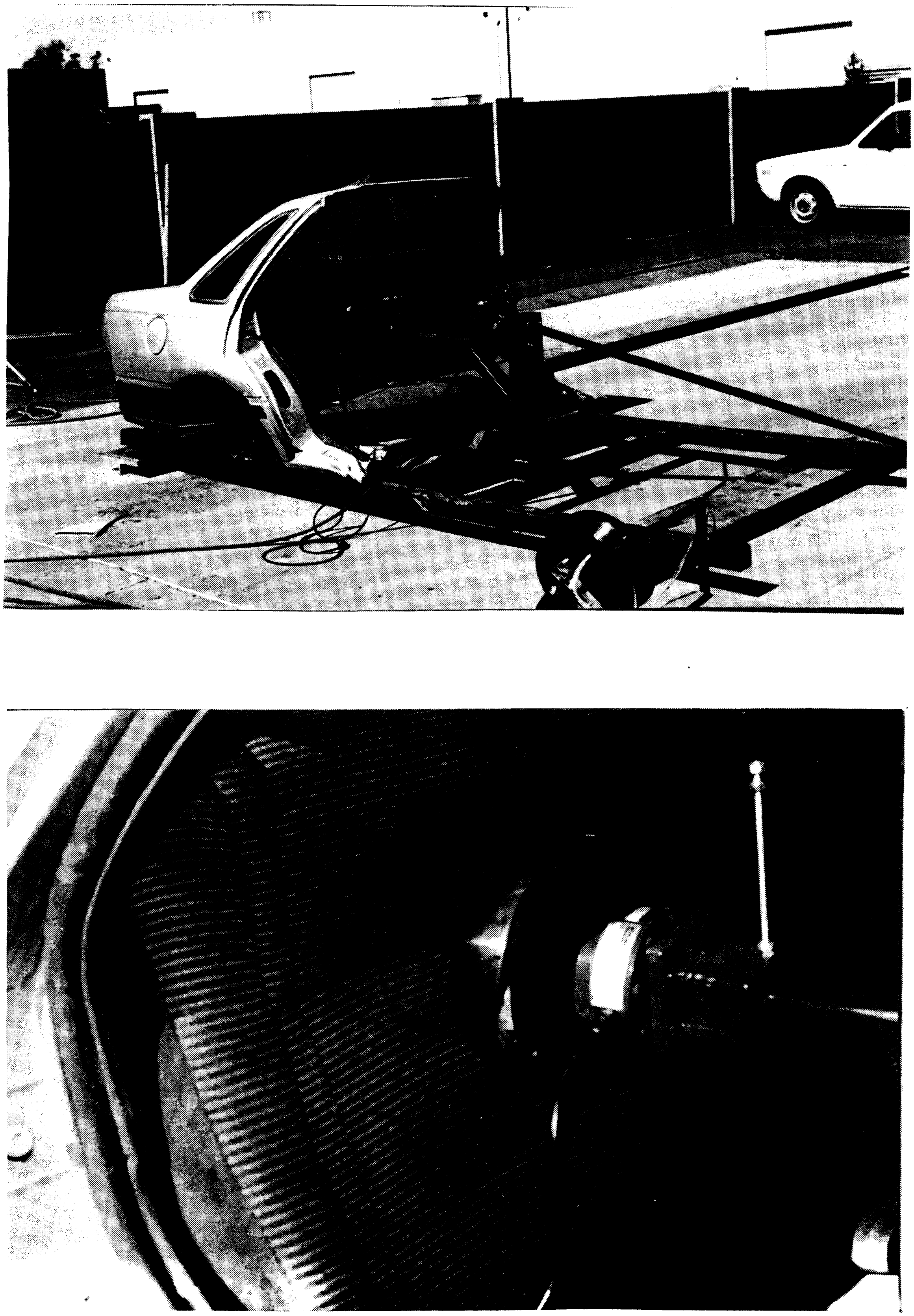


Figure 4 - Head Push Test on Exemplar Rear Clip

With respect to locations of the occupants after the two collisions (i.e., rear impact and then front), it should be recalled that the rear impacted vehicle was shoved forward into the left-turning vehicle in front of the target vehicle, and, this frontal impact, while of a much lower severity than the rear impact, was of sufficient deceleration as to allow the reclined occupant (right front passenger) to slide forward into a position that suggested no contact with the rear of the vehicle. In fact, the driver (lighter occupant) did comment about being thrown forward during this second impact. In contrast to the occupant of the actual accident vehicle, the dummies of the NHTSA test did not apparently move as far rearward which may be due in part to the molded seated pelvic area that is obviously not as flexible as an actual human subject.

Thus, the kinematics of the heavier passenger in the collapsing seat were such that as the seat reclined the passenger slid rearward, about 50 centimeters, struck his head below the top edge of the package tray, received compressive loads to the neck as the lower torso inertia continued to load into the head and neck, and rebounded back forward during the less severe second (frontal) impact.

With regard to the energy absorbing capability of the collapsing seats, tests were run on exemplar seats to duplicate the damage found on the actual seat and determine the approximate amount of energy absorbing benefit received by the restrained passenger with the compressive neck injury. Figure 5 shown below illustrates the torque versus seat back angle curve generated for an exemplar seat which had essentially identical damage to the seat occupied by the seriously injured occupant. The test indicates that the seat absorbed approximately 300 N-m of energy, while the energy generated by moving the 50 percentile occupant's upper body at a velocity of about 30 km/hr would be approximately 1420 N-m. Thus, the collapsing seat would absorb some energy but not enough to prevent the body from continuing rearward with enough energy to forcefully impact into the rear structure of the vehicle.

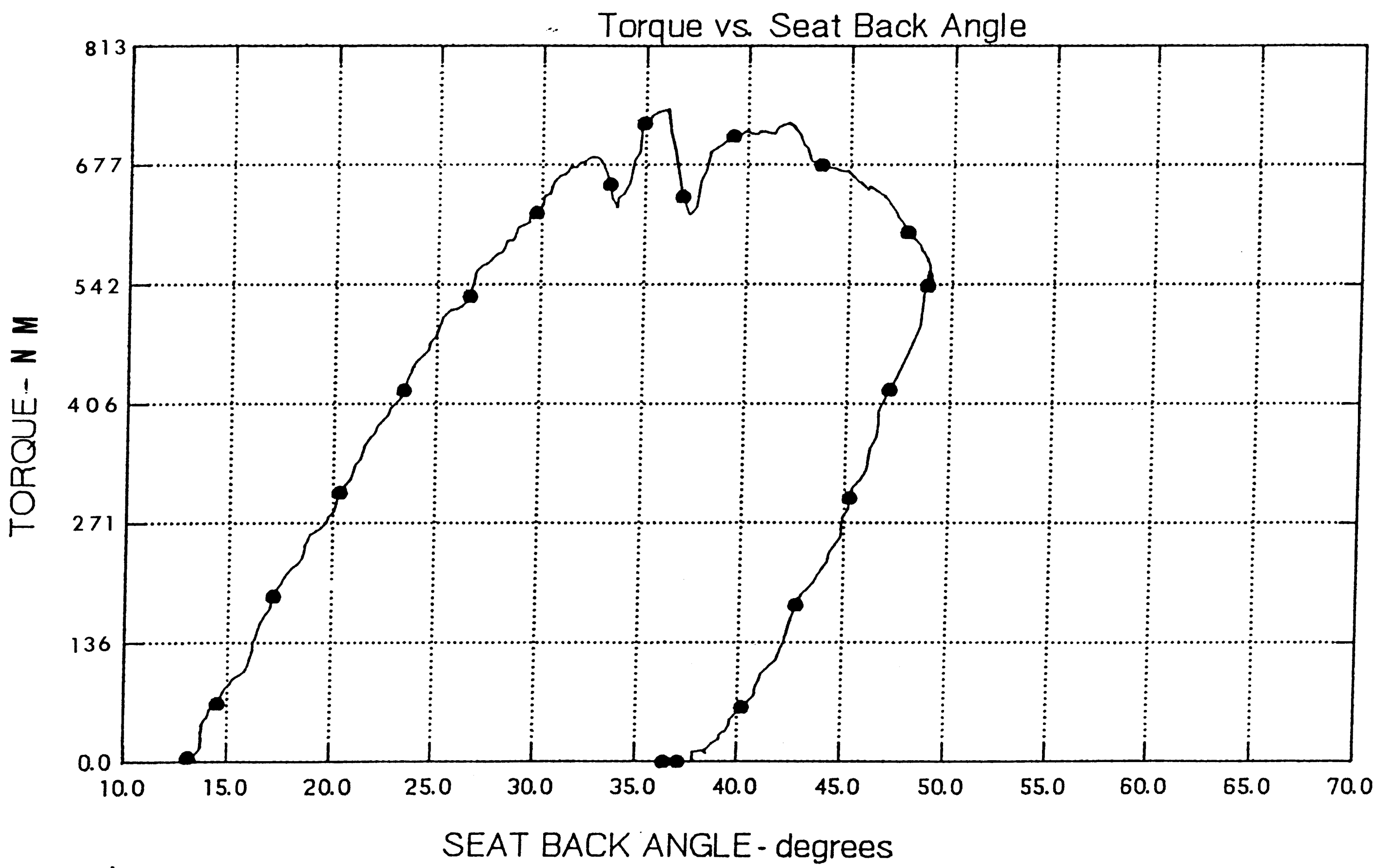


Figure 5 - Torque Versus Deformation Angle for Exemplar Seat of Case I

Case Study II - This case involves a rear impact to a 1977 Toyota Corolla, 2-door sedan struck in the left rear by a 1979 full size van. The target vehicle was occupied by 4 adult male passengers, two in the front and two in the rear. It was unknown if the passengers were restrained or not. The impact caused severe crushing of the left rear area and the calculated change in velocity of the target vehicle (Toyota) was about 44 Km/hr (26.4 mph). Figure 6 illustrates the severe crush on the left rear side of the vehicle.

The seat backs of the target vehicle front bucket seats were mounted asymmetrically to the seat bottom structure by means of a single outboard recliner mechanism that transmitted loads between the seat back and the seat bottom. The inboard connection was a non-torque transmitting hinge pin.

Figure 6 - Damage to Case II Vehicle

Due to the asymmetric load coupling of the two seat components, a greater amount of inboard twisting and bending takes place on the free hinge side of the seat back as compared to the stronger outboard side with the torque load carrying mechanism. This inboard twisting makes it easier for an occupant to deflect rearward and towards the center of the vehicle.

In this particular case the principal direction of force was at about a 15 degree angle from the left rear toward the right front and as a result the right front passenger was deflected not only rearward due to the collapsing seat but also somewhat toward the rear center of the vehicle between the two rear passengers. The 27-year-old right front passenger received massive head injury from impact with a hard surface and died of cardiac arrest secondary to the massive head injury. Figure 7 shows the area of protruding or inward buckle on the rear package tray which lines up with the predicted occupant path of the head of the right front passenger.

The driver of the vehicle moved rearward and inboard toward the load carrying recliner side of his seat back and as such there was not as much deformation noted in his seat. The driver sustained a left temporal head injury and simple fracture of some ribs. The passenger behind the driver was sandwiched between the vehicle crush and the collapsing seat of the driver. This passenger received moderate injuries which included simple fracture of the left clavicle and lower spine injury. The right rear passenger had internal injuries to the abdomen and also had lower spine injury. It is interesting to note that although there were no headrests on the rear seat, neither rear passenger received any neck injury as a result of the accident. The injuries to the rear passengers were attributed to the combined crush of the front passengers in collapsing seats and the rear crush of the vehicle. The injuries to both front passengers were attributed to the deformation of seat backs.

Figure 7 - Interior Impact Region of Case II Vehicle

As in the previous case study, tests on exemplar seats were run to establish the approximate amounts of energy absorption afforded to the front seat passengers. Figure 8 illustrates the torque versus seat back angle data for the passenger seat test. The test data indicates that the passenger seat absorbed about 340 N-m of energy; however, as in the previous case this level was much lower than the kinetic energy associated with the motion of the right front passenger.

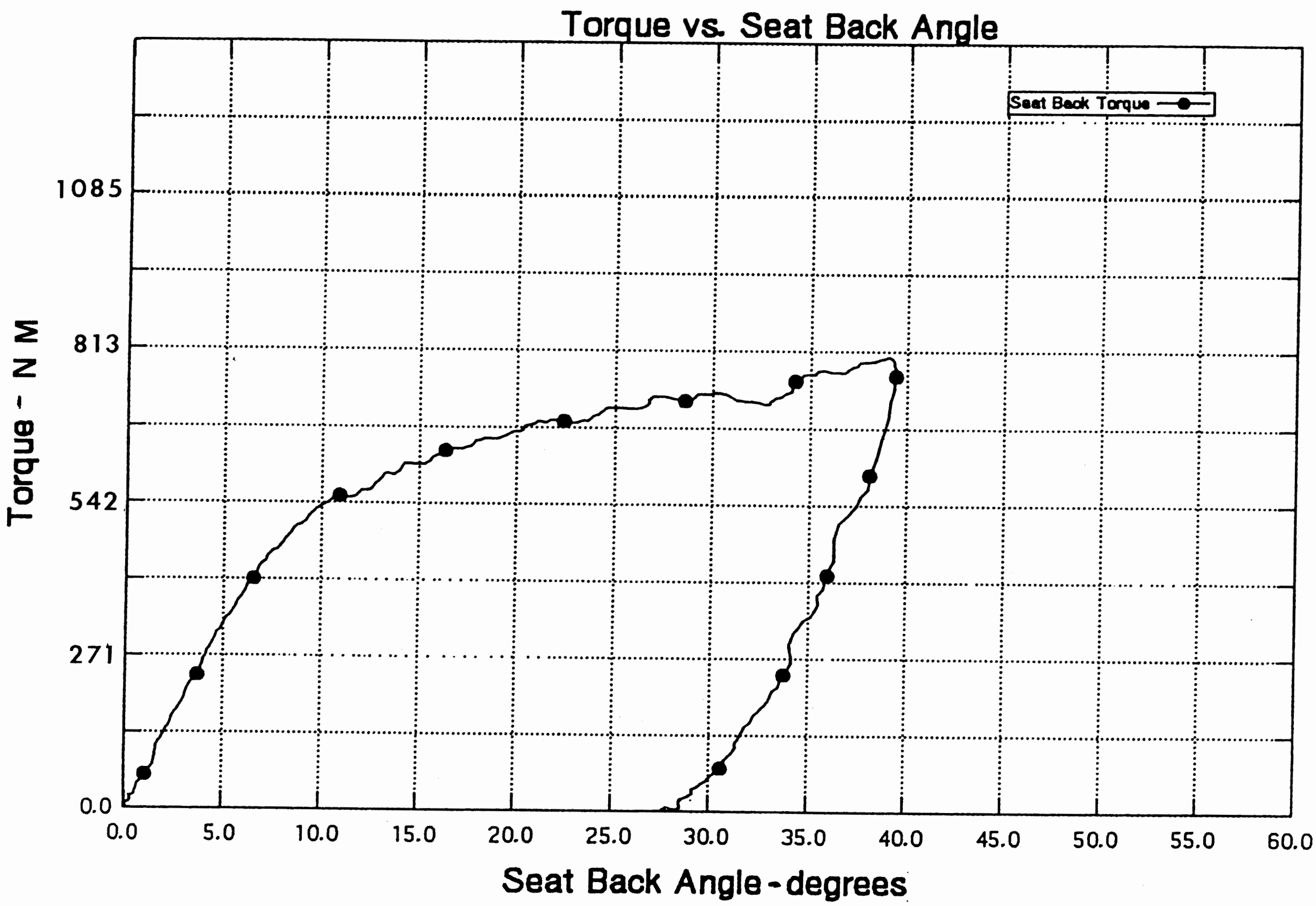


Figure 8 - Torque Versus Deformation Angle For Exemplar Seat of Case II

REAR IMPACT CAR TO CAR CRASH TEST DATA

Additional information on occupant response relative to seat back failure is contained in some NHTSA New Car Assessment Program (NCAP) rear impact tests. The 1979 NCAP tests contained instrumented 50 percentile male dummies. 1980 and later, NCAP tests included non-instrumented 50 percentile male dummies in the front seats, but the dummies were painted to identify head strike zones within the vehicle. Color photographs were taken of these tests to document the head strike zones. The head strike zones indicated that "ramping" of occupants did not occur until the seat backs had reclined fully. No clear documented head strikes on inner roof panels were noted in any tests conducted at Dynamic Science, Inc. during the 1979 or 1980 NCAP program.

As part of the Fuel System Integrity Defect Investigation of Ford Pintos and Chevrolet Vegas, NHTSA also commissioned detailed tests of seat and hatchback crashworthiness in rear barrier and rear vehicle-to-vehicle impact tests [Pirtle, 1978].

At least 19 crash tests in this program were conducted in 1978 and 1979, with instrumented dummies, seats, and vehicle structures. Ground-based and on-board high speed cameras were used to document dummy kinematics. In every test of Pintos and Vegas, permanent deflection of seat structures occurred. In most tests the dummies moved rearward and struck the rear deck or the instrumentation anchorages mounted aft of the driver seat. The only test where seat deflection did not occur was in a 60 Km/hr front-to-rear impact between two 1971 Chevrolet Impalas. Despite having a 50 percentile male driver and 50 percentile male passenger dummy in the front bench seat, no seat failure occurred. This test also resulted in the lowest head and chest injury levels recorded in the test program. The results of this test appear to refute the notion that non-deforming seat backs will result in more injuries.

Similar results were also obtained in a more recently conducted car to car crash test [Slattery, 1990] where the right front passenger dummy, an unrestrained 50 percentile adult male, was seated in a rigidly braced conventional seat, while the driver dummy, also an unrestrained 50 percentile adult male, was seated in the standard collapsing seat. During this test the stationary target vehicle, a 1259 Kg (2770 pound) sports car, was impacted in the right rear (behind the right front passenger seat location) by a 2456 Kg (5404 pound) large sedan traveling at approximately 90 Km/hr (53.5 mph). This impact resulted in severe damage to the vehicle in the area behind the right front passenger seat (non-collapsing) and a vehicle change in velocity of about 62 Km/hr (37 mph).

Film coverage of the event clearly showed that the unbelted passenger dummy in the non-collapsing seat did not ramp up the seat back nor did it violently rebound forward into the dash or windshield area, as is sometimes suggested by advocates of the collapsing seat theory. In addition, the recorded chest loads on the right front passenger in the non-collapsing seat were at about 30 G's and well below the injury thresholds established by human volunteers as discussed earlier in this paper. By contrast the driver dummy flipped violently rearward and buried its head in the shelf of the rear package tray with a peak force of about 225 G's and a pulse width sufficient to indicate potential head injury. As in the car to car crash test results reported by Pirtle [Pirtle, 1978], the Slattery test also refutes the notion that non-deforming or stronger, seat backs will result in more injuries.

The study reported by Pirtle also provided interesting information on the effects of seat deformities resulting from non-symmetric loading on the seats due to the use of a non-load carrying connection or hinge, on the inboard side of many seats.

Seats with no inboard locking seat back latch showed a consistent tendency to fail in a twisting manner, with driver seats twisting clockwise and passenger seats twisting counterclockwise when viewed from behind. This twisting failure mode allows the test dummies to move toward the midline of the vehicle, even during straight in-line rear impacts. This failure mode increases the likelihood of the front seat occupant's torso to move directly away from the shoulder harness. This movement also increases the likelihood of ejection or slippage from the restraint belt system, especially when a single ELR/sliding latch plate system is used. Once tension is relieved on the shoulder portion of this restraint belt, slack can be taken up by the lap portion of the belt. This excess belt slack can and does allow virtually unrestrained rearward motion within the vehicle.

The above study [Pirtle, 1978] also showed that excessive restraint belt slack was induced in all tests where seat back failure occurred. The only tests without significant dummy movement into the rear areas of the vehicle were the two 35 Km/hr rear impact tests that included the Impala to Impala Test (with the 50 and 95 percentile dummies in a bench seat), and the left rear 15 degree angled impact test. This last test shows the large difference in seat deflection when the occupant is moving toward the area of greatest seat back rigidity (i.e. the recliner on the outboard side) compared to the straight rearward or inboard vectors that twist easily due to the lack of torque load carrying capability of the hinge pin connection between the seat back and seat pan structures.

Finally, there are numerous FMVSS 301 rear impact tests and NHTSA defect studies [Pozzi, 1980], that also show the consistent tendency of front seat occupants to strike the rear seat back or rear deck area, even while restrained, in moderate rear collisions. The real world injuries that occur in similar accidents is consistent with these test results.

SUMMARY AND CONCLUSIONS

Among the many results obtained from this study of real world accidents, and associated experiments, it was found that a majority of restrained front seat occupants were either partially or totally ejected from the seat systems during rear impact, even at changes of velocity as low as 30Km/hr (18 mph) or less. These findings are consistent with those observed in the "real world" accident study recently conducted for Transport Canada.

It was also found that many front seat restrained occupants received serious paralyzing injuries in the rear area of the vehicle even though they were found in the front seats post-accident. This suggests that possible improvements in the NASS reporting and evaluation methods might be of value since recent studies using the above data sources show a much lower rate for rear area impact than that observed in this study.

In addition to the above, the results indicate that while collapsing seat structures absorb some amount of energy during impact they also appear to contribute to hazardous situations such as: loss of driver control; entrapment and delay of egress of rear seat passengers; injury to rear seat passengers located in non-collapsing seats; and, as mentioned previously partial and/or total ejection and injury of restrained front seat occupants.

Furthermore, instrumented test dummies in strengthened and collapsing seats suggests that some of the alleged hazards of stronger seats, such as ramping and rebound of unrestrained passengers, may not be a significant problem, even at relatively high velocity changes. As a result of the findings in this study, it is concluded that stronger, less-yielding and non-collapsing seats are more likely to provide improved safety benefits over seat systems which collapse at relatively low energy levels. It is not the intent of the authors to suggest, however, that energy absorption is undesirable in a motor vehicle seat system. Quite the contrary, energy absorption is an important component of crash safety design; but, as shown by the case studies of this paper, many current seat systems only provide a small fraction of the energy absorbing level needed to safely decelerate an occupant in a controlled fashion, even during the moderate impacts such as those discussed in the Case I study. Even in that case, the seat system would have required at least five times more energy absorbing capability to prevent the injurious rear compartment contact of the occupant. What this means is that the seat torque for that specific case would have to be increased from about 730 N-m (6,454 in.-pounds) to at least 3,650 N-m (32,205 in.-pounds) with limited rearward deflection. Also, additional energy absorbing passive occupant protection materials could be mounted beneath the soft comfort foam pads if the seat support structures were designed with increased load and torque capabilities.

Finally, it is noted that the field accident studies investigated by the authors of this paper were based upon forensic analysis and testing during the course of litigation related matters. In such matters there are two sides which spend considerable time, effort and resources to gather valuable quantitative data, such as structural tests, etc., which are ultimately used to determine the most likely cause of a particular system failure and/or injury. In many cases, this data has been made a matter of public record or could be obtained with proper confidentiality agreements. If at all possible, such data should be made available for objective and independent review by data base collection teams that could add the data to a central data base such as NASS, for use by all safety engineers.

The above recommendation would increase the current data base and provide more detailed quantitative data than that usually available to NASS. The initiative for establishing such a program should be taken by groups such as the National Transportation Safety Board (NTSB), NHTSA, and/or the Consumer Product Safety Commission (CPSC).

REFERENCES

[Beeding, 1960]
Beeding, E.L., Jr. and Mosely, J. D.: "Human Deceleration Test," AFMDC-TN-60-2, Holoman Air Force Base, New Mexico, 1960.

[Carr, 1975]
Carr, R. W.: "An Occupant Simulation Handbook," Contract No. N00014-71-C-0318, Dept. of the Navy, Dynamic Science Report No. 6910-75-123, 1975.

[Data Link, 1990]
"Current Issues of Occupant Protection in Car Rear Impacts," Prepared for the Office of Crashworthiness, Rulemaking, NHTSA, Data Link, Inc. Report, Wash. D.C., Feb. 1990, Docket 89-20-N01-021.

[Federal Register, 1974]
Federal Register, Tuesday, March 19, 1974, Volume 39, No. 54, p. 10268.

[Garn, 1983]
Garn, R.: "FMVSS 301 Standards Enforcement Testing of Fuel System Integrity - 1984 Ford Tempo, 4-Door Sedan" Dynamic Science Report No. 301-DYS-83-013, September, 1983.

[Giese, 1973]
Giese, R.; et al; Inventors of Patent No. 3,761,127, Granted to Ford Motor Company for "Safety Seat with a Safety Belt, In Particular for Motor Vehicles," September 25, 1973.

[Glance, 1973]
Glance, Patrick M.; Inventor of Patent No. 3,761,125, Granted to Ford Motor Company for "Energy Absorbing Seat Back," September 25, 1973.

[Habrel, 1989]
Habrel, J.; Ritzl, F.; and Eichinger, S.: "The Effects of Fully Seat Integrated Front Seat Belt System On Vehicle Occupants in Frontal Crashes," ESV Conference, Göteborg, May 1989.

[IIHS Status Report, 1989]
IIHS Status Report, Vol. 24, No. 8, August 26, 1989.

[James, 1991]
James, Michael B.; Strother, Charles E.; Warner, Charles Y.; Decker, Robin L.; and Perl, Thomas R.: "Occupant Protection in Rear-End Collisions: I. Safety Priorities and Seat Belt Effectiveness," SAE 912913, Proceedings of the 35th Stapp Conference, San Diego, CA., November 18-20, 1991.

[Marriner, 1990]
Marriner, Paul C.; Submission of Report entitled: "Evaluation of Seat Back Failures," Prepared by TES Limited for Transport Canada, Submitted to U.S. DOT Docket 89-20-NO1(018), January 1990.

[Mercedes Benz, 1989]
Mercedes Benz advertisement, 1989.

[Nash, 1974]
Nash, Carl: Petition to National Highway Traffic Safety Administration, Docket 74-13-2, February 1974, 208-PRM-000018.

[NHTSA Five Year Plan, 1979]
NHTSA Five Year Plan for Motor Vehicle Safety and Fuel Economy Rulemaking, April 20, 1979.

[Pirtle, 1978]
Pirtle, R.: "Test and Evaluation of Head Restraints, Seat Backs, and Anchorages in Vehicles Subject to Rear Impact Collision," Dynamic Science Rpt. 3005-78-84, DOT-HS-8-01886, Mod. 1, June 1978.

[Pirtle, 1978]
Pirtle, R.: "Test and Evaluation of Seat Belt System and Hatchback Door Lock and Hinge System Integrity in Rear Impact Collision," Phase 1, Dynamic Science Rpt. 8317-78-103, DOT-HS-8-01886, Mod. 2, June 1978.

[Pozzi, 1980]
Pozzi, M.: "Test and Evaluation of Volkswagen Type I Front Seat Integrity in Rear Impact Collisions," Dynamic Science Report No. 8340-80-192, DOT-HS-8-0l886 (Mod-12), November 1980.

[Saczalski, 1989]
Saczalski, Kenneth: Petition to National Highway Traffic Safety Administration, Docket 89-20-N01-001, April 18, 1989.

[Severy, 1958]
Severy, D.M.; Mathewson, J.H.: "Automobile Barrier and Rear-End Collision Performance," presented at the SAE Summer Meeting, Atlantic City, N.J., June 8-13, 1958.

[Severy, 1967]
Severy, D.M.; Bruik, H.M; and Baird, J.D.: "Collision Performance, LM Safety Car," SAE No. 670458, presented at SAE Mid-Year Meeting, Chicago, IL., May 9267.

[Severy, 1968]
Severy, D.M.; Bruik H.M.; and Baird, J.D.: "Backrest and Head Restraint Design for Rear-End Collision Protection," SAE Paper No. 680079, presented at the SAE Congress, Detroit, Michigan, January 1968.

[Severy, 1969]
Severy, D.M.; Bruik, H.M.; Baird, J.D.; and Blaisdell, D.M.: "Safer Seat Design," SAE Paper No. 690812, Proceedings of Thirteenth Stapp Car Crash Conference, Harvard School of Public Health, December 1969.

[Severy, 1976]
Severy, D.M.; Blaisdell, D.M.; and Kerkhoff, J.F.: "Automotive Seat Design and Collision Performance," SAE paper No. 760810, Proceedings of the 20th Stapp Car Crash Conference, 1976.

[Shaw, 1990]
Shaw, L.M.; "Critique of SAE Paper No. 872214" submitted to National Highway Traffic Safety Administration," Docket 89-20-No1, October 31, 1990.

[Slattery, 1990]
Private communication and correspondence regarding Failure Analysis Associates car to car crash test No. AZO-3984 conducted 9/12/90 for Attorney Robert Slattery, Milwaukee, Wisconsin.

[Stapp, 1955]
Stapp, J.P.: "Effects of Mechanical Force on Living Tissue; I-Abrupt Deceleration and Wind Blast," Journal of Aviation Medicine, Vol. 26, No. 4, August 1955, pp. 268-288.

[Strother, 1987]
Strother, Charles E.; and James, Michael B.: "Evaluation of Seat Back Strength and Seat Belt Effectiveness in Rear End Impacts," SAE Paper No. 872214, Proceedings of the 31st Stapp Car Crash Conference, New Orleans, Louisiana, October 9-11, 1987.

[Urai, 1975]
Urai, Muncharu, Inventor of Patent No. 3,922,029 Assigned to Takeji Saito for "Seat Mounting Device for Vehicle," November 25, 1975.

[Warner, 1991]
Warner, Charles Y.; Strother, Charles E.; James, Michael B.; and Decker, Robin L.: "Occupant Protection in Rear End Collisions: II, The Role of Seat Back Deformation in Injury Reduction," SAE Paper No. 912914, Proceedings of the 35th Stapp Car Crash Conference, San Diego, Ca., November 18-20, 1991.

APPENDIX A — SUMMARY OF CANADIAN FIELD ACCIDENT CASE STUDIES [MARRINER, 1990]

CASE 1A:
Circumstances: The case vehicle (1981 Chevrolet Citation) was travelling in the left lane on a divided highway when the driver lost control. The vehicle slid onto the left shoulder and impacted the left rear with a guardrail. This caused the vehicle to rotate counter-clockwise and impact the guardrail with the rear end. The vehicle came to rest on the left shoulder after rotating counter clockwise again about 90°. The driver and left rear passenger were ejected through the hatchback when the rear of the vehicle impacted the guardrail. The right front passenger remained in the vehicle. Both front occupants were using their restraining system during the accident, the rear passenger was not. All three (3) occupants received minor injuries. It was concluded that the failure of the seatbacks to restrain the driver and left rear passenger contributed to their injuries.

Type of Seat Failure:
Front Seats (both) - Mounts broke through floor;
Rear Seat - Seatback deformed

CASE 2A:
Circumstances: The vehicle (1978) Oldsmobile Cutlass) was travelling around a bend to the left on a two-lane road when the driver lost control. The vehicle rotated counter-clockwise 180° and left the roadway backwards, impacting the right side ditch with the rear end. The right front passenger's seatback collapsed backwards, and the occupant ended up in the rear seat. Both driver and passenger were using their restraint system during the accident. Both occupants received minor injuries. It was concluded that the seatback failure may have contributed to the injuries of the right front passenger, but the evidence to support this supposition is not conclusive.

Type of Seat Failure:
Right Front - Seatback support bracket

CASE 3A:
Circumstances: The case vehicle (1983 Toyota Supra) was travelling westbound on a divided highway when the driver lost control. The vehicle rotated counter-clockwise across the median and entered the eastbound lanes. The vehicle was then impacted in the left rear corner by an eastbound vehicle. The case vehicle underwent further rotation before coming to rest in the eastbound lane near the median. The right front passenger was ejected through the rear of the vehicle (either the hatch or left rear window) during the impact with the second vehicle. The driver of the case vehicle was using the restraining system during the accident, but the right front passenger was not. The right front passenger died due to severe head injuries. The driver had no injuries. It was concluded that the deformation of the right front seat allowed the passenger to be ejected from the vehicle and therefore contributed to this person's injury.

Type of Seat Failure:
Right Front - Seatback and floor pan deformation

CASE 4A:
Circumstances: The vehicle (1979 Mazda RX7) was travelling along a two-land highway and hit a moose which had entered the roadway. The vehicle rotated counter-clockwise 90° and struck the left side embankment head on. The vehicle continued to rotate and impacted the right rear with the embankment before rolling over and coming to rest i the left-hand lane. The driver was ejected through the hatch during rollover and landed on the right shoulder of the road. Both the driver and the right front passenger were using their restraint system. The driver had major injuries, and the right front passenger had minor injuries. It was concluded that the driver of the vehicle was ejected due to the deformation of the seatback during the rearward impact, and the seatback failure was therefore a contributing factor this person's injuries.

Type of Seat Failure:
Driver Seat - Seatback deformed;
Right Front - Seatback deformed slightly

CASE 5A:
Circumstances: The case vehicle (1982 Ford Escort, station wagon) was travelling at approximately 25 km/h and was impacted from the rear by a pickup truck travelling at approximately 85 km/h. At the time of impact, the driver's seatback collapsed rearwards. There was an unoccupied child seat in the left rear seat at the time of the accident which was damaged by the falling seatback and occupant in front. The driver was using his restraint system at the time of the accident and had minor injuries. It is concluded that it is not likely that the injury to the driver was contributed to by the failure of the seatback.

Type of Seat Failure:
Driver Seat - Failure of recliner mechanism

CASE 6A:
Circumstances: The case vehicle (1984 Chrysler Reliant, 4 door) was eastbound on a two-land road when the driver lot control. This vehicle rotated clockwise about 120° and veered into the westbound lane where it was impacted by a large truck which was westbound. The truck continued west, and the case vehicle underwent further rotation before coming to rest on the west shoulder. The right rear passenger was ejected due to a seat belt failure during the impact. The driver was in a horizontal position in the vehicle after the accident due to the failure of her seatback. Both occupants were using their restraint system during the accident. Injuries to the

driver were minor and unknown as to the rear passenger. It was concluded that the failure of the driver's seatback did contribute to the injuries sustained by the occupant.

Type of Seat Failure:
Front Seat - Both seatback mounts failed

CASE 7A:
Circumstances: The case vehicle (1986 Chevrolet Chevette, 4 door) was stopped at a traffic light when struck from the rear by another automobile. The vehicle came to rest after rotating counter-clockwise 180°. Both front seatbacks collapsed during impact, and the driver was lying in a horizontal position after the accident. Both occupants sustained head, neck and back injuries. Both were using their restraint systems during the accident. Both occupants had minor injuries. It was concluded that the failure of the seatback did contribute to the injuries of both occupants.

Type of Seat Failure:
Driver - Recliner mechanism failed;
Right Front - Same

CASE 8A:
Circumstances: The case vehicle (1988 Toyota Camry, 4 door) was eastbound on a two-land highway when the driver lost control of the vehicle. The vehicle rotated counter-clockwise into the westbound lane and was impacted in the right rear by a westbound pickup truck. The vehicle then began a clockwise rotation and came to rest on the west shoulder. The driver was ejected through the rear window of the vehicle during impact and died of head injuries. The driver was using his restraint system during the accident. The driver's seat head restraint was detached from the seat during the accident. It was concluded that the failure of the driver's seatback allowed the driver to be ejected from the vehicle and therefore contributed to his injuries.

Type of Seat Failure:
Seatback deformation and detachment of head restraint

CASE 9A:
Circumstances: The driver of the case vehicle (1982 Ford Mustang) lost control, and the vehicle rotated clockwise while entering the oncoming lane. The vehicle was impacted on the driver's side but in a forward direction by an oncoming pickup truck. The left rear of the case vehicle underwent a secondary impact with the right rear of the pickup truck as it continued to rotate after the initial impact. The driver of the case vehicle was ejected through the driver's door, probably during the rotation following the secondary collision. The left rear passenger, a seven week-old infant, was restrained in a child seat but was fatally injured by the detached headrest of the driver's seat. The right front passenger remained in the vehicle during the accident. The driver and right front passenger were not using their restraint systems during the accident and had only minor injuries. It was concluded that the failure of the driver-s seatback contributed to the injuries of the driver as the seatback did not retain him during the accident. The detachment of the headrest on the same seat caused the fatal injury of the rear seat passenger. Whether the seatback failure contributed to the injuries of the right front passenger could not be determined.

Type of Seat Failure:
Driver - Seatback deformation, floor pan deformation, head restraint detachment;
Right Front - Seatback deformation, floor pan deformation

CASE 10A:
Circumstances: The case vehicle (1980 Datsun 310, 5-door hatchback) was rounding a bend to the left on a two-land road when the driver lost control and the vehicle began a counter-clockwise rotation. The vehicle struck the left side embankment head on, then rotated 180° and impacted the embankment with the rear end. The vehicle continued to rotate, coming to rest down the road on the left side shoulder. The driver seatback deformed during the rear impact with the embankment, and the driver was ejected from the vehicle during the subsequent rotation of the vehicle. The driver was not using the restraint system during the accident and received a fatal injury. It was concluded that the deformation of the seatback allowed the driver to be ejected from the vehicle during the accident and therefore contributed to his injuries.

Type of Seat Failure:
Driver - Seatback deformed

CASE 11A:
Circumstances: The case vehicle (1984 Mercury Marquis) was struck in the left rear by another vehicle and began counter-clockwise rotation. A third vehicle impacted the case vehicle in the right front causing it to leave the road and impact a large rock with the rear end. The driver of the case vehicle was ejected through the rear window and suffered minor injuries. It is not know whether or not the driver was using the restraint system at the time of the accident. It was concluded that the driver was ejected from the vehicle due to the failure of the seatback to retain him and this contributed to his injuries.

Type of Seat Failure:
Driver - Self-locking device failed.

CASE 12A:
Circumstances: The case vehicle (1988 Honda CRX) was travelling around a bend to the left on a two-land road when the driver lost control. The vehicle went into a counter-clockwise rotation and left the roadway onto the right-hand shoulder. The car then impacted an embankment rearwards and came to rest after striking a

group of small trees. All three passengers were ejected from the vehicle during the impact, and both seatbacks were permanently deformed. The driver was using the restraint system during the accident. The two right front passengers were sharing one bucket-type seat and were not using the restraint system. The driver received major injuries, and one of the passengers received fatal injuries. The other had minor injuries. It was concluded that the deformation of the driver seatback allowed the driver to be ejected from the vehicle and therefore contributed to his injuries. With two occupants sharing the passenger seat, conclusions regarding the seatback cannot be made.

Type of Seat Failure:
Driver - Seatback deformation;
Right Front - Same

<u>**CASE 13A:**</u>
Circumstances: The case vehicle (1985 Suzuki Samurai) was travelling along a two-land road when the driver lost control, and the vehicle rotated counter-clockwise into the oncoming lane. An oncoming vehicle impacted the case vehicle in the right front, increasing the rotation and causing the right rear of the case vehicle to impact the left rear of the oncoming vehicle. The case vehicle underwent further rotation before coming to rest in the ditch on the right side of the road. During the rear impact of the case vehicle, the driver was ejected through the rear hatch and suffered fatal injuries while exiting. The rear bench seatback was deformed as was the tailgate of the case vehicle by the driver during ejection. Both the driver and passenger of the case vehicle were using their restraint system during the accident. The passenger had minor injuries. It was concluded that the failure of the driver's seatback prevented the seat from retaining her during the rearward collision, and this contributed to her injuries.

Type of Seat Failure: Driver - Recliner mechanism failed

<u>**CASE 14A:**</u>
Circumstances: The case vehicle (1984 Chevrolet Chevette, 4 door) was making a turn at an intersection when the driver's seatback suddenly failed. The driver fell towards the back of the vehicle and landed against the left rear passenger, a three year-old child. The driver was able to pull himself up with the steering wheel and regain control of the vehicle in time to avoid an accident. It is not know whether or not the driver or passenger were using their restraint systems during this incident. Neither passenger received injuries. Fortunately, a serious accident did not occur.

Type of Seat Failure:
Driver - Recliner mechanism failed

<u>**CASE 15A:**</u>
Circumstances: The case vehicle (1982 Toyota Tercel, 2 door) was stopped, waiting to make a left turn and was struck in the rear by a bus travelling at 16 km/h. The seatback failed during the impact, leaving the driver horizontal. The driver was using the restraint system at the time of the accident and suffered minor injuries. It was concluded that the seatback failure contributed to the injuries to the driver's legs, back and neck.

Type of Seat Failure:
Seatback deformed, recliner mechanism failed

<u>**CASE 16A:**</u>
Circumstances: The case vehicle (1984 GMC Vandura) was stopped at an intersection, waiting to turn left and was struck from behind by a large truck. During impact, the driver's seatback collapsed beyond a horizontal position, and the driver was left lying on the floor of the van with the lap belt around his shins after the accident. The driver was using the restraint system during the collision. The driver's seat was an aftermarket product, however; this model was tested to CMVSS 207. The driver received minor injuries. It was concluded that the driver's seatback deformed when the vehicle was impacted, and the seat could not retain the driver during the collision. The seatback failure therefore contributed to the driver's injuries.

Type of Seat Failure:
Driver - Seatback deformed

<u>**CASE 17A:**</u>
Circumstances: The case vehicle (1983 Chevrolet Chevette) was stopped at an intersection and was hit from behind by another vehicle. When the reclining mechanism failed, the driver of the case vehicle fell backwards and landed in a horizontal position against the rear seat. The driver was using the restraint system during the accident and received minor injury. It was concluded that the driver suffered neck injury which was attributed to the seatback failure.

Type of Seat Failure:
Driver - Recliner mechanism failed

<u>**CASE 18A:**</u>
Circumstances: The case vehicle (1984 Oldsmobile Firenza, 4 door) was stopped while in line at a drive-through restaurant, and the driver seatback collapsed when the driver reached for his wallet. The driver fell back, losing control of the vehicle, and it accelerated into the vehicle in front of him. It is not known whether or not the driver was using the restraint system during the accident. It was concluded that it is not known whether the driver was injured during the accident. However, we can conclude that the collision with the vehicle in front of the case vehicle was due to the seatback failure.

Type of Seat Failure:
Driver - Recliner mechanism failed

CASE 19A:

Circumstances: The case vehicle (1987 Chrysler Sundance) was impacted directly in the rear while stopped, and both front seats collapsed rearward. The right rear passenger, a child in a child seat, was impacted by the reclining front seat and passenger. The driver and front passengers were using the restraint systems during the accident and received minor injuries. It was concluded that the failure of the front seatbacks contributed to the injuries of all three occupants.

Type of Seat Failure:

Driver - Recliner mechanism failed;
Right Front - Same

CASE 20A:

Circumstances: The driver of the case vehicle (1982 Ford Mustang) was waiting for the car to warm up, and the seatback suddenly collapsed allowing him to fall backwards. The failure was traced to a bolt which holds the recliner mechanism to the back of the seat. It is not known whether the driver was using the restraint system during the incident. It was concluded that the driver of the vehicle suffered an injury to the neck which was a direct result of the seatback failure.

Type of Seat Failure:

Driver - Recliner mechanism failed

CASE 21A:

Circumstances: The case vehicle (1984 Chrysler Lazer) was following a bend to the right on a two-lane road when the driver applied the brakes. The vehicle entered the oncoming lane, returned to the right lane and began to rotate counter-clockwise. The vehicle left the road on the left-hand side and struck three guide posts with the passenger side before entering the ditch backwards. The rear of the vehicle hit the bottom of the ditch, and the vehicle came to a rest after a number of rollovers. The driver was ejected when the rear of the vehicle impacted the bottom of the ditch and the seatback failed. The driver was not using the restraint system during the accident. The driver received fatal injuries. It was concluded that the seatback collapse allowed the driver to be ejected from the vehicle and therefore contributed to the driver's injuries.

Type of Seat Failure:

Driver - Recliner mechanism failed

CASE 22A:

Circumstances: The case vehicle (1986 Volkswagen Jetta, 4 door) was westbound on a country road and entered a junction with a two-land road. The case vehicle failed to yield right-of-way to a southbound vehicle and was hit broadside by this vehicle midway along the passenger's side of the case vehicle. The case vehicle underwent a clockwise rotation, rolled over onto its roof and came to rest in the southwest ditch facing north. The driver's seatback failed during the impact, and the driver was ejected from the seat during the subsequent rotation of the vehicle. The southbound vehicle also underwent a clockwise rotation and came to rest right-side-up and facing south in the southwest ditch. Both the driver and passenger in the case vehicle were using the restraining systems, but the driver was ejected from his seat and partially ejected through the rear window of the vehicle. The driver died of head injuries caused by his head impacting the right rear interior of the roof during ejection. The right front passenger died of internal injuries sustained during the accident. It was concluded that the head injury sustained by the driver of the case vehicle was caused by his ejection from the seat, and the seatback failure therefore contributed to his injury. For the right front passenger, there is insufficient evidence to conclude that the seatback failure contributed to her injuries.

Type of Seat Failure:

Driver - Recliner mechanism failed, seat back deformed;
Right Front - Seatback deformed

CASE 23A:

Circumstances: The case vehicle (1986 Volkswagen Jetta, 4 door) was southbound on a two-lane highway, and the driver lost control while veering onto the right-hand shoulder to pass a vehicle which was making a left turn. The case vehicle came back onto the roadway and crossed the centerline into the oncoming lane where it was struck on the passenger side by an oncoming vehicle. After some rotation, both vehicles came to rest on the east shoulder of the road. The driver's seatback collapsed during the impact, and the driver was ejected from the seat during the rotation of the vehicle. The driver suffered major injuries and was found partially ejected through the rear window. All the occupants of the case vehicle were using their restraint systems during the accident, and all three received fatal injuries. It was concluded that the driver's injuries were contributed to by the failure of the driver's seatback. The seatback failure also contributed to the injuries of the right rear passenger in that the driver would have impacted this passenger during ejection. There is insufficient evidence to conclude that the seatback failure contributed to the injuries of the right front passenger.

Type of Seat Failure:

Driver - Recliner mechanism failed, seatback deformed;
Right Front - Seatback deformed

APPENDIX B — SUMMARY OF AUTHOR EXAMINED FIELD ACCIDENTS

CASE 1B:
Circumstances: A 1984 Chrysler Lazer vehicle was struck in left rear quarter panel at the start of a passing maneuver by a very large truck. The case vehicle spun counter-clockwise and hit a large tree going backwards. The passenger, possibly belted, was completely ejected and received fatal injuries.

CASE 2B:
Circumstances: A 1977 Dodge Tradesman Van was struck squarely in the rear by a large Ford Thunderbird, while parked but preparing to drive away. The case vehicle was pushed up the curb onto the sidewalk and rolled along the sidewalk, struck a building, and then continued until striking a pole. The vehicle burst into flames and the front occupants seated in captain's chairs were thrown into the rear area of the van. The driver was unable to steer or stop the van and the occupants received serious burns.

CASE 3B:
Circumstances: A 1984 Honda Accord 4dr. vehicle was struck squarely in the rear by a full size GM Blazer. The case vehicle suffered extensive override damage and both front seat occupants were thrown into the rear seat occupants. All occupants were lap and shoulder belted. The left rear passenger received serious eye and facial injuries.

CASE 4B:
Circumstances: A 1984 Nissan 300ZX was struck in the left rear quarter panel by a tractor trailer rig. The vehicle spun counter-clockwise in front of the tractor, and was again impacted by the tractor trailer rig. The driver's seatback collapsed during the first impact and the driver survived the extensive crush of the second impact due to the reclined position of the seat.

CASE 5B:
Circumstances: A 1985 Buick Skylark 4dr. vehicle was struck slightly offset to the driver's side by a 1967 Camaro. The case vehicle spun clockwise to the point of rest and the front seat occupants deformed their bench seat without serious injury to the occupants. The head of the right rear occupant impacted the back light and rear roof header, resulting in paralyzing injuries.

CASE 6B:
Circumstances: A 1985 Ford Mustang LX 5.0 convertible lost control, lightly struck a tree in front, then spun around and struck a large tree while moving backwards. The two right side passengers were belted and not seriously injured. The driver was lap and shoulder belted, and was struck on the back of the head by the retracted convertible top frame, resulting in serious brain injury.

CASE 7B:
Circumstances: A 1982 Ford Mustang Hatchback was struck from behind with offset to the passenger side. The driver's seat and floor collapsed and the driver lost control of the vehicle. The vehicle spun into a sound wall bordering the freeway and the driver was partially ejected from the driver's window, receiving serious head injury.

CASE 8B:
Circumstances: The case vehicle (early 1980 Toyota Tercel, 2 door, hatchback) was struck lightly in the rear by a sports car. The seat back of the heavy adult male driver collapsed rearward and the driver's head impacted an unshielded ball stud attached to the rear hatchback lid strut. The impact caused a localized, punch-through, fracture of the driver's skull occipital region, resulting in permanent brain injury. The seat back of the smaller female right front passenger did not collapse and the passenger only received minor injuries as the driverless vehicle moved out of control after the rear impact.

CASE 9B:
Circumstances: The case vehicle (1979 Mustang) was struck in the rear by a pick-up truck. The impact caused a fire and the driver seat collapsed into the rear of the vehicle. An infant was secured in a child seat in the rear behind the driver. The driver could not remove the infant before the fire reached the rear occupant compartment area and the child received fatal burn injuries. The collapsed front seat contributed to hindering removal of the child.

CASE 10B:
Circumstances: A mid-1970 Datsun B-210 was struck in the rear by another passenger car and pushed into oncoming traffic, incurring a minor front impact. The initial rear impact caused the driver front seat to collapse and allowed the driver head and neck to strike the rear seat back resulting in cervical spine injuries and quadriplegia.

CASE 11B:
Circumstances: A 1985 Astro Van was struck from the rear by a pick-up truck. Both the driver and the right front passenger were wearing seat belts and shoulder harness restraints, and both seats collapsed rearward upon impact. The driver slid out of his restraint and was ultimately ejected from the vehicle. Due to the rear impact, the vehicle yawed clockwise, rolled onto the driver side, slid rearward into a pole, and then rotated around to an upright position. The driver died as a result of the injuries received. The smaller passenger slid partially out from his lap belt but was saved from vehicle ejection when the belt caught around his legs. The passenger only received minor injuries. The driver seat collapsed due to deformation of the seat frame structure. The passenger seat collapsed due to shearing failure of a recliner mechanism bolt.

CASE 12B:
Circumstances: The case vehicle (1983 Oldsmobile Firenza, 4 door sedan) was struck in the rear by a Lincoln Continental. Both the driver and the right front passenger were restrained. Both seat backs collapsed as a result of the rear impact, but neither occupant was ejected from the vehicle. The driver received severe head injury and the passenger received relatively minor lacerations to the face and neck. As in the previous case, the struck vehicle rotated clockwise, rolled onto the driver side, slid rearward, and struck a pole before coming to rest.

CASE 13B:
Circumstances: A 1986 Astro Van was struck in the rear by a jack-knifed tractor trailer. The fully restrained driver and right front passenger, were thrown into the rear of the van when their seats collapsed due to failure of recliner mechanism attachments. Although the driver of the van sustained serious neck injuries, she was able to eventually get back to the steering wheel and steer the van to the side of the road, several hundred feet from the point of impact. The passenger in the right front sustained critical injuries when she was impaled on a protruding object. Of the two children in the rear of the van, one sustained minor injuries and one was not injured.

CASE 14B:
Circumstances: The case vehicle is a 1985 Buick Century 4 door sedan. The vehicle was struck lightly in the rear by a large, late 1970, sedan which left the scene of the accident. The driver of the case vehicle, according to witnesses, collapsed rearward and subsequently lost control of the vehicle. The case vehicle veered to the left, drove partially onto a concrete retaining wall, came back to the roadway and ultimately came to rest in flames. A witness, helped the driver up from the reclined seat back but had difficulty in extricating the 3 rear seat passengers due to the fire and entrapment from the collapsed front seats. All five passengers died as a result of severe burns.

CASE 15B:
Circumstances: A 1985 Ford Tempo was struck in the rear by a tractor trailer vehicle and continued forward incurring a minor impact with the vehicle in front. Both front seat occupants of the case vehicle were fully restrained. The seat back of the heavier adult male right front passenger collapsed rearward upon impact and the passenger struck his head and neck in the rear compartment area resulting in a paralyzing neck injury. The seat of the smaller adult female driver remained essentially upright and she received only minor injuries.

CASE 16B:
Circumstances: The case vehicle (1976 Porsche) lost control while driving on ice-covered road conditions and spun around into the lane of oncoming traffic. At that time it was struck in the rear by an early 1970's large 4 door sedan. The driver seat of the case vehicle collapsed and the unrestrained driver slid rearward into the rear package tray area. The impact resulted in a paralyzing neck injury.

CASE 17B:
Circumstances: A 1975 Plymouth Brougham 4 door sedan was struck in the rear by a City bus. The case vehicle was propelled forward and lightly struck a pick-up truck before coming to rest. The front bench seat of the subject vehicle pulled loose from the floor mounts and the two unrestrained front seat occupants slid rearward into the rear compartment area. The larger adult male right front passenger received only minor injuries, the expectant female driver received paralyzing neck injuries.

CASE 18B:
Circumstances: The case vehicle (1980 Buick Century, 2 door) lost control and spun around moving rearward into the oncoming lane of traffic, where the case vehicle was impacted in the rear by a pick-up truck. The driver front seat collapsed and the unrestrained front seat passenger slid into the rear compartment area where she received paralyzing injuries.

CASE 19B:
Circumstances: A 1977 Toyota Corolla, 2 door sedan is struck in the left rear by a 1979 full size van. The target vehicle was occupied by 4 adult male passengers, two in the front and two in the rear. It was unknown if the occupants were restrained. The impact caused severe crush in the left rear area. Both front seats collapsed and the right front passenger slid rearward between the two rear passengers and struck his head on the hard surface of the intruding package tray which resulted in a depressed skull fracture and ultimately death. The driver of the vehicle experienced serious head injuries and contributed to the moderate injuries of the left rear passenger who was crushed between the intrusion into the left rear of the vehicle and the collapsing seat and driver in front. The right rear passenger only received minor injuries.

CASE 20B:
Circumstances: The case vehicle (1988 Oldsmobile, 4 door sedan) lost control during winter conditions and traveled into the lane of oncoming traffic where the left front of the case vehicle (driver side) impacted the left front of an oncoming tractor trailer vehicle. The case vehicle then rotated counterclockwise striking rearward into the rear area of the tractor trailer and then rotated back across both lanes to the right side shoulder of the original lane of travel for the case vehicle. Both front passengers were restrained. The driver seat remained essentially upright and the driver only received minor injuries. The right front passenger seat collapsed rearward and the belted occupant was ejected from the rear area of the vehicle during the last phase of the collision, ending up face down in the ditch on the right side shoulder of the original lane of travel of the case

vehicle. The front passenger suffered facial lacerations, rib and leg fractures and a serious head injury. Detailed examination of the seat structure indicated that the inboard hinge pin had become dislodged thus reducing the rearward load, torque and bending resistance of the passenger seat structure.

CASE 21B:
Circumstances: A 1985 mid-size van was customized and the original front seats were replaced with swivel seats known as "Captain Chairs." Both the driver and the right front passenger were wearing a lap and shoulder harness restraint. The case vehicle was impacted in the rear by a tractor trailer vehicle which caused severe massive override crush damage into the area behind the driver. The passenger seat collapsed rearward and the passenger was ejected from the restraints into the right rear passenger seat and window area. Ultimately, as the van veered out of control to the right shoulder and rolled over, the passenger was ejected from the vehicle. The driver who was seated in a seat that had less deformation, just in front of the area of massive structural intrusion, remained in the vehicle and received only minor injuries. The passenger received paralyzing injury.

CASE 22B:
Circumstances: An early 1980 Nissan 200 SX, 2-door vehicle lost control, spun around moving rearward across the lane of oncoming traffic and eventually impacted rearward into a tree located off the left shoulder of the 2 lane highway. The seat of the unrestrained driver twisted inboard and deformed rearward allowing the unrestrained driver to slide rearward and impact into the rear window region at about the area of engagement with the fixed object tree. The driver sustained serious neck injury but did not lose consciousness.

CASE 23B:
Circumstances: The case vehicle (1984 Chevrolet Citation 4 door) was struck in the rear, by a 1986 small pick-up, while in the process of making a left hand turn. The front bench seat collapsed rearward due to the rear impact and the case vehicle rotated counter-clockwise. During the subsequent rotation after the rear impact, the right front passenger was ejected from the vehicle and received paralyzing spine injuries, with the case vehicle coming to rest on top of the ejected passenger. The driver remained in the vehicle and received only minor injuries. It was unclear if the occupants were restrained or not in this case.