INJURIES TO RESTRAINED OCCUPANTS IN FAR-SIDE CRASHES

Kennerly Digges
The Automotive Safety Research Institute
Charlottesville, Virginia, USA

Dainius Dalmotas
Transport Canada
Ottawa, Canada
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ABSTRACT

Occupants exposed to far-side crashes are those seated on the side of the vehicle opposite the struck side. This study uses the NASS/CDS 1988-98 to determine distributions of serious injuries among restrained occupants exposed to far-side crashes and the sources of the injuries. Vehicle-to-vehicle crash tests were conducted to study dummy kinematics.

The NASS/CDS indicated that the head accounted for 45% of the MAIS 4+ injuries in far-side collisions and the chest/abdomen accounted for 39%. The opposite-side interior was the most frequent contact associated with driver AIS 3+ injuries (26.9%). The safety belt was second, accounting for 20.8%.

Vehicle-to-vehicle side impact tests with a 60 degree crash vector indicated that different safety belt designs resulted in different amounts of head excursion for the far side Hybrid III dummy. For all three point belt systems tested, the shoulder belt was ineffective in preventing large amounts of head excursion. Restraint was achieved by the lap belt loading the abdomen. A single retractor design with low friction sliding latch plate permitted the greatest head excursion in the far side crash tests. A dual retractor system with a fixed latch plate permitted the least.

INTRODUCTION

Test procedures required by present safety standards for side crashes require the crash dummies to be located on the side of the vehicle closest to the impact. Far-side occupants, those located on the side opposite the impact, are not included. Studies of injuries in far-side crashes may assist in identifying safety systems and test procedures to further improve occupant safety.

An objective of this study was to examine injury patterns for far-side front seat occupants in side collisions and to conduct crash testing to better understand the occupant kinematics that cause the most frequent injuries. The study is a continuation of the analysis that incorporated data from the Miami School of Medicine's William Lehman Injury Research Center (Augenstein, 2000). Previous authors have also investigated the far side injury problem.

Mackay (1991) examined 193 crashes with belt restrained far-side occupants during the period 1983-1989. The 193 cases contained 150 AIS 2 injuries and 15 AIS 3+ injuries. Among those with AIS 2+ head injuries, 35% came out of the shoulder belt. For those with AIS 2+ abdominal injuries, 72% were from contact with the safety belt. Contact with the belt system was the most frequent source of chest injuries (59%).

Frampton (1998) studied 295 crashes with belt restrained far-side occupants between June 1992 and April 1996. These cases included 46 MAIS 2 and 33 MAIS 3+ injuries. The MAIS 2 median deltaV was 25 km/hr. The median MAIS 3+ deltaV was 35 km/hr. Frampton found that MAIS 2+ injury rates were higher in perpendicular crashes than in oblique crashes.

Thomas (1999) investigated a sample of 474 side crashes between 1992 and 1998. The cases contained 226 MAIS 3+ survivors, and 188 fatalities. Thirty-four percent of the MAIS 3+ survivors and 32% of the fatalities were seated on the non-struck side. The distribution of injuries by body region for the 21 MAIS 3+ survivors on the non-struck side and without interaction with other occupants were: Head – 52%; Neck – 14%; Thorax – 19%; Upper Extremity – 38%; Pelvis – 14%, and Lower Extremity 14%. For the fatalities the equivalent : Head – 68%; Neck – 18%; Thorax – 86%; Abdomen – 41%; Upper Extremity – 9%; Pelvis – 9%, and Lower Extremity 18%.

Fildes (1991) examined injuries sustained in side collisions by drivers in Australia. The study was based on the Monash University crashed vehicle file consisting of 227 vehicles and 267 patients from crashes that occurred in Victoria during 1989 and 1990. The file contained 572 variables to describe the crash and the occupant. Fildes found that the injury rate of AIS 2+ head injuries was twice as high in far-side impacts as in near-side impacts. In far-side impacts, head and chest injury rates were about equal. The four most frequent sources of injuries were the instrument panel, the roof, the door panel, and the other occupant. The injury rate due to seat belts was about half that of the four most frequent sources.

METHODOLOGY AND DATABASES

In this study, National Automotive Sampling System/ Crashworthiness Data System (NASS/CDS) for the years 1988 to 1998 was used to examine the distribution of injuries and injuring contacts for belted occupants in far-side impacts.

The National Highway Traffic Safety Administration (NHTSA) maintains the NASS/CDS database of vehicle crashes in the United States. The NASS/CDS is a stratified sample of light vehicles involved in highway crashes that were reported by the police and involved sufficient damage that one vehicle was towed from the crash scene. The database was compiled between 1988 and 1998 and has been used extensively by NHTSA and others to assess the effectiveness of safety systems in reducing casualties in the crashes that occur on US highways.

INJURIES IN FAR-SIDE CRASHES BASED ON NASS/CDS

In the NASS/CDS data query, far-side occupants were defined as drivers in vehicles with right side damage and principal direction of force in the 1 to 5 o'clock direction or right front passengers in vehicles with left side damage and principal direction of force in the 7 to 11 o'clock direction.

In addition, the following restrictions were imposed: belted occupants only, age 16 or older, and no subsequent rollover of the struck vehicle. The data set contained 4696 cases – 3576 drivers and 1120 right front passengers. Of this driver population, 286 occupants had serious (MAIS 3 or greater) injuries with an aggregate of 776 AIS 3+ injuries.

Table 1 shows the MAIS 2, 3 and 4+ distribution by body region for belted occupants in far-side crashes. Each NASS/CDS case contains a weighting factor that is used by the NHTSA to extrapolate the individual cases to the national numbers. The distributions in Table 1 show both weighted and unweighed populations. The average weighting factor is also shown. In NASS/CDS, crashes with higher weighting factors have severities that occur more frequently in the population. The lower weighting factor cases tend to be in the more severe crashes.

All skull, brain and facial injuries were classified as head injuries. Injuries to the chest and abdomen were classified as trunk injuries. Injuries to the pelvis were classified as lower extremity injuries and shoulder injuries are included in the upper extremity category. Based on weighted data, head injuries accounted for 39% of the AIS 2 injuries, 24% of the AIS 3 injuries, and 45% of the AIS 4+ injuries. Spinal injuries contributed another 16% of the weighted AIS 4+ injuries. Chest/abdominal injuries dominated the AIS 3 injuries with 58%.

Table 1.
MAIS 2+ Injury Distribution for Belted Front Seat Occupants in Far-Side Crashes by Body Region, NASS/CDS 1988-1998

MAIS 2

Body	No.	Unwgt	Wgt	Ave Wgt
Head	205	44%	39%	183
Trunk	89	19%	24%	256
Lower X	88	19%	18%	199
Upper X	79	17%	19%	226
Total	461	100%	100%	208

MAIS 3

Body	No.	Unwgt	Wgt	Ave Wgt
Head	34	23%	24%	168
Trunk	62	41%	58%	223
Lower X	33	22%	7%	54
Upper X	21	14%	11%	126
Total	150	100%	100%	160

MAIS 4+

Body	No.	Unwgt	Wgt	Ave Wgt
Head	77	57%	45%	52
Spine	7	5%	16%	204
Trunk	52	38%	39%	66
Total	136	100%	100%	65

Table 2 shows the distribution of AIS 3+ injuries by injuring contact. The columns in Table 2 are similar to Table 1. The AIS 3+ injury distribution by body region and injuring contact is displayed in Table 3. Body regions and contacts that constituted less than 2% of the AIS 3+ weighted injuries were not included in Table 3. In Tables 2 and 3, the Side Interior category includes all interior side surfaces of the vehicle above the floor and below the roof.

Table 2.
AIS 3+ Injury Distribution for Belted Front Seat Occupants in Far-Side Crashes by Injuring Contact, NASS/CDS 1988-1998

Contact	No.	Unwgt	Wgt	Ave Wgt
Far Side Interior	245	31.5%	26.9%	70
Safety Belt	75	9.7%	20.8%	178
Roof	57	7.3%	12.2%	137
All Other	90	11.6%	8.6%	61
Seat	43	5.5%	7.5%	111
Near Side Interior	39	5.0%	7.0%	116
Non Contact	88	11.3%	6.5%	48
Dashboard	55	7.1%	5.2%	60
Other Occupant	58	7.5%	2.9%	178
Steering System	27	3.5%	2.4%	58
Raw No.	777	100.0%	100.0%	83

Table 3.
AIS 3+ Injury Distribution for Belted Front Seat Occupants in Far-Side Crashes by Body Region and Injuring Contact, Weighted NASS/CDS 1988-1998

Body Region	Injuring Contact	Weighted
Trunk	Belt	20.6%
Trunk	Right Side Interior	11.8%
Head	Right Side Interior	11.4%
Head	Roof	10.2%
Head	Left Side Interior	6.1%
Trunk	Seat	5.4%
Trunk	Other Occupant	2.3%
Trunk	Non Contact	2.2%
Head	Non Contact	2.1%
Head	Seat	2.1%
Spine	Roof	2.0%
Head	Dash	1.9%
Trunk	Dash	1.6%

Table 3 provides additional insights into injury mechanisms. The seat belt to trunk contact accounts for virtually all AIS 3+ Seat Belt contact injuries. The Side Interior (generally the opposite side) contacts account for a large fraction of the head injuries. The Roof contact is another significant source of head injuries.

CRASH SEVERITY

NASS/CDS 1988-1998 contains 150 cases of MAIS 3+ injured far side occupants with known delta-V. The distributions of lateral and total delta-V for these cases are shown in Figure 1. Approximately 50% of the MAIS 3+ crashes occur at lateral delta-V less than 30 kph. and 85% occur at lateral delta-V less than 50 kph.

A search of the NHTSA/FHWA crash test database maintained by the National Crash Analysis Center, at George Washington University disclosed one available crash test involving a far side dummy. The test was of a full size 1988 Chevrolet pickup impacted at 31 kph by a movable barrier with a rigid face. The direction of impact was 9 o'clock and the test dummy was a 50% male Hybrid II. The restraint system had a fixed latch plate, and both the shoulder and lap belt were attached to a retractor. In the test, the shoulder belt provided virtually no restraint. Upon the onset of side acceleration, the dummy immediately slid out of the shoulder belt, and was restrained only by the lap belt.

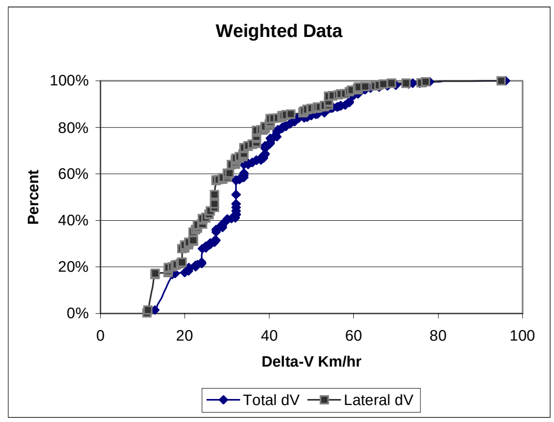


Figure 1. Crash Severity for Belted Far Side Front Seat Occupants with MAIS 3+ Injuries, NASS/CDS 1988-98.

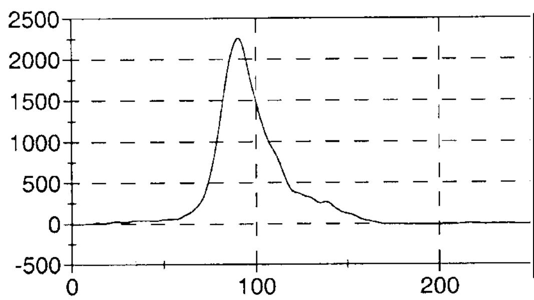
As indicated in Figure 1, far side crashes with MAIS 3+ injuries frequently involve both lateral and longitudinal components of acceleration. It was postulated that a frontal acceleration component would improve the performance of the shoulder belt system. This possibility was explored in crash tests conducted for this study.

CRASH TEST RESULTS

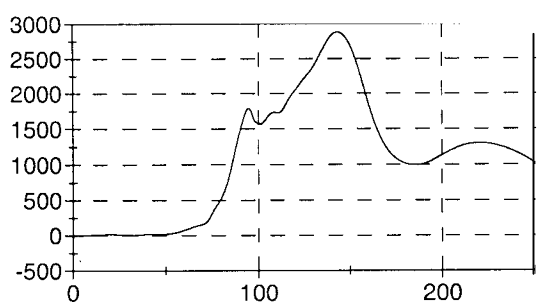
Crash tests were conducted to study the dummy kinematics in far side impacts. The baseline test was a vehicle-to-vehicle side crash with a lateral delta-V of approximately 50 kph. The crash direction was 60 degrees relative to the centerline of the struck vehicle. A 1988 Chevrolet pickup, similar to the one in the NHTSA test was used as the test vehicle. It was impacted at the occupant compartment by a full size passenger car. A belted Hybrid III 50% male dummy was seated on the far-side of the impact. The restraint system was the same as in the 90 degree NHTSA test described earlier.

In the crash, both the lateral and longitudinal components of acceleration reached a peak of around 30g during the initial 12 ms. After 12 ms., the longitudinal acceleration , rapidly decreased, while the lateral acceleration continued for about 80 ms. Maximum lateral acceleration during the 12 to 80 ms. period was 27 g..

The load vs. time for the lap and shoulder belt are shown in Figure 2. The shoulder belt was loaded during the initial 90 ms. of the crash. After 90 ms. the load decreased and the lap belt load continued to increase. The maximum shoulder belt load was 2256N at 90.4ms. The maximum lap belt load was 2882N at 143 ms.



Shoulder Belt Force (Newtons) vs. time, ms.



Lap Belt Force (Newtons) vs. time, ms.

Figure 2. Belt Forces in Vehicle-to-Vehicle Far Side Crash Test

The dummy injury readings were all low. The HIC was 194; the max chest g was 16.7; the max pelvic g's were 21, and the neck Nij was 0.3. None of these readings indicated injuries due to belt loading or head contact as expected based on the injury frequencies listed in Tables 1, 2 and 3. However, the injuries from opposite side head impact and trunk belt loading may not be adequately reflected by the conventional dummy readings. The maximum lap belt load and the extent of head excursion are more likely criteria for these types of injuries.

The position of the dummy at 130 ms after initial impact is shown in Figure 3. This position corresponds to the time of high lap belt loading.

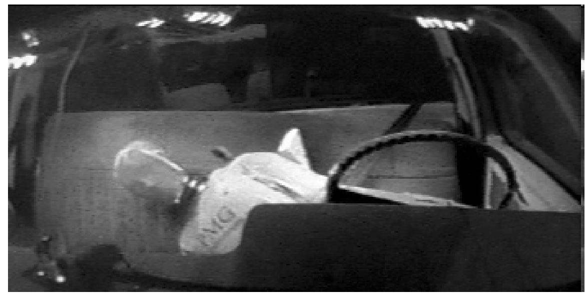


Figure 3. Dummy Position at Maximum Lap Belt Loading

A view from a second camera is shown in Figure 4. This view shows the configuration of the lap belt late in the crash at maximum head excursion. The lap belt, limits the head excursion by loading the abdomen. The shoulder belt loading is also across the abdomen.

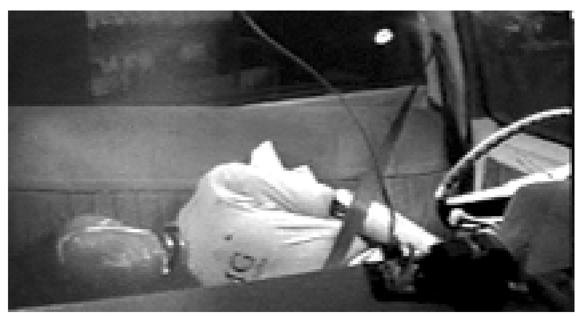


Figure 4. Dummy Position Showing Abdominal Loading

Identical crash tests were conducted for two additional OEM safety belt systems. The first was a belt system with a single retractor and latch ring plate that moved with low friction. This system permitted easy movement of the latch plate along the belt, even when the belt was buckled. A second system was a single retractor belt with a high friction latch ring. The crash test results showed that the low friction latch plate permitted the most head excursion, and the two retractor system discussed earlier permitted the least. All of the systems prevented the dummies from impacting the far side interior of the vehicle.

DISCUSSION

The NASS/CDS data for belted front seat occupants indicates that the safety belt accounts for 20.8% of AIS 3+ injuries in far-side crashes. Earlier studies by Mackay found that 59% of AIS 2+ chest injuries and 72% of abdominal injuries among belt restrained far-side occupants were from seat belt contacts (Mackay, 1991). The NASS/CDS data sample is stratified in such a way that low severity crashes are sampled at a much lower rate than the higher severity crashes. Table 2 shows that belt contacts carry a large average weighting factor, suggesting lower severity crashes, and therefore a smaller than average sample of cases. The NASS/CDS sample may not be sufficiently robust to adequately capture injury modes in the lower crash severity ranges.

The NASS/CDS indicated that the largest source of injury to belted occupants in far-side impacts was the Far Side Interior. For the weighted data the Far Side Interior percentage was 26.9% and for the unweighted data it was 31.5%. Fildes reported the door panel as one of the most frequent injury contacts for Australian far-side AIS 2+ injuries (Fildes, 1991). Mackay reported that the far-side occupant came out of the belt in 35% of the cases with AIS 2+ head injuries (Mackay, 1991). These studies suggest that opportunities exist for improving the occupant retention and chest/abdominal loading of safety belts in far-side crashes.

The crash testing of three different belt system designs showed differences in head excursion, but none of the dummies contacted the opposite side interior. The conventional injury measurements of a Hybrid III dummy were low in the 50 kph lateral delta-V crash tests conducted in this study. The failure to measure any injuries in the crash tests may indicate that the test configuration is not representative of crashes that produce severe injuries in the real world. However, the tests did indicate that the shoulder belt was largely ineffective in preventing large amounts of head excursion, even in far side crashes with longitudinal acceleration. Head contact with the opposite side interior would more likely occur if the vehicle interior were smaller (small car) and/or if significant occupant compartment intrusion had occurred.

Further, the tests showed lap belt loading of the abdominal region. The maximum belt force developed was lower than that permitted in a frontal crash test where the lap belt transmits the loading through the pelvic structure. Different injury criteria would be applicable to belt loading of the abdomen.

Finally, the tests may indicate the need for better fidelity of the dummy in far side impacts. The Hybrid III has biofidelity in a frontal crash, but no attempt has been made to evaluate its performance in a far side crash.

CONCLUSIONS

For belted occupants in far-side crashes, the most harmful injury source is the opposite side of the car (26.9%). The second most harmful injury source is the safety belt (20.8%). Impacts with the roof account for 12.2%. The contacts with the opposite side, roof and belt may be influenced by safety belt design. Crash tests indicate differences in the extent of restraint offered by different belt systems in far side crashes. In all three point belt systems tested, the shoulder belt was ineffective in preventing large amounts of head excursion. Restraint was achieved by the lap belt loading the abdomen. The baseline, belt system with a fixed latch plate and two retractors permitted the lowest head excursion of the systems tested. Additional research in needed to develop dummies with far-side biofidelity and associated injury criteria, test conditions and restraint systems for far side crashes.

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