EVALUATION OF CRASH TYPES ASSOCIATED WITH TEST PROTOCOLS

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Paper Number 399

ABSTRACT

National Automotive Sampling System (NASS) data are analyzed to determine the benefits that would likely result from imposed testing requirements using various frontal crash test protocols. These accident data were categorized by test type according to a set of narrowly defined real-world collision orientations. The crash test protocols were chosen based on commonly conducted international crash testing. The three test protocols considered were the offset deformable barrier (ODB), moving deformable barrier (MDB), and fixed rigid barrier (FRB). The ODB was established as a European Union (EU) test requiring a 40 percent overlap into a deformable, but fixed barrier. This test is best characterized by low accelerations, long duration crash pulses, and moderately high intrusions for the subject vehicles. National Highway Traffic Safety Administration (NHTSA) research has been developing the MDB test that consists of a moving cart with a deformable face impacting the front of a stationary vehicle at an oblique angle with a partial overlap. This test is characterized by short duration crash pulses, high accelerations, and high intrusions for subject vehicles. The final test protocol evaluated was the FRB test that has been used extensively, particularly in the U.S., because of Federal Motor Vehicle Safety Standard No. 208 and New Car Assessment Program (NCAP). This test type is best characterized by short duration crash pulses, high accelerations, and relatively low intrusions for the subject vehicles.

Accident data are analyzed by test protocol to establish the base population of injury-causing crashes that most likely would be addressed by each test. It should be pointed out that, depending on the individual crash test requirements, a given crash test protocol might address some of the same injuries from the other crash types. This analysis provides a rough estimate of the most likely population best addressed by each test protocol. In this analysis, total injury counts, as well as injuries by body region, are examined by crash test protocol.

INTRODUCTION

In order to determine the most effective crash test protocol for improving occupant self-protection, crash data were categorized by crash test protocol type, referred to as “test type.” The three test types considered were the ODB, the MDB, and the FRB. While all of the crash test types may be used to evaluate occupant injuries, this study attempts to determine the degree to which specific injuries are addressed by specific crash tests. The underlying assumption is that the closer the test type is linked to the crash environment, the better the resulting dummy response will be in evaluating the vehicle’s occupant protection potential for a given crash environment.

The crash environment considered in this study is the U.S., as represented by the National Automotive Sampling System-Crashworthiness Data System (NASS-CDS) data. Specifically, NASS-CDS data from 1995–2001 were used to determine the crash environment. Vehicles selected had to have a General Area of Damage (GAD1), primary= Front (F), with the other vehicle (in two vehicle collisions) having any known GAD related to the subject vehicle GAD—front, left, right, or back.

Specific NASS variables used to sort the data by test type were: *heading angles*; *object contacted*; relevant *GAD* of other contacted vehicle (when more than one vehicle is involved); specific horizontal location (*SHL*) of subject vehicle damage; *direct damage width* of subject vehicle; and *undeformed end width* of subject vehicle. *Heading angles* were used to determine the orientation of two vehicles at the time of impact. The object contacted determined if the crash was a vehicle-to-vehicle or vehicle-to-fixed object crash. The use of the relevant GAD of the other vehicle was used in combination with the heading angle to determine the vehicle-to-vehicle configurations. Relevant GAD of the other vehicle is defined as the damage area from the same collision that caused the subject vehicle frontal damage in cases where more than one collision occurred. Overlap, determined from *direct damage width* and *undeformed end width*, was used in combination with other variables to determine the effect of the crash configuration on the acceleration response (crash pulse) and intrusion. The following section will focus on the selection of crash orientations believed to be best duplicated by respective test types. Because of the lack of a comprehensive crash test database, especially at small overlaps and crash configurations (other than front-to-front), these definitions rely heavily on the author's crash-test experience and judgment.

CRASH ORIENTATION BY TEST TYPES

Crashes from NASS-CDS were grouped into three test types according to the definitions shown in **Tables 1–3**. These definitions are dependent on several NASS-CDS crash variables, as listed in the column heading of the tables. "Crash Type" in the first column is simply the object contacted, either another vehicle or a fixed object. In the second column, the "Damage Center" is known in NASS as the *SHL* of the subject vehicle's front end, either "C" for center front, "R" for right front, or "L" for left front. In the third column, the "Other GAD" is the relevant *GAD* for the other vehicle and is listed as "F" for front, "R" for right side, "L" for left side, and "B" for back. An "X" in any of the columns indicates that the parameter is not applicable (i.e., fixed object). The next two columns show the relative angles of impact between the velocity vectors of the two vehicles. The sixth and seventh columns describe the range of overlaps expressed as a percentage of the frontal width for the subject vehicle. The last column describes the test type combined with the *SHL* for the subject vehicle.

Table 1.

NASS parameters used to describe an ODB type test

Vehicle	L	B	-179	-135	0	39	ODB-L
Vehicle	L	B	135	180	0	39	ODB-L
Vehicle	L	F	-10	75	0	29	ODB-L
Vehicle	L	F	-90	-76	0	29	ODB-L
Vehicle	L	L	5	30	0	39	ODB-L
Vehicle	L	R	-175	-150	0	39	ODB-L
Object	L	X			0	29	ODB-L
Vehicle	R	B	-179	-135	0	39	ODB-R
Vehicle	R	B	135	180	0	39	ODB-R
Vehicle	R	F	76	90	0	29	ODB-R
Vehicle	R	F	-75	10	0	29	ODB-R
Vehicle	R	L	150	175	0	39	ODB-R
Vehicle	R	R	-30	-5	0	39	ODB-R
Object	R	X			0	29	ODB-R

Table 1 shows the crash configurations believed to be more closely associated with the ODB test. This crash vehicle is best characterized as having damage either to the left or right front of center. In addition, the angles are close to perpendicular, and the overlaps are very narrow to compare with the "soft" pulse resulting from the ODB crash test with a deformable fixed barrier [1,2]. For crashes into rear or side "softer" structures, NASS overlap range was increased to match these crashes to the ODB type crashes with similar overlap and crash pulse.

Figure 1 illustrates the ODB-type crash into a more rigid structure. This figure shows the range of angles and overlaps for this crash segment, and specifically corresponds to the crash type shown in the fourth row of **Table 1**.

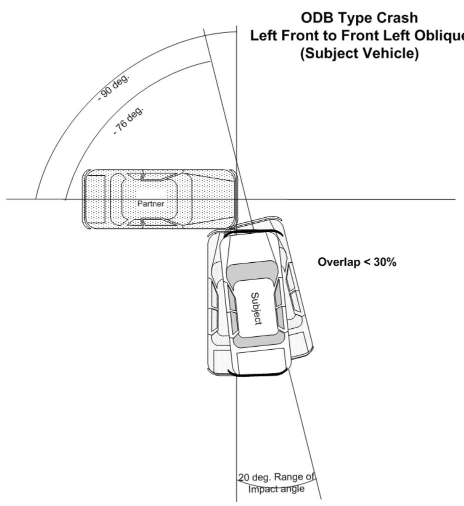

Figure 1. Crash configuration showing an example of ODB type left offset.

The maximum overlap is 29 percent for this case; but the 76 degree oblique angle increases the effective overlap by preventing decreasing overlap during crush. This effective increase in overlap is due to the angular motion of the vehicle, causing greater engagement as the crush increases. In ODB and car-to-car collinear-offset crash testing, conducted with no angular motion, it was observed that the actual overlap decreased significantly during the crush of the vehicle. This phenomenon is explained by the fact that the offset test produces lateral forces that tend to separate the vehicles during the crash. For completeness, the entire range of 0–29 percent were included in this group, though the occurrence of very small overlaps (less than 15 percent) was rare.

Figure 2 shows another example of the ODB type crash. In this example, the subject vehicle impacts in a more typical front-to-front configuration. In this crash type the angle can vary between -10 degrees and +75 degrees, with an overlap between 0–29 percent. In this example, oblique angles approaching +75 degrees increase the effective overlap, while angles approaching -10 degrees decrease the effective overlap. The average or median angle between the two extreme angles increases the effective overlap. This crash type is defined in the third row of **Table 1**.

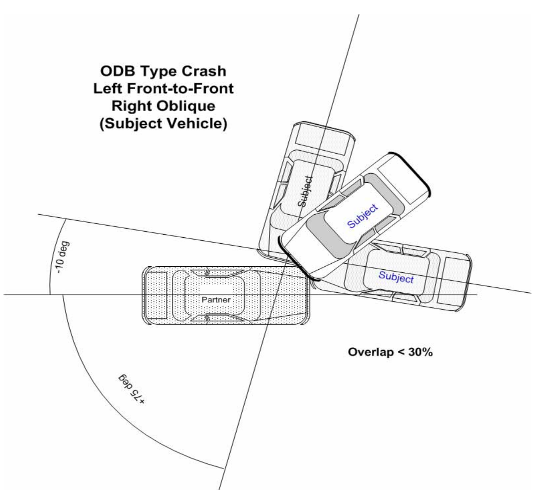

Figure 2. Crash configuration showing example of ODB type crash for a left offset, with an oblique angle.

Table 2 below shows the real world crashes most closely associated with full barrier crash test types. These crashes are best characterized with center ("C") damage to the subject vehicle with a narrowly defined range of impact angles and overlaps close to perpendicular and full engagement. **Figure 3** shows a typical example of a fixed rigid barrier crash configuration. This crash configuration is described in the third row of **Table 2**. An example of a front-to-rear crash is shown in **Figure 4** and is described in **Table 2** in the first and second rows. A front-to-side crash example is shown in **Figure 5**. In this case, the subject vehicle may hit near the front corner or along the left side of the partner vehicle. This crash is described by the parameters in the fourth row of **Table 2**.

Table 2.

NASS parameters used to define an FRB type crash

Crash Type	Damage Center	Other GAD	Low Angle	High Angle	Low Overlap	High Overlap	Test Type
Vehicle	C	B	-179	-135	86	100	FRB
Vehicle	C	B	135	180	86	100	FRB
Vehicle	C	F	-10	10	86	100	FRB
Vehicle	C	L	31	80	86	100	FRB
Vehicle	C	L	100	149	86	100	FRB
Vehicle	C	R	-149	-100	86	100	FRB
Vehicle	C	R	-80	-31	86	100	FRB
Object	C	X			86	100	FRB

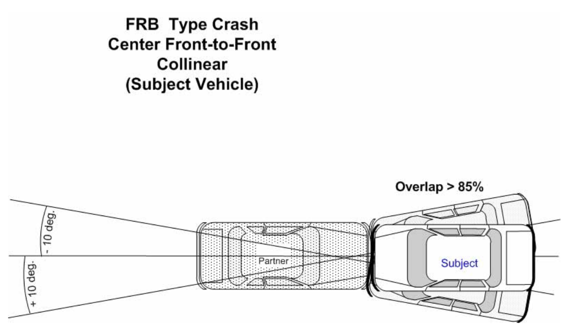

Figure 3. Crash configuration showing a typical example of a full-frontal, nearly full-engagement, head-on crash.

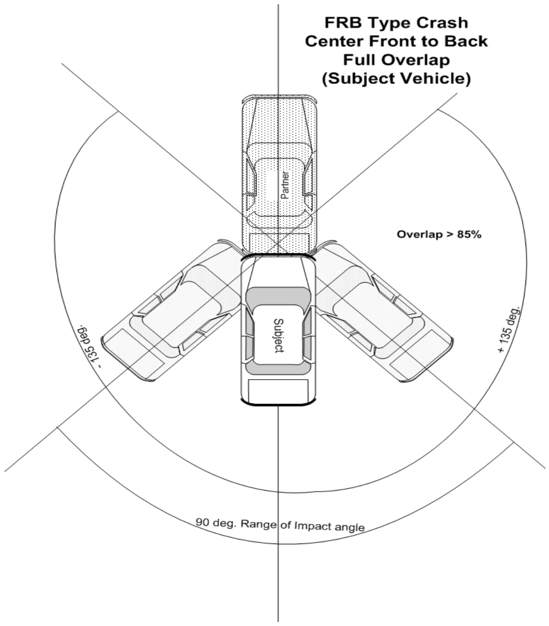

Figure 4. Example of a front-to-rear FRB type crash.

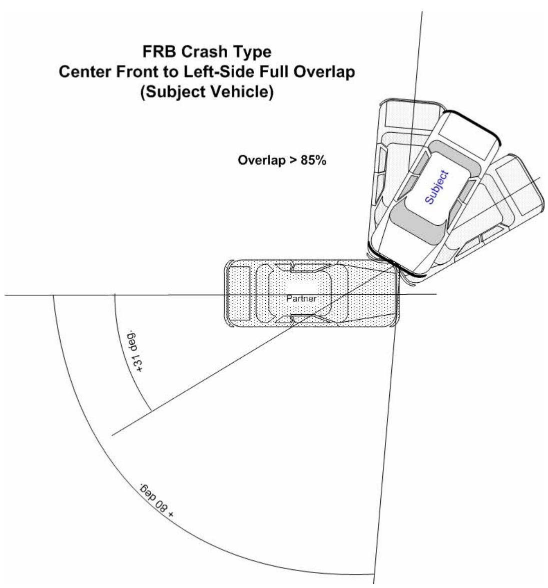

Figure 5. Typical example of a full engagement side or oblique front-corner impact

Table 3 lists the crash conditions best represented by the MDB. This type of crash is characterized by significant angles of impact with overlaps falling between those of the FRB and ODB type crashes.

An example of the MDB type impact is shown in **Figure 6**. This crash example is a right offset/oblique crash, as described in the 20th row of **Table 3**. This crash occurs when the subject vehicle strikes the left front corner of the other vehicle with an overlap to the right side and a positive oblique angle. The symmetrically opposite left offset/oblique crash is described in the 11th row of **Table 3**.

Another example of the MDB type crash is depicted in **Figure 7**. This crash occurs when the subject vehicle strikes the rear end of the other vehicle within a wide range of oblique angles and with a left overlap. This crash is defined in the first and second rows of **Table 3**.

All of the above-described MDB type crashes are differentiated from the similar ODB type crashes by larger overlaps (greater than 40

Table 3.

NASS parameters used to determine an MDB type crash

Crash Type	Damage Center	Other GAD	Low Angle	High Angle	Low Overlap	High Overlap	Test Type
Vehicle	L	B	-180	-135	40	100	MDB-L
Vehicle	L	B	135	180	40	100	MDB-L
Vehicle	C	B	-179	-135	40	85	MDB-L
Vehicle	L	F	-75	75	30	100	MDB-L
Vehicle	C	F	-75	-45	30	100	MDB-L
Vehicle	C	F	11	44	30	100	MDB-L
Vehicle	L	L	31	80	40	100	MDB-L
Vehicle	L	L	100	149	40	100	MDB-L
Vehicle	C	L	31	80	40	85	MDB-L
Vehicle	L	R	-149	-100	40	100	MDB-L
Vehicle	L	R	-80	-31	40	100	MDB-L
Vehicle	C	R	-149	-100	40	85	MDB-L
Object	L	X			30	100	MDB-L
Vehicle	R	B	-179	-135	40	100	MDB-R
Vehicle	R	B	135	180	40	100	MDB-R
Vehicle	C	B	135	180	40	85	MDB-R
Vehicle	R	F	-75	75	30	100	MDB-R
Vehicle	C	F	-44	-11	30	100	MDB-R
Vehicle	C	F	45	75	30	100	MDB-R
Vehicle	R	L	31	80	40	100	MDB-R
Vehicle	R	L	100	149	40	100	MDB-R
Vehicle	C	L	100	149	40	85	MDB-R
Vehicle	R	R	-149	-100	40	100	MDB-R
Vehicle	R	R	-80	-31	40	100	MDB-R
Vehicle	C	R	-80	-31	40	85	MDB-R
Object	R	X			30	100	MDB-R

percent). They also are differentiated from other MDB type crashes with a minimum overlap of 40 percent rather than 30 percent, to compensate for the relative “soft” pulses typical of impacts into rear and side “soft” structures.

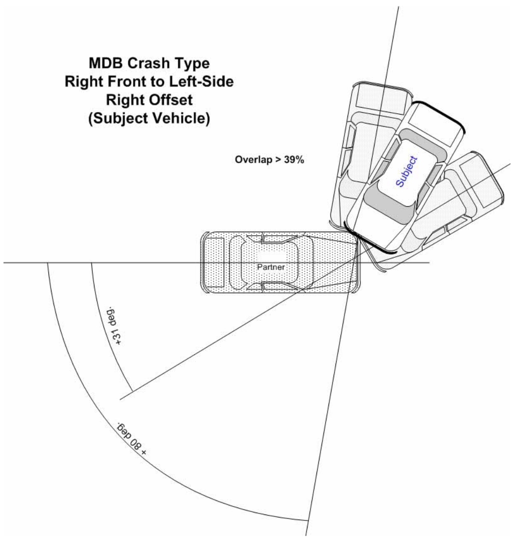

Figure 6. Example of an MDB type crash with a right oblique right offset configuration

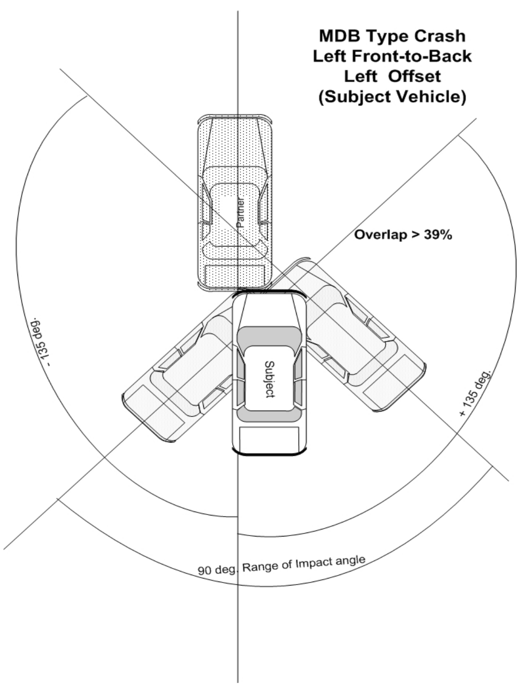

Figure 7. MDB type front-to-rear crash configuration

An example of a “stiff” pulse MDB type crash is shown in **Figure 8**. This crash is shown in the fourth row of **Table 3**, with left front damage, a wide range of angles (-75 degree to +75 degree and a minimum overlap of 30 percent. The overlap range for this type of crash includes a lower minimum overlap to compensate for the stiffer structure of the opposing vehicle. Some of the subject vehicles in these stiff pulse crashes have ‘C’ damage. These MDB crashes are differentiated from the FRB type crashes by having an oblique angle.

CRASH DATA

Analyzing seven years of NASS-CDS data (1995–2001), according to the preceding definition of crashes, allows us to examine each of the test protocols in terms of accident exposure and injuries. Analyzing the data by non-air bag and air bag vehicles serves as a prediction tool for future all-air bag fleets of vehicles.

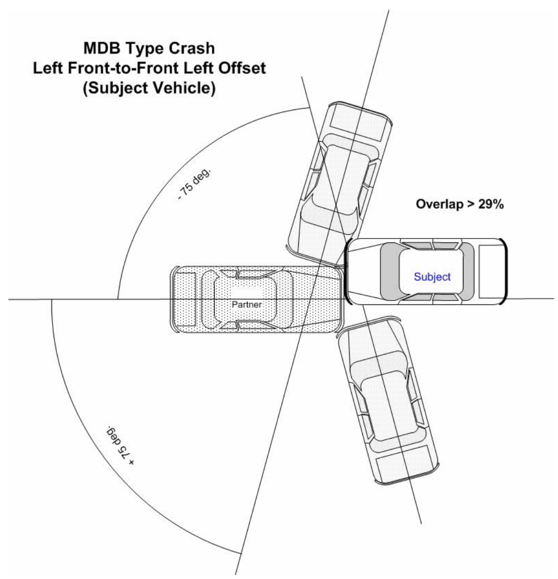

Figure 8. MDB front-to-front crash configuration

First, looking at accident exposure, **Figure 9** shows the number of crashes that occur by crash type and air bag availability. This chart shows that most crashes involve configurations related to the MDB type test. This chart also shows a slightly higher incidence of non-air bag crashes than air bag crashes. Since the current sale of new light duty vehicles is 100 percent air bag equipped, obviously the number of subject crashes will approach 100 percent in the near future. For this reason, the following analysis will focus mostly on air bag-equipped vehicles.

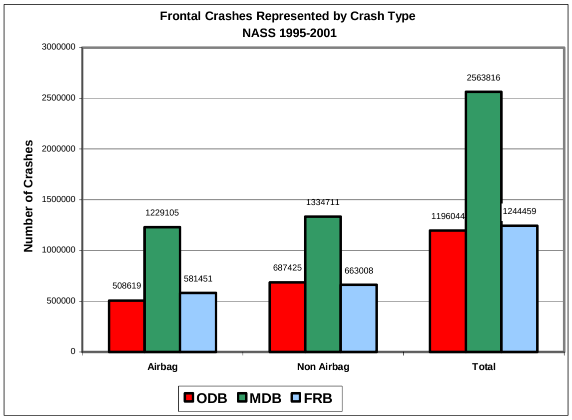

Figure 9. Accident exposure by crash type and air bag availability.

INJURY DATA

Next, looking at injuries, **Figure 10** shows overall injuries by crash type and air bag availability. Just as in the case of accident exposure, the injury count shows the MDB-type crash exceeding either of the other two crash types. Another way of looking at the accident data is by the risk posed by the three crash types. Risk is the relative probability of receiving an injury calculated by normalizing for exposure. Risk is useful to determine the crash type most likely to cause injury, but it should be viewed in conjunction with the total number of injuries or the exposure to crash types. The risk comparison is shown in **Figure 11**. This figure shows that the probability of receiving an injury is highest in the MDB crash type, with the ODB risk slightly higher than the FRB crash type.

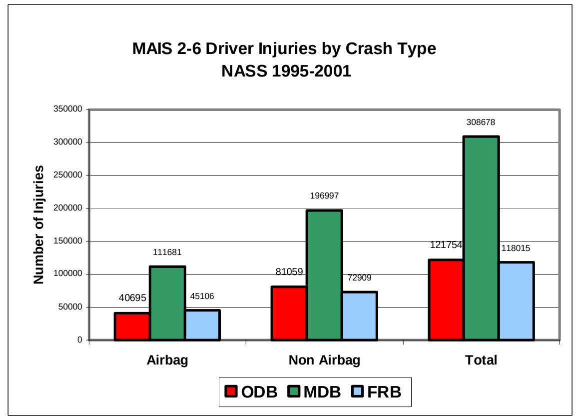

Figure 10. MAIS 2-6 Injury distribution by crash type and air bag availability.

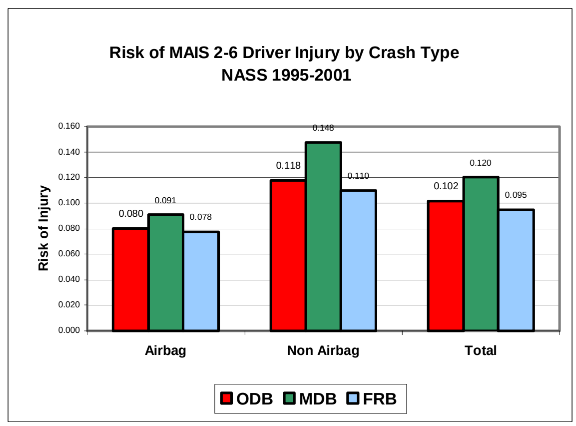

Figure 11. Risk of injury by crash type and air bag availability.

As mentioned previously, most of the analysis will focus on air bag-equipped vehicles. However, another variable affecting occupant protection is the usage of belts with air bags. **Figure 12** shows the usage rate for the NASS-CDS data.

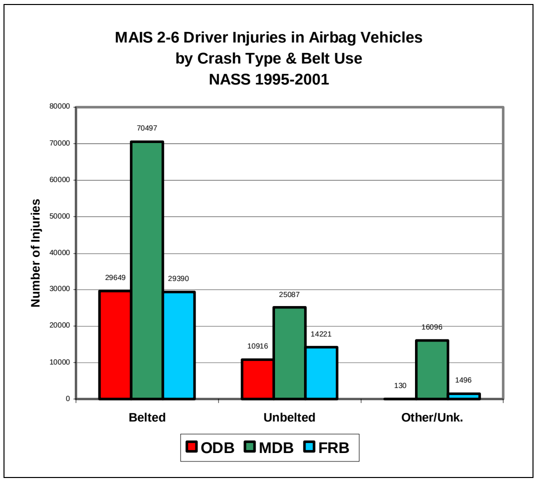

Figure 12. Distribution of belt use for the crash types.

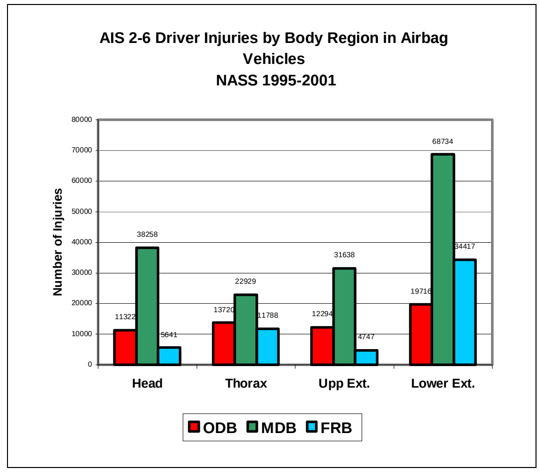

Figure 13. Distribution of driver injuries by body region for air bag-equipped vehicles.

As can be seen from this graph, the majority of air bag-restrained occupants in the study were belted. Of those with known seat-belt usage, 72 percent were wearing belts. Additionally, the trend for seat-belt usage appears to be increasing. This is good news, not only in terms of occupant protection, but also for designers in allowing optimization of occupant protection systems for belted occupants.

INJURY DATA BY BODY REGION

To examine the data by injuries received for each of four major body regions, **Figure 13** shows the number of AIS 2-6 injuries for the head, the thorax, the upper extremities, and the lower extremities. Much of recent testing has focused on injuries to the lower extremities, because they were not well addressed by traditional barrier crash testing. In fact, the ODB type test was designed primarily to address lower extremity injuries. **Figure 13** shows the distribution of these body-region injuries by crash type for air bag-equipped vehicles. This distribution determines the extent to which each crash type contributes to lower extremity and other body-region injuries. The MDB test type overwhelmingly exceeds the other two test types in all injury categories, particularly for head and lower extremity injuries.

Figure 14 examines the risk of body-region injuries by belt use. Risk is calculated by dividing the number of each body-region injury by the total number of drivers, either belted or unbelted, in each crash type. Only air bag vehicles were included in the data samples to avoid confounding results and to address the population of future vehicle fleets. This analysis assumes all occupants in all crash types are belted at the 72 percent level, as previously calculated for the overall population of drivers in crashes. Due to the smaller sample sizes of each segment shown on the chart, this assumed belt use may not be consistent and may lead to somewhat erroneous conclusions.

Several interesting observations can be made from this graph. The first obvious conclusion is that the risk of injury for most body regions is higher for unbelted drivers, as would be expected. One exception is for upper extremity injury risk, which is shown to be lower for the unbelted driver. No logical explanation could be found for this anomalous behavior, except for errors in assuming consistent belt usage rates for the overall crash population, as previously discussed. Another exception is that the risk of injury to the lower extremity for the MDB type crash remains nearly the same in both the belted and unbelted data. One explanation for this apparent anomaly is that toepan intrusion is the primary injury mechanism, rather than the occupant inertially loading the toepan through the foot. This hypothesis appears to be confirmed by looking at the comparison of belted to unbelted FRB type crashes, in which the risk is reduced by belt use. In FRB crashes, the inertial loading injury mechanism is predominating, rather than intrusion. Therefore, by restraining the occupant by belts as well as the air bag, the inertial loading through the foot is reduced, as is shown by a reduction in risk.

The risk of injuries for the lower extremities is higher than for other body regions. The risk of injury to the lower extremity for the belted occupant is slightly higher for the MDB crash type than the FRB crash type, but both are much higher than the ODB crash type. When this risk factor is coupled with the higher number of MDB crash types, the MDB crash type can be shown to contribute to the majority of lower extremity injuries.

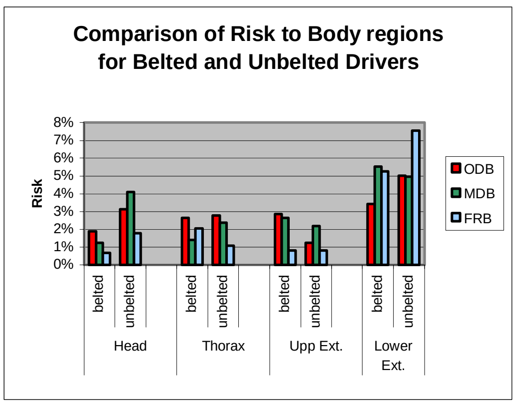

Figure 14. Comparison of risk for belted and unbelted drivers for each of four body regions and three crash types.

Figure 15 shows the number of injuries by body region that are attributed to the three crash types. Because of the focus on injuries to belted occupants, **Figure 15** only includes injuries to belted drivers in air bag-equipped vehicles. It is readily seen from this chart that the largest number of all body-region injuries occur in MDB type crashes, with lower extremity injuries in MDB type crashes far exceeding the other two crash types.

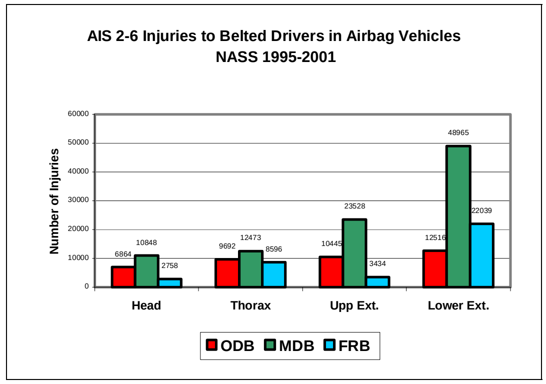

Figure 15. Injuries to belted drivers by body region for crash types.

SUMMARY AND CONCLUSIONS

To better understand the crash environment relative to crash test types, this paper attempts to sort NASS-CDS crash statistics by crash type. The variables used to distinguish the crash types were angular orientations of two vehicles in vehicle-to-vehicle crashes, overlap of the direct damage, general area of damage (front for the subject vehicle and all areas for the opposing vehicle in vehicle-to-vehicle crashes), and the specific area of damage for the subject vehicle (right, left, or center of the front). Both fixed-object and vehicle-to-vehicle crashes were considered.

The study found MDB type crashes to be the predominate cause of both overall injuries and injuries to the lower extremities for the target population of air bag-equipped vehicles with belted drivers. Only driver injuries were considered in the study since it was necessary to extract the largest representative sample of vehicle crashes that involved at least one occupant. It also may be concluded that belts have little if any influence on reducing lower leg injuries to drivers in MDB type crashes, thereby suggesting the influence of intrusion and not inertial loading on the lower leg. This finding is important in showing that the MDB test procedure, combined with appropriate injury criteria, is the most effective crash test to evaluate and thus mitigate lower leg intrusion related injuries.

Further analysis needs to be performed with crash testing, finite element analysis, and distribution of crash data by crash-test type and specific parameters, such as orientation angles. Some of these analyses will require a larger base of data to provide a more representative sample.

The user of this study should be cautioned in using the results to select an appropriate, real-world crash test protocol. While this study attempts to sort the crash data into established crash test protocols, no one protocol can be 100 percent effective in evaluating all the crashes considered within that crash type. For instance, while there are certain commonalities associated with a fixed-barrier test, one test will not address all the occupant protection issues for fixed-object crashes. Conversely, while one fixed-barrier test may address some of the issues for fixed-object crashes, it also may address some of the issues for offset and oblique vehicle-to-vehicle crashes.

With that said, the MDB proves the most promising test protocol to address the largest number of injuries inadequately addressed by currently employed test types.

ACKNOWLEDGEMENTS

The author would like to thank Sue Partyka of NHTSA and Osvaldo Fessahie from ISSI for their patience and cooperation in providing NASS-CDS data using SAS analysis software. The author is also grateful for the valuable editorial comments and assistance provided by Heather Ragland, technical editor.

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