December 30, 1999

The Honorable Rosalyn G. Millman
Acting Administrator
National Highway Traffic Safety Administration
400 Seventh Street S.W.
Washington, D.C. 20590

49 CFR Parts 552, 571, 585, and 595
Federal Motor Vehicle Safety Standards;
Occupant Crash Protection
NHTSA Docket No. 99-6407, Notice 1

Dear Ms. Millman:

In September 1998 the National Highway Traffic Safety Administration (NHTSA) proposed to upgrade Federal Motor Vehicle Safety Standard (FMVSS) 208 to address risk to out-of-position occupants from inflating airbags and to upgrade occupant protection in high-speed frontal crashes. This was an ambitious and complicated rulemaking that attempted to expand the range of occupants who would be protected. For the first time the agency proposed to add a 5th percentile female Hybrid III dummy to existing high-speed crash test requirements. In addition, neck injury measures and a new chest trauma index were proposed. Dummies representing small females, infants, and three- and six-year-old children were included in a variety of test alternatives proposed to reduce risks from inflating airbags. Finally, NHTSA's Notice of Proposed Rulemaking (NPRM) sought to remove the option of certifying unbelted frontal crash protection using the generic 30 mph sled test. This meant that, once again, the 30 mph rigid-barrier crash test would be the only allowable method of certification for unbelted occupants.

In earlier comments to these proposals, the Insurance Institute for Highway Safety has strongly supported efforts to better assure that FMVSS 208 requirements benefit small adults as well as average-size males. We also have supported the establishment of test requirements to minimize the risk of inflating airbags to out-of-position occupants (Insurance Institute for Highway Safety, 1998). In this Supplemental Notice of Proposed Rulemaking (SNPRM), the agency has simplified proposed test requirements designed to minimize the risk from airbags because of concerns that the testing burden was unrealistic and overly complicated. The Institute believes the agency's actions in this regard are well reasoned; requirements to minimize injury from inflating airbags, as outlined in the SNPRM, are adequate. The test matrix focuses on the appropriate population at risk and provides a choice of test procedures that should allow manufacturers to be flexible in their technological approaches to address airbag problems. Therefore, the Institute continues to support the agency’s proposals to minimize risks from deploying airbags.

Proposed Injury Criteria
The agency also proposes in its SNPRM additional revisions to the injury criteria proposed in the NPRM. These include:

- adopting a 15 ms head injury criterion (HIC_{15}) with a limit of 700 in place of the previous 36 ms head injury criterion (HIC_{36}) with a limit of 1000;
- discarding the proposed chest trauma index in favor of individual limits on chest acceleration and deflection; and
- modifying the neck injury index (n_{ij}) by changing the allowable neck tension and compression forces.

The Institute supports HIC_{15} with the limit of 700. HIC_{15} already has been accepted by the Canadian Department of Transport and is more consistent with the biomechanical data upon which HIC is based. However, this revision does not address the role of head rotation in serious head and neck injury; NHTSA therefore should pursue research to establish appropriate limits on this potentially important source of serious injury. Such a measure could be particularly important in assessing injury to the smallest out-of-position occupants, among whom closed head injuries have been observed under conditions that have produced high rotational accelerations in Institute tests with dummies (Zuby and Powell, 1999).

The Institute also supports NHTSA’s revised treatment of chest injury, although with reservations about the continued use of spinal acceleration to assess chest injury. As the agency is aware, the injuries observed in crashes generally result from deformation of the chest, which can be measured in the Hybrid III family of dummies by monitoring chest deflection and deflection rate or the viscous criterion. In contrast, chest acceleration is a coarse measure of the restraining force experienced by a dummy and does not take into account how the forces are distributed and hence the amount of deformation it causes. Some test programs have provided examples in which spinal accelerations are high, but chest deflection is within acceptable limits, and vice versa. This suggests that the use of spinal acceleration could place unnecessary restrictions on restraint system designs that are, in fact, protective in regard to thoracic injury in frontal crashes. Alternatively, it could provide unfounded confidence that risk of serious internal organ injury is low. For these reasons, other test programs (for example, EuroNCAP, Canadian Department of Transport) no longer consider spinal acceleration in the assessment of thoracic injury likelihood. Thus, although the Institute supports NHTSA’s current proposals for measuring thoracic injury, it urges the agency to reconsider as soon as possible its continuing reliance on spinal acceleration.

The Institute supports the addition of neck injury criteria to FMVSS 208. However, the maximum tension forces allowed by the current proposal are troublesome. This is especially the case for small female and midsize male dummies, for whom the proposed tension limits were raised, compared with the limits specified in the NPRM, without sufficient biomechanical evidence of the appropriateness of the new limits. The Institute also is concerned about the neck tension limits proposed for 12-month, 3-year-old, and 6-year-old dummies that will be used in out-of-position testing. The goal of out-of-position testing is to assure that fractures at the junction of the head and neck no longer occur. The neck tension limits proposed in the SNPRM could allow neck forces that have been associated with serious and fatal injury in biomechanical tests with pigs. However, the Institute also recognizes that the proposed combination of limits on neck axial forces and bending forces would have excluded all cases of biomechanical tests with serious neck injury. Therefore, we support the agency’s neck injury proposal in the SNPRM, but NHTSA should closely monitor the adequacy of these limits.

Return to Unbelted Crash Testing

The most contentious issue in the SNPRM is the proposed return to full-scale crash tests for the certification of unbelted occupant protection in frontal crashes. Although we understand NHTSA’s desire to assure unbelted occupant protection to the extent possible, we do not agree that a high-speed barrier test using unbelted dummies will necessarily lead to improved protection for any occupants, belted or unbelted. In particular, we have grave concerns about the reinstatement of a test procedure that might result in some vehicles having airbag inflator power levels that in the last few years have resulted in too many unnecessary deaths and injuries to occupants in low-speed crashes.

If NHTSA determines that a return to high-speed unbelted crash testing is unavoidable, the Institute would support one of the three options proposed by the agency -- the full-front rigid-barrier test (perpendicular and ±30 degrees) at 25 mph for unbelted occupants, 35 mph for belted occupants. Our support is based on several factors. First, for most vehicles the 25 mph test provides a crash pulse only marginally more severe than the 30 mph generic sled pulse; as a result, the unbelted test provision should not force a return to the overly energetic airbag designs of the past. In addition, the front and front-angle tests should be marginally useful in assessing airbag sensor performance. Finally, increasing the speed of the full-front barrier test for belted occupants from 30 to 35 mph can be expected to accelerate the improvement of frontal crash protection afforded by light trucks. Although many vehicles already perform well in NHTSA's New Car Assessment Program, which includes full-front barrier crash tests with belted occupants at 35 mph, light trucks have been an exception. Their stiff frames and short front ends (relative to their mass) have led to short crash pulses that make it difficult to design effective, nonaggressive airbag systems. The Institute expects that one result of subjecting all passenger vehicles to a 35 mph belted requirement would be a softening of the front ends of light trucks. This development would benefit not only the occupants of light trucks but also the occupants of other vehicles with which the trucks collide. To maximize the likelihood that structural changes, rather than more aggressive airbag systems, would be incorporated to meet the new requirements of FMVSS 208, the Institute urges NHTSA to consider a longer phase-in for full compliance of light trucks if a 35 mph belted crash test requirement is adopted.

No Return to 30 mph Unbelted Crash Test

The Institute's support for the 25/35 option should not be interpreted as support for NHTSA's position that an unbelted crash test requirement is necessary or, indeed, useful in improving occupant protection in frontal crashes at this time. Indeed, the Institute continues to question the agency's logic in this regard, and we strongly object to any suggestion of returning to testing for unbelted protection with crash pulses as severe as the 30 mph rigid-barrier test.

NHTSA claims that, unless it returns to this test, airbags will offer inadequate protection to many unbelted occupants, especially large people in more severe frontal crashes. This claim is based on flawed analyses of the dynamics of unbelted occupants in real-world crashes. In a number of studies of airbag performance in moderate to severe frontal crashes, the Institute has shown that drivers are not dying because airbags offer too little protection (Cammisa et al., in press; Ferguson, 1996; Lund et al., 1996); rather, drivers are dying because of overwhelming intrusion that no airbag design can overcome, ejection of occupants, or because of injury from the airbag itself.

These observations call attention to two flaws in the agency's logic for returning to the 30 mph unbelted test. First, if airbags were not powerful enough, there should be some real-world cases in which the energy of deploying bags was inadequate to protect individuals in otherwise survivable frontal crashes. The Institute is not aware of any such cases.

The agency's own review of real-world data appear to support this conclusion. NHTSA's estimates of the additional people who would be expected to die as a result of airbag depowering as manufacturers certified their vehicles using a 30 mph sled test instead of the 30 mph unbelted barrier test have varied enormously. In December 1996, the estimate of lives lost ranged from 328 to 1,182; in February 1997, 46 to 409; in August 1998, 335 to 405. The most recent estimates in the SNPRM range from 214 to 722 lives that would be lost. However, despite anticipation that a large number of additional lives will be lost, during the two years the sled test option has been allowed, NHTSA has provided no real-world evidence to support the increased loss of life. Airbag energy levels have been reduced on the driver and passenger side since the 1998 model year, but there are no data indicating additional occupant deaths. Moreover, the Preliminary Economic Assessment that accompanies this rulemaking reports no reduction in the effectiveness of 1998 models compared with 1996 and 1997 models for unbelted or belted occupants. Thus, the agency’s concern that airbags certified to the unbelted generic sled pulse will be less effective in frontal crashes has no foundation in real-world crash data.

A second problem is that NHTSA repeatedly has failed to appreciate that serious and fatal injuries from deploying airbags are happening not only in low-speed crashes but also in the high-speed crashes in which airbags are supposed to be most effective. A recent update (including 1996 data) of Institute analyses of driver fatalities in airbag-equipped cars indicates airbags were the most likely source of the fatal injuries in about 15 percent of frontal crash deaths (Cammisa et al., in press). How can this occur if the unbelted test that certified these airbag systems is protective of unbelted occupants? The answer is that such systems are protective of only some occupants who are not using belts. In the real world, the positions of unbelted occupants are unpredictable. Unlike the unbelted barrier test, in which dummies always are sitting back in the seat in a position to ride down a fully inflated airbag, unbelted people in high-speed crashes often are close to their airbags during inflation because of braking before impact, previous but less severe impacts, or late firing of the airbags. As a result, only some unbelted occupants in severe real-world crashes will benefit from airbags that certify to the more severe 30 mph barrier test; other occupants likely will be out of position and potentially will be injured when airbags deploy. The agency’s estimates of the additional lives that would be lost if manufacturers certify to the generic sled pulse make no allowance for the fact that in about 15 percent of the deaths in frontal crashes of vehicles certified to the barrier test, the fatal injuries were caused by airbag energy. NHTSA must account for these deaths, as well as those more easily documented in low-speed crashes, before it can justify a return to the 30 mph unbelted full-front crash test.

Unwarranted Faith in Technological Advances

The agency’s rationale for returning to the 30 mph unbelted barrier test may be based on the assumption that auto manufacturers will solve the problem of serious and fatal airbag injuries by using appropriate advanced technologies. For example, dual-stage airbags could have a benign first deployment stage to minimize airbag injuries in low-speed crashes and a more powerful second stage than current levels to protect people in crashes at higher speeds. Unfortunately, this assumption ignores the fact that people are sustaining serious and fatal injuries from airbags in high-speed crashes. As currently proposed, the test procedures designed to minimize harm to occupants would require manufacturers to certify that any stage or combination of stages that would be deployed in crashes of 18 mph or slower meet the specified injury criteria. However, until more advanced technology is available to detect occupant position in real time during a crash, more powerful second stages would be deployed in high-speed crashes involving unbelted occupants who are out of position. If these airbags are too energetic, the occupants will be at risk of serious airbag injuries. It is ironic that the very people intended to be protected by the proposed rule change -- unbelted occupants in high-speed crashes -- are those most likely to be out of position and injured by their airbags. Some belted occupants also may be injured.

NHTSA crash tests indicate that some vehicles may meet the unbelted 30 mph barrier test without adding more energy to the airbags; yet the agency must recognize that this may not be possible in all, or even most, cases. When compliance becomes difficult, it will be far too easy for manufacturers to meet the 30 mph unbelted test requirement by increasing airbag inflation energy (or the second stage of the airbags). Nothing in the proposed standard would prevent this.

The agency also appears not to appreciate that two-stage inflators, as currently designed, bring new problems along with their partial solutions to the airbag injury problem. One goal of such inflators is to make sure high-energy inflation (second stage) does not occur until higher crash severity thresholds when more power is needed to protect occupants. However, higher severity thresholds also mean longer delays in an airbag system’s decision to deploy at all. This will result in a delay in the first stage of deployment as well, because the decision to deploy the second stage is actually a choice between low and high energy. Thus, although two-stage inflators provide the possibility of low-energy deployments that reduce injury risk to out-of-position occupants in low-severity crashes, they also provide new challenges to sensors -- deployment decisions will need to be made late enough to ensure that the second stage is not needed but not so late that occupants are so far out of position that the first stage is ineffective.

Although two-stage inflators are not the only advancements to improve airbag performance, the Institute is unaware of any technology without shortcomings. Even the simplest technology -- seat sensors that detect when children are riding in front seats and suppress passenger airbag deployments -- are unproven. It is foolhardy to rely on unproven technology to offset the proven risk of unnecessarily high-energy airbag inflation.

The Future of FMVSS 208: Preventing Intrusion Injuries
The agency is proposing a third alternative test procedure for assessing unbelted occupant protection -- a full-width rigid-barrier test for belted occupants, most likely at 30 mph, coupled with a 30-35 mph offset deformable barrier test for unbelted occupants. The Institute argued in earlier comments that NHTSA should consider such a test if it determines that a return to unbelted crash testing is absolutely essential. The primary justification is that the offset test directly addresses the problem of intrusion in frontal crashes far more effectively than either the full-front or angle-barrier tests currently specified in FMVSS 208. Analyses by both NHTSA and the Institute of frontal crash injury risk indicate the critical importance of intrusion, and it is one of the agency's stated reasons for abandoning the generic sled pulse, which provides no assessment of vehicle intrusion.

The Institute believes NHTSA should focus on adoption of offset test procedures in future efforts to further improve occupant protection in frontal crashes. For purposes of international harmonization, it would be logical to use the deformable barrier test procedure already in use in Europe, Australia, and the United States. However, this procedure would not make a good candidate for assessing unbelted crash protection within the timetable of this rulemaking. The offset test, when coupled with a deformable barrier, presents crash detection problems for airbag sensors that are made especially difficult by the need to manage the energy of an unbelted occupant. There are three potential solutions to these sensor problems:

- develop new sensor technology or vehicle structures that increase the predictability and discrimination of the offset test crash pulse;
- increase airbag inflation energy, so if the severity of a crash is detected late the airbag can still inflate quickly enough to cushion an unbelted 50th percentile male moving out of position; or
- decrease the deployment threshold for high-energy airbags to make sure the bags deploy in offsets.

The first possibility is the preferable solution, but its success is uncertain. The latter two move airbag designs in undesirable directions. The second potential solution would produce airbags that may be unnecessarily powerful and therefore risky to out-of-position occupants. The third option would result in many additional deployments of moderately high-energy airbags in crashes in which airbags are not needed. Therefore, the Institute does not recommend the offset deformable test for the assessment of unbelted crash protection at this time.

Conclusion
The Institute urges NHTSA to more closely consider real-world experience with airbags. This experience shows that airbags certified to the generic sled test have reduced the risk of serious injury in frontal crashes; at the same time, there is no evidence that airbag effectiveness in reducing fatalities has declined. NHTSA has expressed concerned that, without a severe crash test for unbelted occupants, manufacturers may reduce airbag inflation energy, or the size of airbags, thereby compromising their effectiveness. The fact is, however, that such changes are constrained by other crash tests to which manufacturers are subject. The New Car Assessment Program’s belted 35 mph frontal crash test requires that airbags be reasonably deep in order to prevent dummies’ heads from striking through the bags. Offset crash testing by the Institute and others worldwide means manufacturers must continue to install airbags with sufficient radial size to keep occupants squarely behind their airbags, even under conditions of sharp vehicle rotation.

Current experience with airbags does not call for dramatic action by the agency. Rather, what is needed is careful fostering of the evolution of technology that already appears to be working. It is reasonable to require that benefits for small adults be demonstrable in crash tests. It is reasonable to facilitate efforts to further reduce the risks of airbag inflation injury to out-of-position occupants in low-speed crashes. The addition of neck injury criteria to the testing protocol to better reflect the kinds of injuries we are seeing in airbag-equipped vehicles also makes good sense. However, it does not make sense to require the 30 mph unbelted flat-barrier test with its uncertain benefits for the very people it is intended to protect.

Sincerely,

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cc: Docket Clerk, NHTSA Docket No. 99-6407, Notice 1

Attachment: Cammisa et al., in press

References

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Driver Fatalities in Frontal Crashes of Airbag-Equipped Vehicles: A Review of 1989-96 NASS Cases

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ABSTRACT

Using data from the National Automotive Sampling System/Crashworthiness Data System (NASS/CDS) for 1995-96, this study updates previous analyses of driver fatalities in airbag-equipped vehicles in the NASS/CDS database for 1989-93 and 1989-94. A total of 59 cases of frontal crashes of airbag-equipped vehicles with driver fatalities were identified in these 8 years of NASS/CDS data, but in 9 cases the fatalities were not related to the impacts (e.g., fire, medical condition). Vehicle intrusion was the cause of the fatal injuries in 27 cases, and 7 drivers died from injuries sustained when they were either partially or totally ejected from their vehicles. There was one case in which the airbag did not deploy, although the crash conditions indicated it should have. One driver died from contact with a nonintruding vehicle surface, and the causes of the fatal injuries in 5 cases were unknown. There were no cases in which drivers died because airbags had insufficient power to prevent the fatal injuries, although in one of the vehicle-intrusion-related fatalities the airbag deployed in the first of two impacts and thus was not able to protect the driver throughout the crash sequence. There were 9 cases in which airbags likely contributed to the drivers' fatal injuries. Seven of these occurred in higher severity crashes with delta Vs greater than 30 km/h (20 mi/h), one was in a crash with a delta V of 26 km/h (16 mi/h), and one had an unknown delta V.

INTRODUCTION

Beginning in model year 1999 (vehicles manufactured on or after September 1, 1998), all new passenger cars, passenger vans, utility vehicles, pickups, and large/cargo vans with gross vehicle weight ratings of 3,856 kg (8,500 lb.) or less and unloaded vehicle weights of 2,495 kg (5,500 lb.) or less sold in the United States are required to have driver and passenger airbags for frontal crash protection [1],* but many manufacturers installed airbags in their vehicles prior to the requirement to do so. As of May 1999, more than 87 million of the 200 million passenger vehicles on U.S. roads have driver airbags; more than 59 million of these also have passenger airbags. Currently, about 1 million airbag-equipped vehicles are added to the U.S. vehicle fleet each month, and it is estimated that driver airbags have deployed in more than 3.3 million vehicle crashes in the United States through December 1998 [2].

Airbags save lives and mitigate the severity of serious injuries associated with motor vehicle crashes [3-7]. It is estimated that deaths in frontal crashes are reduced 26 percent among drivers using seat belts and 32 percent among drivers not using belts [4]. The risk of serious and moderate head injuries is reduced 75 percent for drivers using lap/shoulder belts in airbag-equipped vehicles compared with a 38 percent reduction for drivers protected by belts alone [3].

Despite the overall effectiveness of airbags in preventing fatalities, some very severe crashes occur in which the airbag is unable to prevent fatal injuries, and there have been some instances where airbags have been identified as the source of injuries [8,9], including deaths to drivers [8,10,11] and passengers [11,12]. The National Highway Traffic Safety Administration's (NHTSA) Special Crash Investigation (SCI) program has reported that through April 1, 1999 there have been 132 deaths caused by airbags in low- to moderate-severity crashes, comprising 52 drivers, 6 adult passengers, 58 children, and 16 infants [11].

*Numbers in brackets designate references at the end of the paper.

The basis for the effectiveness of airbags is their ability to deploy early in the crash so the fully inflated airbag can dissipate the frontal crash forces experienced by the driver over a larger body area, gradually decelerating the occupant's head and torso and preventing contact with other interior surfaces. To accomplish this, the airbag must deploy rapidly (in less than 0.05 sec.); consequently, an occupant positioned extremely close to the airbag module at the time the airbag begins to inflate is exposed to highly localized forces that can cause serious injury or death. Fatal injuries to the chest, neck, and brain have been identified with these out-of-position or near-position occupants.

Primarily in response to the SCI program's identification of deaths due to airbags in low- and moderate-severity crashes, NHTSA modified Federal Motor Vehicle Safety Standard (FMVSS) 208 in March 1997 to permit the installation of less aggressive airbags. Although depowered airbags will not eliminate airbag injuries, it is expected that such systems will reduce airbag-related fatalities among out-of-position occupants.

Using the most recent data available from the National Automotive Sampling System/Crashworthiness Data System (NASS/CDS), this study updates two previous analyses of driver fatalities in airbag-equipped vehicles [13,14] to determine if there is any evidence that airbags fail to protect drivers in frontal crashes, either because the airbag had insufficient energy to restrain the driver's forward movement or because the airbag contributed to injury. Because there are relatively few cases in NASS of passenger fatalities in frontal crashes of vehicles equipped with passenger airbags (six in calendar years 1989-96 [14]), this analysis and the two previous studies that it updates consider only driver fatalities in airbag-equipped vehicles. (For a preliminary analysis of passenger airbag effectiveness, see Ferguson [15].) Although manufacturers began installing passenger airbags before government mandates, there is much less exposure for passenger airbags than driver airbags because there are fewer vehicles equipped with passenger airbags, and in about two-thirds of vehicle trips the right front seat is unoccupied [16]. All of the vehicles in this study were manufactured prior to the March 1997 modifications to FMVSS 208, because the NASS database had not been updated with crashes that occurred after calendar year 1996 at the time of this review.

METHODS

Fifty-nine cases were identified in the NASS database for calendar years 1989-96 in which a driver death occurred in a model year 1990 or newer airbag-equipped vehicle in a crash where the principal crash event was a frontal impact. Included are 15 frontal impact cases from an earlier study of all driver fatalities in airbag-equipped vehicles in the 1989-93 NASS database [13] and 10 frontal cases from 1994 NASS data, which were reviewed as part of a study of airbag performance in the United States [14].

Publicly available NASS case materials were reviewed for each of the fatalities identified. Case materials included data collection forms describing the crash circumstances (e.g., vehicles involved, objects impacted), interior vehicle damage (including possible occupant contact points and measurements of occupant compartment intrusion), and exterior vehicle damage (used to estimate crash severity). Photographs (slides) of the crash site and the interiors and exteriors of the vehicles involved are included in most cases.

In the earlier studies of NASS cases [13,14], the fatal injuries were classified into one of six categories: intruding vehicle surface, nonintruding vehicle surface, airbag, ejection, nonimpact related, and unknown. This paper adds a seventh category, nondeployment of airbag, to include fatal crashes in which airbags failed to deploy when crash conditions indicated they should have.

RESULTS

Figure 1 shows the distribution of the 59 cases by the seven cause-of-death categories. Intrusion-related injuries were the most prevalent cause of death, accounting for 27 fatalities (46 percent). Airbag-related injuries accounted for 9 deaths (15 percent), as did nonimpact injuries. In 7 cases (12 percent), the fatality resulted from injuries related to driver ejection. Contact with a nonintruding surface caused 1 death (2 percent), and 1 fatality (2 percent) occurred because the airbag failed to deploy despite crash conditions that should have triggered a deployment. For 5 cases (8 percent), the cause of the fatal injuries could not be determined from the information available in the case materials.

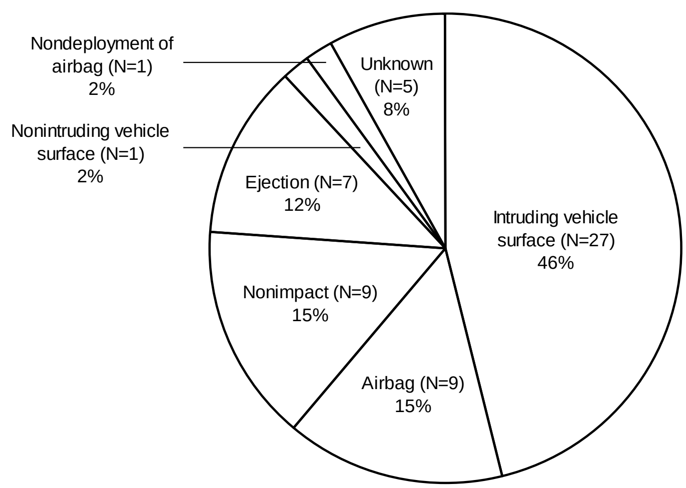

Figure 1 – Causes of Death to Drivers of Airbag-Equipped Vehicles in Frontal Crashes (1989-97 NASS/CDS)

Table 1 lists all 59 cases grouped by cause of death along with information on crash severity (delta V), belt use, and the body region where the most critical injury was located. An overview of the cases in each of the known cause-of-death categories is presented below.

Table 1 – Summary of Driver Fatalities in Airbag-Equipped Vehicles in Frontal Crashes (1989-96 NASS/CDS)

Case ID	Cause of Death	Body Region of Critical Injury*	Crash Event	Belt Use	Delta V (km/h)	Airbag Deployment
12-025A 1994	Intrusion	Unknown	Multiple	Belted	—	Yes
11-111A 1990	Intrusion	Unknown	Multiple	Belted	—	Yes
11-112A 1993	Intrusion	Head	Single	Belted	—	Yes
41-199A 1994	Intrusion	Head	Single	Belted	—	Yes
45-053B 1996	Intrusion	Head	Single	Belted	—	No
12-072A 1994	Intrusion	Abdomen	Single	Belted	—	Yes
75-158A 1996	Intrusion	Unknown	Multiple	Belted	13	Yes
43-069J 1996	Intrusion	Head	Multiple	Belted	42	Yes
75-103A 1995	Intrusion	Unknown	Single	Belted	47	Yes
11-192A 1996	Intrusion	Head	Single	Belted	63	Yes
74-033A 1996	Intrusion	Head	Multiple	Belted	76	Yes
09-010B 1996	Intrusion	Chest	Single	Belted	78	Yes
82-057A 1991	Intrusion	Chest	Single	Belted	95	Yes
12-064A 1994	Intrusion	Head	Single	Unbelted	—	Yes
08-084A 1996	Intrusion	Chest	Single	Unbelted	34	Yes
81-014A 1996	Intrusion	Head	Multiple	Unbelted	34	Yes
75-098A 1996	Intrusion	Chest	Multiple	Unbelted	47	Yes
79-139A 1991	Intrusion	Chest	Multiple	Unbelted	48	Yes
13-149A 1995	Intrusion	Head	Single	Unbelted	50	Yes
12-163A 1995	Intrusion	Head	Single	Unbelted	55	Yes
78-122A 1996	Intrusion	Unknown	Single	Unbelted	61	Yes
75-023A 1991	Intrusion	Chest	Single	Unbelted	63	Yes
41-069A 1995	Intrusion	Chest	Multiple	Unbelted	68	Yes
13-208A 1995	Intrusion	Chest	Single	Unbelted	74	Yes
74-157A 1994	Intrusion	Chest	Single	Unbelted	76	Yes
72-082A 1994	Intrusion	Lower extremity	Multiple	Unbelted	92	Yes
74-144B 1996	Intrusion	Chest	Multiple	Unknown	90	Yes
41-024A 1996	Airbag	Chest	Multiple	Belted	26	Yes
05-125A 1993	Airbag	Chest	Single	Belted	47	Yes
08-133A 1993	Airbag	Chest	Multiple	Unbelted	—	Yes
09-167A 1995	Airbag	Head	Multiple	Unbelted	—	Yes
06-006A 1993	Airbag	Chest	Single	Unbelted	47	Yes
11-150A 1994	Airbag	Chest	Single	Unbelted	61	Yes
79-021A 1991	Airbag	Chest	Single	Unbelted	74	Yes
08-100A 1996	Airbag	Chest	Single	Unknown	37	Yes
02-140A 1995	Airbag	Chest	Multiple	Unknown	47	Yes
48-122A 1992	Ejection	Head	Multiple	Unbelted	21	Yes
04-029A 1995	Ejection	Head	Multiple	Unbelted	34	Yes
49-135A 1995	Ejection	Head	Multiple	Unbelted	34	Yes
73-117A 1995	Ejection	Head	Single	Unbelted	35	Yes
43-210A 1992	Ejection	Head	Multiple	Unbelted	58	Yes
74-125A 1994	Ejection	Head	Multiple	Unbelted	74	Yes
49-195A 1996	Ejection (partial)	Head	Multiple	Belted	18	Yes
79-002A 1995	Nondeployement of airbag	Head	Single	Unbelted	50	No
72-026B 1996	Nonimpact	N/A	Multiple	Belted	—	No
45-082A 1995	Nonimpact	N/A	Single	Belted	14	Yes
11-128A 1993	Nonimpact	N/A	Multiple	Belted	24	Yes
45-100A 1995	Nonimpact	N/A	Multiple	Belted	64	Yes
12-072A 1995	Nonimpact	N/A	Single	Unbelted	19	Yes
08-021A 1993	Nonimpact	N/A	Single	Unbelted	26	Yes
49-129A 1992	Nonimpact	N/A	Multiple	Unknown	—	Unknown
49-243C 1993	Nonimpact	N/A	Multiple	Unknown	—	Yes
11-036A 1996	Nonimpact	N/A	Single	Unknown	18	Yes
06-021A 1994	Nonintruding surface	Abdomen	Single	Unbelted	—	Yes
78-024A 1996	Unknown	Head	Multiple	Belted	21	Yes
13-113B 1996	Unknown	Head	Multiple	Unbelted	13	Yes
12-081B 1996	Unknown	Unknown	Multiple	Unbelted	42	Yes
79-501A 1995	Unknown	Abdomen	Multiple	Unbelted	60	Yes
72-074A 1994	Unknown	Head	Single	Unknown	—	Yes

* Head region includes injuries to the head and/or neck
— not calculated

INTRUSION-RELATED FATALITIES – Fatalities in this category generally occurred in higher severity crashes, with occupant compartment deformation resulting in loss of survival space for the driver. In these cases, vehicle structure was the limiting factor. The velocity changes (delta Vs) were estimated for 20 of these 27 crashes and averaged 60 km/h (37 mi/h). Estimated delta V was 50 km/h (31 mi/h) or greater in 13 cases and 30-50 km/h (19-31 mi/h) in 6 cases. In one case (75-158A 1996), delta V was estimated to be 13 km/h (8 mi/h); however, the vehicle rolled onto its roof, resulting in catastrophic vertical intrusion into the occupant compartment.

Included within this classification was a case (45-053A 1996) in which the left front of the subject vehicle underrode the side of a commercial trailer, resulting in unsurvivable levels of intrusion into the driver's space from the left front door window frame, windshield header, and roof. The airbag did not deploy, and the two restrained child occupants, one in the right front and one in the right rear seating positions, were not injured.

There was one case (75-098A 1996) in this category in which the airbag was thought to have deployed in the first of two frontal impacts with utility poles and likely was not available to protect the driver in the second impact. Massive intrusion of the occupant compartment — nearly 50 cm (20 in.) for the steering assembly, 36 cm (14 in.) for the left instrument panel, and more than 46 cm (30 in.) for the driver toepan — indicated this crash likely was unsurvivable even if the airbag had deployed in the second impact; therefore this fatality was considered intrusion related.

AIRBAG-RELATED FATALITIES – Nine drivers died from injuries related to airbag deployment. In these cases, vehicle intrusion was not so great as to eliminate space for the driver to ride down the airbag and dissipate some of the crash energy. Delta Vs ranged from 26 km/h to 74 km/h (16 mi/h to 46 mi/h), with an average of 48 km/h (30 mi/h) for the 7 cases for which delta V was estimated in NASS. Eight of the drivers died from chest injuries, and one died from head injuries. Table 2 lists for each of the airbag-related cases the crash severity (delta V), number of crash events (single or multiple), belt use, and driver age, gender, height, and weight.

In 6 of the 8 cases involving fatal chest injuries, sufficient information was available to conclude the driver likely was in close proximity to the steering wheel at the time of airbag deployment. Of these 6 cases, 3 drivers were reported to have suffered incapacitating illnesses prior to the crash. According to the investigator, they were unbelted and likely slumped over the steering wheel at the time of impact. In another case, the driver's seat back was displaced 30 cm (12 in.) forward in the impact. Driver belt use and the cause of the seat back displacement could not be determined from the case materials, but the forward movement of the seat likely would have put a belted or unbelted driver close to the deploying airbag. There were 2 cases involving short female drivers — 157 cm (62 in.) and 160 cm (63 in.), one belted and one unbelted — who likely were seated close to the steering wheel. The remaining 2 cases with fatal chest injuries involved elderly male drivers. In the first case (41-024A 1996), the 79-year-old male was driving a 1995 Ford Escort that was struck on the right front side by a 1995 Honda Prelude at an intersection. The Escort made minor sideslap contact with the Prelude and sideswipe contact with a stop sign before striking a small tree with the left front center of the vehicle. Estimated delta V was 26 km/h (16 mi/h) for the Escort's impact with the tree. The 175-cm (69-in.), 82-kg (180-lb.) driver was belted and sustained a heart laceration and flail chest from contact with the airbag. In the second case (08-100A 1996), the 85-year-old male, whose height, weight, and belt use were unknown, was driving a 1995 Nissan Maxima and sustained flail segment rib fractures in a left frontal offset collision with a 1994 Ford Explorer that had lost control on a two-lane roadway. Estimated delta V for the Maxima was 37 km/h (23 mi/h), but the NASS zone center noted there was greater crush above the bumper than at the bumper; therefore, the estimated delta V may be inaccurate, and the airbag's deployment may have been delayed by late engagement of the stiff structural elements of the Maxima.

The only case (09-167A 1995) with an airbag-related fatality resulting from head injuries occurred when a 1995 Infiniti J30 veered leftward off the roadway, striking a concrete bridge abutment with its left front. The collision redirected the vehicle back onto the roadway where it struck the rear of a 1988 Hyundai Excel. The Infiniti's

Table 2 – Driver Airbag-Related Fatalities

Case ID	Belt Use	Crash Event	Delta V (km/h)	Age	Gender	Height (cm)	Weight (kg)
05-125A 1993	Belted	Single	47	62	Female	157	81
41-024A 1996	Belted	Multiple	26	79	Male	175	82
06-006A 1993	Unbelted	Single	47	64	Male	170	73
08-133A 1993	Unbelted	Multiple	—	58	Male	183	85
02-140A 1995	Unknown	Multiple	47	66	Male	168	93
11-150A 1994	Unbelted	Single	61	23	Female	160	57
79-021A 1991	Unbelted	Single	74	35	Male	168	73
09-167A 1995	Unbelted	Multiple	—	30	Male	183	93
08-100A 1996	Unknown	Single	37	85	Male	Unknown	Unknown

— not calculated

delta V was not estimated for either impact, but damage to the front of the vehicle was substantial. The NASS investigator concluded the airbag deployed during the impact with the bridge abutment. The 30-year-old, 183-cm (72-in.), 93-kg (204-lb.) male driver, who was unbelted and impaired with a blood alcohol concentration of 0.23 percent, died from atlanto-occipital joint dislocation and cerebral contusions from contact with the roof, where the NASS investigator noted hair transfers. The unbelted driver likely moved forward during the crash into the deploying airbag, which directed his head into the roof near the rearview mirror.

NONIMPACT-RELATED FATALITIES – Nine of the 59 driver fatalities were not directly caused by injuries sustained during the crash. Airbag performance in these crashes was essentially as expected and unrelated to the fatal outcomes. Four of the drivers' deaths were attributed to medical conditions, such as cardiac arrest, prior to the crash. Three deaths were attributed to medical complications secondary to the crash. Another death in this group was due to a fire that preceded the crash, and in one case, the driver drowned after the vehicle went off a bridge into a lake.

EJECTION-RELATED FATALITIES – Seven driver fatalities resulted from ejection during the crash. Six of these drivers were unbelted and completely ejected from the vehicle. The only case (49-195A 1996) of a restrained driver involved a guardrail crash with an estimated delta V of approximately 18 km/h (11 mi/h). The driver's head was outside the left front window and was struck by a metal light pole just outboard of the guardrail. It could not be determined from the case materials whether the 18-year-old male driver was traveling with his head outside the window or if his head was ejected by the force of the impact with the guardrail. The driver died of head injuries, and the death was classified as ejection (partial). Airbag performance in these driver ejection crashes was essentially as expected and unrelated to the fatal outcomes.

NONDEPLOYMENT OF AIRBAG – One death occurred in a crash in which the airbag did not deploy (79-002A 1995). The vehicle, a 1995 Ford F-150 pickup, traveled across a parking lot and straight into a brick wall. The estimated delta V for the pickup was 50 km/h (31 mi/h). The 41-year-old, 178-cm (70-in.), 77-kg (170-lb.) male driver was unrestrained and sustained fatal brain injuries from contact with interior surfaces. Although deployment of the airbag in such a crash would be expected (it is similar to the FMVSS 208 barrier crash test), no conclusions were presented concerning why the system failed to deploy.

CONTACT WITH NONINTRUDING VEHICLE SURFACES – One death was caused by driver contact with nonintruding vehicle surfaces. In this case (06-021A 1994), a 1993 Buick LeSabre crossed the center median and struck a tractor trailer combination. The collision diagram indicated the left front of the LeSabre struck the left side of the trailer near the rear wheels. The front of the LeSabre likely was pulled along by the trailer, causing the vehicle to rotate counterclockwise (the twisted hood and other frontal damage is consistent with this scenario). The airbag deployed, but the motion of the LeSabre would have directed the unbelted driver toward the right side of the vehicle rather than the steering wheel. Physical evidence observed by the NASS investigator identified occupant contacts with the right instrument panel, rearview mirror, and passenger door, resulting in multiple liver and aorta lacerations.

CONCLUSIONS

Since their introduction in the passenger vehicle fleet, airbags have saved more than 4,000 lives [11]. The cases in this study show, however, that the presence of a driver airbag does not guarantee survival in a severe impact crash. It is important to analyze these fatalities to determine if airbag performance directly or indirectly contributed to the fatal injuries, and to consider if airbag design changes might lead to improved occupant protection.

In this NASS/CDS-based study of driver fatalities in airbag-equipped vehicles, the most common cause of the fatal injuries was vehicle intrusion, accounting for nearly half the deaths. In these cases, the vehicle structural design was the limiting factor, and the airbag would not be expected to protect the driver from the loss of survival space in the occupant compartment resulting from the intrusion. Changes in airbag design would not be expected to help prevent these fatalities. Instead, these crashes should be reviewed for possible improvements in structural design that could increase occupant protection by preventing massive occupant compartment intrusion while absorbing crash energy.

Airbag-related injuries contributed to fatalities in 15 percent of the cases. Crash severity was moderately high in these cases, but the fatal injuries were related to the force of the deploying airbag. There were no cases in which drivers died because airbags had insufficient power to prevent the fatal injuries. This indicates that a reduction in airbag deployment energy may benefit out-of-position occupants in moderate- and high-severity crashes as well as in lower severity crashes, which were expected to benefit most from the reductions made possible through the modifications to FMVSS 208.

Many of the airbag-related fatalities occurred with drivers who likely were in close proximity to the steering wheel at the time of deployment, and some likely were slumped over the steering wheel due to illness prior to the crash. Occupant position sensors that would reduce the inflation energy or suppress the deployment if the driver is too close to the airbag might provide some benefit in these types of cases.

It should be noted that among the drivers sustaining fatal injuries related to airbag deployment, two were elderly males ages 79 and 85. The elderly are more susceptible to fatal injuries in a crash [17], and it may be that the structural features of their bones and other tissues are contributing factors to their risk of injury from a deploying airbag. A reduction in airbag energy may benefit this population.

The remaining cases in which fatal injuries were not a result of vehicle intrusion or airbag deployment involved nonimpact-related injures (e.g., fire, medical condition), ejection, or contact with nonintruding interior surfaces. There was one fatality in which the airbag did not deploy, although the crash conditions indicated it should have.

The overall results are consistent with earlier analyses of smaller numbers of NASS/CDS cases that found vehicle intrusion the most common cause of fatal injuries among drivers in airbag-equipped vehicles in frontal crashes in 1989-93 NASS [13] and 1989-94 NASS [14] data. Airbag-related fatalities continue to occur among unbelted and belted drivers, even in moderately severe crashes. Analysis of these fatalities indicated the depowered airbags allowed in vehicles manufactured after March 1997 should reduce the risk of fatal airbag-related injuries without an offsetting increase in deaths from steering wheel contact from drivers bottoming out the airbag.

Along with depowered airbags, other improvements to occupant restraint systems are being developed and phased in. A few automakers currently install dual-threshold airbags that have higher deployment thresholds for belted occupants. In a relatively low-speed crash in which seat belts alone would provide sufficient protection, the airbag would not deploy if the occupant were belted. Widespread application of this technology could prevent as many as half the airbag deployments for belted occupants [14], greatly reducing the risk of injury from airbags themselves. Two-stage inflators that vary inflation forces according to crash severity are beginning to be installed in some vehicles. This technology likely will reduce airbag-induced injuries in low- and moderate-severity crashes while maintaining current levels of protection in higher speed crashes. Occupant sensing systems are being developed that can determine the weight and position of occupants — information that could be used in a crash to tailor airbag deployment, suppressing it, if necessary, to balance protection with injury risk among people of different sizes and those who might be out of position and very close to the airbag.

Fatality and injury reductions also are possible by improving aspects of vehicle design other than occupant restraint systems. Passenger vehicle occupants are injured when they experience deceleration forces exceeding their tolerance. Occupant crash protection involves using the vehicle structure and restraint systems to dissipate crash energy so that not all the energy is transmitted to the occupants, who are protected by an occupant compartment (or safety cage) that should remain intact during the crash [18]. This study shows that, although improvements to occupant restraint systems may reduce the likelihood of fatal injuries in a crash, the ability of the vehicle structure to absorb crash energy while retaining survival space for the driver in the occupant compartment is currently more critical.

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