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AIR BAG INJURIES TO INFANTS, CHILDREN AND SMALL ADULTS

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INTRODUCTION

The concept of an air bag as an occupant safety restraint device is not new.

The idea for an "air cushion" was outlined as early as 1941 with patents appearing for such designs as early as the 1950's.

In the 1960's there were numerous air cushion equipped cars that had both crash tests and road use experience demonstrating a potential effectiveness and reliability for at least this general type of a restraint or safety system.

As early as the mid 1970's, auto manufacturers such as General Motors, Ford and Volvo sold or leased vehicles, including fleet vehicles, numbering in excess of 12,000 which were equipped with air cushions.

According to information compiled by Allstate Insurance Company from the National Center for Statistics and Analysis, as early as 1980 there had been 1.4 billion front seat occupant miles traveled by these air cushion equipped vehicles. These vehicles had been involved in 245 crashes in which the air cushions had inflated. There were 349 front seat occupants protected by these inflated cushions. Of these crash events there were a total of only 9 documented injuries above the level of AIS 4.

European air cushions are designed to protect the face and head of the driver and rely on the overwhelming percentage of occupants driving vehicles to be utilizing belt restraint systems. The airbags in vehicles sold in the United States manufactured prior to 1998 were larger and more aggressive than the bags installed in European sold vehicles. It was alleged that this was necessary in order to comply with Federal Motor Vehicle Safety Standard 208, to protect an "unbelted occupant" in a 30 mph fixed barrier impact.

Congress, as of 1998, has exempted the portion of FMVSS 208 that requires the air bag to be tested with an unbelted 50th percentile male occupant into a fixed barrier at 30 mph.

Since "de-powered" bags have appeared in U.S. automobiles, there have been only two recorded deaths through the end of December of 1999 thought to be associated with the deployment of a de-powered bag.

Data and information prior to 1998 concerning severe air bag injuries and fatalities clearly indicates that even without the "de-powering" of air bags, that some air bags in vehicles had obvious differences in occurrence of serious and fatal injuries from one manufacturer to the other.

CURRENT INFORMATION CONCERNING AIR BAG FATALITIES AND SERIOUS INJURIES

By April 15th, 1997, NHTSA had documented 63 fatalities attributed to air bags. Of these, 38 involved children in the front passenger seat, 25 cases involved adults of which 22 were drivers and 3 were front seat passengers.

Of the 38 children, there were 9 infants in rear facing child safety seats and the other 29 involved children who were forward facing. Of these 29, virtually all of them were unrestrained or thought to be improperly restrained.

In addition to the fatality cases, NHTSA had documented another 16 cases of serious injury resulting from occupant to air bag interaction.

Of interest, in the 25 child cases that were reviewed by Kleinberger and Summers, there was little to no intrusion into the occupant compartment and an average velocity change of 12 mph.

Only one driver in these 25 cases sustained any significant injury. There were 7 drivers who were identified as small females with heights not exceeding 5'3". Of these, 3 were restrained by the available seatbelts and 4 were apparently unrestrained. These 7 small female drivers sustained only minor injuries.

NHTSA updated the above statistics, and as of November 1st of 1997 there were an additional 14 cases associating air bag deployment and fatality. These were primarily low speed crashes. NHTSA determined that none of the occupants would have died had they not been seated in front of an air bag, and in all of these the vehicles were said to have been traveling less than 15 mph when the air bag deployed.

Despite the occurrence of these serious injuries and fatalities, there is virtually no data that has been accumulated to dispute the fact that air bags have become one of the "single most valuable passive safety devices available".

Data from State Farm Insurance Institute shows that comparing air bag equipped vehicles to vehicles equipped with only belts, there is a significant reduction in seriousness of injuries in moderate and severe crashes in those vehicles with air bags.

There is also a significant decrease in medical, rehabilitation and lost wage experienced cost per insured vehicle in those cars equipped with air bags.

Although all statistics show that air bag systems have a positive effect on injury and fatality reduction, a significant number of cases with serious injury, harm and death have occurred. Through careful investigation of these cases, a better understanding as to the mechanism of how these injuries and fatalities occurred can be obtained, and methods to prevent these unfortunate occurrences may be found.

Computer modeling, improvements in bio-fidelity of anthropomorphic test devices, more sophisticated crash tests, evaluation of data from sources such as the Fatal Accident Reporting System, NASS Crashworthiness Data System, and from sources such as team approach investigations of auto crash fatalities can be utilized to ascertain the types of injuries that occur with air bag deployment and their potential mechanisms.

BASIC PRINCIPLES OF AIR BAG DEPLOYMENT

The concept of an air cushion supplemental restraint system is simple. It depends on a sensor that will "tell the system" to activate. There are various types of sensors. The placement of sensors varies from manufacturer to manufacturer. Typically, they are in the forward area of the vehicle within the frontal crush zone. In general, they detect a change in velocity of the vehicle as the vehicle interacts with some structure resulting in deformation and slowing of the vehicle, which triggers the crash sensor.

Once the system has been told to activate, it depends on an inflator or gas generator that will cause the bag, which is housed either within the hub area of the steering wheel or some portion of the passenger side of the instrument panel, to begin to inflate. When sufficient pressure has been obtained within the bag, the bag causes the containment package to rupture. This package consists of the overlying hub cover and housing and the overlying plastic or fascia trim in the area of the passenger side bag. Once the bag and membrane have breached the integrity of their container, the bag continues to inflate and fill the space between the occupant and the forward structures of the vehicle.

In order to have met Federal Motor Vehicle Safety Standard 208, all of this must occur within the blink of an eye or 1/30th of a second or less. Speeds of the bag reach 200 plus mph during deployment.

To better understand injuries associated with air bag deployment, certain terminology should be understood that is being universally accepted by people working in the area of automotive medicine and research.

Three primary mechanisms are associated with injuries from air cushions. They are defined as follows:

PUNCH OUT

"Punch Out" is defined as the event of the air bag rupturing its capsule or container, such as the steering hub cover and/or the passenger side instrument panel fascia.

During punch out the bag is reaching maximum velocity, much as a bullet fired from a gun reaches maximum velocity at the muzzle. In addition to the rapidly deploying bag, the plastic housing of the hub and instrument panel have been implicated in a number of such injuries. It is also at this time the maximum VC (Viscus Criteria) may be produced.

MEMBRANE LOADING

The second reaction is termed "membrane loading". Membrane loading is result of the bag pressure acting to fill the bag, and as the bag and the occupant interact, the bag wraps around the occupant with forces being created between the bag membrane and occupant.

With an increase in the positive internal pressure within the bag, membrane stress occurs when tension in the air bag fabric surface results from an effort to contain the positive increasing internal pressure within the bag. With the rapidly rising combination of bag surface tension and internal bag pressure, this may produce a catapult like action on body components that are submerged within the surrounding air bag surface.

BAG SLAP

Of somewhat less importance, a third potential type of injury mechanism occurs called "bag slap". These are usually insignificant soft tissue injuries such as abrasions or contusions with the exception of potentially more significant eye injuries such as retinal detachments. During this injury mechanism, the bag actually "slaps" the body.

It is obvious that the occurrence of an injury associated with an air bag can be, and usually is, a product of multiple factors. These factors include the characteristics of the module cover, the method used to fold the bag, the deployment speed of the bag and the deployment characteristics at the ignitor and gas generator, and the distance of the bag's intrusion into the occupant space.

Although there has been some suggestion that the characteristics of bag fabrics, including the weave, thickness of the bag, types of seams and tether straps, may play roles in the production of injuries. These seem to be of minor importance as compared to the other above factors.

INJURIES TO INFANTS IN REAR FACING CHILD SAFETY SEATS

As of April of 1997, the National Highway Traffic Safety Administration had identified 25 child death cases involving rear facing child safety seats. All were thought to have been properly restrained within an appropriate CSR. All but one of the CSR's was properly secured in the vehicle. It is thought that the one case in which the child safety seat was not secured appropriately may have contributed to the severity of the infant's injuries.

Because of the typical position of the rear facing child safety seat in the right front seat of the vehicle, the back of the CSR is in close proximity to the passenger side instrument panel face. The deploying air bag and module cover may actually crack or break the plastic shell of the CSR. The impact with the child safety seat results in the entire seat being accelerated rearward. As this occurs, it may impact the child's head resulting in blunt force injury with skull fractures and associated intra-cranial hemorrhage, brain laceration and contusion.

These fractures, depending on the orientation of the infant's head, may be posterior in the occipito-parietal area or may be lateral because of outward bending of the parietal bosses of the skull. In some cases, the child safety seat is able to actually rock rearward through an arc, taking the child and the seat with great speed toward either the passenger side B pillar or in some cases to unfriendly structures associated with the head rest and vehicle seat back frames. In such cases, the possibility of cervical injuries is also likely.

It is unusual to find other types of injuries as long as the infant remains contained within the child safety seat and there is no significant loss of occupant compartment space. Because the child's head is typically contained within the child safety seat and the myelinization process is not complete in the early stages of infancy, classical diffuse axonal injury patterns do not occur.

INJURY TO INFANTS/CHILDREN IN FORWARD FACING CHILD SAFETY SEATS

There were 17 case fatalities reviewed through April of 1997 in which the infants or children were seated forward facing. Thirteen of the 17 of these were thought not to be restrained by the available restraint system. Three of the 17 were wearing only the lap belt portion of the 3 point belt system.

In a frontal collision these infants, whether in a CSR or in the vehicle's three point restraint system, should not have injury producing interaction with the air cushion/bag, assuming the above systems are working properly. If, however, they are only lap belted, or the child safety seat is not properly secured, then the infant's face, head and neck will move through a predicted arc with the head moving toward the instrument panel. In some crashes where there is pre-impact braking, a child in a forward facing CSR improperly secured or a child seat improperly secured by the vehicle restraint system, may begin to translate forward before enough deceleration has occurred to deploy the air bag. This places the child in close proximity to the instrument panel and can result in blunt force axonal injury from the air bag cover or impact and acceleration injuries from the deploying air bag itself. Such interactions have resulted in cervical spine injuries with atlanto-occipital distractions and dislocations as well as other high cervical spinal cord injury. Fatalities in these cases occur predominately secondary to closed head injury with subdural hemorrhage, subarachnoid hemorrhage, and other brain injury. There have been reports of contused lungs and trauma to the heart when the chest is in close proximity to the module cover and the rapidly deploying bag. In some cases it is postulated that the child or infant may actually be lifted and essentially thrown into other vehicle structures such as the windshield, windshield header, roof or into other parts of the occupant's cabin.

AIR BAG INJURIES TO SMALL ADULTS

In examining injuries to small adults we are looking at, anthropometrically, someone of 5"2" or 3" or less in stature.

Typically, the small adult will sit more closely to the steering wheel or instrument panel than a larger adult. This is often true for the right front seat passenger or occupant as well.

As of April of 1997, NHTSA had identified 22 cases in which it was thought that the driver's air bag either caused or significantly contributed to the fatality of an adult. Many of these were short statured women. In addition to the 22 drivers, there were 3 adult passengers who were fatally injured as a result of a deploying passenger side air bag.

It is important to consider the pulse of a frontal collision which typically is in the range of 100 milliseconds. During this 100 milliseconds the occupant's head may have an excursion, even when belted, of some 20 plus inches.

When comparing the 50th percentile adult male to a 5th percentile female, and assuming her position to be relatively closer to the steering wheel, within the first 30 milliseconds of the crash pulse, her head will be much closer to the deploying air bag than will the 50th percentile adult or larger individual.

This places her head, without even considering the consequences of braking and other factors, closer to the membrane and module cover during it's maximum deploying velocity phase. Studies have shown that rearward air bag displacement may be as little as 12 inches to as much as 20 inches into the occupant's space on the driver's side. Deployment times may vary greatly from 21 milliseconds to as high as 47 milliseconds.

The small adult who is usually already within 15 to 20 inches of the hub of the steering wheel, within the first 30 milliseconds may move well into the zone of the deploying air bag before it has reached 80% of maximum inflation.

Pre-impact braking may result in the occupant's face or upper torso coming in contact with the hub cover or very close to the passenger's side module cover. During punch out or break out, the covers may impact the face or chest resulting in facial fractures, eye injuries, fractures of teeth, and in rare instances, skull fractures. Typically an adult's skull thickness makes it unlikely for a fracture to occur from the module cover. Instead, it is more likely that blunt impact trauma with sagital and rotational acceleration of the brain may result in shearing of vessels causing subdural hematoma, epidural hemorrhage, brain contusion and diffuse axonal injury.

If the chest is in contact with the hub or the break out panel on the passenger side, contusion to the chest wall, sternal fractures, rib fractures, and other injury to the viscera of the thorax and abdomen may occur.

In membrane induced injuries there may be very little evidence of external trauma. An occupant close to the bag or module cover at this time may experience significant head accelerations with hyperextension resulting in atlanto-occipital distraction and other cervical spine injuries. In small adults and small adult females in particular, whose bone structure, upper body torso mass and muscle mass may be less than a similar adult male of the same stature, there may be significant chest compression and chest deflection resulting in the viscous criteria exceeding one meter per second. This can result in visceral injury and, with enough chest deflection, rib fractures.

The air bag being draped over the upper torso when the head and neck are still moving forward can result in violent and differential motions between body parts resulting in excessive neck moments, shear and tension.

In addition to the above, the air bag has the potential to actually catapult the occupant out of the normal safety area of their own occupant space.

CASE EXAMPLES

Case 1: A 17 year old female driver approximately 4'11" and 126 pounds was involved in a left off-set frontal collision with a reported speed of only 9 mph. She was found in the vehicle with her seat back reclined. Her injuries included a massive basilar skull fracture, abrasions to the face, chin and anterior neck. She was dead as a result of this incident. Inspection of the subject vehicle revealed the seat back to be statically reclined rearward out of a normal driving angle and an area of deformation to the upper rear windshield header, inboard at the C-pillar/header junction.

Forensically, it is more likely than not the basilar fracture resulted from hitting the rear header area rather than it occurring from the module cover. The module cover, although expanding outward and rearward at a rapid rate, can still conform to the face and head sufficiently enough to preclude the occurrence of major calvarial fractures. However, impact of the skull with the more substantial header area in the rear certainly could result in basilar fractures. The evidence of rearward propulsion is the seat back as well as the witness mark on the rear header trim. Certainly, at 9 mph, rebound into the seat back would not be expected to cause the recliner mechanism to allow the seat back to deform rearward.

Case 2: A 42 year old female driver, approximately 5"2', 130 pounds and was involved in a low delta-v left side impact with a minor left frontal impact. The driver's side air bag deployed and the driver sustained a diffuse axonal injury. The 13 year old in the right front seat who was fully restrained sustained only chest wall bruising from the restraint system.

These cases document the possible complexity and severity of injuries that can result in small adult occupants, especially females, during very low delta-v crash events.

POTENTIAL WAYS TO MITIGATE INJURIES FROM AIR BAGS AND AIR CUSHIONS

First, air bags were originally referred to as "cushions". In movie stunts, where individuals fall from heights onto inflated cushions, they do not hit the cushion as it is inflating, they hit it as the energy between the inflation pressure and the tensile forces of the bag have been equilabrated. This allows the bag to absorb the impact and cushion the fall of the stunt person.

The air bag is a cushion, the purpose of which is to cushion, slowly decelerate and protect the occupant from impacting less friendly vehicle interior structures, primarily in frontal and off-set frontal collisions. (This is not considering the fact that as of 1998 numerous types of air cushions and air bags are now available in vehicles, including front and rear occupants, side door air bags, A pillar and header bags, knee bolster bags, and even some roof bags).

The air bag or air cushion is a supplemental restraint system. It was not designed and is not employed to act as the sole protector to the occupant.

All children, infants and even some small adults would certainly be better off if they were in the rear occupant area of a vehicle. This would preclude them from being involved in the air bag deployments that occur in frontal collisions which comprise the great majority of automotive crashes.

If many of the injuries are indeed the result of the occupants proximity to or even contact with the air bag module covers, a number of things can be done to mitigate injuries that might result from this.

Restraint systems with pretensioners, belt sensitive devices, and improvements in belt geometry are methods by which the occupant's distance from the module cover and the bag during its most aggressive phase of deployment can be improved. This is true for both the 95th percentile and 5th percentile occupant as well.

Presently, the overwhelming majority of drivers and front seat occupants are belted. Most states in this country now have mandatory belt use laws, and drivers and passengers have a better understanding of the effectiveness and injury reducing capabilities of the restraints than they have had at any time in the past. Because of this, the air bag can truly become what it was designed to be, which is, "a supplemental restraint system". They will no longer have to be designed to act alone if the occupant is not restrained.

In such circumstances, the volume of both the driver and passenger bag can be reduced. (This has already occurred.) The time in which the bag must reach full deployment can also be expanded.

It has been clearly shown that tethered bags offer greater safety and result in fewer injuries from the bags themselves than un-tethered bags. This is to some degree common sense in that the un-tethered bags have a greater rearward extension into the occupant's space than do tethered bags in general. The tethering of the bag also changes the contour of the front of the bag as it interacts with the occupant.

It has been further shown that different methods of folding or packaging of the bag results in fewer injuries from bag expansion and slap.

De-powered inflators certainly would result in lower velocities and less expansion into the occupant's space. This results in lower punch out and membrane velocity.

For many years there have been dual stage deployment devices available for air bags. Various types of inflators and ignitors also have been available. These may greatly alter the pulse of the inflating bags such that the initial punch out pressure and velocity may be moderated. The remaining bag filling pressure and its velocity of expansion can be phased to the occupant's predicted movement. This allows the module cover to separate with decreased force and also a moderation and alteration of the remaining filling pressure and velocity curve. Such staged inflation of the bag will result in much different occupant to bag and occupant to module cover interaction.

Finally, there are the "smart bags". Smart air bags have the potential for sensing the presence of an occupant in a particular seated position. They can sense the weight of the occupant, the occupant's position on the seat and it's position on the seat track. Smart bags can time the deployment rate and alter the deployment characteristics of the bag itself.

Raising the velocity change at which air bags deploy should be seriously considered as a method to mitigate injuries caused by the bag themselves.

Since the majority of occupants now are being restrained in motor vehicle crashes, and since even in low velocity crashes unrestrained occupants typically do not receive serious and fatal injuries in many cases, the necessity of an air bag deploying at 6, 8, 9, or even 15 mph, must be closely evaluated as to whether this is reasonable or necessary.

When velocity changes approach 18 to 20 mph, especially with the unrestrained occupant, air bags may reduce injury and mitigate major trauma. At these velocity changes a properly functioning 3-point restraint system should be able to manage, in most cases, the crash forces, so that occupants do not receive significant or fatal injury.

It has been clearly shown that modern day 3 point restraint systems can manage forces and in most cases prevent death and serious injury at delta v's of even 35 and 40 mph and possibly even greater.

If the above is true, and if the air bag is actually a supplemental system, then the necessity of it deploying at velocity changes below 20 mph must be given serious consideration.

There are estimates that, with the present first generation air bags, 4 fatalities have resulted from every 1000 air bag deployments. In contrast, it is also estimated that nearly 2000 lives have been saved by air bags during the same study period.

SECOND GENERATION AIRBAGS AND REAL LIFE EXPERIENCE

The University of Michigan Transportation Research Institute (UMTRI) compiled a report at the end of 1999 concerning crashes involving 1998 or later model vehicles in which a de-powered or Next Generation airbag had deployed.
Some history is necessary to understand what is meant by the Next Generation/Second Generation airbag.

The National Highway Traffic Safety Administration went through several rule making proposals to not only define what a Second Generation or Smart airbag was but to attempt to understand some of the problems with this proposed new rule.

This final rule concerning "Smart Airbags" is under Federal Motor Vehicle Safety Standard 208 Section 4.5.5, and states:

> The airbag does not deploy when a total mass of 30 kilograms or less is present on the front outboard passenger seat.
>
> The airbag uses sensors to prevent deployment if an infant in a rear facing seat or an unbelted or improperly belted child is present in this position.

The bag deploys in a manner that does not create risk to any of the above.

This final rule also includes three new warning labels for visors and a temporary label for a dash. The final rule also requires that rear facing child seats have a new enhanced warning label.

NHTSA has stated clearly that it is "unacceptable to have a safety device that kills occupants".

Additionally, the federal rule includes adopting a 125 millisecond sled test and adding a neck injury criteria to the standard. This rule concerning the sled test expires September 1, 2001.
It further states in reference #6 of the new rule that it is not acceptable for a safety device to cause fatal injuries in circumstances in which fatalities or serious injuries would not otherwise occur. It states that it is particularly unacceptable that occupants being killed are children.

The new study by UMTRI investigated crashes involving 160 occupants.

In the above study of 120 case vehicles there were 120 drivers and 40 right front passengers where a frontal impact airbag deployed.

Further breaking this down into a more understandable database:

- 24 drivers and 5 right front passengers weighing 200 pounds or more.
- 11 short adult drivers and 9 short adult right front passengers all with statures of 5’2” or less.
- 16 elderly drivers and 4 elderly right front passengers of age 65 or more.
- 3 pregnant drivers.
- 6 children in the right front passenger location of less than 12 years.
- 32 drivers and 9 right front passengers who were not wearing the available three point restraint system.

The preliminary results of this study allowed the researchers to make the following observations and preliminary conclusions:

- The Next Generation de-powered driver and passenger airbags provided effective protection to the head, face, chest and abdomen of belt restrained adult occupants of all sizes involved in moderate and severe frontal impacts. The airbag protection for unbelted occupants was more limited than that for belt restrained occupants, primarily because the pre-crash positioning or movement of the occupant during the impact often caused the body to get over or around the airbag and into the vehicle’s interior. In essence, the occupant is missing the airbag. This is not unique to de-powered bags.

- NHTSA’s initial concern that heavy unbelted occupants would overpower de-powered bags was not supported by this initial database. An extreme of a 6’7” tall 230 pound occupant in a 40 mph impact indicated that the bag was able to mitigate the fatal injuries.

- De-powered airbags appeared to be notably less aggressive in causing serious injuries to out of position occupants than prede-powered bags.

  However, one instance of a fatality was noted in this study from an out of position child who was overriding the instrument panel due to pre-impact braking. In these special circumstances, life threatening head and chest injuries to children and adults still can occur but with a much reduced frequency.

- Three pregnant drivers in the database with de-powered bags resulted in no injuries to the driver or fetus. These individuals were properly restrained.

  In this new study there were no serious chest and abdominal injuries thought to be related to the de-powered bags. Some occupants did have chest injuries that could be due to their interaction with the belt restraints.

The findings indicate that improvements in occupant belt restraints could result in decreased frequency of such injuries.

- The de-powered airbags appeared to have no significant effect over pre de-powered bags in reducing significant and disabling injuries to the lower extremities.

  The study further points out the need to improve protection of the lower extremities to prevent disabling injuries to the joints of the feet, ankles and hips.

The cases in the UMTRI study de-powered airbag crash injury database suggest that de-powered airbags are as protective as pre-de-powered airbags for both belted and unbelted adult occupants and that they are less likely to cause serious injuries to the forearms, chest, neck and head of all occupants.

SUMMARY

The above study continues to add to the accumulated history and data that airbags, as a supplemental restraint system, are very effective in reducing serious injury and fatality.

These studies further indicate that the airbags placed into millions of production vehicles in the early 1990s were, for many occupants, not only highly dangerous but had a significant capacity to cause fatality.

It has taken complaints and concerns raised by safety conscious public interest groups and members of the medical profession to force new technology to be introduced that has a greater potential for mitigating serious life threatening injuries than systems that were installed in millions of vehicles in the early 1990's and will still be used by literally hundreds of thousands of individuals over the next 5 +/- years.

Occupant safety and protection is not a product of any single vehicular safety characteristic. It should be, and is, the result of the entire system within the vehicle working effectively to reduce and prevent injury.

The airbag is only a small but important part of this "safety package".

REFERENCES

HISTORY OF SAFETY RESEARCH AND DEVELOPMENT ON THE GENERAL MOTORS ENERGY-ABSORBING STEERING SYSTEM - John D. Horsch, David C. Viano & James DeCou, General Motors Research Labs., Biomedical Science Dept., Warren, MI 912890

IS GM DEFLATING THE AIR BAG? - Reprinted through the courtesy of Consumer Reports April 1980, DOT-HS-805 324
BIOMECHANICAL AND DESIGN ISSUES IN A PASSIVE RESTRAINT/AIRBAG CASE - Dr. Murray Mackay - Professor Of Transport Safety Accident Research Centre, University Of Birmingham, Birmingham, England

AIR BAGS: A CHRONOLOGICAL HISTORY OF DELAY - Editor: Anne Fleming, Insurance Institute For Highway Safety, Watergate 600, Washington, DC 20037, International Standard Book Number 0-932016-05-7

MYTHS AND FACTS ABOUT AIR

CUSHIONS - Editor: Anne Fleming, Insurance Institute For Highway Safety, Watergate 600. Washington, DC 20037, 1984, International Standard Book Number: 0-932016-06-5

ASSESSMENT OF AIR BAG DEPLOYMENT LOADS - John Horsch, Ian Lau, Dennis Andrzejak, David Viano, and John Melvin, General Motors Research Laboratories, Biomedical Science Dept., Warren, MI & Jeff Pearson, David Cok, and Greg Miller, General Motors Current Product Engineering, General Motors Technical Center, Warren, MI, 902324

THE INFLUENCE OF FORCE LIMITER TO THE INJURY SEVERITY BY USING A 3-POINT BELT AND DRIVER AIR BAG IN FRONTAL COLLISIONS - Dimitrios Kallieris, Andreas Rizzetti, Bernd V. Wiren, Rainer Mattern, Institute for Legal Medicine, University of Heidelberg Germany, Paper No. 96-S3-O-08

OPPORTUNITIES TO IMPROVE FIRST GENERATION AIR BAGS - Jerome M. Kossar, Research and Development, National Highway Traffic Safety Administration, United States, Paper Number 96-S3-O-07

BIOMECHANICS AND CRANIOCEREBRAL TRAUMA- Lawrence E. Thibault, Sc.D. & Thomas A. Gennarelli, M.D.

FATAL INJURIES IN A MINOR TRAFFIC COLLISION - Mary I. Jumbelic, M.D., Journal of Forensic Sciences, Volume 40, No. 3, May 1995, pp 492-494

ACCELERATION DAMAGE TO THE BRAIN - Thomas A. Gennarelli, M.D. and Lawrence E. Thibault, Sc.D. - Department of Neurosurgery and Bioengineering, University of Pennsylvania, Philadelphia, Pa. 19104 U.S.A.

AIR BAG DEPLOYMENT CHARACTERISTICS, Sullivan & Kossar, NHTSA, 2/92

AIR CUSHION SYSTEM EXPERIENCE - 1972 thru 1980, National Center for Statistics and Analysis, National Highway Traffic Safety Administration, U. S. Department of Transportation; and Allstate Loss Prevention Division, February 15, 1981
AIR BAG SAFETY - Memo to Owners of GM Vehicles with Passenger Air Bags - General Motors Corporation, December 1996

KINEMATIC BEHAVIOR OF THE HUMAN BODY DURING DECELERATION, - Civil Aeromedical Research Institute, Federal Aviation Agency, Oklahoma City, OK, Report No. 62-13., 1962

ESTIMATES OF CURRENT AND FUTURE RESTRAINT EFFECTIVENESS IN FATAL AUTOMOBILE CRASHES; Huelke, et al., (University of Michigan), Appendix A," February 2, 1978

CAUTION: AIR BAGS AT WORK - Jerry Shine, Popular Science, June 1994

DEPLOYMENT OF AIRBAGS IN TRAFFIC ACCIDENTS: CHARACTERISTICS AND CONSEQUENCES - Edmund Lau, Rose M. Ray and Louis Y. Cheng, Failure Analysis Associates, Inc., Menlo Park, California USA - 41st Annual Proceedings, Association

For The Advancement Of Automotive Medicine, November 10-11, 1997, Orlando, Florida

THORACIC RESPONSE AND TRAUMA OF OUT-OF-POSITION DRIVERS RESULTING FROM AIR BAG DEPLOYMENT - J. R. Crandall, S. M. Duma, C. R. Bass, W.D. Pilkey, University of Virginia, Charlottesville, Virginia, S. M. Kuppa, Conrad Technologies, Inc., Washington, D.C., N. Khaewpong, R. Eppinger, National Highway Traffic Safety Administration, Washington, D.C. - 41st Annual Proceedings, Association For The Advancement Of Automotive Medicine, November 10-11, 1997, Orlando, Florida.
MECHANISMS OF INJURIES FOR ADULTS AND CHILDREN RESULTING FROM AIRBAG INTERACTION - Michael Kleinberger and Lori Summers, National Highway Traffic Safety Administration, Office of Crashworthiness Research, Washington, D.C. - 41st Annual Proceedings, Association For The Advancement Of Automotive Medicine, November 10-11, 1997, Orlando, Florida.

INTELLIGENT RESTRAINT SYSTEMS - WHAT CHARACTERISTICS SHOULD THEY HAVE? - Murray Mackay, Stephen Parkin and Andrew Scott, Birmingham Accident Research Centre (BARC) University of Birmingham, England - Advances in Occupant Restraint Technologies: Joint AAAM-IRCOBI Special Session, September 22, 1994, Lyon, France.

SMART TM AIRBAG SYSTEM" - Bradley W. Smith, Dietrich Bergfried and Ian Faye - Morton International Research and Development Staff United States, Robert Bosch GmbH Electronic Systems Development Staff Germany and United Airbag Systems GmbH (UNAS) Airbag Systems Development Staff Germany - Proceedings of the 14th International Technical Conference on Enhanced Safety Vehicles, PPG. 570-577, Paper No. 94-S4-O-11, May 23-26, 1994, Munich, Germany.

OPPORTUNITIES AND LIMITS OF AN AIRBAG OPTIMIZATION BASED ON THE PASSIVE REQUIREMENTS OF STANDARD 208 - Klaus Kompab - Bayerische Motoren Werke AG - Proceedings of the 14th International Technical Conference on Enhanced Safety Vehicles, PPG. 549-555, Paper No. 94-S4-O-08, May 23-26, 1994, Munich, Germany.

MID-ATLANTIC DRIVER AIR BAG - David J. Romeo - Romeo Engineering Int'l, Inc., Alpine, Wyoming - Proceedings of the 14th International Technical Conference on Enhanced Safety Vehicles, PPG. 562-569, Paper No. 94-S4-O-10, May 23-26, 1994, Munich, Germany.

AN EFFECTIVENESS ANALYSIS OF CHRYSLER DRIVER AIRBAGS AFTER FIVE YEARS EXPOSURE - W. Randall Edwards - Chrysler Corporation, United States - Proceedings of the 14th International Technical Conference on Enhanced Safety Vehicles, PPG. 556-561, Paper No. 94-S4-O-09, May 23-26, 1994, Munich, Germany.

ACTIONS TO REDUCE THE ADVERSE EFFECTS OF AIR BAGS - FMVSS NO. 208 - DEPOWERING - FINAL REGULATORY EVALUATION - NHTSA Office of Regulatory Analysis Plans and Policy - February 1997.

AIR BAGS & ON-OFF SWITCHES -

INFORMATION FOR AN INFORMED DECISION - U.S. Department of Transportation National Highway Traffic Safety Administration - Pamphlet No. DOT HS-808-629, 1998.

Joint Petition for (1) inclusion of vehicle-specific air bag specifications in the NHTSA brochure “Air Bags and On-Off Switches: Information for an informed decision and (2) issuance of an order pursuant to 49 U.S.C. Section 30117 requiring that automobile manufactures provide air bag specifications to new car purchasers at point of sale; American Academy of Pediatrics, Center for Auto Safety, Consumer Federation of America, Parents for Safer Air Bags, Public Citizen; February 12, 1998.

A Discussion of the Air Bag System and Review of Induced Injuries; Tyler A. Kress, David J. Porta, Stefan M. Duma, John N. Snider and Nurry M. Nino; University of Tennessee, Bellarmine College and University of Tennessee; Occupant Protection Technologies for Frontal Impact: Current Needs and Expectations for the 21st Century SP-1144, Society of Automotive Engineers, SAE Paper No. 960658; February 26-29, 1996.

Injury Patterns of Car Occupants Under Air Bag Deployment; A.C. Malliaris, K.H. Digges and J.H. DeBlois; DeBlois Associates, Inc.; Society of Automotive Engineers; SAE Paper No. 950867; February 27 - March 2, 1995.

Passenger-side airbags: Which perform the best? An analysis of fatality rates by make and model; Public Citizen and the Center for Auto Safety; July 2, 1997.

Airbag Study Shows Huge Variation in Safety Records; Public Citizen News Release; July 3, 1997.

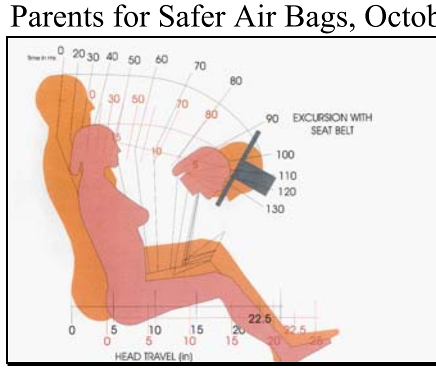
Airbag-induced Eye Injuries: A Report of 25 Cases; Stefan M. Duma, Tyler A. Kress, et. al.; University of Tennessee, University of Cincinnati, University of Louisville School of Medicine and Bellarmine College; The Journal of Trauma, Vol. 41, No. 1, PP. 114-119; July 1996.

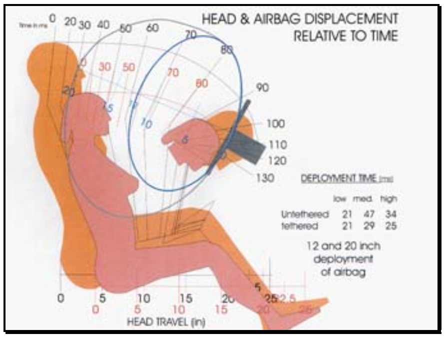
Preliminary Report on Real-World Performance of Next-Generation (Depowered) Airbags, in Response to SNPRM Federal Motor Vehicle Safety Standards; Occupant Crash Protection RIN 2127-AG70; Docket No. NHTSA 99-6407; Notice 1, December 30, 1999, Lawrence Schneider and Joel MacWilliams, UMTRI.

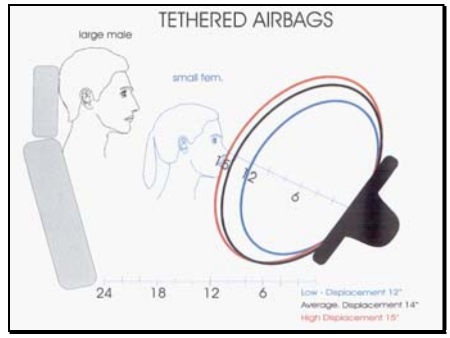
The Air Bag Crisis: Causes and Solutions, Parents for Safer Air Bags, October 1997.

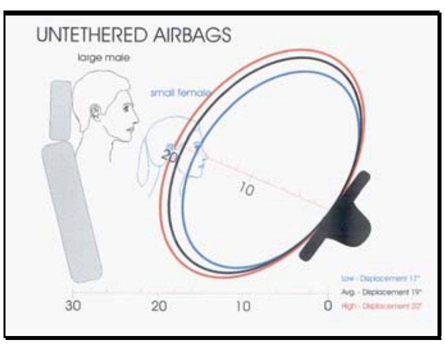
ATTACHMENT A

Illustrations of occupant and airbag relationships



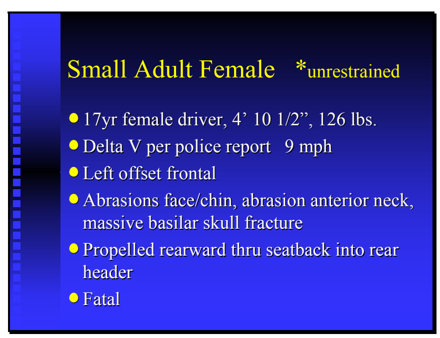


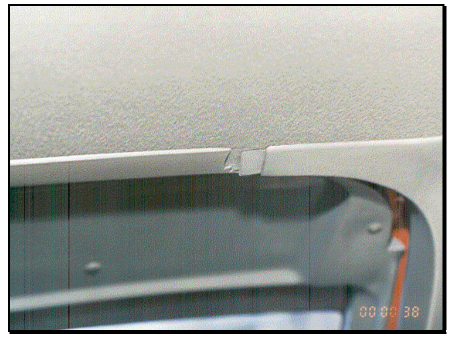




ATTACHMENT B

Case Examples



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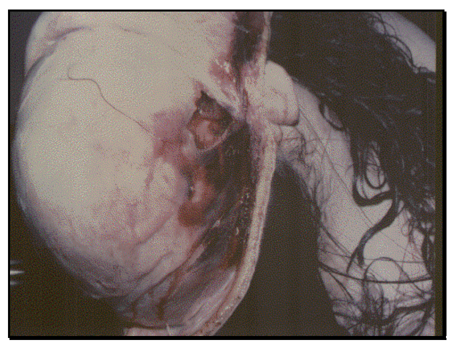
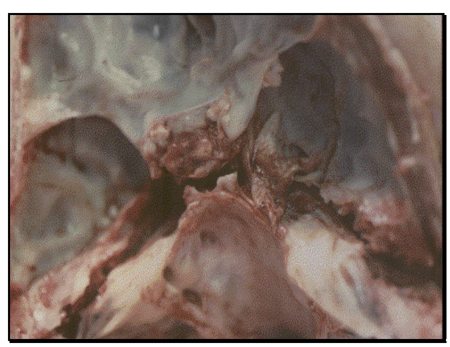
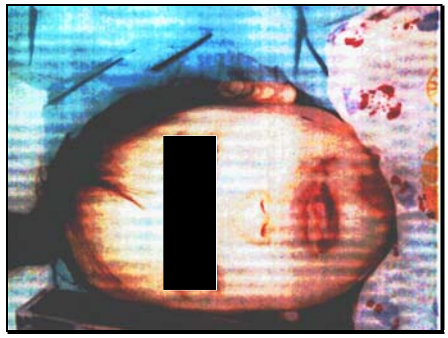




Small Child *questionable restraint use

- 6yr female RF occupant, 44” , 51 lbs.
- Delta V 7mph per NHTSA, frontal collision
- Unvented, untethered, 150L bag
- Diffuse subarachnoid hemorrhage, DAI, multi focal injuries to brain including brain stem
- Fatal



Small Adult * 3 point restrained

- 42yr female driver, 5’2” , 130 lbs.
- Low delta V
- Minor left side impact followed by minor left frontal
- DAI, right ankle fracture
- 13yr RFO fully restrained, chest wall tenderness, no significant injury

Small Child *questionable restraint use

- 3yr male RF occupant, 43”, 40 lbs.
- Frontal collision, delta V 15mph or less
- Untethered 15 +/- L bag
- Fatal injuries including atlanto-occipital dislocation, multiple facial and neck abrasions
- Mother(driver) 50%tile ? restrained, no injuries (driver air bag deployed)