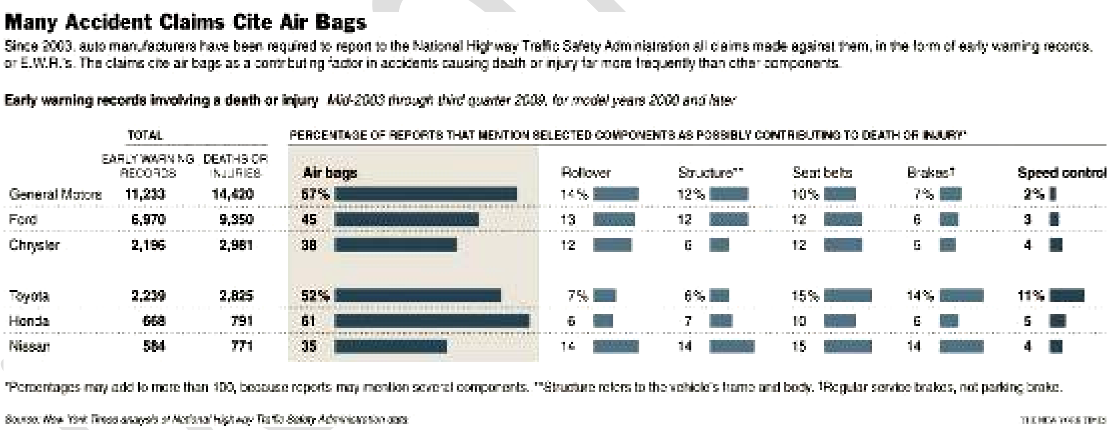
AIRBAG DEPLOYMENTS, VEHICLE STRUCTURE AND OCCUPANT SAFETY ISSUES

Airbags in modern automobiles have been around for many years and their record in improving occupant safety in crashes is generally well accepted. However, questions still arise regarding their deployment and performance. This note provides an overview of airbag engineering principles and of field performance data.

Some Recent Airbag-Related Reports:

- A report from the Insurance Institute for Highway Safety (Braver *et al*, "How Have Changes in Airbag Designs Affected Frontal Crash Mortality?" *IIHS, February, 2010*) found that the newest airbags provide 'suboptimal protection' for belted drivers and that the mortality rate for belted drivers was higher in airbag-equipped vehicles that comply with the law for frontal crash protection (FMVSS208, Advanced Airbag Rule) than in vehicles not certified as meeting this latest version of FMVSS.

- According to a recent story in the New York Times, airbag-related claims dominate the cases of accidents with injuries or fatalities as reported in the Early Warning Records submissions.



Many Accident Claims Cite Air Bags

Since 2003, auto manufacturers have been required to report to the National Highway Traffic Safety Administration all claims made against them, in the form of early warning records, or E.W.R.'s. The claims cite air bags as a contributing factor in accidents causing death or injury far more frequently than other components.

Early warning records involving a death or injury *Mid-2003 through third quarter 2009, for model years 2000 and later*

	TOTAL		PERCENTAGE OF REPORTS THAT MENTION SELECTED COMPONENTS AS POSSIBLY CONTRIBUTING TO DEATH OR INJURY*					
	EARLY WARNING RECORDS	DEATHS OR INJURIES	Air bags	Rollover	Structure**	Seat belts	Brakes†	Speed control
General Motors	11,233	14,420	57%	14%	12%	10%	7%	2%
Ford	6,970	9,350	45	13	12	12	6	3
Chrysler	2,196	2,981	38	12	6	12	5	4
Toyota	2,239	2,825	52%	7%	6%	15%	14%	11%
Honda	668	791	61	6	7	10	6	5
Nissan	584	771	35	14	14	15	14	4

*Percentages may add to more than 100, because reports may mention several components. **Structure refers to the vehicle's frame and body. †Regular service brakes, not parking brake.

Source: New York Times analysis of National Highway Traffic Safety Administration data

THE NEW YORK TIMES

- Two reports in the Kansas City Star (Casey & Montgomery, *"Airbags raise new alarms – Some didn't deploy in fatal crashes, newspaper learns"*, October 21, 2007; *"Front airbags don't inflate in hundreds of crashes"*, October 22, 2007) estimated 1400 fatalities during the years 2001 to 2006 in frontal crashes due to non-deployment of frontal airbags.

- The estimate from NHTSA for the same period was of 576 fatalities occurring in frontal crashes where the front airbags didn't deploy.

- Advances in airbags continue and new possibilities continue to be explored by manufacturers (*"Air bag arms race: Carmakers see who can add most safety advances"*http://www.detnews.com/apps/pbcs.dll/article?AID=/20070503/AUTO01/705030385/1148#ixzz0lrISmleW).

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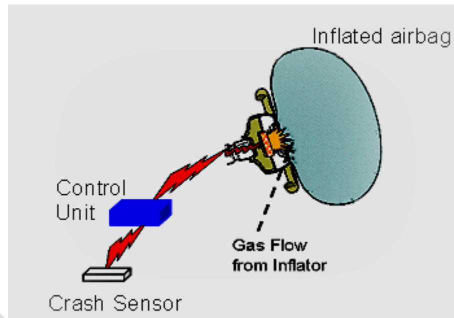
BASIC QUESTION: *'Did the airbag perform properly?'* consists of two parts – (a) *Did the airbag deploy when it should have*? and (b) *Did the airbag provide the optimal amount of occupant protection*? Another question faced by automobile manufacturers as well as by product liability experts is – *Was there another feasible design that would have further optimized the occupants' safety*?

AIRBAG TECHNOLOGY

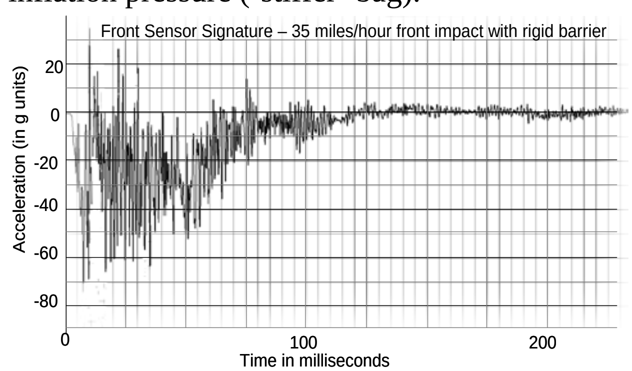
When a vehicle is involved in a crash, onboard sensors measure the vehicle's structural responses and transmit these to a central control unit. This unit compares the sensor data to pre-programmed information and decides whether deployment is desirable. If so, an electrical signal is sent to the inflator unit which ignites the propellants. The gas thus generated inflates the airbag. For frontal or lateral impacts, the bags remain inflated for a fraction of a second. For rollover airbags, the duration can be several seconds.



Two of the key issues in airbag design for cars are - a) conditions under which to deploy airbags, and b) the bag's shape, volume, gas pressure and the rate of inflation. One of the important considerations is that the airbags themselves add no significant injuries to the occupants. Larger airbags such as frontal crash protection bag for front passenger may sometimes consist of two stages or parts with only one part being inflated in some cases.

Deployment and non-deployment criteria are developed by each vehicle manufacturer based on tests and are designed to maximize the advantages of deployment while minimizing unnecessary deployments

Bag's shape, volume, gas pressure and the rate of inflation are determined to a large extent by FMVSS as well as by other high-speed crash test regimen and ratings systems, such as the frontal and lateral NCAP tests by NHTSA and the frontal offset crash test and the side impact test conducted by the IIHS. In general, the higher the test speed at which airbag-equipped cars have to meet high-ratings requirements (numbers measured on test dummies to be below certain thresholds), the faster the required inflation speed of the bag ('faster deployed') and the higher is the total inflation pressure ('stiffer' bag).



Airbag Deployment:

What data are used to make the decision? The automobile's structure provides the most significant information for deciding whether airbag(s) should be deployed in a crash.

Sensors attached to the vehicle structure measure the dynamic response – acceleration, velocity or displacement - during the crash. These data are communicated to the control unit which is pre-programmed with the decision-making algorithms. Sensors for frontal and lateral crashes generally provide a time record of acceleration (acceleration versus time data). A typical 'signature' from such a sensor is shown here as a record of acceleration in units of gravity ($1g = 981\ cm/sec^2$).

Sensors for rollovers usually provide a time record of angular velocity about the roll axis of the vehicle which is used to estimate the likelihood of the vehicle rolling over.

Principles governing deployment: Since an airbag deploys only once and stays inflated for a very short duration, it is important that deployment take place only when significant benefits are likely and that these be maximized in airbag-to-occupant interactions.

1. The overriding requirement is that the *airbag deployment must meet all applicable laws regarding such performance.*
2. In addition, airbags should:
a) *deploy in crashes when such deployment is likely to significantly reduce the severity of injuries suffered by the occupants;*
b) *not deploy when no additional protection of occupants is likely from such deployment;*
c) *not deploy in cases where such deployment itself may cause injuries.*

These principles pose many engineering challenges because automobile manufacturers must design their products for occupants of all ages, all sizes and myriad different biometric properties. They also have to take into account the fact that occupants of an automobile may be wearing seatbelts or be unbelted and at the moment of crash, may be seated properly or in some unusual position. Since the occupants' posture or biometric data is not available in airbag deployment calculations, these decisions have to be based only on the data from sensors attached to the vehicle.

Crash Sensors:
Front: These sensors are usually accelerometers attached to the vehicle's floor or underneath the front seat(s). In many vehicles, the sensor and the control unit are integrated into one box referred to as a 'sensing and diagnostic module'. Some automobiles also incorporate additional forward sensor(s) that are attached to structural members underneath the hood and closer to the front end of the vehicle. These additional sensors are intended to detect localized impacts.
Side: Sensors for side airbags also are generally accelerometers that measure the lateral response at the attachment location. These sensors may often be integrated with the front sensors into a 'sensing and diagnostic module'. In other vehicles, they may be located in the side pillar or in close proximity.
Rollover: The sensors for determining deployment of curtain airbags in cases of imminent rollovers are angular rate sensors.

PERFORMANCE EXPECTATIONS

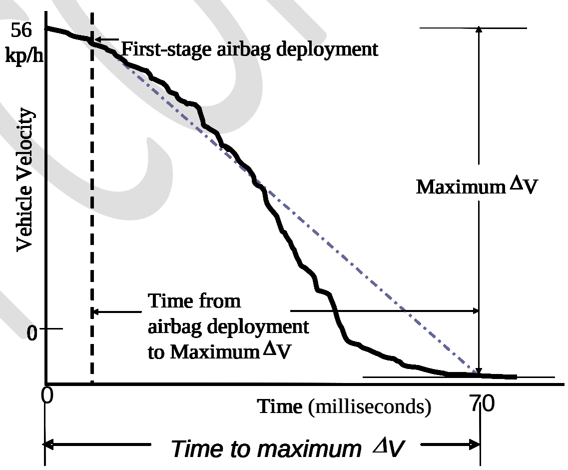
Concerns regarding airbag performance generally fall into two categories – deployment issues and occupant protection issues. There may also be instances where the airbag was not perceived as providing the expected amount of protection to the vehicle occupants.

The reason behind deployment-related concerns may be the expectation that airbags will be deployed in all 'severe crashes' and that visible damage to a vehicle is an indicator of such crash severity. However, airbag deployment criteria have to be based on expected improvement in occupant safety and not on the extent of visible damage to the vehicle since airbag deployment is a one-time-only and a very short-duration event which needs to maximize occupant protection.

<u>How is Crash Severity Perceived?</u> In present-day accident reconstruction techniques, the severity of in-plane crashes is estimated principally in terms of ΔV at the vehicle's center of gravity which is defined as 'the change in the vehicle's speed during the crash'. Rollovers are not considered to be in-plane and are a separate category. Because relationships between crash severity and occupants' injuries have been often presented as statistical functions of ΔV, perceptions may exist that the ΔV alone determines the probability of injury.

The questions of interest are the following – *Is ΔV the proper measure of a vehicle's crash severity? Should it be used as <u>the</u> deciding factor in airbag deployment decisions?*

<u>Crash Severity Definition</u>: An 'averaged' definition of accident severity requires that both the ΔV and the time during which this ΔV occurs be defined. As an example, in a crash test of an automobile into a rigid barrier at 56 kilometers/hour, the maximum ΔV equals the sum of the initial velocity and the maximum rebound velocity, whereas the 'time to maximum ΔV' may be 70 milliseconds in the example shown here. Both these parameters are necessary for estimating severity of the crash event as an 'averaged' deceleration. Of course, the complete response in a crash is a continuously varying event and a time-history record over the entire duration is needed in order to recreate the crash in detail.



<u>AIRBAG OPERATION</u>

<u>Properly Working Airbag</u>: Two aspects must be considered in deciding whether an airbag performed properly:

1. Reliability: Airbags and other occupant protection systems must have the highest possible degree of reliability so that they will perform as intended. Such reliability is also implicit in US laws for crashworthiness (FMVSS) in form of requirement that <u>all</u> the sold vehicles pass mandated test(s). The total system reliability is the product of the constituents' reliabilities and requires the evaluation of reliability of each component in the expected operating environment. Some of the constituents that must be considered are:

- *vehicle structure* → integrity of the load path from impact point to sensor location, dynamic response properties;
- *sensors* → electromechanical integrity, functionality under operating conditions;
- *electrical circuit & wiring* → integrity and functionality under operating conditions;

- *control unit* → electric/electronic integrity, functionality in operating environment;
- *inflator module* → functionality, combustion properties;
- *airbags* → bag integrity, functionality in operating environment;
- *mounting surfaces (steering column, instrument panel, etc*.) → structural integrity, load carrying properties, functionality of deployment mechanism*;*

Several additional factors may need to be evaluated for specific vehicles, such as the presence of multiple stages, operation of tethers, etc.

2. Performance: This implies that the airbag will optimize occupant protection.

Airbag(s) may be visualized as filling up the space between an occupant's body segments and the vehicle parts, thus reducing the relative impact velocity experienced by the body segments in the crash. Also, an airbag interposed between a moving body segment and a part of the vehicle distributes the impact forces over a wider contact area, thus reducing the peak acceleration that the body segment would otherwise experience.

Curtain airbags are designed to improve containment of the occupants inside the vehicle, thus reducing the likelihood of contacting injury-producing surfaces outside the vehicle.

Airbags are 'supplemental restraints' and provide optimum safety benefit when the vehicle occupants properly wear seatbelts. The enhanced occupant protection from airbags is a combination of several factors:

- *Vehicle Structure* → primary mechanism for dissipating crash energy, determining vehicle motion, maintaining occupant compartment integrity;
- *Interior parts of vehicle* → seats determine occupant position and motion during crash; steering column and instrument panel affect the available space for airbag and impact velocity of occupants in front crashes; doors' interior and trim affect the response in lateral and rollover crashes, structure of roof, pillars and doors determine the airbag and impact locations in many crashes.
- *Seatbelts* → primary mechanism for reducing occupants' impact velocities and for keeping occupants in place for proper interaction with airbags if used properly. Several vehicles also have pyrotechnic pre-tensioners that further tighten the belts when a crash is sensed.

Several other factors e.g. occupant posture, seat location and recline, sunroofs and side window openings, effect of prior collisions (from repair records, CARFAX), seatbelt configuration on the occupant, etc. need to be examined when evaluating specific cases.

THE STATISTICS

Published Research: A detailed study of airbag deployments and the role of ΔV has been published (Verma *et al*, "*A Study of US Crash Statistics from Automated Crash Notification Data*", Paper 07-0058, ESV Conference, 2007) and some results from this are described below. Shown in Figure 1 are the maximum values of ΔV for frontal crashes where airbag was deployed. It is seen from this figure that airbag deployments occur over a wide range of maximum ΔV.

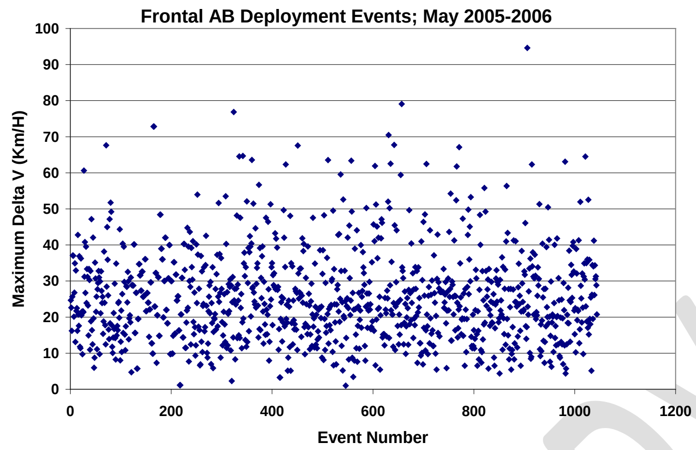


Figure 1: Maximum ΔV in Frontal Crashes with Airbag Deployment

Also reported were the ΔV values for crashes where the airbag did not deploy but the ΔV reached a specified threshold (Figure 2). It may be observed that the ΔV values were more than 78 km/hour (or 45 miles/hour) in some non-deployment cases.

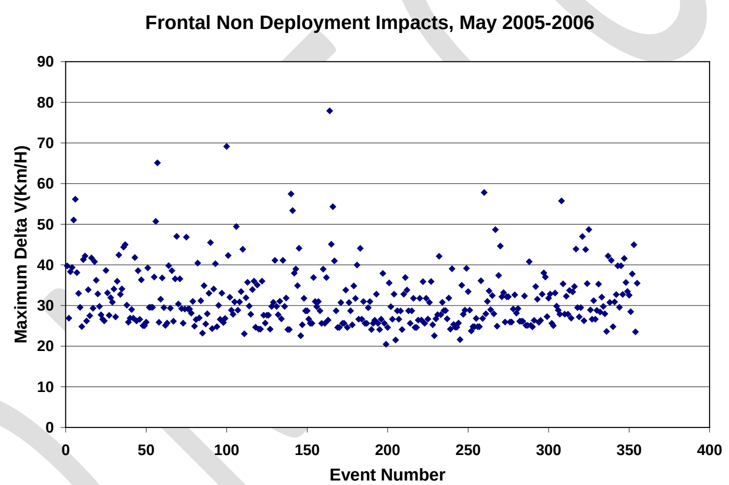


Figure 2: Airbag Non-deployment - Maximum ΔV in Frontal Crashes

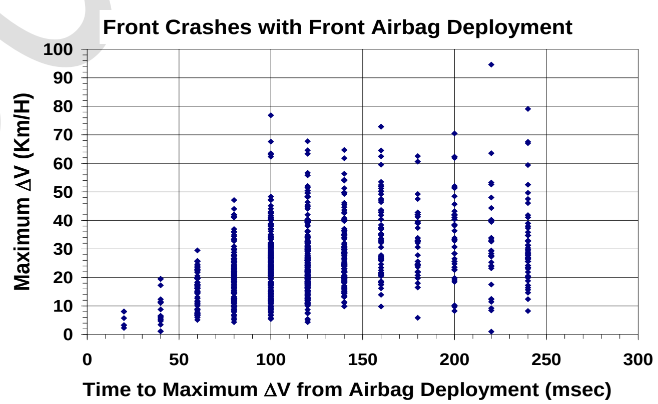


Figure 3: ΔV –versus- Time Record for Front Airbag Deployments

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In order to relate these data to 'average' crash severity, ΔV values were combined with the estimated time information (Figure 3). Each crash may then be defined by an 'average deceleration' which is the slope of the line connecting the data point to the 'time zero'. Analysis of each individual crash (point in the plot) showed that all these cases met the 'must deploy' criteria in terms of crash severity parameters.

A similar analysis of non-deployment cases of Figure 2 has shown that each case was below the 'must deploy' thresholds when defined as *'vehicle velocity (magnitude and direction) change versus time duration*'. For example, one of the thresholds for front airbags may be '*must deploy in frontal crashes into a fixed rigid barrier with ΔV exceeding 25 km/hour*' (this is an assumed value for purposes of discussion and does not represent the actual values used by any vehicle manufacturer). None of the cases in Figure 2 violated these criteria, although ΔV itself may appear high.

Another observation in the above-mentioned paper relates to the high speed tests governing the design of airbag-equipped vehicles. As mentioned earlier, several airbag parameters such as maximum inflation pressure, rate of inflation, etc are governed to a large extent by the need to meet the criteria of the highest severity crash tests. In the US, these 'highest severity' crash tests are the frontal and the lateral NCAP tests and the IIHS offset crash test and the lateral impact test. The frontal NCAP test severity was plotted on the time scale (Figure 4) and it was observed that the severity of these tests exceeded almost all the observed actual crashes on the roads.

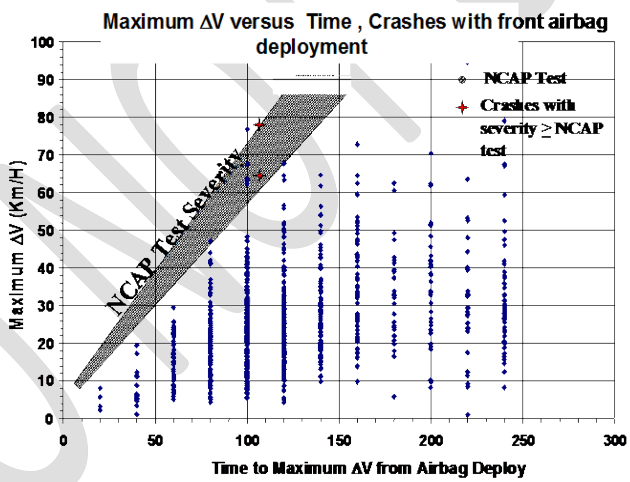


Figure 4: ΔV and Time Record for Front Airbag Deployments

<u>Statistical Analysis of US Crash Data</u>

Results from analysis of the National Automotive Sampling System – Crashworthiness Data System ('NASS-CDS') for the year 2008 are shown in Figure 1. For the NASS-CDS database, the NHTSA conducts detailed investigations of approximately 5000 crashes every year in the US and then makes statistical projections of overall trends in automotive crashes and injuries. The present analysis includes only vehicles with airbags and only cases with known ΔV. Cases of vehicle rollover and rear impacts were excluded. For the first curve in Figure 5 (shown as a continuous line) the plot of airbag deployment ratio was obtained by dividing 'the estimated number of cases where the airbag was

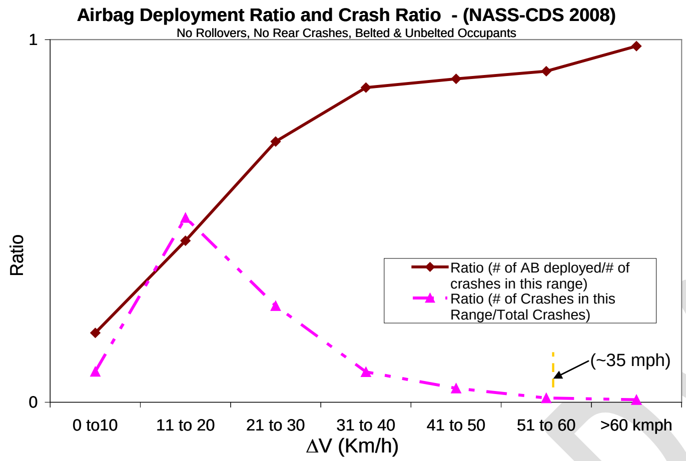


Figure 5: NASS-CDS 2008 Data - *Airbag deployment ratio-versus-ΔV*

deployed' by 'the total number of crashes in that range of ΔV'. It is observed that *the lower the ΔV of the vehicle in the crash, the smaller the percentage of airbags deployed.* For example, for crashes with estimated ΔV in the range of 11- 20 kilometers/hour, airbags were deployed in only 44% of the cases.

The second curve in Figure 5 is of the ratio 'the number of crashes in the ΔV range' to the 'total number of estimated crashes'. It is observed that (a) *more than 50% of the estimated crashes have ΔV in the range of 11 to 20 kilometers/hour; and (b) the higher the ΔV beyond this range, the lower the number of crashes".*

The distribution of injury severities is shown in Figure 6 for belted occupants only and is based on reported maximum AIS ('Abbreviated Injury Severity') value for the vehicle's occupants. Each bar represents the ratio of 'number of cases of the AIS level' to the 'total number of cases with AIS between 0 and 6'. The trend observed here is of higher severity

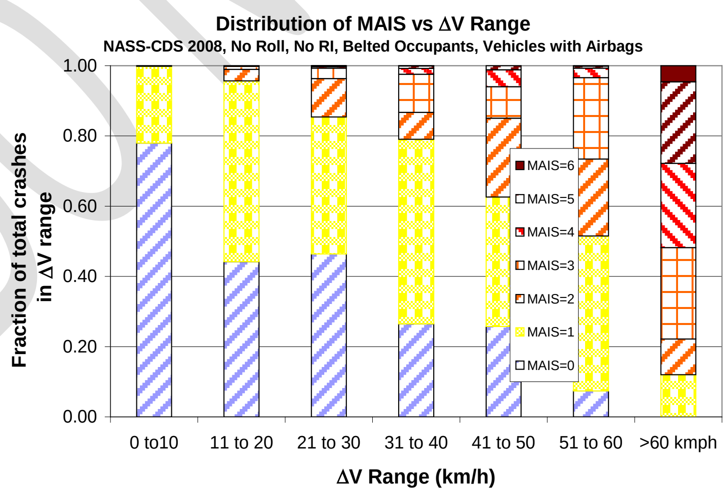
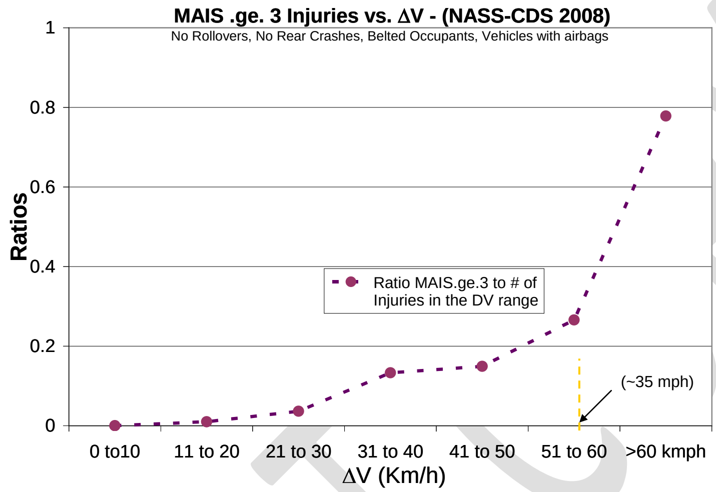


Figure 6: *Distribution of Maximum AIS level of Injuries versus ΔV*

injuries being predominant at higher levels of ΔV.

These data were further aggregated to clarify the trend (Figure 7) and plotted is the ratio of '*number of cases with maximum AIS of 3 or higher*' to the '*total number of crashes in that ΔV range*'. It is observed that as ΔV increases, more of the sustained injuries are at a higher level. For example, only about 1% of the cases with ΔV in the 11-20 km/hour range have occupants with injuries of maximum AIS level 3 or higher, whereas for ΔV in the 51- 60 km/hour range, more than 25% of the cases have occupants with injuries of maximum AIS level 3 or higher.



<u>Figure 7:</u> *Ratio of Injuries with Maximum AIS ≥ 3 for various ΔV ranges*

SUMMARY

- Airbag deployments are based on a vehicle's structural response in a crash as measured by sensors and compared with pre-programmed thresholds.
- The crash speed or the ΔV of a vehicle is not a unique and complete measure of the vehicle's crash severity. Time data is also required for reliably quantifying this severity and for making occupant safety decisions.
- Evaluation of proper airbag deployment in a specific crash requires consideration of several factors - crash parameters, structural integrity and response, sensor location & calibration, electrical circuitry integrity, power supply, control unit function and pre-programmed thresholds, any previous impacts to the car, etc.
- Assessment of protection provided by an airbag also requires integrated analysis – crash parameters, vehicle kinematics in crash, structural dynamics, timing of sensor commands, seatbelt properties, airbag parameters (multi-stage function, bag shape, inflation pressure etc), seat structure, occupant's position and other biometric data, etc. Occupants of different sizes/ages/biometric properties have different injury thresholds and thus may receive varying degrees of protection.
- The high-speed crash test requirements of FMVSS and of consumer information programs largely govern the design of airbags in cars and these tests need to be reevaluated to assure maximum occupant protection across the entire spectrum of crash conditions, vehicle parameters and occupant-related factors.