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DaimlerChrysler Corporation

April 13, 2000

Mr. Stephen R. Kratzke
Associate Administrator for Safety Performance Standards (NSP-01)
National Highway Traffic Safety Administration
400 Seventh St. S.W.
Washington D.C. 20590

Dear Mr. Kratzke:

Re: NHTSA Docket No. ~~99-6407~~ 00-7013-13 – Notice 1
FMVSS 208, Occupant Crash Protection

During your visit to DaimlerChrysler on February 11, 2000 a brief two part overhead slide presentation was made to you regarding: 1.) a DaimlerChrysler analysis of NASS data concerning the effectiveness of pre-depowered airbags and the appropriateness of the 30 mph unbelted occupant requirement in the SNPRM; and 2.) the distinguishability of different crash speeds as a function of their speed separation. That presentation has been documented and is attached for NHTSA's reference and benefit. We trust this information will aid NHTSA in its development of a final rule regarding advanced restraint technology.

Sincerely,

Matthew C. Reynolds
Director, Vehicle compliance &
Safety Affairs

A Company of the DaimlerChrysler Group

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Auburn Hills MI USA 48326-2757

Supporting Material for DaimlerChrysler Response to the FMVSS 208 SNRPM

Need for Separation in Test Speeds for Low Risk Deployment Air Bag Stage Tests and High-Speed Rigid Barrier Tests

March 31, 2000

1. Summary of DaimlerChrysler's Comments Regarding Test Speed Overlap

This narrative provides details on DaimlerChrysler's response to the FMVSS 208 SNPRM in regard to the need for separation in test speeds for low risk deployment air bag stage tests and high-speed rigid barrier tests.

The proposed regulation does not allow a separation in speeds between the low-risk deployment threshold compliance test speed and the lower bound of the high speed unbelted compliance test. Small (or non-existent) separation in compliance test speeds would result in an increased number of late fires and reduced effectiveness of air bags in real-world crashes. This condition may limit a manufacturer's ability to develop a low-power/low-risk deployment inflator stage in their air bag system for low velocity impacts. The proposed regulation calls for meeting assessment values for both a 5th percentile female and a 50th percentile male occupant during a rigid barrier compliance test at speeds ranging from as low as 18 mph to as high as 25 - 30 mph. There is a simultaneous requirement for out-of-position tests to be conducted with whichever air bag stage is deployed during an identical 18 mph rigid barrier test. Setting the compliance test requirement at 25 mph creates the possibility that the same stage will fire at 18 mph during compliance testing, forcing out-of-position tests to be conducted with the most powerful stage of the airbag system.

2. Air Bag Effectiveness

One of the most important reasons to develop a low-power/low-risk deployment inflator stage is to provide the occupant restraint benefit of an air bag in low velocity impacts. Low velocity impacts represent the conditions where the air bag is most effective in limiting fatalities and serious injuries.

Actual field data in the National Automotive Sampling System (NASS) database was examined for the period 1991-1997. Both fatalities and AIS 3+ injuries were analyzed for conditions where there was no air bag as well as those where an air bag deployed. This study considered the effectiveness as a function of impact velocity (delta V). The effectiveness metric was defined based on fatality and injury rates (r) as follows:

$$e = 1 - \frac{r_{\text{AirBag}}}{r_{\text{NoAirBag}}}$$

Based on this definition of effectiveness, a positive effectiveness means that it is beneficial to have an air bag in a particular type of impact (there is a higher rate of injury or fatality when there was no air bag). Conversely, a negative effectiveness means it is better not to have an air bag (there is a higher rate of injury or fatality when there was an air bag).

Figure 1 shows the driver air bag effectiveness versus change in velocity (delta V) for head fatalities in purely frontal (12 o'clock) collisions. Although only head fatalities are shown in Figure 1, the same trend is seen for all fatalities in purely frontal impacts. The effectiveness is calculated for ranges of delta V. The results for both unbelted and belted occupants are shown. As expected, the effectiveness of the air bag is essentially zero for the lowest range of delta V (0-10 mph) due to the very small incidence of fatalities at these speeds. The effectiveness of the air bag is positive for delta V in the range of 10-22 mph for both unbelted and belted occupants (the air bag is reducing fatalities). The higher speed range tells a remarkably different story. The effectiveness of the air bag is positive for belted occupants for delta V ranging from 22-52 mph, but the air bag effectiveness is negative for unbelted occupants in the same delta V range. The unbelted occupants have a lower rate of fatal head injuries at high speeds when they do not have an air bag deployed.

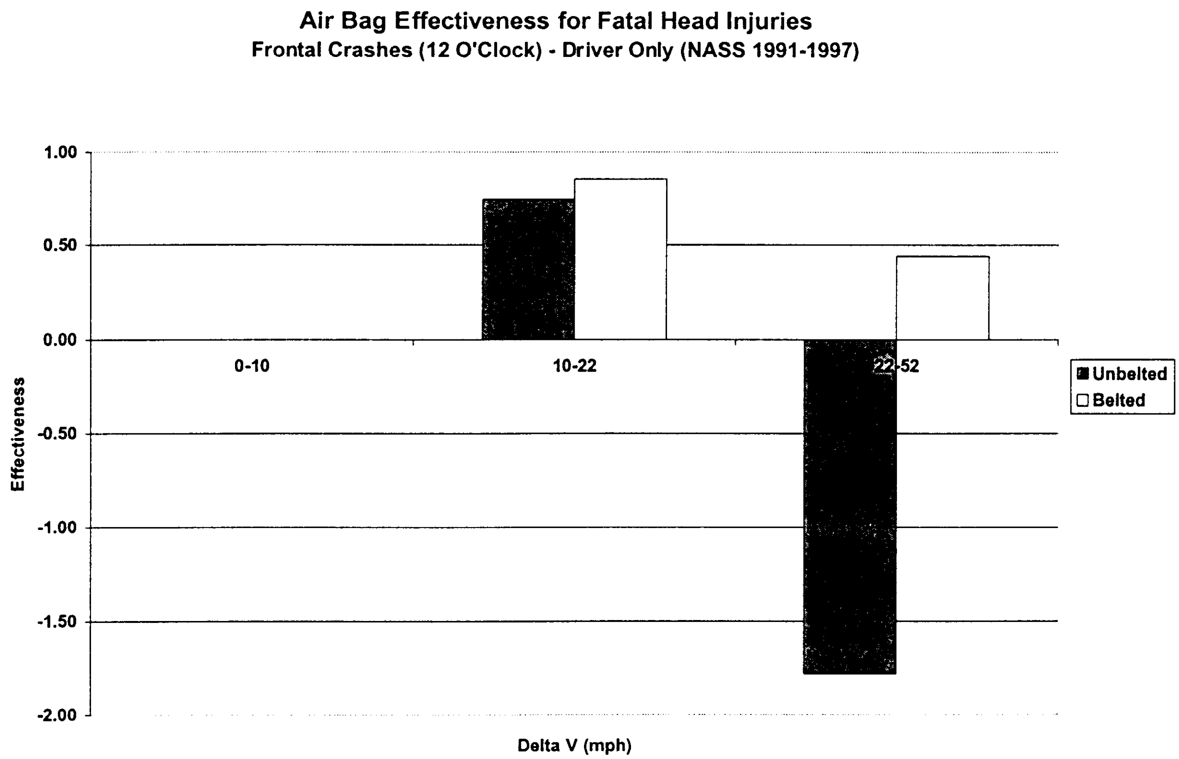

Figure 1. Air Bag Effectiveness for Fatal Head Injuries in Purely Frontal Impacts

The results shown in Figure 1 are an indication of trend. Due to the small sample sizes available, the values shown should be used for comparison purposes rather than for assessments of absolute values. However, the general trend was confirmed by performing the same analysis on AIS 3+ head injuries for the same classes of collisions. There are many more recorded incidents in the NASS database for AIS 3+ injuries than fatalities, resulting in better estimates of the rates at the various delta V ranges. It is reasonable to expect that fatal head injuries should follow the same trend as is seen in AIS 3+ head injuries. Figure 2 shows the driver air bag effectiveness versus change in velocity (delta V) for AIS 3+ head injuries in purely frontal (12 o'clock) collisions. The effectiveness of the air bag is positive in the lowest range of delta V (0-10 mph) for both unbelted and belted occupants (in contrast to the near zero effectiveness seen in the fatality results). This is due to the larger amount of data available for AIS 3+ head injuries in comparison to head fatalities at these speeds. The AIS 3+ effectiveness of the air bag is also positive for delta V in the range of 10-22 mph for both unbelted and belted occupants (confirming the results seen for fatalities). Most significantly, the higher range of speeds (22-52 mph) shows that the effectiveness of the air bag is positive for belted occupants, but negative for unbelted occupants in the same delta V range. The unbelted occupants have a lower rate of AIS 3+ head injuries at high speeds when they do not have an air bag deployed.

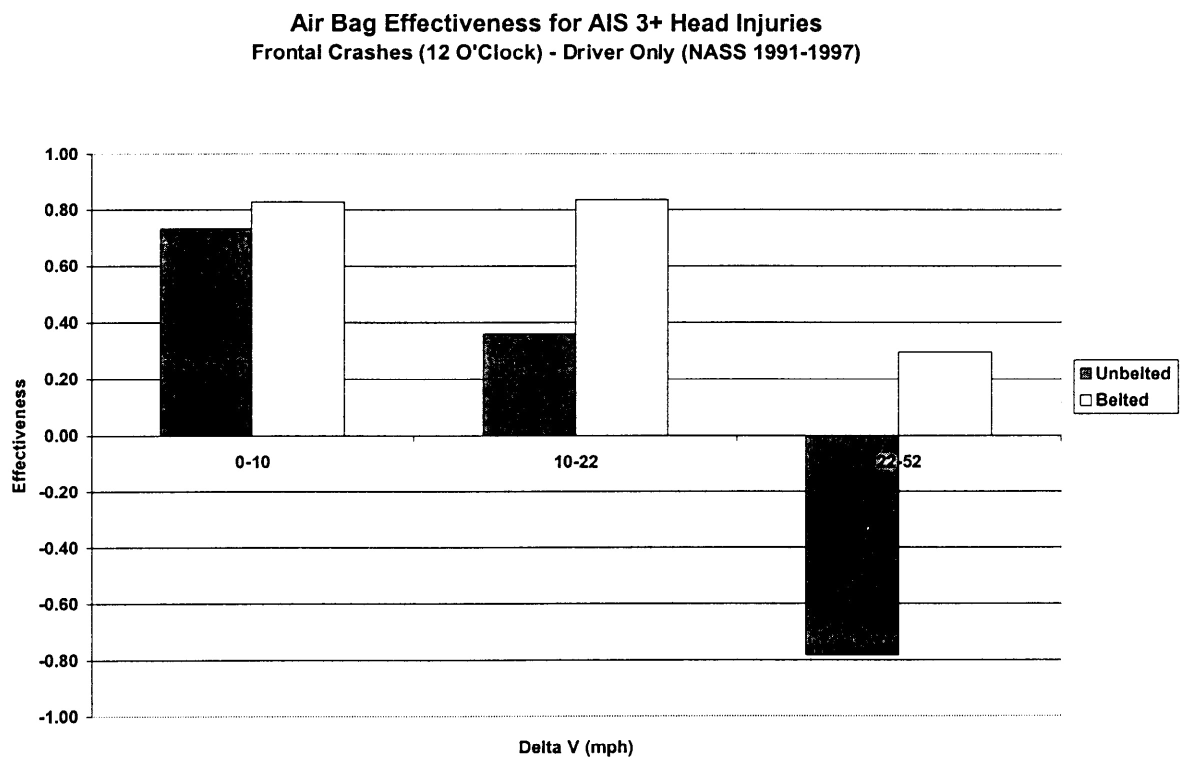

Figure 2. Air Bag Effectiveness for AIS 3+ Head Injuries in Purely Frontal Crashes

In a follow-on analysis, the coarsely categorized effectiveness data was transformed in a way that allowed effectiveness to be examined at any velocity in the recorded range of data. The AIS 3+ rate data was categorized into 2 mph increments of delta V and smoothed by using a moving average. The result is a continuous function that relates air bag effectiveness with delta V. The results of this operation are shown in Figure 3. The same operation could be done on the fatality data, but the scarcity of data for the fatalities in the small delta V increments makes the results unreliable. The smoothing operation provides a trend-indicating metric. The smoothed effectiveness results at any given speed are not exact numbers after smoothing due to the mathematical operation performed on the data.

The smoothed data for AIS 3+ effectiveness indicates that belted occupants will receive a benefit from the air bag throughout the range of speeds being considered. The peak effectiveness of the air bag is between 8 and 18 mph for unbelted occupants and between 8 and 23 mph for belted occupants. The unbelted occupant will receive a benefit from the air bag for speeds up to approximately 25 mph. Most significantly, the air bag has a negative effectiveness for unbelted occupants for a delta V greater than 25 mph.

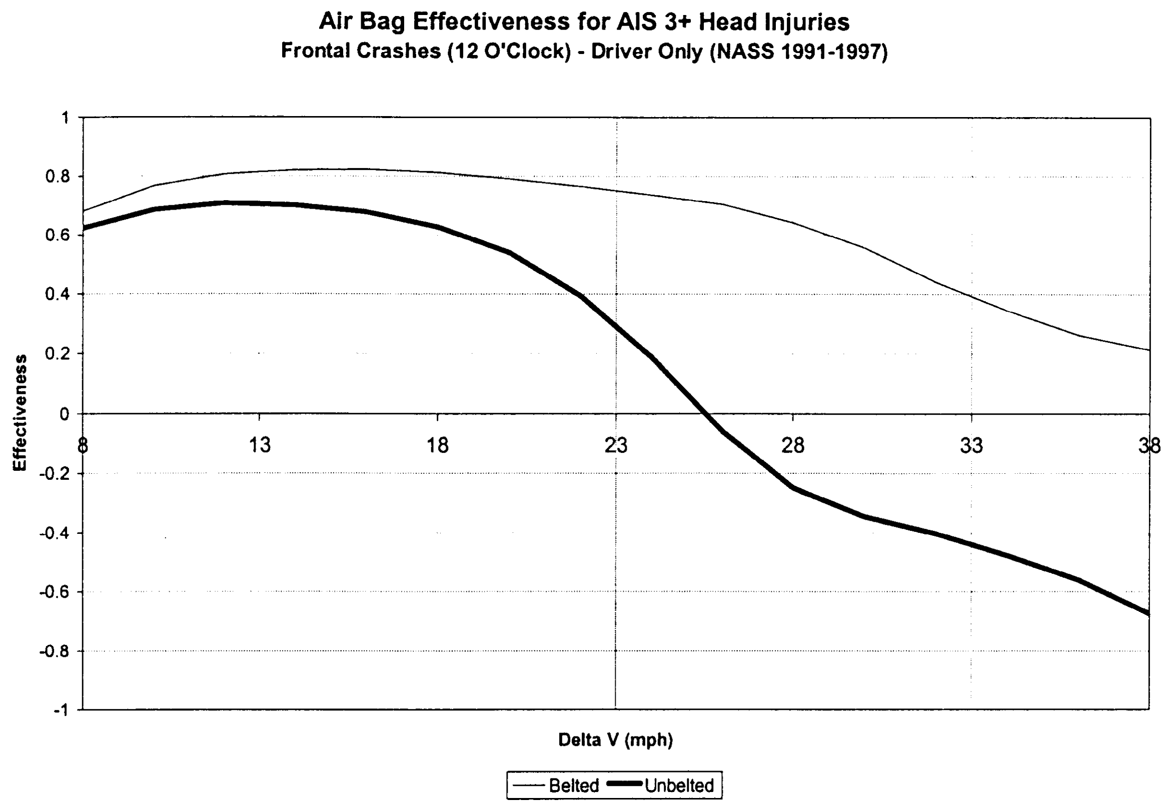

Figure 3. Air Bag Effectiveness for AIS 3+ Head Injuries in Purely Frontal Crashes (Smoothed Using Moving Average)

It can be concluded from this analysis of field data that air bags have their highest effectiveness in reducing head injuries and fatalities at low velocities. This is particularly apparent for the unbelted occupant. A low-power/low-risk deployment inflator can offer protection to occupants in the type of crashes where the air bag can have the most effect, while minimizing the risk to out-of-position occupants.

3. Air Bag Fire Time Probability

Vehicle crashes and the information available to air bag sensors are probabilistic events. Air bag system performance will improve when more information is available. Air bag controllers are forced to estimate, in a very brief time window, if a crash event is more severe than some threshold for deployment. More time will allow a more accurate estimate of velocity to be made. If a decision on the impact velocity could be made after the crash is over, the estimate of impact velocity would be very accurate. However, the air bag would deploy too late to be useful. Conversely, if a decision is made on the impact velocity at the start of a crash event, the air bag could, in general, be very effective, but there will be increased unnecessary deployments because the amount of information available will be almost zero and the uncertainty in velocity will be large. As Figure 4 illustrates, as the difference between the actual crash velocity and the deployment threshold velocity decreases, the time interval required, with a given confidence level, to estimate that a collision exceeds the pre-determined deployment velocity increases.

When a higher degree of confidence in the accuracy of the estimate is required or the gap between the threshold velocity and the estimated velocity of the crash decreases, the amount of time to make a decision to deploy an air bag dramatically increases. In other words, a narrow separation in threshold speeds (fire versus don't fire) results in more time being needed to make a confident decision that an air bag should be deployed.

The effect of increasing the amount of time to make confident air bag deployment decisions is seen in Figure 5. Figure 5 illustrates a 50% probability threshold speed of 14 mph for different maximum times to fire. Ideally, the probability of firing the air bag should be zero for all speeds less than 14 mph and 100% for all speeds greater than 14 mph. This ideal condition has no "gray zone" of uncertainty. Since real vehicle crashes are probabilistic events, this is not achievable. When an air bag sensor attempts to detect whether a crash speed is in excess of a threshold, some time is required to be confident in that decision. If a very small amount of time is allowed to make the decision to deploy the air bag, the gray zone could be significant in terms of velocities where the air bag could fire. If a large amount of time is allowed to make a decision to deploy, the gray zone of velocities where the air bag could fire could be narrow. Unfortunately, waiting a long time to deploy an air bag results in out-of-position occupants and other problems that diminish the effectiveness of the restraint.

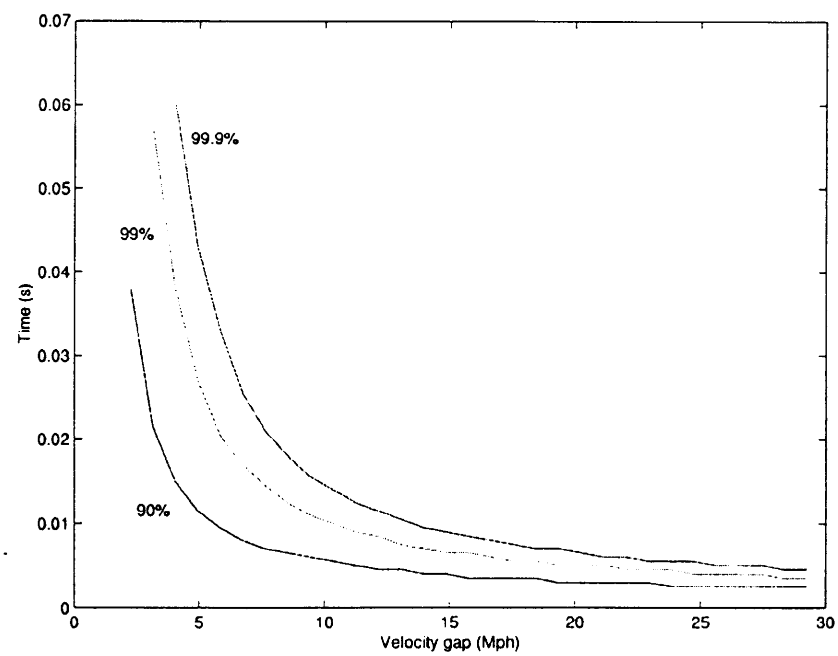

Figure 4. Sensing Time to Confidence Level Curves for the Best-Case Theoretical Estimates of Crash Speed by an Air Bag Sensor

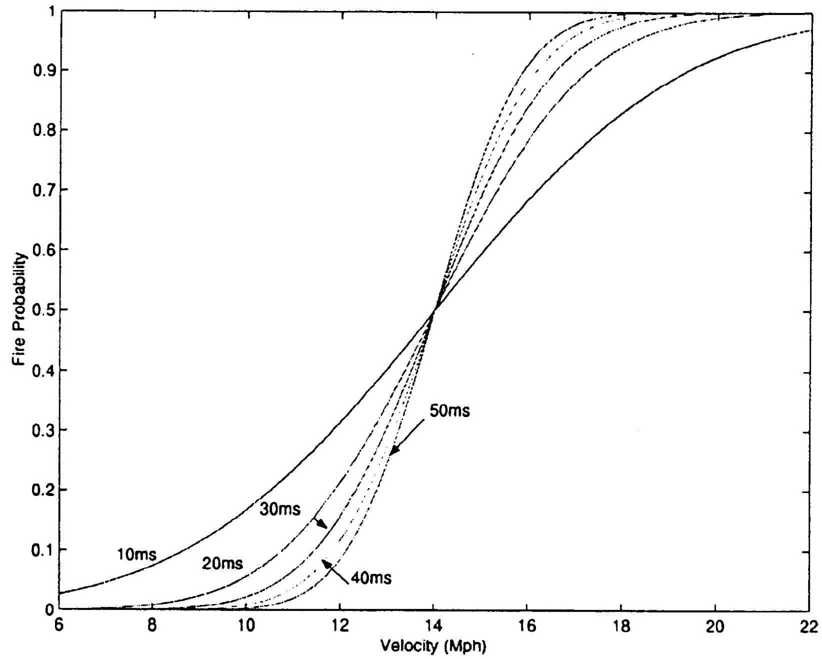

Figure 5. Air Bag Fire Rates to Assure 50% Probability of Deployment at 14 mph

Another way to see the effect of the probabilistic nature of air bag deployments is to require a 95% confidence that an air bag will deploy at a threshold speed. The effect of the time required to attain 95% confidence is shown in Figure 6. In this example, the threshold is 18 mph. The probability of firing the air bag is 95% at this speed of impact for all decision time intervals. The gray zone is illustrated for various time intervals allowed to make a deployment decision. If the time interval is very small (e.g., 10 ms), deployments may occur with some significant probability at speeds as low as 4 - 6 mph. If more time is allowed for the sensor to make a decision, the gray zone decreases. However, a smaller gray-zone occurs at the expense of the effectiveness-diminishing problems associated with late-fires.

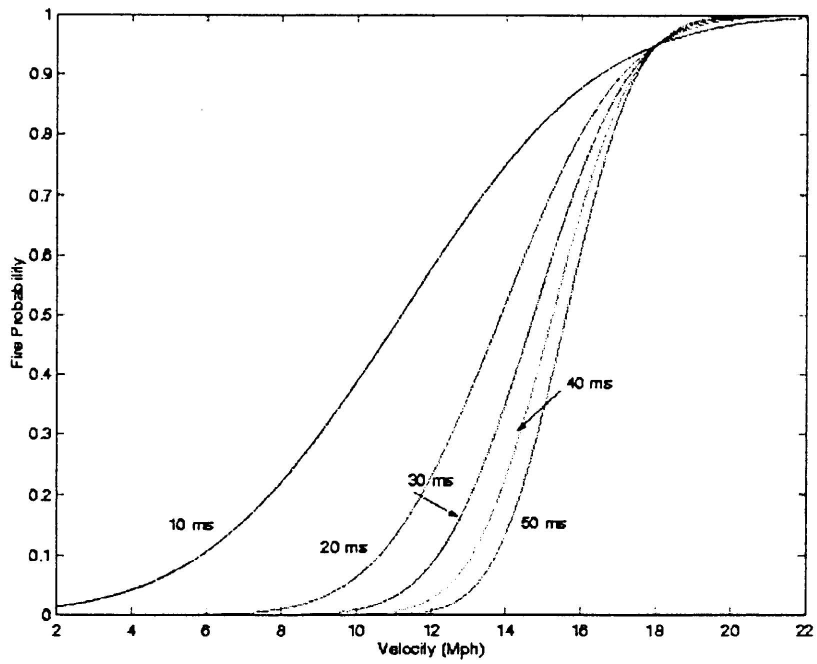

Figure 6. Air Bag Fire Rates to Assure 95% Probability of Deployment at 18 mph

The results presented in Figure 4, Figure 5 and Figure 6 are theoretically-derived, best estimates for simple barrier-like impacts. Actual barrier impacts will require longer times to produce equivalent confidence. Figure 7 provides confirmation of these results from an actual development vehicle with dual-stage air bags. Deployment probability is shown in terms of impact velocity and seat belt buckle status. These results suggest that the gray zone for guaranteed deployment can be over 10 mph in width for low-speed first stage deployments and over 20 mph in width for second stage deployments with all fires occurring at 30 mph, if the time to fire is kept short. However, if more time to fire is allowed, the gray zones can be reduced.

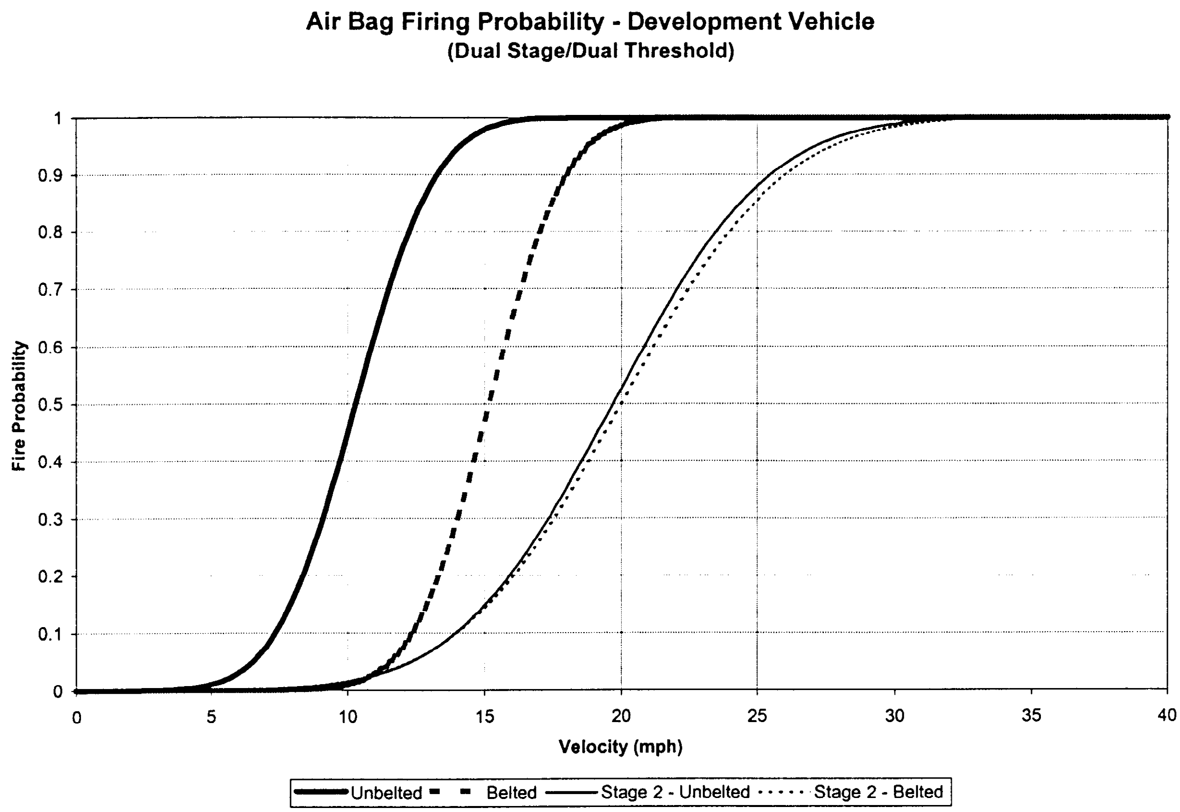

Figure 7. Air Bag Fire Rates for a Development Vehicle

Preventing late-firing and the associated out-of-position risks requires rapid decisions, all made within the confines of the gray zone. The need for rapid decisions results in some deployments at speeds lower than a threshold and some at speeds higher than a threshold. If an air bag stage must deploy at a specified speed in a regulated test, some deployments may occur at speeds lower than the specification to assure "100%" conformance. If an air bag system has an inflator stage that must fire during a 25 mph rigid barrier compliance test, this stage may also deploy in some 18 mph compliance tests. Under the proposed regulation, this stage of the system would also have to comply with applicable out-of-position tests. A single stage of an inflator cannot be capable simultaneously of meeting assessment values for a 50th percentile male in an 25 mph rigid barrier collision and also offer low risk for ISO 1 and ISO 2 out-of-position tests.

There is a clear need for separation between the lower bound of the unbelted occupant test speed and the low-risk deployment test speed that dictates out-of-position tests. This will allow low-power air bags for low-speed collisions -- protecting occupants in the most frequent types of collisions where the air bag has been demonstrated by field data to be the most effective.

4. Alternatives to the Proposed Low Risk Deployment/Unbelted Test Speeds

In its response to the FMVSS 208 SNPRM, DaimlerChrysler recommended lowering the low-risk deployment speed test to 15 mph and raising the lower bound on the unbelted test to 25 mph (+0/-1 mph). This separation will allow manufacturers to develop low-risk restraint systems.

This position is the result of careful consideration of the analysis described above which clearly demonstrates the need for separation in test speeds due to the probabilistic nature of vehicle crashes and the associated performance of the air bag system.

Another alternative to the test speeds described in the FMVSS 208 SNPRM has also been suggested by others. This is to specify 16 mph as the low risk deployment test speed and 20 - 25 mph as the unbelted test speed. While this proposal is an improvement over the test conditions specified in the SNPRM, it still does not provide enough separation in test speeds. This lack of separation will not allow short times to fire, which can result in late deployments of air bags and the associated loss of effectiveness.

5. Conclusions

- The greatest benefit of air bags is at low impact velocities. Air bags have their peak effectiveness in reducing fatalities and serious injuries in low speed crashes.
- Air bags appear to offer no net benefit to unbelted occupants at speeds above 25 mph. All efforts should be made to assure that high speed unbelted tests do not compromise the benefits of a low speed/low risk air bag.
- Air bag fire decision times need to be short in order to limit out-of-position deployments and their associated risks.
- Short fire decision times result in uncertainty in estimates of crash velocities by air bag sensors (large gray zone).
- Since uncertainty results in deployments below a threshold speed, there must be separation between the low risk deployment test speed and the high speed unbelted test speed.
- DaimlerChrysler continues to recommend lowering the low risk deployment test speed to 15 mph and raising the lower bound on the unbelted test speed to 24 mph to allow manufacturers to develop air bag systems which include low risk deployment at low velocities. It may be possible to have smaller separation in test speeds, but this will be at the expense of longer fire times in some vehicles, while the low risk deployment option may not be possible in other vehicles.