INJURY OPTIMIZATION OF THE FRONTAL CRASH SUPPLEMENTAL RESTRAINT SYSTEM (SRS) DEPLOYMENT MATRIX

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ABSTRACT

With the introduction of the FMVSS 208 upgrade for U.S. frontal crash safety, many new requirements were added. In order to meet these new requirements, manufacturers had to develop new methodologies for sensing, controlling, and deploying airbags. The standard achievement method is to use dual stage airbags with two firing thresholds.

The objective of this research was to improve three key areas of the standard method:

1) Prevent risk of inadvertent high output deployment for small occupants.
2) Improve occupant injury by achieving the ideal deployment mode
3) Reduce the complexity of the system to increase robustness.

In order to achieve these goals, it was proposed that a single ideal deployment mode could be developed by performing a parametric study where Time to Fire (TTF) and the delay between firing the first and second stage were varied independently for the driver and passenger Anthropomorphic Test Devices (ATDs). This was done for AM50% and AF5% ATDs in a front 40 km/h unbelted test mode. Once the 'ideal' TTF/delay was determined, the test speed was increased to 48 km/h and 56 km/h respectively for both belted and unbelted occupants.
The research showed that for the driver, an early TTF (10-15 ms) with a 20-30 ms delay provided the best combination of restraint for the AM50% ATD. This also allowed for good injury results in the AF5% low risk deployment mode. For the passenger, an early TTF (10-15 ms), with a longer delay (130 ms) showed the best combination of injury results. This allowed for successful Out of Position (OOP) deployments as well as good frontal crash results. It was also discovered during this research that there are some key interior lay out items that must be maintained in order to use this type of deployment strategy.

INTRODUCTION

Prior to the FMVSS 208 upgrade, most vehicles used a single stage inflator with a simple on/off firing threshold.

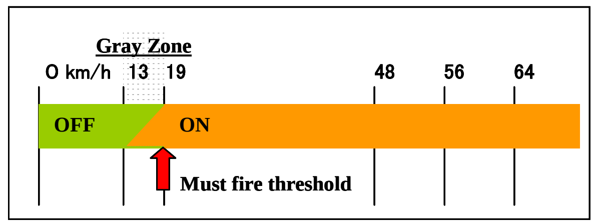

Figure 1: Pre FMVSS208 upgrade firing strategy

In this case the airbag would be guaranteed not to fire below 13 km/h, and guaranteed to fire above 19 km/h. A gray zone is created between these speeds were either condition may occur, which is shown in Figure 1. This airbag firing strategy was designed to protect for the regulation matrix shown Figure 2.

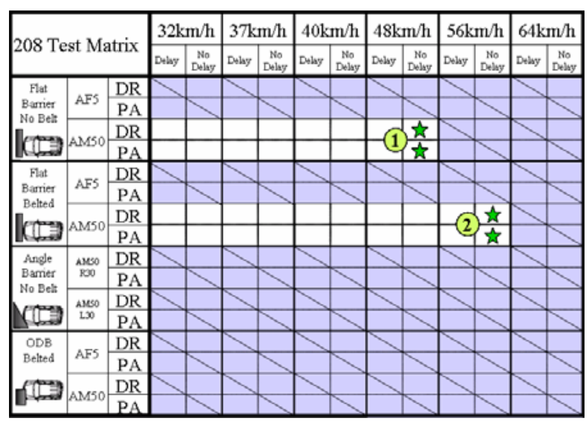

Figure 2: Pre FMVSS208 upgrade regulation matrix

In an effort to increase protection for children and smaller stature adults, the U.S. government upgraded FMVSS208 to include Low Risk Deployments (LRD) for AF5% drivers and the OOP deployments for CRABI, C3Y, and C6Y children. Increased frontal crash regulations were also added to the FMVSS 208 upgrade [1-FMVSS]. The updated frontal crash regulation matrix is shown in Figure 3.

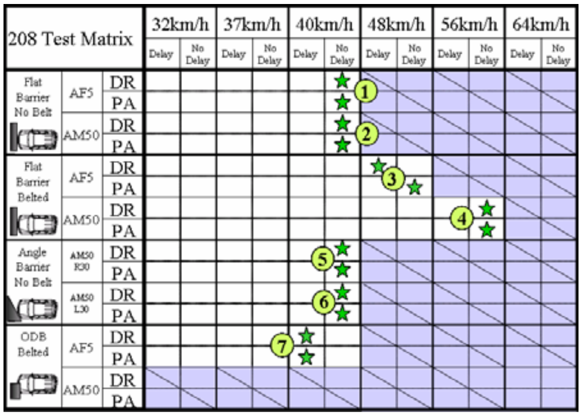

Figure 3: New FMVSS208 upgrade regulation matrix

This change in regulation necessitated a new approach involving dual stage airbags coupled with a redesigned SRS firing map to control them. Manufacturers needed a way to fire the airbags in a 'soft' deployment for AF5% and OOP children, which meant a delay prior to the second stage being fired, but also be able to fire both stages at the same time for AM50% occupants in more severe crash modes. This resulted in the SRS map shown in Figure 4.

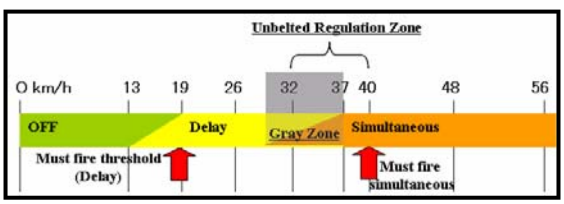

Figure 4: New FMVSS208 upgrade SRS firing map

The OOP portion of the regulation is written so that the firing time for the OOP occupant will be the same as the firing time that occurs when an AF5% occupant is placed in the passenger seat and the vehicle impacts a flat barrier at 26 km/h. Ensuring that a delay fire occurs at 26 km/h results in a gray zone between the belted and unbelted regulation zones where a vehicle could fire in either delay or simultaneous mode. To guarantee the regulation, the test matrix shown in Figure 5 is required. As can be seen, this gray zone requires four additional test modes.

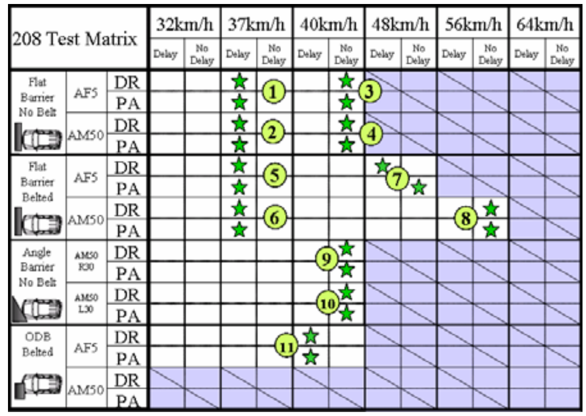

Figure 5: New FMVSS208 upgrade test matrix

METHODS

Crash Simulator System and Test Devices

This parametric study was done using AM50% HYBRID III test devices positioned according to the FMVSS 208 regulation [1-FMVSS]. The ATDs were seated in a sled buck which was built by cutting a full vehicle body in front of the A-pillar and just behind the B-pillar. Full instrument panel, steering system, pedals, and seats were applied to the sled buck, shown in Figure 6.

Figure 6: Crash simulator test buck

The crash simulator, shown in Figure 7, is a hydraulically controlled G-pulse matching device. This device includes full linear acceleration control as well as vehicle pitch control, which is shown in Figure 7.

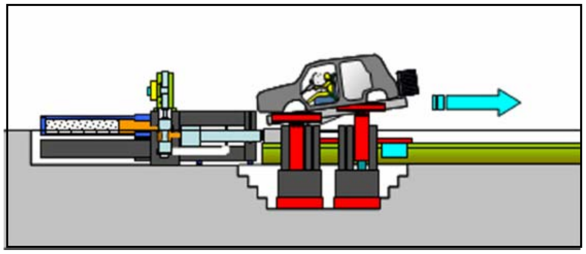

Figure 7: Crash simulator

A vehicle deceleration pulse is taken from a full CBU frontal impact then applied to the crash simulator software. The software interpolates the pulse and recreates it on the sled buck with a high degree of accuracy. An example comparison of crash simulator and crash barrier Floor G is shown in Figure 8.

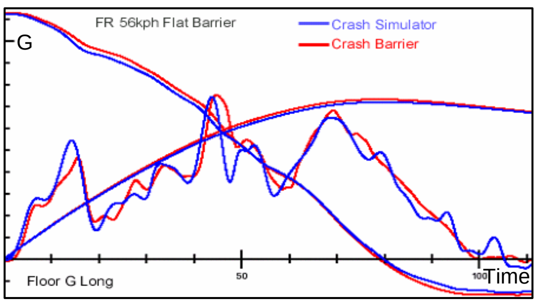

Figure 8: Crash simulator G-pulse vs. actual full vehicle frontal impact G-pulse

This accuracy and repeatability is ideal for this type of parametric study where the change in one variable can be assessed.

Test Matrix and Injury Metrics Assessed

Although all FMVSS 208 injury metrics were recorded, HIC, Chest G, Chest Deflection, and Neck Injury (NIJ) were the primary focus for comparison. Since the goal of the study was to determine the ideal TTF and delay for the airbag, the following test matrix in Figure 9 was used.

40 km/h	AM50%	No Belt	10ms	30ms
40 km/h	AM50%	No Belt	20ms	40ms
40 km/h	AM50%	No Belt	30ms	50ms
40 km/h	AM50%	No Belt	10ms	30ms
40 km/h	AM50%	No Belt	10ms	40ms
40 km/h	AM50%	No Belt	10ms	50ms
40 km/h	AM50%	No Belt	10ms	60ms

Figure 9: Initial testing matrix

Real World Injury Assessment

In addition to the primary goals of this study, it was deemed important to confirm that the ideal firing case for the AM50% dummy at the regulated velocity of 40 km/h would not cause a negative effect on unbelted occupants at speeds above the regulation. An additional test matrix was proposed to assess this possibility by comparing the traditional TTF/delay vs. the proposed 'ideal' TTF/delay.

				Driver	Passenger
40 km/h	AM50%	No Belt	10ms	40ms	140ms
56 km/h	AM50%	No Belt	10ms	40ms	140ms
40 km/h	AM50%	No Belt	10ms	15ms	
56 km/h	AM50%	No Belt	10ms	15ms	

Figure 10: Additional testing matrix

RESULTS / DISCUSSION

Once the initial test matrix was run, the resulting injury data was collected and graphed. The data was normalized as a percentage of target injury. 100% injury represents 80% of the FMVSS 208 regulation values.

Unbelted Driver Injury Comparison with Variable Second Stage Airbag Delay

The first comparison was done on the Driver. In this test series, the TTF was maintained at 10 ms and the second stage firing was varied from 20-60 ms. The critical injury parameters in this mode were Chest G, Chest Deflection, and NIJ. These were compared with the standard TTF/delay of 10/15 ms.

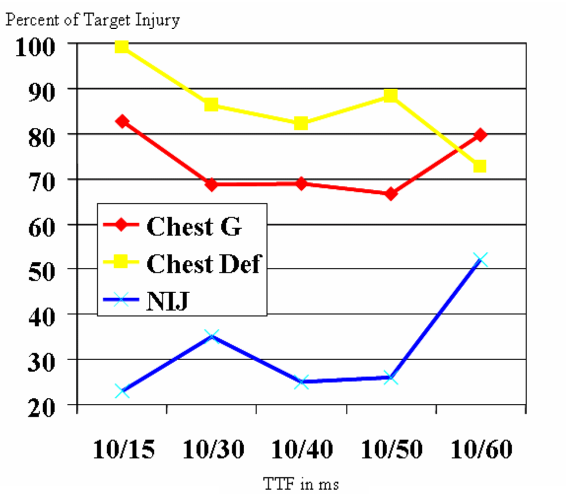

Figure 11: Unbelted Driver Injury for Variable Delay

In this case, the 'ideal' delay timing was from 30-40 ms. It became apparent that for the driver in the unbelted mode, the maximum amount of airbag restraint was preferable. This was accomplished by firing the airbag early (10 ms) to get it into position, than increase the bag pressure with the second stage fire just before the unbelted occupant made contact. The delay limit was 50 ms. At this point the second stage was pressurizing the bag while it was contacting the occupant. This caused the bag to get under the chin and increase the neck tension and extension.

Figure 12: 50ms Delay Causing Increasing Neck Injury

Although the neck injury was below the max target injury level, this mode was deemed to be unacceptable.

Unbelted Driver Injury Comparison With Variable Time to Fire

The second portion of the test matrix was to identify the 'ideal' initial fire time.

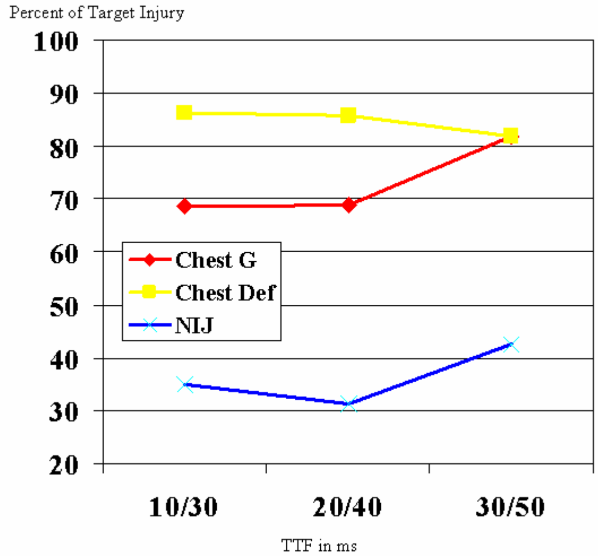

Figure 13: Unbelted Driver Injury for Delayed TTF

Based on the test results, it was determined that a fire time between 10-20 ms was preferable. At 30 ms, the airbag was not able to get into position on time and occupant injury began to increase.

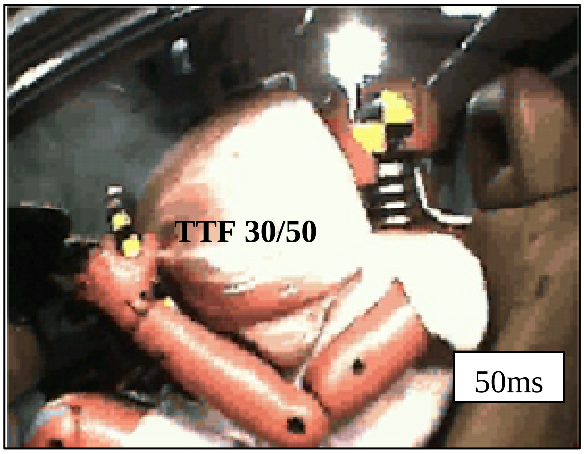

Figure 14: Airbag getting into position late with a 30ms TTF

Unbelted Passenger Injury Comparison With Variable Second Stage Airbag Delay

The passenger test matrix includes delays from 5ms to 140 ms. The long delay of 140 ms is considered a disposal stage and occurs after peak occupant injury. As can be seen in Figure 14, the increase in delay has only minimal impact on the occupant injury.

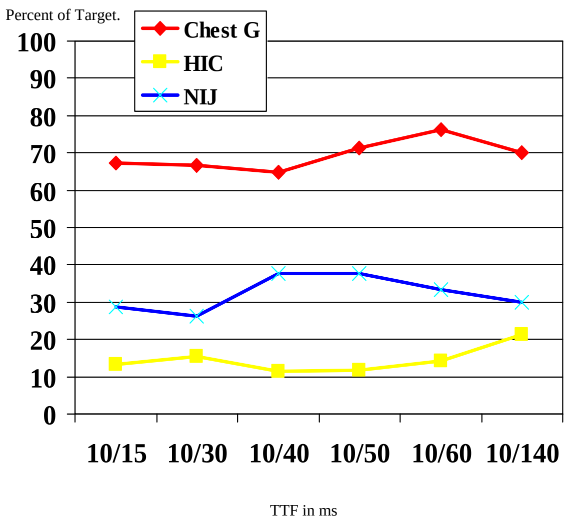

Figure 15: Comparison of delay timing on passenger injury

It is important to note that the passenger side occupant's pelvis must be restrained sufficiently to allow the head to arc into the airbag without contacting the windshield. This causes the occupant to use a much greater portion of the airbag allowing it to be softer [2-Miller].

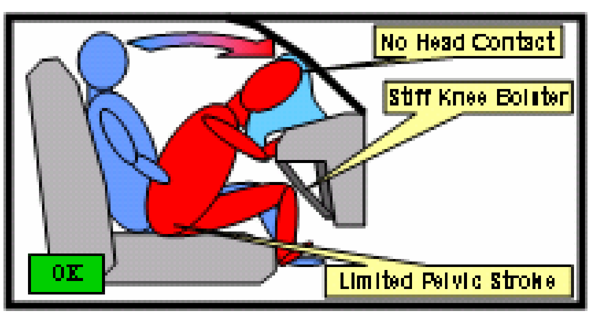

Figure 16 Illustration of head arcing with no windshield contact

Unbelted Passenger Injury Comparison with Variable TTF

The passenger side TTF was varied from 10 to 40 ms and judged according to mode and restraint performance. Again, an early deployment (10-20 ms) was preferable. By 40 ms, the airbag was unable to get into position on time.

Figure 17: Occupant is contacting the airbag before it is in position.

This late deployment reduces restraint and allows the airbag to get under the chin resulting in high neck moments.

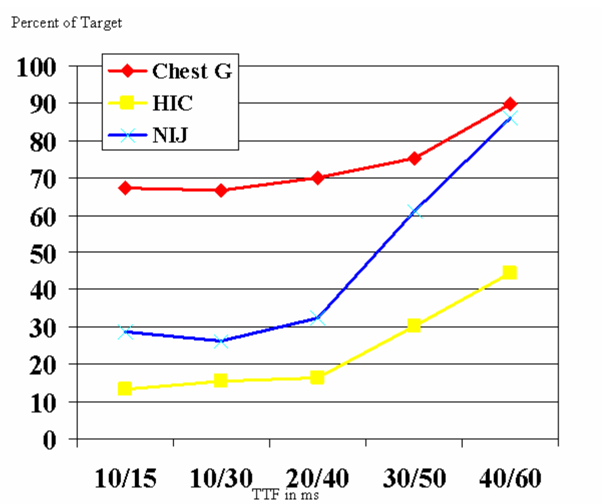

Figure 18: Passenger injury comparison with variable TTF

The final step for this study was to investigate the TTF/delay effect on AM50% occupants in a high speed (56 km/h) unbelted condition. The injury was then compared to a typical TTF/delay.

Although all injury was compared, head and Chest Gs for the driver are shown below for comparison.

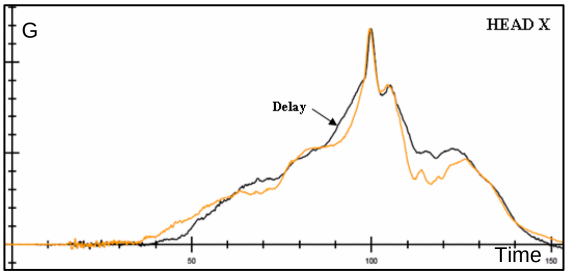

Figure 19: Driver head injury comparison

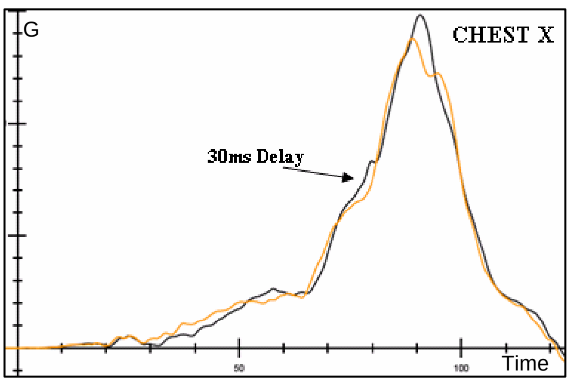

Figure 20: Driver chest injury comparison

Although the injury levels are high, as would be expected in a high speed unbelted crash, there is no significant difference in injury between the standard mode and the new proposed mode. This holds true for the passenger results which have slightly lower injury values with the new longer delay mode.

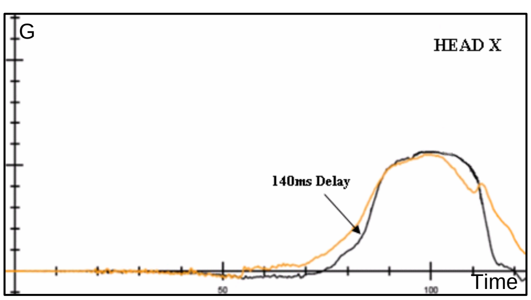

Figure 21: Passenger head injury comparison

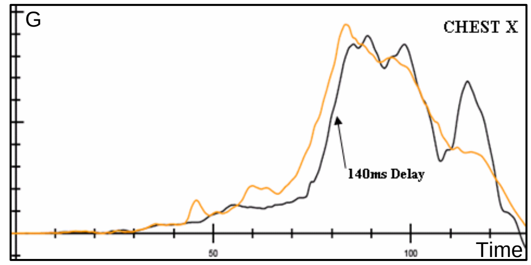

Figure 22: Passenger chest injury comparison

CONCLUSIONS

Although this was a relatively straightforward study, the conclusions are very significant. By creating an ideal TTF/delay time for the driver and passenger, the sensing system only needs to fire in one mode. This removes the gray zone from the SRS map [3-Miller].

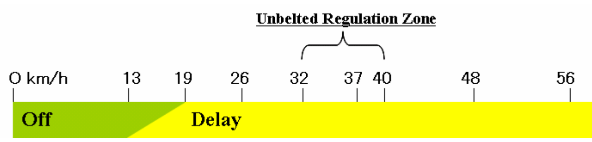

Figure 23: SRS map with only one firing mode

Since there is no longer a gray zone, crash verification no longer needs to be done for those speeds in the zone.

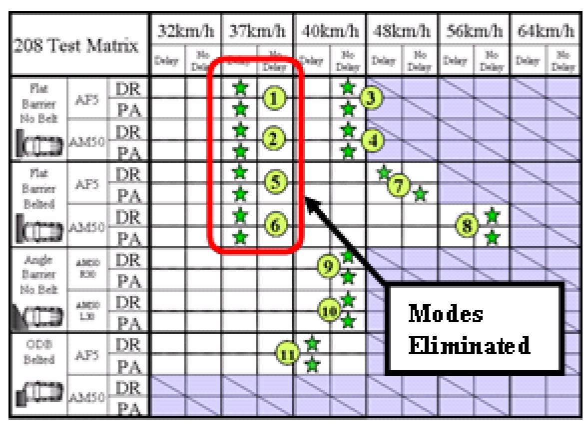

Figure 24: Verification test matrix with gray zone eliminated

This creates a more robust system with less chance for unintended deployment modes. This also opens up the future possibility of using a different firing mode to help protect occupants, like AM95% size occupants, that are currently not covered by regulation.

Due to the significant softening of the passenger airbag deployment (130 ms delay) further benefits can be realized for in-position as well as out of position small stature occupants and children.

Following the conclusion of this research, a full series of FMVSS 208 test were run using complete body units (CBU) with the 'ideal' TTF/delay SRS map. The results are summarized in Figure 25 below.

Mode	Results
FR40 km/h Flat Barrier AM50% No Belt	**OK**
FR40 km/h Flat Barrier AF5% No Belt	**OK**
FR48 km/h Flat Barrier AM50% Belted	**OK**
FR48 km/h Flat Barrier AF5% Belted	**OK**
FR40 km/h Right Angle AM50% No Belt	**OK**
FR40 km/h Left Angle AM50% No Belt	**OK**
FR40 km/h ODB AF5% Belted	**OK**
Low Risk Deployment AF5% Pos 1	**OK**
Low Risk Deployment AF5% Pos 2	**OK**
Out of Position C6Y Pos 1	**OK**
Out of Position C6Y Pos 2	**OK**

Figure 25: CBU confirmation test matrix

REFERENCES

[1] Code of Federal Regulations., US DOT, Office of the Federal Register National Archives and Records Administration. Washington, D.C.: 2004

[2] Miller, United States Patent Application, 2006/0174689, Published August 10, 2006

[3] Miller et al, United States Patent Application, 2006/0175807, Published August 10, 2006