A study of dummy kinematic and restraint system for IIHS Small overlap

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ABSTRACT

The IIHS (Insurance Institute for Highway Safety) introduced the small overlap frontal crash test in 2012. The small overlap frontal crash performance is evaluated in terms of injury assessment, structural assessment, and restraint and dummy kinematics. The test involves limited horizontal structural engagement at the corner. The small overlap condition is designed such that longitudinal structural members of vehicle have less interaction than during the IIHS' moderate overlap frontal test. Dummy kinematics can be affected if the structure does not absorb the crash impact energy or the driver airbag is not in position to provide restraint to the head. In the IIHS Status Report newsletter (Issue 47, No. 6 August 14, 2012) the IIHS' small overlap test results showed that most of the injury assessments were similar to that of the IIHS' moderate offset crash tests. However, vehicle structure and dummy kinematics were more severe in the small overlap as compared to the IIHS' moderate offset crash test. This study provides restraint system development guidance for dummy head protection in the IIHS' small overlap crash condition.

INTRODUCTION

Today many countries have motor vehicle regulations and Consumer Metric tests with the objective of reducing traffic fatalities. In the US, the NHTSA (National Highway Traffic Safety Administration) established the FMVSS (Federal Motor Vehicle Safety Standard) 208 for Occupant crash protection. This safety standard is frequently amended and supplemented. In terms of consumer information, NHTSA's NCAP (New Car Assessment Program) and the IIHS' crash tests evaluate vehicle crash performance to reduce injuries and fatalities. When an automotive manufacturer launches a new vehicle, safety crash tests are conducted to evaluate crashworthiness and occupant protection. Consumers may consider the vehicle's available crashworthiness information in their vehicle purchase decisions. It is therefore advantageous for automotive manufacturers to have good vehicle crashworthiness and restraint system performance. Manufacturers install and develop airbags, safety belt and other restraint systems, as well as the vehicle structure to provide occupant protection

In a study published by Rudd [2009], the combination of seat belt use and frontal air bags reduces front seat occupants' fatality risk by an average of 61 percent compared to an unbelted occupant in a vehicle without frontal airbags.
NHTSA's FMVSS208 requirements include rigid 0° to 30° angle barrier impacts with unbelted test dummies at speeds ranging from 32km/h and 40km/h. FMVSS208 also includes belted test dummies in a rigid barrier test at speeds ranging from 0 to 56kph. IIHS conducts 40% offset deformable barrier crash tests with a belted driver at 64 km/h. Through these efforts, consumers have had available to them safer vehicles from which to choose.

In the tests which are conducted for FMVSS208 and NCAP, and the IIHS 40% offset deformable barrier test, the vehicle's longitudinal energy-absorbing structure is able to absorb the crash energy. Also, the direction of the impact force is around twelve o'clock which results in mostly forward occupant trajectories and therefore good engagement with the driver airbag and safety belt. Today, a large majority of new vehicles are receiving the top level of crash performance rating, and the occupants are well protected.

However, in case of the IIHS' small overlap, the extreme offset results in significant lateral rotation of the vehicle relative to the occupant. The longitudinal energy-absorbing structure can be missed entirely and therefore other parts of the vehicle must absorb and deflect the crash energy. Also the direction of impact force in a corner impact is not only from

twelve o'clock. The driver dummy could sometimes have less interaction with the frontal airbags as they moved forward and laterally relative to the vehicle interior. A-pillar, dash and toe-pan intrusion can exacerbate the severity for the dummy as compared to the 40% overlap condition.

The paper "Fatalities in Frontal Crashes Despite Seat Belts and Air Bags – Review of All CDS Cases – Model and Calendar Years 2000-2007 –122 Fatalities" DOT HS 811 202, explained the factors influencing the outcome of fatal crashes using data from the NASS CDS (Crashworthiness Data System of the National Automotive Sampling System). The paper describes a primary factor as a necessary condition at or just after the crash which contributes to the fatal outcome, and a secondary factor as increased risk and consequences, sometimes a result of a primary factor.

Figure1 and Figure 2 show each factor weight for the population of fatal crashes studied.

From Figure 1, 78% of the crashes had "crash configuration" or "crash partner" as the primary factor. It shows that the crash configuration is a key factor for the fatal outcome. Extreme offset and corner impacts with other vehicles are examples of crash configurations classified as a primary factor.

From Figure 2, 22% of the crashes had "restraint performance" as the secondary factor.

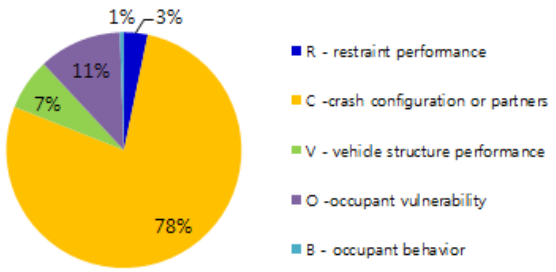

Figure1. Primary factor

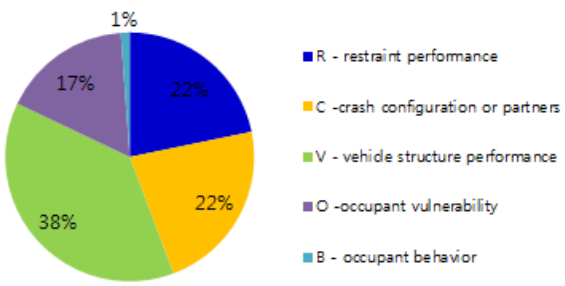

Figure2. Secondary factor

Figure 3 shows the importance of occupant and airbag interaction. Poor occupant-airbag interaction is a factor in 32% of the fatal crashes.

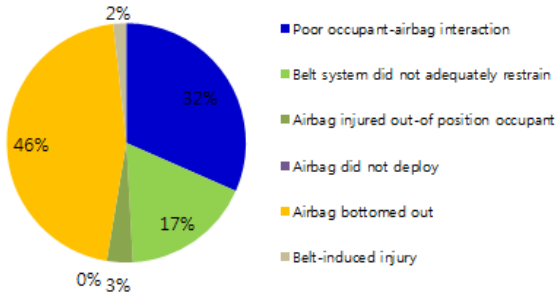

Figure3. Restraint performance factor

IIHS recently released small overlap crash test (25% overlap of a car's width on the driver side striking a rigid barrier at 64 km/h) protocol. The protocol includes assessment of the dummy restraint and kinematics (Table1.)

Table1.
Restraint and dummy kinematics demerit

Frontal head protection	
Stable frontal airbag interaction, or	0 demerits
Partial frontal airbag interaction, or	1 demerit
Minimal frontal airbag interaction	2 demerits
Excessive lateral steering wheel movement (>10 cm)	1 demerit
Two or more hard head contacts with structure	1 demerit
Late deployment or non deployment of frontal airbag	Automatic poor
Lateral head protection	
Side head protection airbag deployment with sufficient forward coverage, or	0 demerits
Side head protection airbag deployment with limited forward coverage, or	1 demerit
No side head protection airbag deployment	2 demerits
Excessive head lateral movement	1 demerit
Frontal chest protection	
Excessive vertical steering wheel movement (>10 cm)	1 demerit
Excessive lateral steering wheel movement (>15 cm)	1 demerit
Occupant containment and miscellaneous	
Excessive occupant forward excursion	1 demerit
Occupant burn risk	1 demerit
Seat instability	1 demerit
Seat attachment failure	Automatic poor
Vehicle door opening	Automatic poor
Overall restraint and dummy kinematics rating	
Good	0-1 demerits
Acceptable	2-3 demerits
Marginal	4-5 demerits
Poor	6+ demerits

The purpose of this study is to provide restraints system development guidance for improved driver dummy head protection in the IIHS' small overlap test.

METHOD

IIHS' Status Report newsletter (Vol. 47, No. 10 December 20, 2012) published the test results of small overlap crash tests conducted using 18 midsize vehicles. Some vehicles received a "Good" rating for restraints and dummy kinematics. The vehicles which the IIHS rated "Good" for restraints and dummy kinematics were studied to find ways to improve head-to-airbag interaction. The body

intrusions for A-Pillar and IP structure, and column movement were rated acceptable.
The driver airbags in the 18 small overlap test vehicles varied widely in appearance. Two examples are shown in "Figure 4".

Structure	Restraints & kinematics	Fully deployed	Loading
Acceptable	Good		
Acceptable	Good		

Figure4. Driver airbag type each automaker

An occupant CAE model was constructed to represent a typical small car. The interaction of the dummy's head with the driver airbag was studied in order to understand the effect of changing the airbag depth and width in the IIHS small overlap condition. The dummy lateral head excursion was studied in sled tests. The IIHS small overlap condition results in increased lateral displacement of the vehicle as compared to the IIHS' moderate offset crash. In the sled tests, identical driver airbags were used, and the sled buck angle was adjusted in order to compare dummy kinematics in two different impact angles. The ability to affect the driver dummy head through the driver airbag was evaluated.

ANALYSIS

- **Occupant CAE result**

In the occupant CAE evaluations, we investigated methods to increase driver head to airbag interaction. The driver dummy in the small overlap condition moves forward and laterally, with respect to the vehicle, more than during the moderate offset crash tests. The driver airbag is important to protect the driver in frontal impact crashes. But a small offset crash in the field with a significant oblique component or no engagement of the longitudinal member may result in lateral dummy displacement and less engagement with the driver airbag. Based on the driver airbag shape variation observed in the 18 IIHS tests, it was decided to investigate the effect of airbag volume.

Table2 shows the airbag design concepts evaluated with the CAE model. The base (Case #1) and an airbag with 6% increased cushion volume (Case #2) were evaluated. The same airbag inflator was used, and the vent hole size was the same in the two airbag CAE models. There are many techniques to affect the airbag volume. For this study, the 6% airbag cushion volume increase was obtained through a 12% increase in the depth and a 4% increase in the diameter of the airbag, in an inflated condition.

Table2.
Airbag design concepts

	CASE#1 (Base cushion volume)	CASE#2 (6% increased cushion volume)
Depth	Base	Base + 12%
Width	Base	Base + 4%

To evaluate the effect of airbag volume, the displacement of dummy head in both the forward X-direction and the lateral Y-direction was monitored. Figure 5 shows the schematic of the dummy's head motion in the occupant CAE. Point A is the initial point at the head CG (center of gravity) at 0ms. Line BC indicates forward movement of the dummy's head CG. Line AB represents lateral movement of the dummy's head CG.

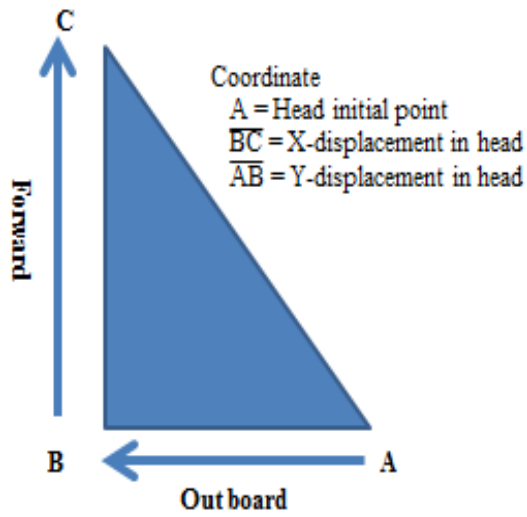

Figure5. Measurement in CAE of dummy head displacement

Figure 6 shows the dummy kinematics in the IIHS small overlap condition as a result of the two airbag volumes. Blue color, Case #1, is the small width and depth, and red color, Case #2, is the large width and depth. The larger volume airbag in Case #2 resulted in reduced occupant forward excursion in the IIHS small overlap condition.

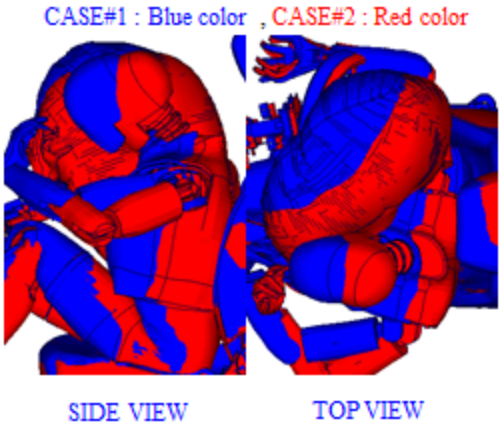

Figure6. Effect of driver airbag volume

Figure 7 shows the head CG forward displacement and lateral (outboard) displacement. Forward displacement was reduced by 23% with the larger volume airbag. Lateral displacement increased by 15%.

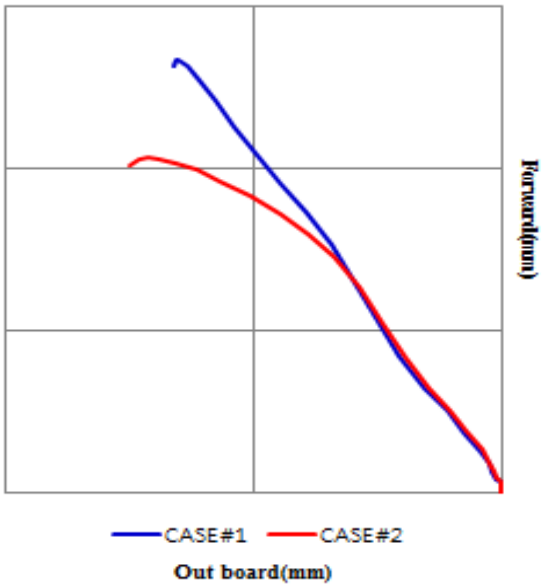

Figure7. Head forward and lateral displacement

Figure 8 shows that the larger volume airbag has more interaction with the dummy's head.

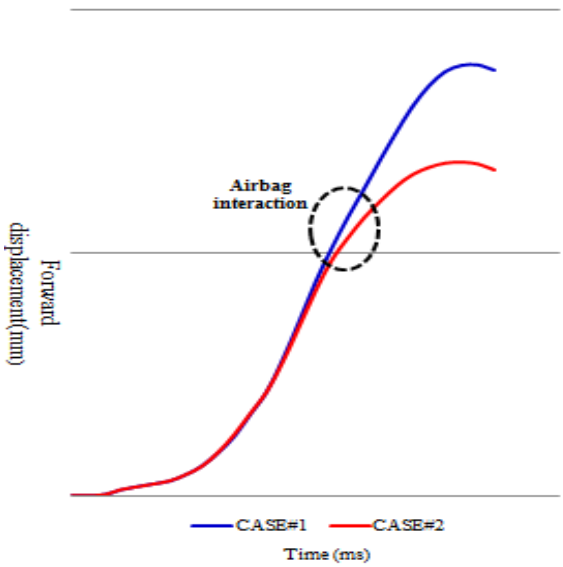

Figure8. Head forward displacement versus time

Figure 9 shows lateral displacement of the dummy's head CG. Lateral displacement of the head increased with the larger volume airbag in this IIHS small overlap condition. Additional countermeasures to reduce lateral displacement may be desired.

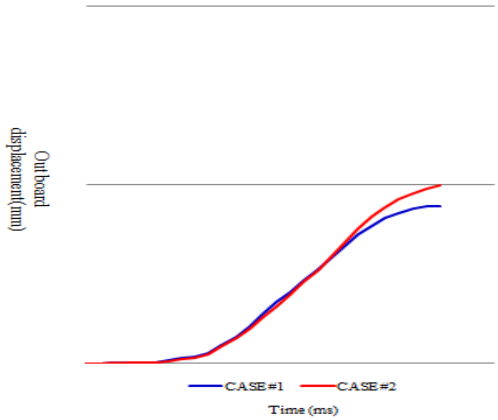

Figure9. Head lateral displacement versus time

These CAE simulations show that in the IIHS small overlap condition, the increased driver airbag cushion volume could affect the dummy's head forward displacement. This is due to more interaction between the dummy and the airbag, even though the larger volume airbag has lower internal pressure.

- **Sled test result**

From the occupant simulation study result, we observed that occupant forward kinematics may be improved by increased airbag volume.

The paper "Injury analysis of real-world small overlap and oblique frontal crash" (Number 09-0555 ESV) studied occupant fatal injury severity in co-liner and oblique condition. It shows an oblique condition is more severe than co-liner condition at the occupant's head region.

We studied the influence of vehicle rotation angle (Yawing) during small overlap crash condition with sled tests. The yawing can be expressed by rotating sled buck angle. We conducted a sled test to check the forward & lateral occupant kinematic influence with same restraints system (airbag and safety belts) according to the different sled buck angle.

Table3 shows the angle variation in the buck. Sled tests were conducted using the same longitudinal deceleration pulse, but with the buck rotated on the sled fixture.

Table3.
Angle variation in buck

No.	Angle variation in buck
CASE#3	Base angle
CASE#4	Base angle + 6degree

Figure 10 shows the instrumentation used to measure occupant excursion in the sled tests. IIHS' latest protocol and excursion template were used.

Figure10. Occupant excursion measurement

As shown in Table4, dummy forward excursion decreased by 4%. But lateral occupant excursion was increased by 28%. Increasing buck angle influenced the lateral movement more than forward movement.

Table4.
Dummy excursion

	Angle variation	Dummy excursion	
		Forward	Lateral
CASE#3	Base angle	Baseline	Baseline
CASE#4	Base angle + 6degree	-4%	+28%

Figure 11 shows occupant front view in sled test. Left side is the CASE#3 (base angle) and right side is the CASE#4 (base angle + 6 degree) motion for occupant. The dummy head in the CASE#4 moved in the lateral direction closer to the A-pillar.

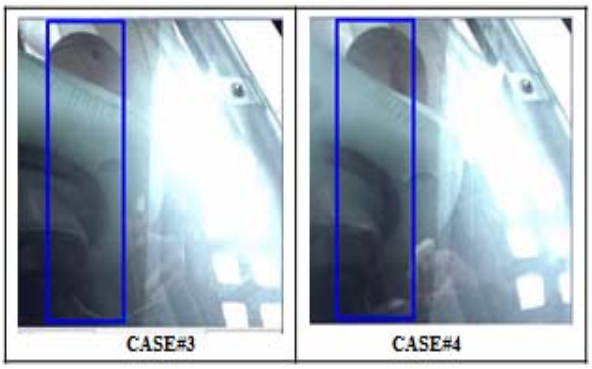

Figure11. Front view

It was observed that the side curtain airbag prevented dummy head from hitting the A-pillar.
Although the small overlap is a frontal crash event, the lateral component is important to comprehend in order to improve occupant kinematics and protection.

CONCLUSIONS

This study, though limited in scope, showed that dummy forward excursion in the IIHS Small Overlap condition can be improved with a 6% larger volume driver airbag. The dummy's head was also observed to interact with side curtain airbag, indicating potential for further excursion improvements in this area.

The effect of increased airbag volume would need to be evaluated in the US NCAP frontal impact, IIHS moderate overlap impact and the belted and unbelted FMVSS208 conditions, including the driver low risk deployment conditions. The driver airbag needed to balance the small overlap crash test in addition to existing crash tests might be sophisticated and complicated.

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