REQUIRED AIRBAG CHARACTERISTICS FOR OCCUPANT RETENTION IN ROLLOVER CRASHES

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Paper Number 05-0226

ABSTRACT

Evaluating performance of occupant retention countermeasures at the side windows through full-scale crash tests are typically expensive and yield inconclusive results. The results are inconclusive due to the non-repeatable nature of this testing. Another approach utilizes guided impact testing that propels an attached headform into a window to evaluate performances of these safety systems. This may provide some procedural value in generating repeatable results with limited objectives.

The capability to limit the guided impact headform displacement relative to a vehicle's exterior window plane is assumed to represent reduced risk of occupant ejection. However, it is not known what ejection risk is represented for a given headform excursion.

This study characterized headform excursions in guided impact testing for a given window airbag design with a range of restraint capabilities. Not surprising, disparities in the headform excursions were observed depending on the impact location of the impact on the airbag. System level evaluation of the airbag design in a rollover environment was conducted to determine which restraint capabilities represented a reduced risk of occupant ejection.

A correlated computer model of NHTSA's Dynamic Rollover Fixture (DRF) was used to identify the restraint characteristics for the airbags in which occupant ejection occurred as well as those where occupant retention was achieved in order to establish a relationship to headform excursion. However, the relationship for a given headform excursion to ejection risk was not apparent due to disparity in the headform excursion results.

Review of simulations in the DRF showed that as the occupant interacted with the airbag, occupant moved from the region of the airbag where excursions were the lowest, towards the region of the airbag where headform excursion was greatest. The dummy moved forward until it "pocketed" in the un-inflated front zone of the airbag or until it escaped out of the zone with the highest allowable excursion.

BACKGROUND

The fatality rate for an ejected vehicle occupant is three times as great compared to occupants who remain inside of the vehicle. More than 5,000 ejected fatalities are through front side windows with over 2,000 of these from partial ejections. For that reason reducing occupant ejections through side windows offers the potential for significant safety benefits [1].

The National Highway Traffic Safety Administration (NHTSA) has been conducting research for several years on ejection mitigation, which includes evaluations of a guided impactor test to characterize occupant ejection potential as a possible approach to addressing occupant ejection through the side window. A guided impactor is a device with a headform attached to the end of a shaft and is propelled linearly at a potential countermeasure, as shown in figure 1. The impactor device can measure the headform distance traveled when impacting the countermeasure. Guided impact testing has shown to be an excellent method in measuring excursion.

Figure 1. Guided impactor used by NHTSA

NHTSA has applied ejection mitigation research towards characterization of window airbag systems that deploy down from the roofline above the door to protect occupants in side crashes. Some of these airbag systems have shown capability to

significantly limit the headform excursion of the guided impactor.

However, it is not clear on what basis an excursion criterion could be established for evaluating performance of countermeasures to mitigate occupant ejection. It has been observed, for example, that the deflection of the airbag may create additional potential for ejection as shown in figure 2.

Figure 2. Opening created by guided impactor

The fundamental question one could ask, as it relates to guided impact testing, is what is an appropriate metric to mitigate occupant ejection.

Meaningful energy levels, locations and limits for excursion testing have not been agreed upon. NHTSA is evaluating 4 impact locations points around the perimeter of the window as depicted in figure 3 [2]. Another impact location being considered by industry is located at the centroid of the window.

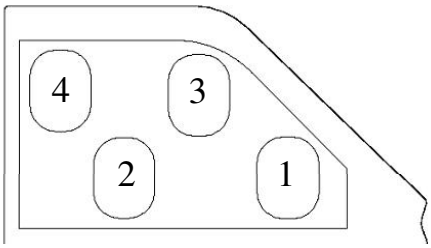

Figure 3. NHTSA's impact positions

The perimeter locations attempt to address not only the likely impact points of the occupant's head during a rollover, but also critical locations where other parts of the body may try to escape with some significant energy associated with them. Impact energy levels of the guided impact testing ranged from 150J to 400J, based on analysis of velocities of unbelted occupants during a rollover [3]. Occupants to window velocities ranging from 15-24kph have been shown in rollover tests.

Part of the challenge with creating a universal metric at a component level is that rollover scenarios are wide ranging. Of course, there is also the challenge of creating a test in a static environment that can provide insight into a system level response.

It has been observed, while guided impact testing can assess the capability of a system to contain a headform at a given location, the airbag countermeasure reacts to the impact and alters the area of designed coverage. This deflection may also alter how an occupant reacts with the airbag. It may be possible for an occupant to migrate towards areas of an airbag design that may not mitigate ejection effectively.

The changes in coverage can also affect partial ejection for a given system. When an occupant loads a system, it most often moves outboard and towards the roof, leaving a gap at the top of the beltline. This gap is typically in a critical area where partial ejection can occur. Partial ejection is usually associated with non-fatal injuries, but at numbers higher than those with full ejections [4].

GUIDED IMPACT CHARACTERIZATION

The airbag system used in this study was designed for a mid-size SUV and met all requirements for primary impact performance (FMVSS 201/ 214, IIHS) as well as offering extended inflated duration for rollover protection. Coverage of the subject airbag design for all seated occupants is shown in figure 4.

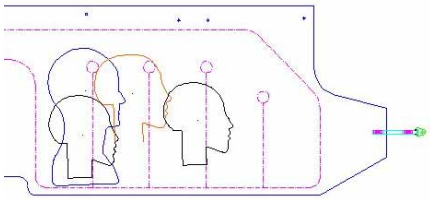

Figure 4. CAD coverage of airbag designed for study

The guided impact testing used an 18kg (40lb) HIII headform. The head was oriented with the front of the head facing forward and the side of the head adjacent to the impacting surface of the airbag. The initial impact location of the testing was position 3 as identified by the NHTSA impact positions. This

position was chosen as it potentially represented a challenge for window airbag designs due to the vehicle geometry. The impact energy was 183J, which represents a headform impactor-to-window velocity of 16kph.

Figure 5 shows the guided impact test setup with the airbag in the deployed position. The amount of excursion outside of the vehicle plane was measured using a potentiometer zeroed when the headform contacts the inside surface of the window plane. All deflection values listed are measured from the window plane.

Figure 5. Guided impact test setup with headform impacting the airbag at position 3

The pressure for the airbag design was varied for a series of guided impact tests. The pressure was varied to characterize a range of headform excursions for this study. Note that the specific pressure needed is dependent on the airbag design and the geometry, for this reason specific pressure values will not be listed, and the airbags at varying pressures will be listed by letter.

Results of the guided impact testing for this setup demonstrated retention characteristic of the airbag design to limit the headform excursion at 183J for a given pressure [5].

Computer Modeling

Data from the guided impact testing was correlated to a MADYMO model of the airbag design for additional analysis. Figure 6 shows the excursion test data with the 183J headform impacting at position 3 compared to the correlated MADYMO results of an airbag variant.

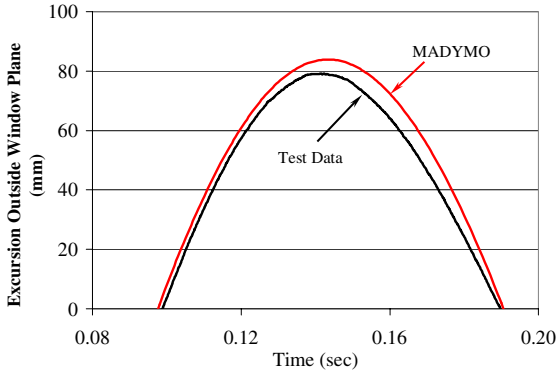

Figure 6. Comparison of headform excursion outside the window plane (MADYMO model versus test data)

The correlated model was used to simulate a range of airbag pressures in the guided impact test in order to assess their headform excursion. Variations of the retention characteristics were based on a range of pressure expected in the system during a late-term event such as rollover. The excursions for the range of airbags in the guided impact test are shown in figure 7.

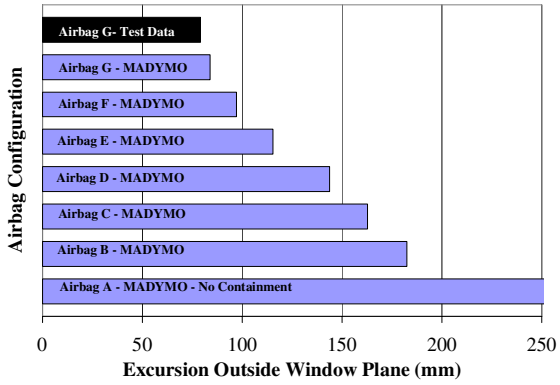

Figure 7. Excursion of airbag design in the guided impact test condition at position 3 for various pressures

When impacting at position 3 with 183J, this range of airbags showed performance ranging from the headform traveling only 85mm outside of the vehicle plane to the headform pushing though the airbag with little resistance and traveling to the end of its stroke. An end view of the maximum headform excursion of two of these systems tested is shown in figure 8.

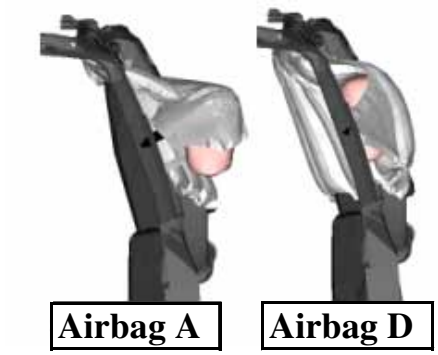

Figure 8. Comparison of headform excursion outside the window plane (airbag A versus airbag D) tested at position 3

ROLLOVER EVALUATION

The Dynamic Rollover Fixture (DRF), a NHTSA research tool for evaluating countermeasures in rollover, was used for the rollover evaluation in this study due to its demonstrated capability to eject a dummy repeatability [6].

The DRF (shown in figure 9) can achieve roll rates of 360 degrees per second as well as occupant to window velocities ranging from 15-30kph, all within the range of real-world scenarios [7].

Courtesy of NHTSA

Figure 9. Dynamic Rollover Fixture (DRF)

The test that was used for this study had a maximum roll rate of 360 degrees per second. Based on analysis conducted by NHTSA with at this roll rate with the unbelted 5th percentile female dummy in this position, occupant to window velocity would be approximated at 15kph [8]. This roughly approximates the velocity seen in the guided impact testing. The DRF fixture is a key element to this analysis. There is a great deal of data on various rollover scenarios and which are most prevalent [9].

A MADYMO model was created using the roll rate and kinematic response of the DRF testing with an unbelted 5th percentile female dummy. This occupant was selected because there was a fairly large data set of tests on the DRF from which to correlate the model. The smaller dummy and lower impact point would likely present challenges for the system. The vehicle geometry of the roof rail in the MADYMO simulation was modified to represent the mid-size SUV that the airbag was designed for.

Figure 10. DRF test with unbelted 5th percentile female dummy versus MADYMO simulation

Once the model was created and validated, as illustrated in figure 10, a comparison was made between the impact location used in the guided impact tests (position 3) and the impact location of the unbelted occupant in the DRF test condition. Figure 11 shows a comparison of position 3 used for guided impact testing and the location where the head contacts initially in the DRF test condition.

Figure 11. Impact Locations - Guided Impact Test Versus DRF

The location of impact seen in the DRF testing was considerably aft (~300mm) of the position 3 used for the analysis. Therefore it was necessary to simulate additional guided impact testing at a position corresponding to the point where the unbelted occupant would load the airbag system in the DRF test condition. This will be referred to as the DRF position, corresponding approximately to position 4 in figure 3. The comparison of the simulations is shown in figure 12.

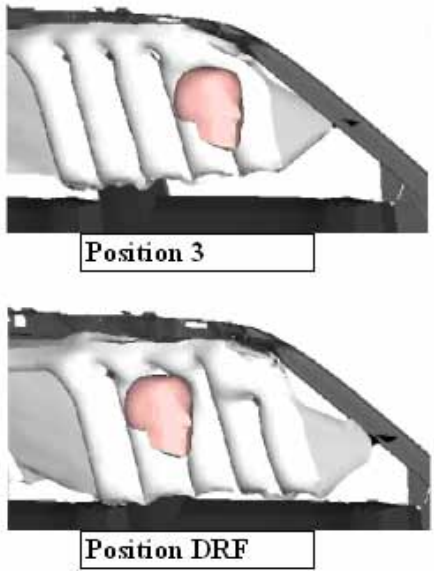

Figure 12. Simulation Impact Locations – Position 3 Versus DRF

The guided impact test series was repeated with the impact location based on that seen in the DRF analysis. The results are shown in figure 13.

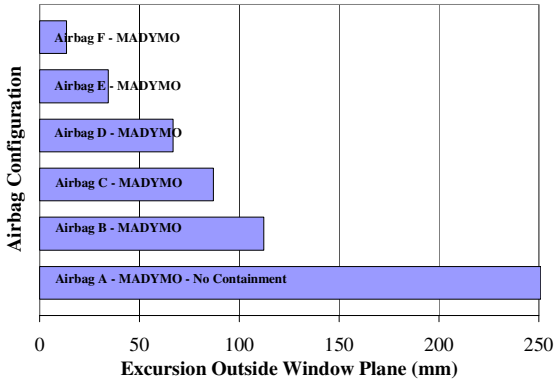

Figure 13. Performance of different airbag designs in the guided impact test condition at the DRF position

The trend of the excursion was the same, but the magnitudes of excursion were much less. The next step in the investigation was to evaluate an unbelted 5th percentile female occupant in the DRF test.

RESULTS

The results of the two sets of excursion testing (position 3 and DRF) as well as the DRF response are shown below in Table 1. The third column indicates which airbag variations contained the occupant and which did not.

Table 1.
Performance of different airbag designs in the guided impact test conditions and the DRF test

	Impact Position 3	Impact Position DRF	DRF Test
	Excursion (mm)	Excursion (mm)	Containment (Y/N)
Airbag A	Not contained	Not contained	No
Airbag B	183	112	No
Airbag C	163	87	No
Airbag D	144	67	Yes
Airbag E	115	34	Yes
Airbag F	97	14	Yes

The results of the DRF testing subsequently focused attention on airbags C and D. Additional scrutiny was given to airbags C and D due to the fact that with a very small change in the airbag characteristics, one system did not contain the occupant in the DRF test (C), while the other did (D). The guided impact results for airbags C and D have substantially different excursion values based on their impact locations. These discrepant results make it difficult to define an allowable excursion criterion. Figure 14 shows the occupant response in the DRF test.

Figure 14. Performance of airbags C and D in the DRF test with an unbelted occupant

A comparison of airbag C and D shows approximately 20mm of difference in their response in the guided impact test, regardless of impact position. Their respective excursions are shown in figures 15 and 16.

Figure 15. Performance of airbags C and D in the guided impact test at position 3

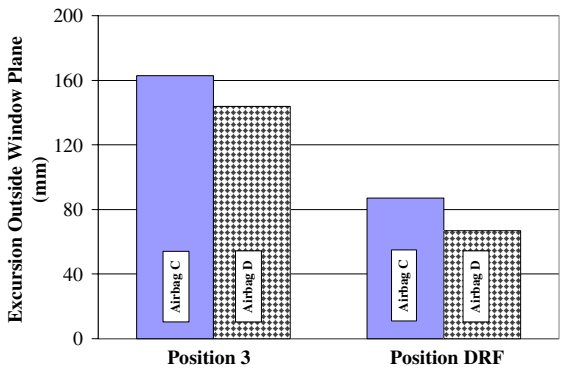

Figure 16. Performance of airbags C and D in the guided impact test at position 3 and position DRF

DISCUSSION

It was observed in analysis of DRF simulations that the occupant moves in the forward direction as it loads the countermeasure (regardless of the airbag variant). This is relevant to the guided impact testing in that the occupant moves from a position with a lower excursion (position DRF, 13mm to 112mm) to a position with a higher excursion (position 3, 97mm to 182mm).

This response consistently shows the unbelted occupant taking the "path of least resistance", out of the vehicle in some cases. With the seat and b-pillar limiting the occupant's movement in the aft direction, and the airbag at the DRF position limiting it in the outboard direction, the dummy moves forward (there are also kinematic contributions such as the mass of the inboard arm swinging forward). The dummy moves forward either until it "pockets" in the un-inflated front zone of the airbag (approximately at position 3) or until it escapes out of the zone with the highest allowable excursion.

The forward motion simulated in the DRF model is illustrated in figure 17 and this forward motion is consistent with different countermeasures [3].

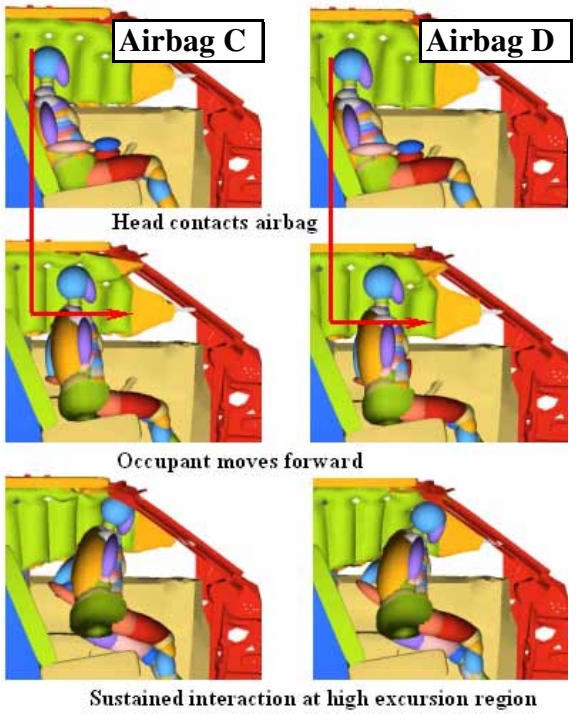

Figure 17. Forward movement during DRF test of airbags C and D

This phenomenon should affect guided impact strategy. Regardless of the guided impact response of the airbag at the point of initial impact, if there exists a region of the airbag with little or no retention properties, an unbelted occupant will move toward that area. If this area is sufficiently large, the occupant may eject in spite of whatever retention is offered in other areas of the airbag.

Additional study on the effect of a single region of the rollover system that offers comparatively less resistance to excursion than other regions and its effect on the overall ejection mitigation performance will be conducted.

CONCLUSIONS

This study analyzed headform excursions for a given window airbag design and varied restraint characteristics to achieve a range of headform excursions in guided impact tests. This study then attempted to find threshold values for excursion in guided impact testing that would either result in occupant ejection or occupant retention in a given rollover environment.

There appears to be at most a qualitative relationship between guided impact head excursion results and risk of ejection, within the limits of this study.

Consequently, use of guided impact testing at a single location, as a means to quantify and inexpensively evaluate curtain designs with regards to ejection mitigation is limited.

The excursion values in the guided impact tests, along with the DRF analysis, do appear to offer insight into the retention performance of a system during the rollover event. The movement forward of the occupant from an area of greater stiffness (lower excursion values) to one of less stiffness (greater excursion values) indicates a phenomenon that should affect the occupant retention strategy of airbag design.

RECOMMENDATIONS

Until some guided impact test standard is developed it is recommended that caution be used in predicting occupant ejection risk using guided impact test results.

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