

## A Study of Occupant Ejection Mitigation

**Jeff Dix**

**Koichi Sagawa, Lalitkumar Sahare**

Nissan Technical Center North America

United States of America

**Selim Hammoud, Alex Cardinali, Daniel Fulk**

Nissan North America

United States of America

**Abe Mitchell**

Autoliv North America

United States of America

Paper Number 11-0368

### ABSTRACT

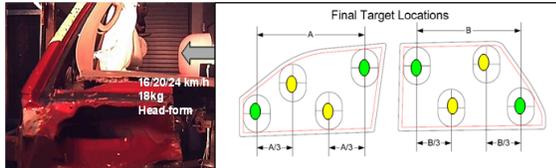
The National Highway Traffic Safety Administration (NHTSA) has identified ejection mitigation as a top priority, issuing a notice of proposed ruling making (NPRM) for FMVSS 226, Ejection Mitigation, in December of 2009. The NPRM proposed a linear impact test that uses a featureless head-form with a mass of 18 kg to impact a vehicle's side windows' daylight opening at various positions. The test measures the excursion of the head-form beyond the plane of the window glazing. The intention is to evaluate the ability of a vehicle's ejection mitigation system, such as the curtain airbag or other vehicle features, to manage the impactor energy and limit excursion. The NPRM consists of two tests conducted 1.5 and six seconds after the ejection mitigation countermeasure is deployed at impactor speeds of 24 km/h (400 Joules) and 16 km/h (178 Joules) respectively. In January of 2011, the agency issued a final rule for FMVSS 226 revising the impact speed for the higher speed test from 24 km/h to 20 km/h, thus reducing the energy to 280 Joules. This paper will present the results of a case study using computer modeling to understand the roles of the seatbelts and curtain airbags in mitigating ejections, as well as studying a representative energy level that can be employed for evaluating ejection mitigation systems considering both rollover and side impact crashes. The results of the computer modeling will be compared with the energy levels outlined in the NPRM and final rule for FMVSS 226. Furthermore, the authors will also present the results of a parameter study in which the stiffness of a curtain airbag is optimized to balance the requirements of ejection mitigation with the injury prevention targeted by other side impact regulation such as FMVSS 214: Side Impact Protection.

### INTRODUCTION

Ejections have a significant impact on occupant injuries in motor vehicle crashes, representing 8,605 fatalities as well as 20,000 injuries in 2007 [1]. For 2008, it has been reported that 20% of fatally injured passenger car occupants were ejected, either totally or partially [2]. For this reason, NHTSA has been studying ejections for a number of years. In November of 2006, NHTSA published details of a component test method being used for researching ejection mitigation, which was being considered for rule making [3]. The agency's test consists of a linearly guided impactor that projects an 18 kg impacting mass in the shape of a featureless head-form. This 18 kg mass is designed to be representative of the impacting mass of an AM50 occupant. Four impact locations are tested on each of the daylight openings to which the evaluated countermeasure is applied. Using a potentiometer, the impactor measures the excursion of the head-form beyond the inside glazing surface of the daylight opening. At the time NHTSA was researching two proposals summarized in Table 1. Both proposals consisted of two test conditions: the first test was conducted at a 1.5 second delay (time after curtain deployment); the second test was conducted at a 6 second delay. For the first test, there were two energy levels NHTSA considered, 280 Joules or 400 Joules. The proposed impact energy for the second test (6 second delay) was 178 Joules. These test conditions were determined on the basis of dummy pendulum testing, video analysis of full scale rollover tests, and sled testing, replicating rollover and side impact events, outlined by NHTSA in the Advanced Glazing First Status Report [4]. Figure 1 shows a typical setup for the ejection mitigation component test, and it outlines the method for determining the impact locations for each daylight opening.

**Table 1.**  
**NHTSA Linear Impactor Test Conditions**

	Impact Mass	Test Energy	
		1.5 second delay	6.0 second delay
Proposal 1	18 kg	400 Joules Test Speed = 24 km/h	178 Joules Test Speed = 16 km/h
Proposal 2		280 Joules Test Speed = 20 km/h	



**Figure 1. NHTSA ejection mitigation linear impact component test setup.**

In December of 2009, NHTSA issued a notice of proposed rule making (NPRM) for Federal Motor Vehicle Safety Standard (FMVSS) No. 226 "Ejection Mitigation" [5]. In the NRPM the agency proposes a component test based on 'Proposal 1' of its research test method with the first test conducted at an impact energy of 400 Joules (24 km/h) 1.5 seconds after the curtain airbag is deployed. A second test is conducted at an impact energy of 178 Joules (16 km/h) with a 6 second delay after deployment. In January 2011, NHTSA published the final rule for FMVSS 226. In the final rule the agency reduced the test speed for the first test from 24 km/h to 20 km/h, thus the final rule is based on 'Proposal 2' [6].

During NHTSA's advanced glazing research, Willke et al. estimated that of 7,636 fatalities in 1999 involving partial or complete ejections through glazing, 2,864 of those occurred in planar crashes [7]. The NPRM for FMVSS 226 used 1997-2005 NASS CDS data adjusted to 2005 FARS level to estimate that 6,174 fatalities occurred in crashes involving ejections through side windows, including the first two seating rows [5]. Of these 6,174 fatalities, 1,568 occurred specifically in side impact planar collisions. In a more recent analysis, the NHTSA National Center for Statistics and Analysis (NCSA) examined vehicle occupants in fatal crashes from 2003 to 2007 (FARS data) to study ejection factors. In these crashes, 54,505 occupants were ejected, including both fatalities and survivors. Approximately 72% (39,312) of these 54,505 occupants were involved in rollovers. Approximately 21% (11,459) of these 54,505 occupants were ejected when the initial impact was on either the left or right side. While the data does not indicate how many of these side

impacts also involved a subsequent rollover, it is interesting to note that a larger percentage (13.1%) of occupants were ejected when the initial impact was against the side of the vehicle versus the front (9.8%) or rear (10.6%). The only other describable type of initial impact which resulted in a larger percentage of ejections at 42.9% is a non-collision. Non-collisions are thought to consist largely of rollovers; "...many rollovers occur without being initiated by an impact with other vehicles or fixed objects" [8] (ref: DOT HS 811 209).

The intent of the current study is to research representative energy levels for testing ejection mitigation systems considering rollover and side impact crashes in belted and unbelted conditions and compare these results with the test parameters outlined in the FMVSS 226 NPRM and final rule.

## METHOD

Curtain airbags developed for ejection mitigation must serve two purposes: to help mitigate the risk of ejection in rollovers while also providing occupants protection in side impacts. As such, care should be taken to balance the performance requirements when developing the restraint systems. The purpose of this research was to study this balance in the development of curtain airbags. To accomplish this, this study was divided into two portions:

- Occupant Containment Energy Case Study
- Curtain Airbag Parameter Study

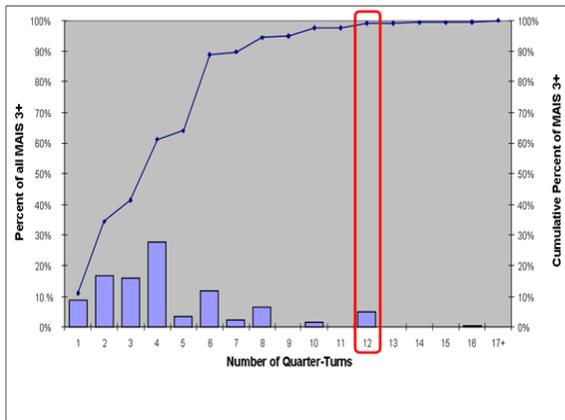
### Occupant Containment Energy Case Study

**Rollover case** Four rollover tests were considered for analysis (reference Table 2). For the purposes of this study, the authors chose to use the number of quarter-turns as a comparative metric for rollover severity. This was deemed to be reasonable given Moore's finding that the risk of ejection increases from 5% and 20% for less than 4 quarter-turns to 10% and 80% for greater than 12 quarter-turns for belted and unbelted occupants, respectively [9]. Thus, as the number of quarter-turns increases so does the risk of ejection. Of the four tests considered, the FMVSS 208 Dolly rollover had the highest number of quarter-turns with a total of 12. Furthermore, the 12 quarter-turns value represents over 98% of field incidents with a MAIS 3 or greater injury (Figure 2). Therefore, it was concluded that the dolly rollover was the most severe of the tests considered, and while not a repeatable test, it

provides a reasonable representation of a severe rollover for the purposes of this particular study.

**Table 2**  
**Rollover testing summary**

Test Mode	Test Speed (km/h)	No. of Quarter-Turns (Severity)	Peak Angular Rate (Degrees / second)	Duration (Seconds)
FMVSS 208 Dolly Rollover	50	12	450	4.5
Corkscrew Rollover	70	1	209	4.2
Curb Trip Rollover	27	2	168	3.7
Ditch Rollover	25	1	115	4.5



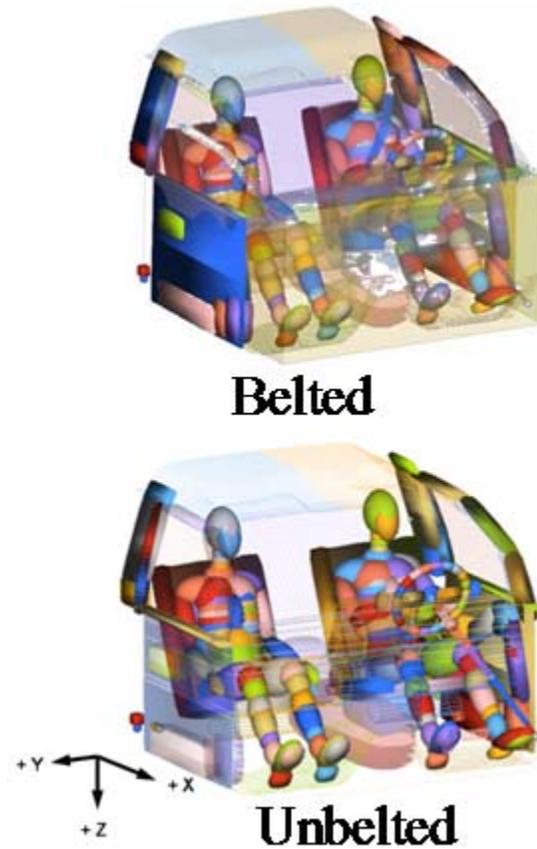
**Figure 2.** MAIS 3+ injuries vs. number of quarter turns [10].

The test vehicle was instrumented to measure the accelerations and angular velocities in the X, Y, and Z directions in the vehicle's local coordinate system. This data was then used as inputs for a MADYMO model using a prescribed motion technique as proposed by Yu, et al. [11]. The following conditions were used for the analysis:

1. AM50 occupants were used in the front outboard seating positions.
2. Both belted and unbelted conditions were considered for analysis.
3. All components which the dummy interacted with were included in the model (Figure 3).

Figure 4 shows the occupant kinematics from the MADYMO model. The vehicle orientation relative to the global coordinate system is also shown for reference. To estimate the maximum energy with which an occupant may impact an ejection mitigation countermeasure, the energy transfer between the

interior components and the dummy was measured in the simulation. In a rollover, occupants tend to move outward and upward interacting with the side window glazing and the headliner. The balance in the energy sharing between these two components will vary depending on the vehicle layout and occupant position. Therefore, it is difficult to predict an appropriate energy considering only the impact with the window glazing on these two vehicle layouts. For this reason, the sum of the energy transfers between the occupant and both the window glazing as well as the headliner were used.



**Figure 3.** MADYMO ellipsoid model for rollover with belted and unbelted occupants.

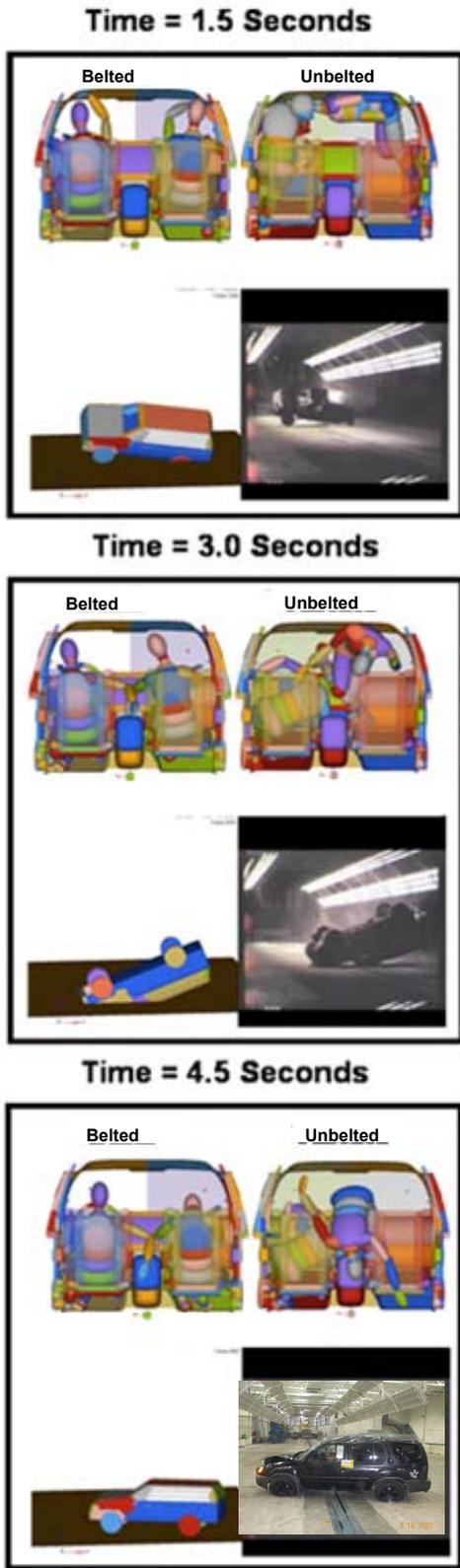


Figure 4. Occupant and vehicle kinematics for the dolly rollover test.

**Side impact case** In order to select a representative delta velocity for the simulations used in this study, two side impact tests conducted per the New Car Assessment Program (NCAP) moving barrier protocol were examined. One test was conducted on a passenger car and the second on a sport utility vehicle to cover a wide range of vehicle architectures. Both vehicles showed a delta velocity of approximately 24 km/h as measured at the vehicle center of gravity. While research which relates delta-velocities to ejection rates in planar crashes appears to be limited, NHTSA did publish such information in support of its Ejection Mitigation NPRM. Their study, which consisted of analyzing 1995-2004 NASS-CDS data, shows that 65.5% of side impact ejections occur at delta velocities less than 24 km/h (Figure 5) [5]. Also mentioned in the NPRM is that NHTSA simulated two conditions in tests it performed to develop the impactor mass – one representative of a rollover and one of a side impact. “For the test designed to be more representative of a side impact condition, the test was conducted at an impact speed of 24 km/h”. Thus, indicating that the vehicle tests chosen for this study provide a reasonable representation of side impact crashes in the field.

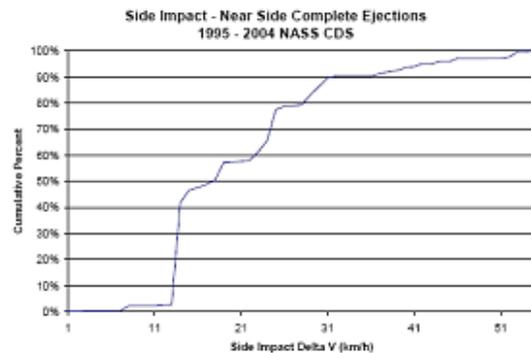
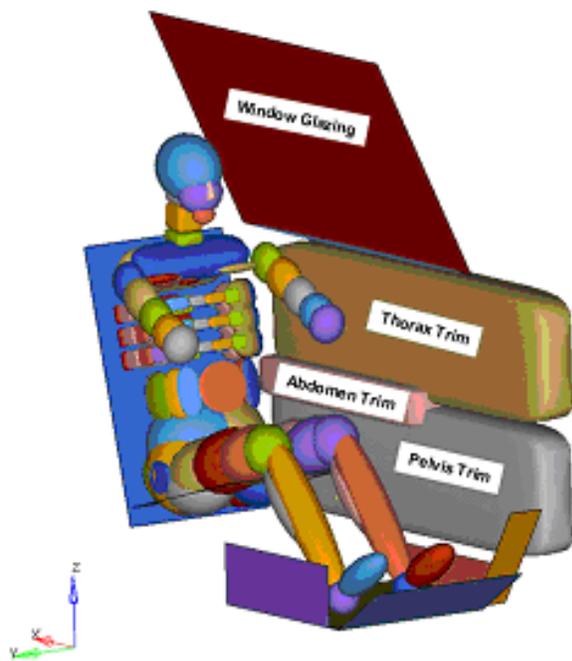


Figure 5. Completely Ejected Occupants vs. Delta-V in side impact crashes (Source: Notice of Proposed Rulemaking Ejection Mitigation (FMVSS 226), Figure 1.6 – generated from 704 unweighted ejections and 15,062 weighted ejections).

Both vehicles used in the NCAP tests were instrumented to measure the velocity at the test vehicle C.G., struck side door at the chest, abdomen, and pelvis; as well as the struck side roof rail above the occupant’s head. This set of data was used as the inputs in a MADYMO model using a prescribed motion technique. The model consisted of four sections: 1) Pelvis trim, 2) Abdomen trim, 3) Thorax trim and 4) Window Glazing, with an AM50 (ES2)

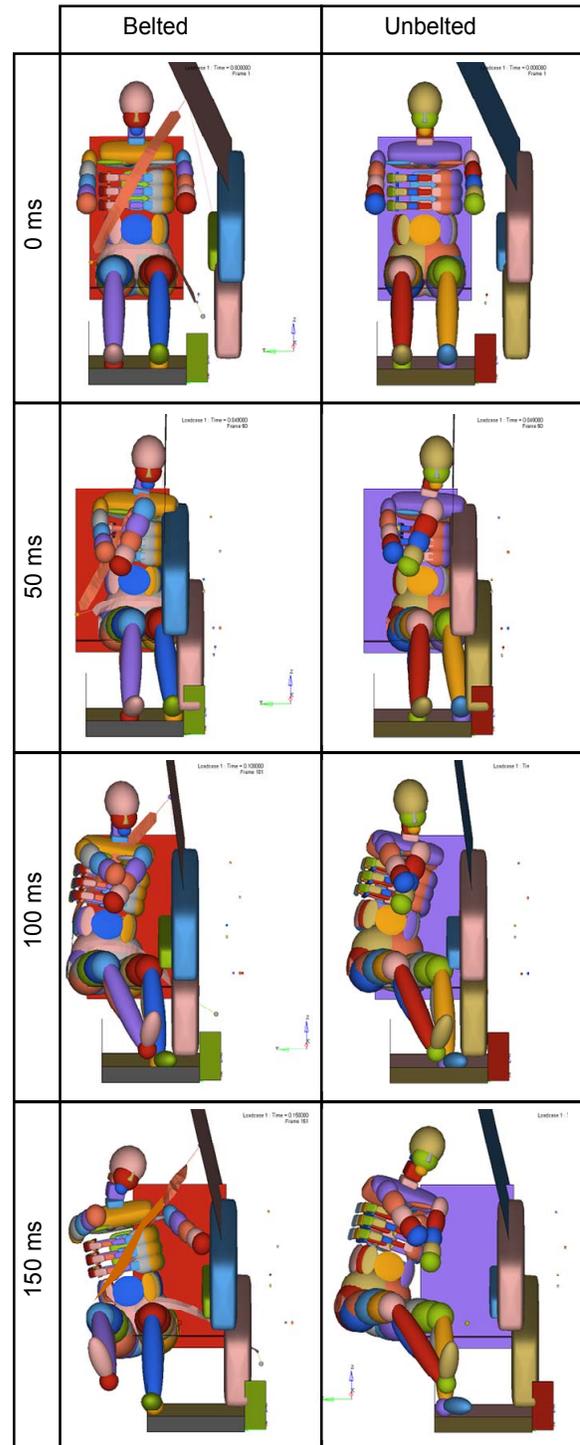
ellipsoid dummy positioned on the driver seat. The velocity measured at the vehicle C.G. was applied to the seat and floor pan of the model, while the chest, abdomen, and pelvis velocities were applied to the applicable trim ellipsoids. The trim stiffness, obtained from component testing, was provided to the translational joints of each of the ellipsoids to reflect the trim deformations due to dummy loading. The velocity of the top of the window glazing was set to match that of the roof rail measured in the vehicle test, with the bottom of the glazing attached to the chest trim ellipsoid by means of a revolute joint so that the side window glazing kinematics match that of the vehicle test. Figure 6 shows the MADYMO model used for this study.



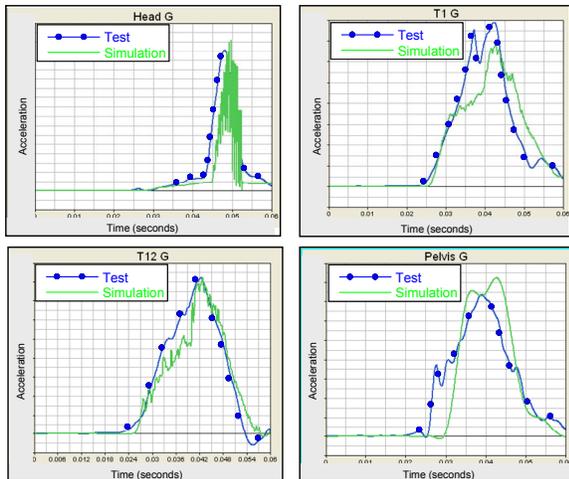
**Figure 6. MADYMO ellipsoid model for side impact (unbelted model shown).**

To ensure the occupant kinematics in the simulation correctly captured that of the vehicle test, the head, upper and lower spine (T1 and T12), and pelvis accelerations were correlated to the vehicle test. Figure 7 shows the kinematics of the occupant in the MADYMO model while Figure 8 displays the comparison of the correlated dummy responses for the passenger car vehicle and simulation. To estimate a representative occupant containment energy level that a curtain airbag may experience in a planar side impact crash, the energy transfer between the occupant and the side window glazing was measured. Figure 9 shows a comparison of the

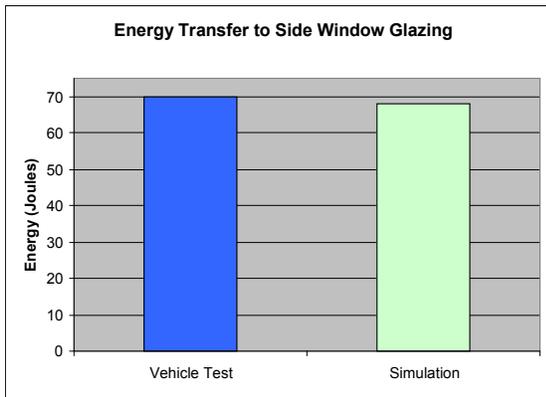
energy transfer in the simulation compared with that measured in the vehicle test.



**Figure 7. Typical Occupant Kinematics in the MADYMO model used for side impact.**



**Figure 8. Occupant response comparison between the MADYMO side impact model and the vehicle test.**



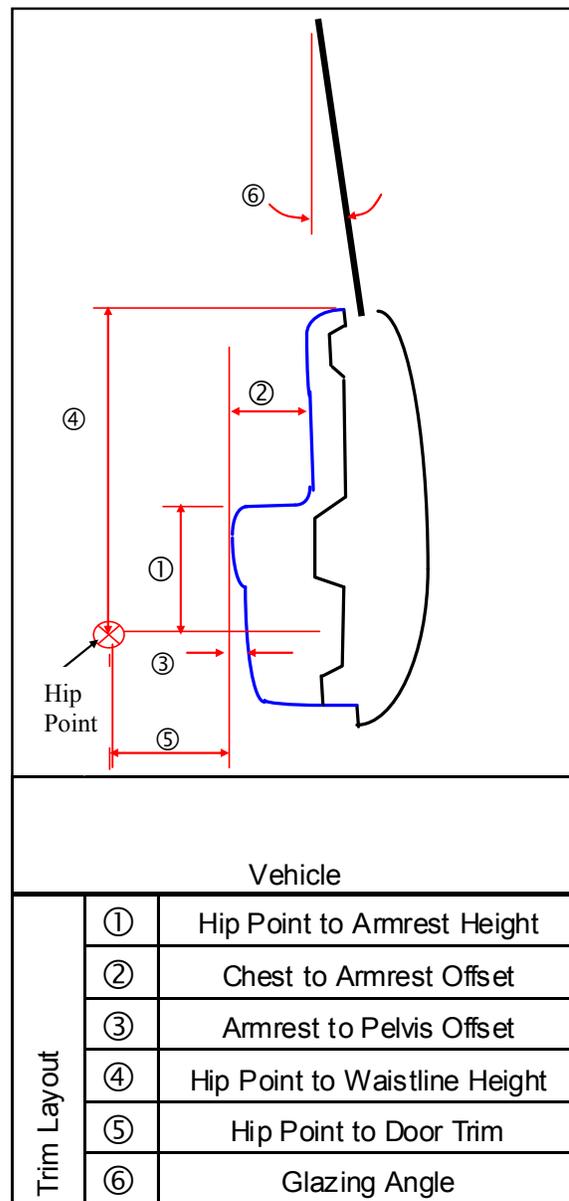
**Figure 9. Comparison of the vehicle test and simulation occupant energy transfer to the side window glazing.**

Once the correlation was completed, a parameter study was conducted to investigate the various interior layout parameters which may affect the energy transfer to the window glazing. A total of six interior dimensions were considered for this study:

1. Hip Point to armrest height
2. Chest to armrest offset
3. Armrest to pelvis offset
4. Hip Point to waistline height
5. Hip Point to door trim
6. Side window glazing angle

Figure 9 shows how each of the parameters were defined. A total of eight vehicles ranging from a sub compact car to a full size truck were analyzed to determine the range of values to consider for each

parameter in the study. Based on the observed ranges for each of the parameters, a sensitivity analysis was conducted at 3 levels for each to determine which interior layout parameters most affect the energy transfer to the glazing. Table 3 summarizes the levels used for the sensitivity analysis (reference Table 4 in the appendix for a detailed summary of each of the vehicles studied). Once the most sensitive interior layout parameters were determined, the most severe interior layout was evaluated in more detail to determine the maximum energy transferred to the window glazing.



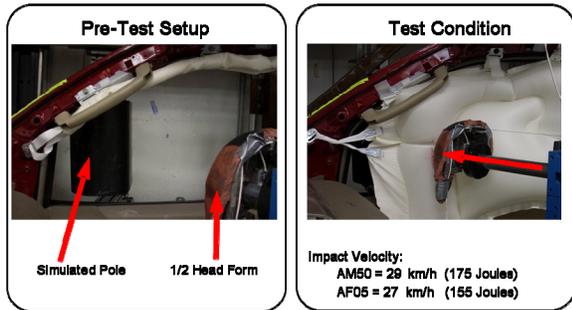
**Figure 10. Interior layout parameters considered for this study**

**Table 3**  
**Summary of interior dimensions and sensitivity analysis levels.**

Measurement			Sensitivity Analysis			
			Level 1	Level 2	Level 3	
Trim Layout	①	Hip Point to Armrest Height	(mm)	168	198	227
	②	Chest to Armrest Offset		34	51	68
	③	Armrest to Pelvis Offset		1	41	81
	④	Hip Point to Waistline Height		314	408	502
	⑤	Hip Point to Door Trim		281	296	310
	⑥	Glazing Angle		(deg)	2.8	15.8

**Curtain Airbag Parameter Study**

A linear impact testing method was used to simulate an oblique pole side impact test at 32 km/h as outlined in FMVSS 214 [12]. A 254mm simulated rigid pole was positioned directly behind the Head C.G. impact location. The test setup is shown in Figure 11. A Hybrid III AM50 half head-form was mounted on a linear actuator with an effective mass of 5.5 kg. Testing was conducted for both the AM50 and AF05 seating positions. The impact speed was adjusted to achieve the desired impact energy for the AM50 or AF05 occupants depending on which position was tested. The head injury criterion (HIC) was predicted based on the peak force measured in the component test.



**Figure 11. Linear impact test setup used to simulate the FMVSS 214 oblique pole test.**

Ejection mitigation testing was conducted per the NHTSA proposed test procedure at the 1.5 second delay for both the 280 Joules and 400 Joules testing

conditions (20 and 24 km/h). Figure 1 shows the impact points used for this testing.

For this study a rollover curtain airbag with the following specifications was used (reference Figure 12 for a picture of the deployed airbag).

1. A stored gas inflator was used for this study.
2. The curtain airbag covered all impact locations for both the oblique pole test positions (AM50 and AF05) as well as the ejection mitigation test points.
3. There was full overlap with the B-Pillar.
4. The airbag was tethered to the base of the A-Pillar and overlapped the door waistline by approximately 100 mm.
5. The chamber depth was 200 mm.



**Figure 12. Curtain airbag used for airbag pressure parameter study.**

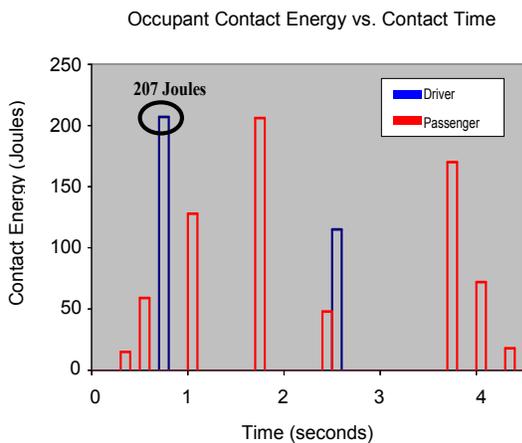
**RESULTS AND DISCUSSION**

**Occupant Containment Energy Case Study**

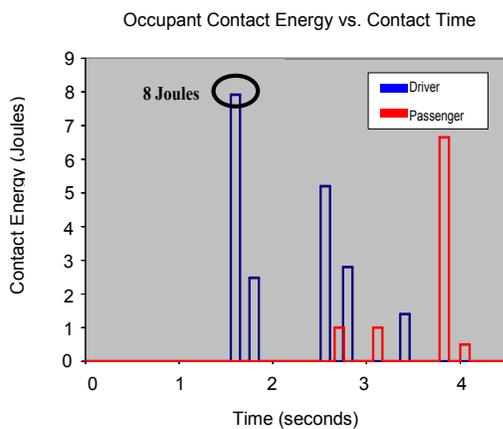
**Rollover case** In case of the belted condition, the seatbelt functioned to restrain the occupant in the seat during the duration of the event, and provided for much more controlled occupant kinematics as is shown in Figure 4. Furthermore, since the seatbelt restrained the occupant in their seat it will mitigate the risk of ejection regardless of the ejection path in this case, while the curtain airbag will only function to mitigate the ejection risk through the side windows. Therefore, the seatbelt should be considered the

primary countermeasure to help mitigate the risk of ejection.

Figure 13 and 14 summarizes the simulation results plotted as occupant contact energy versus time. Figure 13 displays the results for the unbelted occupant while Figure 14 show the results for the belted occupant. There were multiple contacts with the interior for both the driver and passenger occupants (both belted and unbelted) throughout the duration of the event. In the unbelted case, a peak contact energy of 207 Joules was observed for the driver at 0.75 seconds; as opposed to a peak contact energy of 8 Joules in the belted case at 1.5 seconds. The peak passenger energy in the unbelted case was 206 Joules, occurring at 1.75 seconds while the peak passenger contact energy in the belted case was 7 Joules at 3.8 seconds.

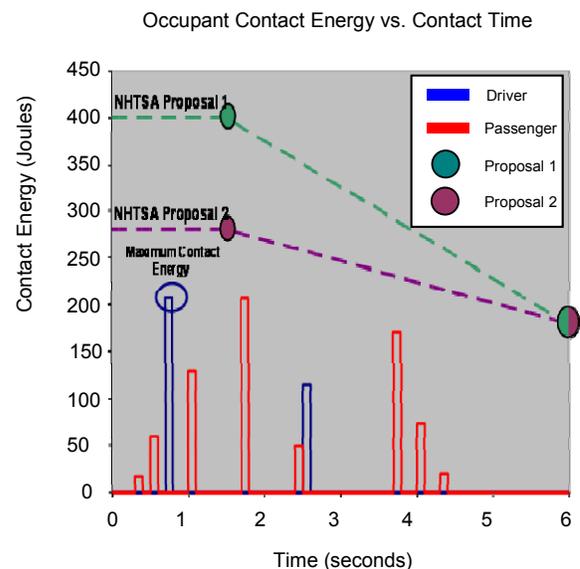


**Figure 13. Occupant contact energy for the FMVSS 208 dolly rollover test simulation with unbelted occupants.**



**Figure 14. Occupant contact energy for the FMVSS 208 dolly rollover test simulation with belted occupants.**

Figure 15 shows the results of the unbelted case (most severe case studied) compared to each of NHTSA’s proposals for ejection mitigation testing. The circles show the test energy at the appropriate delay times. A dashed line is drawn in to represent, in theory, the minimum performance that might be expected from a curtain airbag if developed to meet the performance requirements of each of the two proposals. It should be noted, however, that the dashed lines are provided for visualization purposes, and the actual performance of a curtain airbag may differ from this line. As can be seen, the occupant energy levels for both the driver and the passenger observed in the test analyzed fall below the thresholds of either of NHTSA’s proposals. Thus, either of NHTSA’s proposed energy levels appear adequate for the energy levels studied in this particular case.

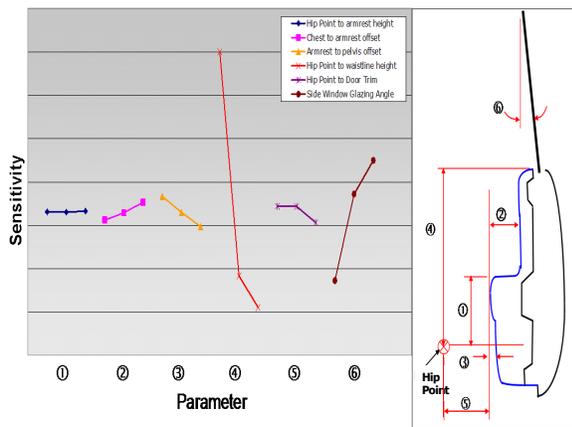


**Figure 15. Occupant contact energy for the FMVSS 208 dolly rollover test simulation with belted occupants compared with each of the NHTSA proposals for ejection mitigation testing.**

**Side impact case** In the side impact case there was not a discernible difference in the energy transferred to the window glazing between the belted and unbelted conditions. During the initial impact, the coupling between the occupant and the vehicle in the lateral direction through the seatbelt was negligible resulting in similar occupant kinematics during the initial impact for the unbelted and belted conditions. However, during the rebound the seatbelt functioned to restrain the occupant in the seat similar to the rollover case providing more controlled

occupant kinematics (Figure 7). Furthermore, all simulations were conducted with glazing in place; as result, it does not show the benefit of the seatbelt when the glazing is not present. As such, the authors feel the seatbelt is still the primary countermeasure for ejection mitigation in side impact crashes while the curtain may help further mitigate the risk of ejection through the side windows.

Figure 16 summarizes the results of the sensitivity analysis for the interior layout parameters. By far the most sensitive interior parameter affecting the energy transfer to the glazing was the waistline height. Window glazing angle did show some influence on the energy transfer, however, it was not nearly as significant as the waistline height. The other interior parameters showed very little effect on the energy transfer.

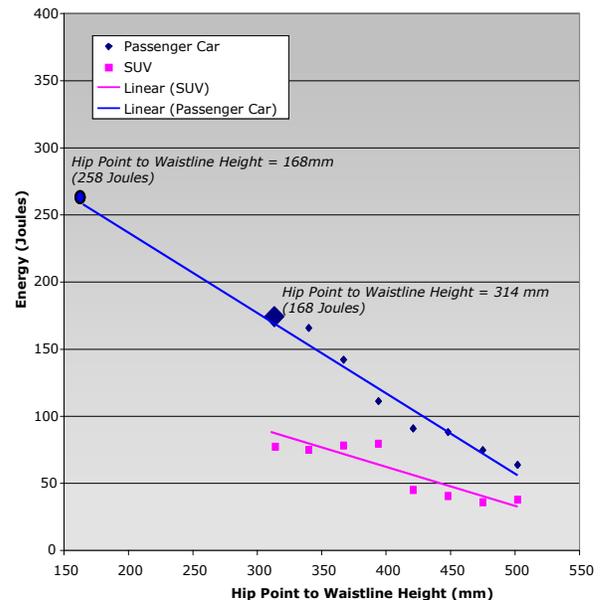


**Figure 16. Sensitivity of the various interior layout parameters on the energy transfer to the window glazing.**

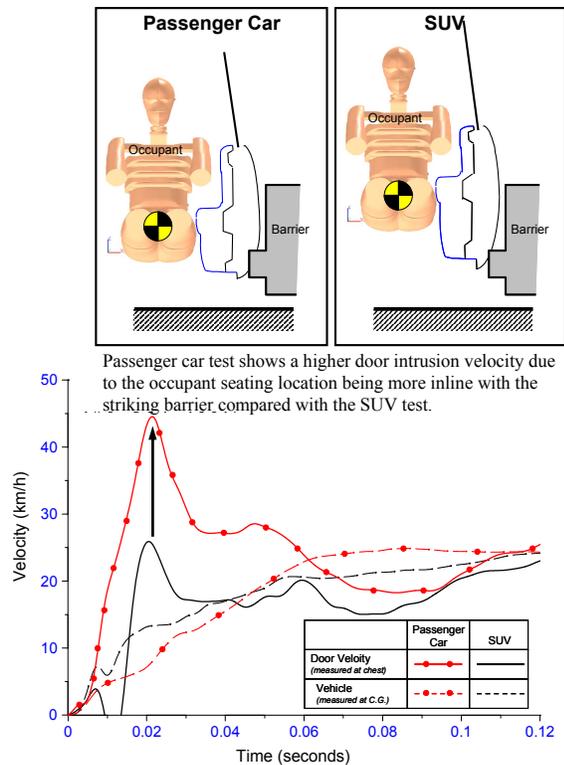
Therefore, to better understand the effect of waistline height on the energy transfer to the side window glazing, a more detailed simulation study was conducted. This was done by setting all of the interior parameters to the most severe levels based on the sensitivity analysis, and then varying the waistline height. Figure 17 shows the energy transfer to the glazing versus the waistline height. As in the sensitivity analysis, the amount of energy transferred to the glazing increased as the waistline was lowered. In all cases the passenger car showed higher energy values for a given waistline height than did the SUV. This was due to the fact that while the delta velocity as measured at the vehicle center of gravity was similar for both vehicles, the SUV had substantially lower door intrusion velocities as measured at the occupant chest due to the fact that

the occupant was seated higher than the impacting barrier, whereas in the passenger car, the occupant is more inline with the barrier as shown in Figure 18.

The maximum energy transfer to the window glazing observed was 168 Joules, which occurred in the passenger car test condition at the lowest waistline height observed for the vehicles investigated (314mm Hip Point to waistline height) in this study. Furthermore, if the waistline height is further reduced to the point that it is flush with the top surface of the armrest (168 mm hip point to waistline height), the maximum energy transferred to the side window glazing was 258 Joules, still below the 280 Joules outlined in the final rule for FMVSS 226. Thus a curtain airbag developed to the 280 Joules test is expected to be adequate to mitigate the risk of an ejection in the side impact tests evaluated in this study.



**Figure 17. Energy Transfer to glazing versus Hip Point to waistline height**

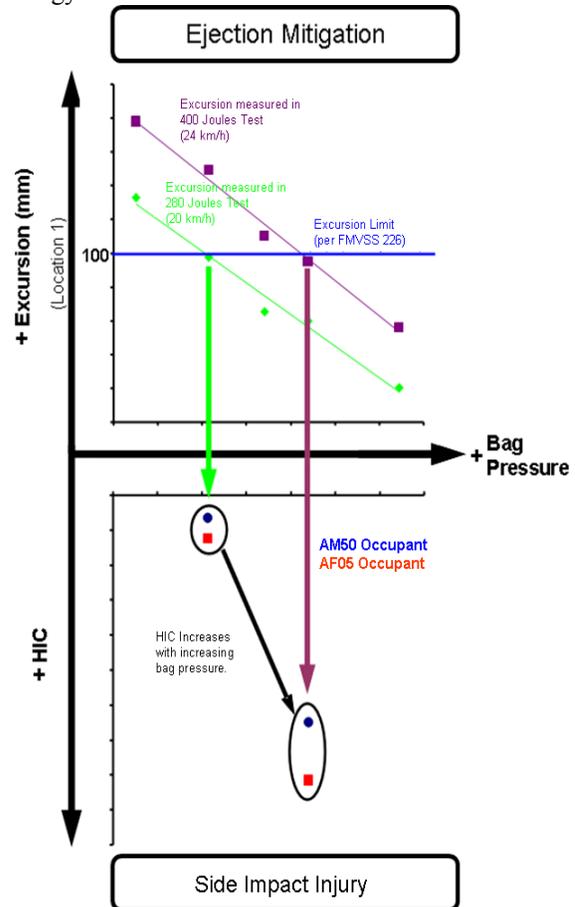


**Figure 18 Comparison of Door and Vehicle C.G. velocities for the Passenger Car and SUV tests.**

### Curtain Airbag Parameter Study

Several airbag pressures were evaluated using the ejection mitigation component test. Pressures were determined which would achieve the excursion criteria proposed by NHTSA (100mm beyond the plane of the side window) for both the 280 and 400 Joules test conditions. Linear impact testing simulating the oblique pole condition was then conducted at each of the pressures. The results are summarized in Figure 19. The upper plot shows the maximum excursion from the ejection mitigation tests for both the 400 and 280 Joules test conditions versus the bag pressure. The excursion measured at location 1 was used for this plot, as it consistently showed the highest result (reference Figure 20 in the appendix for detailed results). The lower plot shows the predicted HIC from the simulated side impact as a function of the bag pressure. As would be expected, the excursion seen in the ejection mitigation test reduced as the bag pressure was increased. Furthermore, lower excursions were observed in the 280 Joules test as compared with those observed in the 400 Joules test at the same airbag pressures. However, in the side impact component testing, HIC levels increased by 37% and 42% for the AM50 and AF05 occupants, respectively, when the curtain

pressure was optimized to the 400 Joules ejection mitigation test as opposed to the 280 Joules test. Thus, there is a trade-off for side impact when optimizing for ejection mitigation at the higher energy level.



**Figure 19. Curtain airbag pressure sensitivity considering rollover and side impact.**

### CONCLUSION

1. In the cases studied, the seatbelt was effective to help control the occupant kinematics functioning as the primary ejection mitigation countermeasure. The occupants remained restrained in the seat throughout the duration of the events studied. Furthermore, in the rollover cases the energy transferred to the side window glazing was substantially lower in the belted cases than in the unbelted cases. The curtain airbag may help further mitigate the risk of ejection through the side window glazing in the cases studied.

2. Either of NHTSA's proposals of 280 and 400 Joules would likely be adequate in both the rollover and side impact cases studied.
  - a) Maximum energy observed in the rollover case was 207 Joules for the unbelted AM50 occupants.
  - b) Maximum energy observed in the side impact case was 258 Joules for the unbelted AM50 occupants.
3. A curtain airbag optimized for the 400 Joules ejection mitigation test will likely have a higher HIC in side impact than one optimized for the 280 Joules test condition. Therefore, it is concluded that the 280 Joules ejection mitigation test condition allows for a better balance with side impact injury mitigation while likely still providing adequate protection for ejection mitigation in the events simulated. For this reason, the authors agree that NHTSA's direction to reduce the test speed for the 1.5 second delay ejection mitigation test to 20 km/h is preferred as compared to the previously proposed 24 km/h.

Administration, Docket No. NHTSA-2006-26467-0001, November 2006

4. "Ejection Mitigation Using Advanced Glazing A Status Report, November 1995", Advanced Glazing Research Team, National Highway Traffic Safety Administration, November 1995.
5. Notice of Proposed Rulemaking, Federal Motor Vehicle Safety Standard No. 226 "Ejection Mitigation", National Highway Traffic Safety Administration, Docket No. NHTSA-2009-0183, December 2, 2009
6. Department of Transportation, Standard No. 226 Ejection Mitigation, Part 571.226
7. Willke, Donald, et al., "Ejection Mitigation Using Advanced Glazing, Final Report", National Highway Traffic Safety Administration, August 2001.
8. "Factors Related to the Likelihood of a Passenger Vehicle Occupant Being Ejected in a Fatal Crash", National Center for Statistics and Analysis, National Highway Traffic Safety Administration, DOT-HS-811-209, December 2009.
9. Moore, Tara L.A., et. al "Biomechanical Factors and Injury Risk in High Severity Rollovers." 49<sup>th</sup> Annual Proceedings of the Association for the Advancement of Automotive Medicine (AAAM), pp. 133-150. 2005.
10. Hare, Barry M., et al. "Analysis of Rollover Restraint Performance with and without Seat Belt Pretensioner at Vehicle Trip." SAE 2002-01-0941.
11. Yu, H, C.E. Sturgess, A.M. Hassan, "Simulation of vehicle kinematics in rollover tests with quaternions", DOI: 0.1243/0954407JAUTO360, July 2006.
12. Department of Transportation, Standard No. 214 Side Impact Protection, Part 571.214

## ACKNOWLEDGMENTS

The authors would like to thank our colleagues for their technical and analytical support. In particular we would like to thank the following people: Erik Robins, Stewart Richards, Brett Garner, Marc Folsom, Doug Stein, Andrew Wesolowski, Brian Roeser, and Analia Jarvis.

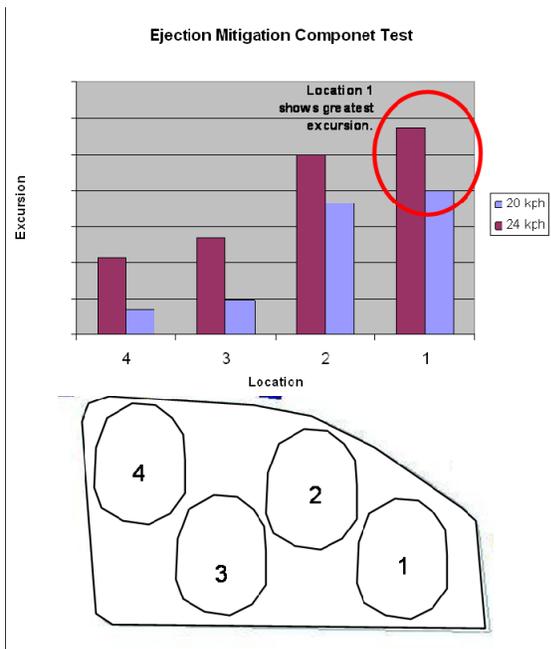
## REFERENCES

1. "Motor Vehicle Traffic Crash Fatality Counts and Estimates of People Injured for 2007" National Center for Statistics and Analysis, National Highway Traffic Safety Administration. DOT-HS-811-034, Updated February 2009.
2. Traffic Safety Facts 2008: "Passenger Vehicles", National Center for Statistics and Analysis, National Highway Traffic Safety Administration, DOT-HS-811-368.
3. "Research Test Procedure for Ejection Mitigation Testing", Office of Crashworthiness Standards, National Highway Traffic Safety

APPENDIX

**Table 4**  
**Summary of interior dimensions for eight vehicles**  
**studied for the side impact sensitivity analysis.**

Measurement		Vehicle							
		A	B	C	D	E	F	G	H
Trim Layout	① Hip Point to Armrest Height	172	227	200	200	207	168	260	184
	② Chest to Armrest Offset	64	65	34	39	40	68	77	79
	③ Armrest to Pelvis Offset	1	26	31	29	28	67	81	27
	④ Hip Point to Waistline Height	429	457	502	473	475	342	427	314
	⑤ Hip Point to Door Trim	281	298	295	300	305	285	302	310
	⑥ Glazing Angle	(deg)	6.32	20.4	28.8	23.7	25.2	17.3	15.4



**Figure 20. Typical excursion plot in the ejection mitigation test showing location '1' with the highest excursion.**