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PRELIMINARY REGULATORY IMPACT ANALYSIS

Notice of Proposed Rulemaking
FMVSS No. 226
Ejection Mitigation

Office of Regulatory Analysis and Evaluation
November 2009

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APPENDIX

EXECUTIVE SUMMARY

This Preliminary Regulatory Impact Analysis (PRIA) analyzes the potential impacts of new performance requirements and test procedures for ejection mitigation systems in rollover and certain side crashes. The intent of the rulemaking is to protect both belted and unbelted occupants from partial or complete ejection through side windows in vehicle crashes.

Test Requirements

The proposed rule requires that the occupant containment countermeasure be tested by impact from a guided 18 kg featureless head form traveling laterally and horizontally. The performance criterion is a displacement limit, measured by the impactor, of 100 mm beyond the inside surface of the window at the target location being tested. It requires that each side window, for up to three vehicle rows, be impacted at any of four locations referenced to the edges of the window opening at two impact velocities (16 and 24 km/h). The 16 km/h impact will occur 6 seconds after air bag deployment and the 24 km/h impact will occur 1.5 seconds after air bag deployment.

Countermeasures

The agency believes that curtain air bags will be used to pass the test. We believe that most manufacturers will have to make changes to the air bags that have been or will be installed in vehicles in response to the recent pole test upgrade of FMVSS No. 214.[1] Side curtain air bags will be made wider or combination (combo) air bags will be replaced with a curtain to pass the impactor test. Vehicle manufacturers would install a single-window curtain for each side and these window curtains are assumed to provide protection for both front and rear seat occupants.

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[1] 72 FR 51908

Although the majority of vehicles tested met the linear impactor head form (headform) test requirement at the upper portion of the window opening, none of the vehicles met the requirement at all impact points. For current OEM ejection countermeasures, a particularly difficult point to meet the test is the front lower corner of the front window near the A-pillar (test point A1).

We examined two different types of countermeasures that are designed to meet the proposed headform impact requirements. One approach is to cover the opening with a wider curtain air bag (called "full curtain" in the PRIA). However, we believe that even if the window is completely covered with a header-mounted curtain air bag and limited the headform displacement to some value less than 100 mm, some partial ejections could occur through a potential gap along the bottom of the air bag between the air bag and vehicle's window sill. As an alternative to this design approach, manufacturers may install laminated glazing in the window opening (called "partial curtain plus laminated glazing") to prevent ejections through test point A1 and the lower gap. There is still a question whether a window curtain and laminated glazing could pass Point A1 at 24 km/h (15 mph). In this PRIA, we explore the implications of the agency lowering the test speed at Point A1 to 20 km/h (12 mph) in the 1.5-second test and how manufacturers would design an ejection mitigation system under such a condition (a third countermeasure called "A1 full curtain").[2]

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[2] As discussed, the goal is to cover the whole window opening. As part of the rulemaking effort, the agency tested a prototype curtain ejection mitigation system developed by TRW in a dynamic rollover fixture (DRF). The test results showed that in a near worst case ejection condition an unrestrained small child could be ejected through a small window opening (target position A1) when the area is not fully covered, even when initially aimed at another part of the window (target position A2). For additional discussion, see a report titled "NHTSA's Crashworthiness Rollover Research Program," Summers, S., et al., 19th International Technical Conference on the Enhanced Safety of Vehicles," paper number 05-0279, 2005. These benefits estimates are based on lateral rollovers. We do not

Benefits

The agency estimates benefits for both partially and completely ejected occupants in rollovers and certain side crashes. The agency's annualized injury data from 1997 to 2005 National Automotive Sampling System (NASS) Crashworthiness Data System (CDS) and fatality counts adjusted to 2005 Fatal Analysis Reporting System (FARS) levels show that there are 6,174 fatalities and 5,271 Maximum Abbreviated Injury Scale (MAIS) 3+ non-fatal injuries for occupants ejected through side windows. The potential benefits estimated in the 214-FRIA for the upgrade to FMVSS No. 214 were excluded from the ejection mitigation benefits. After adjusting for assumed full compliance with Electronic Stability Control (ESC) penetration in the model year (MY) 2011 vehicle fleet and current compliance with the proposed rule, we estimated that the proposed rule being met by the full curtain would save 390 to 402 lives and prevent 296 to 310 serious injuries, annually.[3] For the estimated benefits, we assumed that the belt use rate observed in 2005 remains unchanged. The majority of the benefits are for unbelted occupants but the analysis shows that 13 percent of the benefits would be from belted occupants: 10 percent from rollovers and about 3 percent from side crashes considered.

Costs

Potential compliance costs for the linear impactor headform test vary considerably and are dependent upon the types of the FMVSS No. 214-head/side air bags that will be installed by

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know the effectiveness of these bags in other rollover events, such as end-to-end or more complex rolls. We suspect that the effectiveness would decrease noticeably in non-lateral rollovers.

[3] The benefit estimate was made based on particular assumptions used in the analysis. The range of potential benefits is due to different assumptions about where in the opening occupants are ejected. The benefit chapter in the PRIA discuses the assumptions used for occupant ejections. In addition, when inputs that affect the analysis are uncertain, the agency makes its best judgment about the range of values that will occur through sensitivity analyses, as discussed in Chapter VII.

vehicle manufacturers to comply with the oblique pole test requirements. For vehicles with two rows of seats to be covered with a curtain air bag, we estimate an ejection mitigation system (consisting of 2 window curtains, 2 thorax air bags for the front seat occupants only, 2 side impact sensors and 1 rollover sensor) would cost about $299.44, when compared to a vehicle with no side air bags. This is $49.97 more than a vehicle with a side air bag system designed to meet the FMVSS No. 214 pole and MDB tests. The estimated MY 2011 sales show that 25% of light vehicles will have a third row seat. When the first through 3rd row are covered with a curtain air bag, we estimated the cost per vehicle will increase by $61.92, when compared to a vehicle equipped with a FMVSS No. 214-curtain system.

The manufacturers' plans for MY 2011 head air bag sales show that about 1%, 44% and 55% of vehicles would be equipped with combination air bags, curtain air bags without rollover sensor and with rollover sensors, respectively. Thus, manufacturers are planning to provide 55% of the MY 2011 vehicles with an expensive part of the cost of meeting the ejection mitigation test, the rollover sensor which is estimated to cost $38.02. Our analysis shows that most vehicles that are equipped with combination air bags would be convertibles (about 1%). The agency asks for comments on the feasibility of installing countermeasures other than header mounted air bag curtains such as door-mounted ejection mitigation curtains in convertibles on a widespread basis and the associated costs and benefits. Given that 25% of light trucks have 3 rows of seats, we estimate the average cost per vehicle would increase by $54 if there were no voluntary compliance by manufacturers for MY 2011.[4] Manufacturers' plans for MY 2011 indicate at least $20 per vehicle of costs toward this proposal. Thus, compared to the manufacturers' plans

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[4] We estimated that a total cost of $920 million when all light vehicles are equipped with rollover ejection curtains. For the $920M, $583M would be a result of the final rule and the remaining $337M would be resulting from voluntarily installed rollover curtain bags.

this proposal will add about $34 per light vehicle at a total cost of $583 million for the full curtain countermeasure.

Total and Average Vehicle Costs*
($2007)

Costs	Ejection Mitigation System	Weighted MY 2011 Manufacturers' Plans	Incremental Costs
Per Vehicle Costs	$54	$20	$34
Total Costs (17 million vehicles)	$920 million	$337million	$583 million

* The system costs are based on vehicles that are equipped with the 214-curtain system. According to vehicle manufacturers, 98.7% of MY 2011 vehicles will be equipped with curtain air bags and 55% of vehicles with curtain air bags will be equipped with a roll sensor.

Cost per Equivalent Life Saved and Net Benefits

Estimates were made of the net costs per equivalent life saved. For the full curtain countermeasure[5], the low end of the range is $1.57 million per equivalent life saved, using a 3 percent discount rate. The high end of the range is $2.04 million per equivalent life saved, using a 7 percent discount rate.

Net benefit analysis differs from cost effectiveness analysis in that it requires that benefits be assigned a monetary value, and that this value is compared to the monetary value of costs to derive a net benefit. When we assume that the percentage of MY 2011 air bag sales remain unchanged (i.e., 1%, 44% and 55% of vehicles would be equipped with combination air bags, curtain air bags without rollover sensor and with rollover sensors, respectively), it resulted in $1,605 to $1,680 million net benefits using a 3 percent discount rate, and $1,158 to $1,217

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[5] The cost equivalent and net benefits analyses showed that the full curtain would have a cost per equivalent of $1.57M and $1.98M discounted at 3% and 7%, respectively, when the weighted risk of distribution method is used. When the uniform distribution method is used, the full curtain would have a cost equivalent of $1.63M and $2.04M discounted at 3% and 7%, respectively. For the "A1 full cover" curtain, we estimated $1.61M and $2.02M discounted at 3% and 7%, respectively, with the weighted distribution method and $1.70M and $2.14M discounted at 3% and 7%, respectively, with the uniform distribution method

million using a 7 percent discount rate. Both of these are based on a $6.1 million cost per life,[6] as shown below:

Analysis of Alternatives

The following tables show the estimated benefits, costs, cost per equivalent life saved, and net benefits for the three alternative countermeasures considered.

Incremental Benefits

Countermeasure	Weighted risk of ejection method		Uniform risk of ejection method	
	Fatalities	Serious Injuries	Fatalities	Serious Injuries
Full Curtain	402	310	390	296
A1 Full Curtain	391	301	377	286
Partial Curtain plus Laminated Glazing	494	391	490	386

Incremental Costs
Cost (in 2007 economics)

Countermeasure	Per Average Vehicle	Total (in millions)
Full Curtain	$34	$583
A1 full Curtain[7]	$34	$583
Partial Curtain plus Laminated Glazing	$88	$1,494

Cost per Equivalent Life Saved and Net Benefits, with two methods

Countermeasure	Total Cost	with Weighted Distribution (in $M)				with Uniform Distribution me (in $M)			
		Cost per Equivalent Life Saved		Net Benefits		Cost per Equivalent Life Saved		Net Benefits	
		3%	7%	3%	7%	3%	7%	3%	7%
Full Curtain	$583	$1.57	$1.98	$1,680	$1,217	$1.63	$2.04	$1,605	$1,158
A1 full Curtain	$583	$1.62	$2.03	$1,615	$1,166	$1.68	$2.11	$1,534	$1,101
Partial Curtain plus Laminated Glazing	$1,494	$3.27	$4.12	$1,293	$720	$3.30	$4.14	$1,271	$706

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[6] The Department of Transportation has determined that the best current estimate of the economic value of preventing a human fatality is $5.8 million ("Treatment of the Economic Value of a Statistical Life in Departmental Analyses," Tyler D. Duval, Assistant Secretary for Transportation Policy, February 5, 2008. The $6.1 million comprehensive cost was based on the $5.8 million statistical life.

[7] The "full curtain" and the "A1 full curtain" cover the window opening area fully. Since the incremental costs are based on the increase in material cost, we assumed that the incremental costs are the same for these two full-cover bags. Accordingly, we believe that the "A1 curtain" bag could be re-designed, without additional materials, to meet the proposed 24 km/h requirement at the lower impact point, A1.

The estimated benefits from the ejection mitigation systems considered show that the partial curtain plus laminated glazing system would result in most benefits (494 lives saved) followed by the full curtain and the partial curtain. However, the curtain plus glazing system would be the most costly system ($1,494 million) followed by the full curtains. When the comprehensive saving (for preventing a statistical life) was considered, the net benefit analysis showed that the full curtain would result in the lowest cost per equivalent life saved and the highest net benefits.

I. INTRODUCTION

General: As a crash type, rollovers are second only to frontal crashes in the annual number of fatalities in light vehicles. Figure I-1 shows the distribution of fatalities by crash type from 1992 to 2004 in the Fatal Analysis Reporting System (FARS). Although frontal crash fatalities have remained fairly steady at around 12,000 per year, going back to 1992, rollover fatalities have be steadily increasing from 8,600 in 1992 to 10,600 in 2004. In 2004, 33% of fatalities were in rollover crashes.

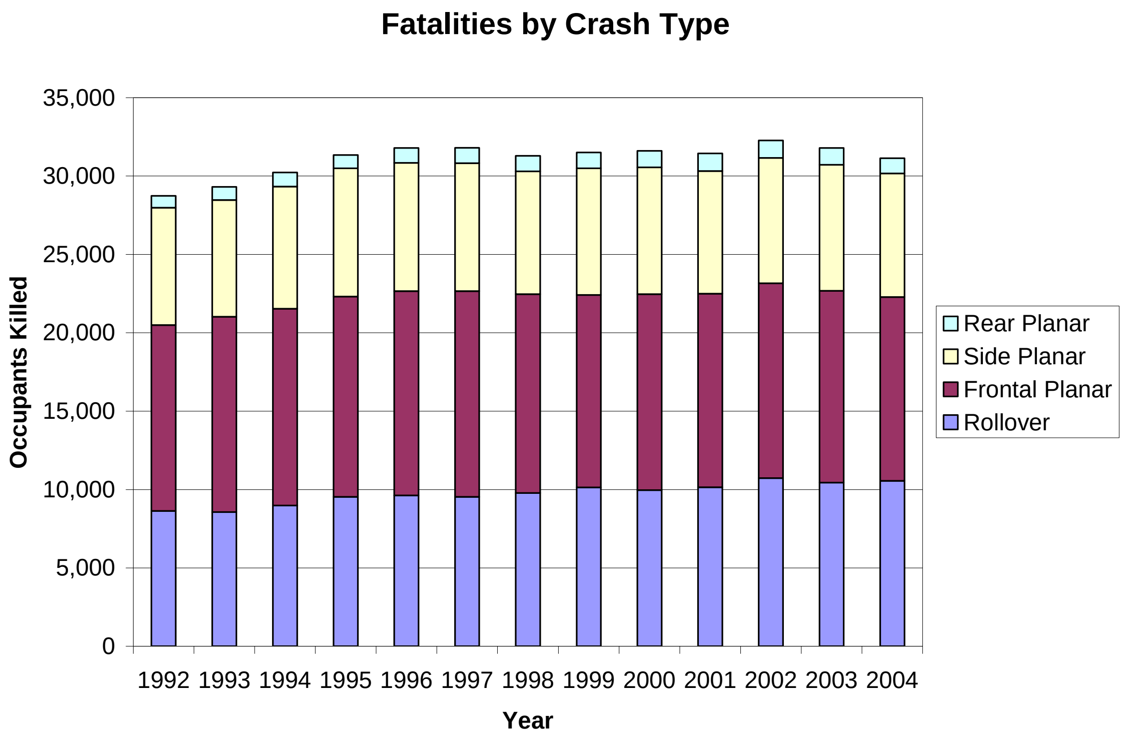

Figure I-1 Fatalities by Crash Type – 1992 to 2004 FARS

The National Automotive Sampling System (NASS) General Estimates System (GES) can be used to determine the frequency of particular crash types as documented by police accident reports (PARs). Dividing the number of fatalities in each crash type by the frequency of the crash type gives a measure of the relative risk of fatality for each crash type. Figure I-2 graphically represents this relative risk. This data clearly shows the deadly nature of rollover crashes. An occupant is 14 times more likely to be killed in a rollover than in a frontal crash.

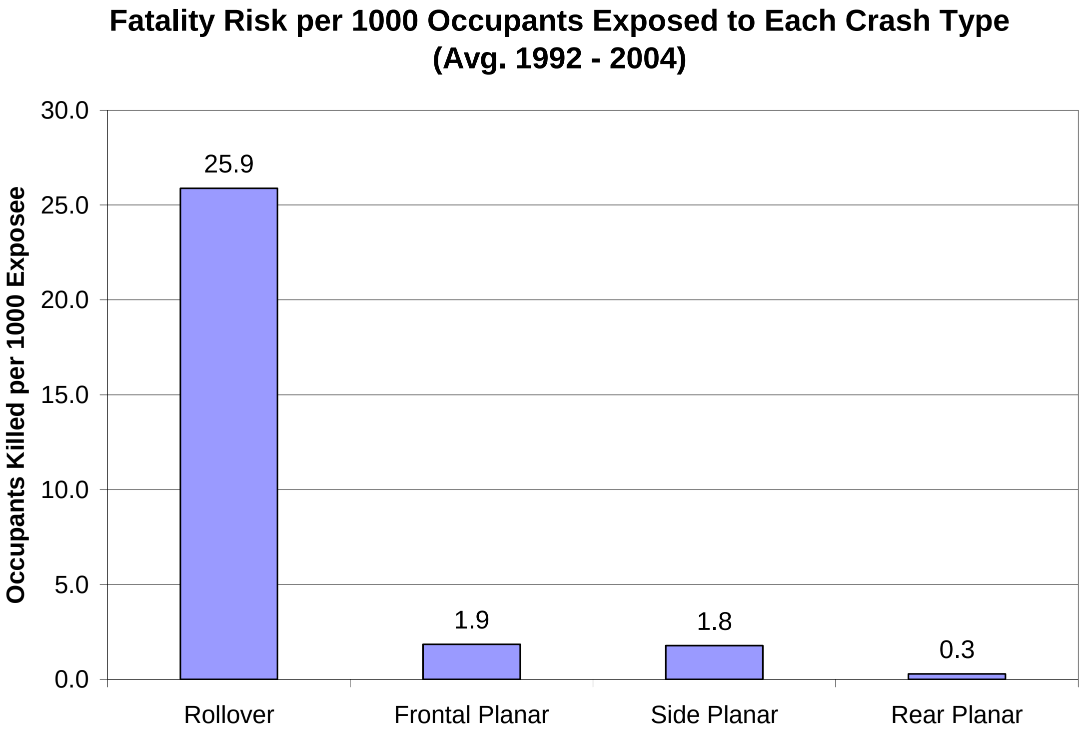

Figure I-2 Fatality Risk per 1000 Occupants Exposed to Each Crash Type (Avg. 1992 – 2004 FARS)

As stated above, rollover fatalities have been increasing for many years, with the number in 2004 about 2,000 more than in 1992. The main reason for this has been an increase in rollover fatalities in the sport utility vehicle (SUV) segment. Figure I-3 shows the rollover fatalities by vehicle type, over time. There were approximately 800 SUV rollover fatalities in 1992 as compared to approximately 2,900 in 2004. So, the increase in SUV rollover fatalities accounts for the overall increase in rollover fatalities.

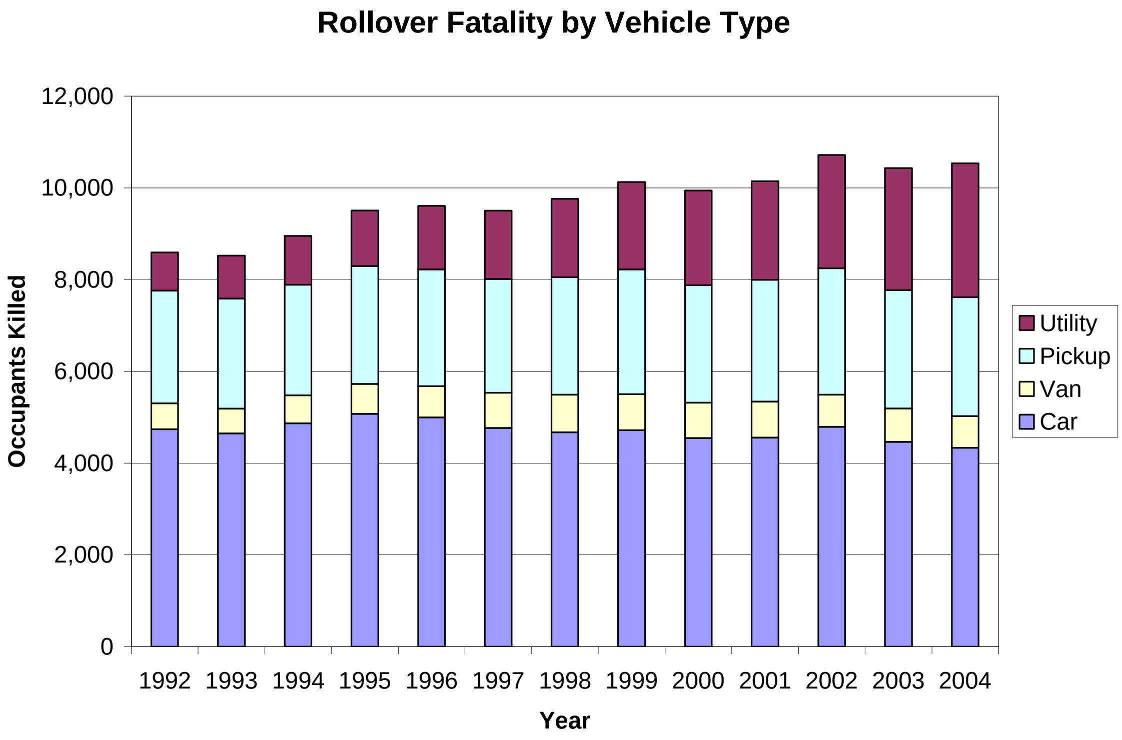

Figure I-3 Rollover Fatalities by Vehicle Type- 1992 to 2004 FARS

Using FARS data shown in Figure I-4 we see that over the last 13 reporting years about half of the occupants killed in rollovers are completely ejected from the vehicle. Note that in this graph the FARS data lumps partially ejected and un-ejected occupants together. This is because partially ejection is sometimes difficult to determine and we do not expect the PAR generated FARS data to have an accurate representation of partially ejected occupant fatalities.

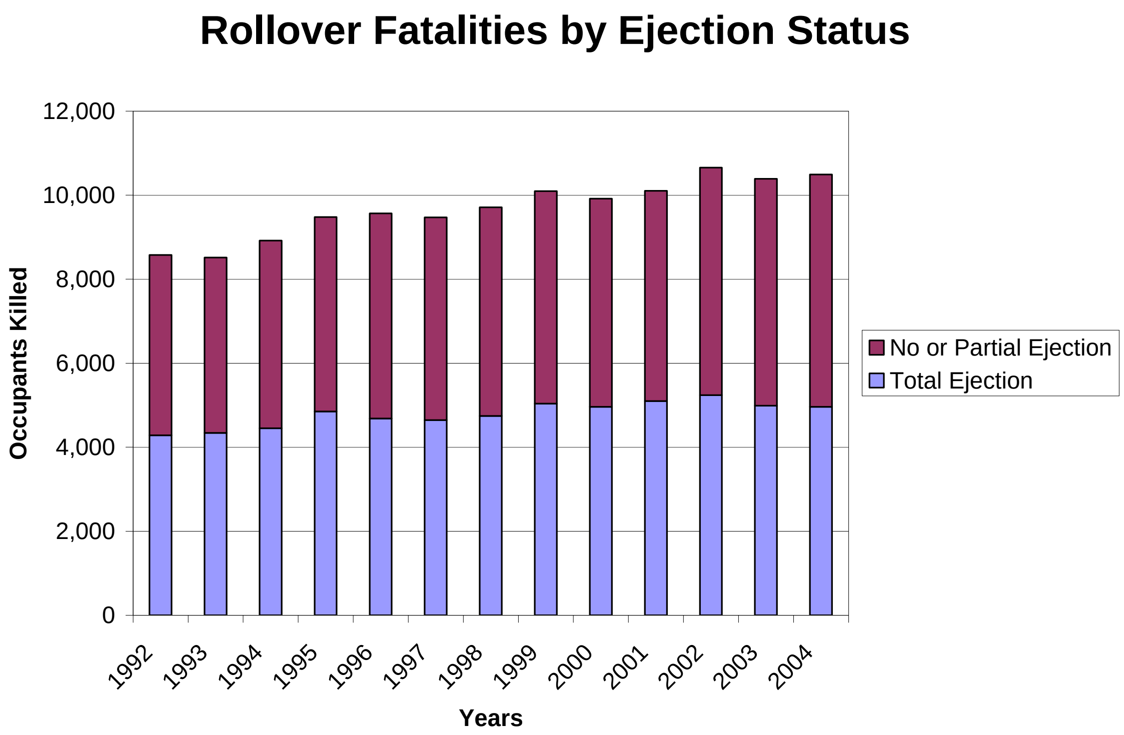

Figure I-4 Rollover Fatalities by Ejection Status-1992 to 2004 FARS

The FARS data in Figure I-4 can be used in conjunction with NASS GES data to determine the relative risk of being killed in a rollover as a function of whether or not the occupant is fully ejected. Figure I-5 shows this risk averaged over the period of 1992 to 2004. There are 317 fully ejected occupants killed for every 1,000 fully ejected occupants in rollover crashes or a 32% probability of being killed if fully ejected. By comparison 14 of every 1,000 occupants not fully ejected are killed in rollover crashes or a 1.4% probability of being killed. Thus, an occupant is 23 times more likely to be killed if fully ejected. This clearly shows the benefit of preventing complete ejections in rollovers.

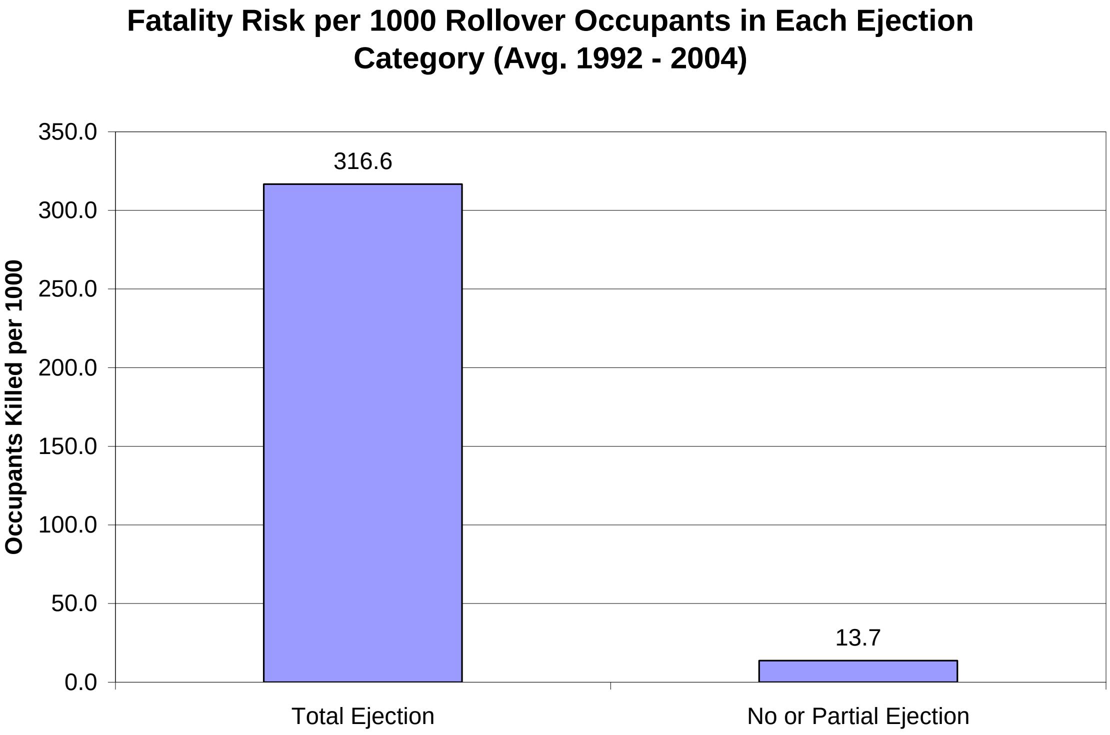

Figure I-5 Fatality Risk per 1000 Rollover Occupants in Each Ejection Category (Avg. 1992 – 2004 FARS)

Injuries and Fatalities by Rollover Severity: The majority of occupants exposed to rollover crashes are in vehicles that roll 2 ¼-turns or less. However, the distribution of ejected occupants who are seriously injured (maximum abbreviated injury scale (MAIS) 3+) and killed is skewed towards rollovers with higher degrees of rotation, as shown in Figure I-6. The graph was generated from NASS CDS data of occupant exposed to a rollover crash from 1988 to 2005. All rollover crashes were included irrespective of whether it was coded as the most harmful event. Note that half of all fatal complete ejections occurred in crashes with 5+ ¼-turns.

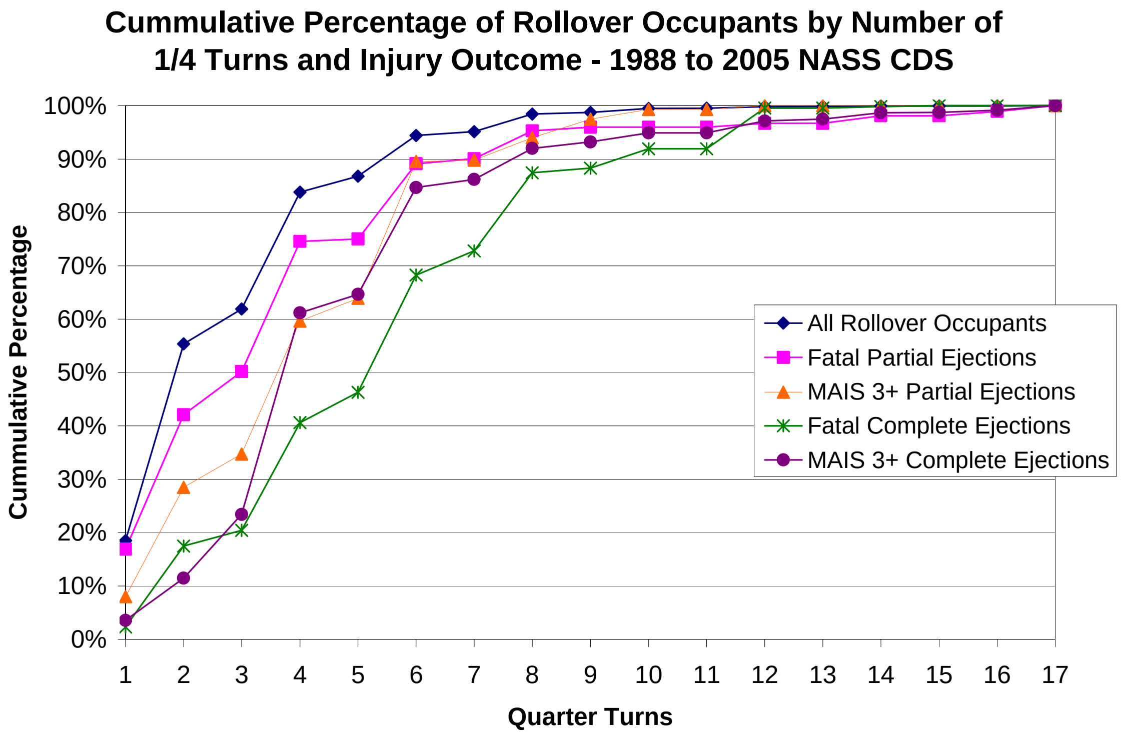

Figure I-6 Cumulative Percentage of Rollover Occupants by Number of 1/4 Turns and Injury Outcome - 1988 to 2005 NASS CDS

Ejection Routes in All Crashes: In this section, we used annualized injury data from 1997 to 2005 NASS CDS and fatality counts adjusted to 2005 FARS levels to analyze ejection routes. All unknowns have been distributed and all crash types are included. However, the counts are restricted to ejection occupants that were injured. In addition, in NASS CDS the ejection route for side windows is only explicitly coded for the front (Row 1 Window) and rear (Row 2 Window). The third and further rearward side window ejections should be coded as "other glazing." This is because there are specific codes available for coding roof glazing, windshield and backlight. However, when extracting NASS cases of known ejections through "other glazing," we observed 17 unweighted occupants. A hard copy review of these cases showed that 9 were known 3rd row side window ejections, but five cases were miscoded. Four were actually backlight ejections and one was a sunroof ejection. The known 3rd row ejections were recoded as “Row 3 Window” ejections.

Table I-1 shows the MAIS 1-2, MAIS 3+ and fatality distribution of ejected occupants by eight potential ejection routes. Table I-2 gives the percentage of the total at each injury level. Ejection through side windows makes up the greatest part of the ejection problem. There are 6,174 fatalities, 5,271 MAIS 3+ injuries, and 18,353 MAIS 1-2 injuries for occupants ejected through side windows. These make up 61%, 47% and 68% of all ejected fatalities, MAIS 3+ injuries, and MAIS 1-2 injuries, respectively.

Table I-1
Occupant Injury and Fatality Counts by Ejection Route in All Crash Types
(Annualized 1997 – 2005 NASS, 2005 FARS)

Ejection Route	MAIS 1-2	MAIS 3+	Fatal
Row 1 Window	15,797	4,607	5,209
Row 2 Window	2,533	621	906
Row 3 Window	23	43	59
Windshield	1,923	1,565	1,155
Backlight	1,625	1,677	515
Sun Roof	1,127	305	237
Other Window	1	51	0
Not Window	3,870	2,411	2,068
All Side Windows	18,353	5,271	6,174
Total	26,899	11,280	10,149

Table I-2
Occupant Injury and Fatality Percentages by Ejection Route in All Crash Types
(Annualized 1997 – 2005 NASS, 2005 FARS)

Ejection Route	MAIS 1-2	MAIS 3+	Fatal
Row 1 Window	58.7%	40.8%	51.3%
Row 2 Window	9.4%	5.5%	8.9%
Row 3 Window	0.1%	0.4%	0.6%
Windshield	7.1%	13.9%	11.4%
Backlight	6.0%	14.9%	5.1%
Sun Roof	4.2%	2.7%	2.3%
Other Window	0.0%	0.5%	0.0%
Not Window	14.4%	21.4%	20.4%
All Side Windows	68.2%	46.7%	60.8%
Total	100.0%	100.0%	100.0%

The crash data show that most of ejections occurred through side window in rollovers. (Note that some of the rollovers are preceded by side crashes. These side-then-roll crashes were analyzed separately in the benefit chapter.) There are 4,128 fatalities, 4,095 MAIS 3+ injuries, and 12,229 MAIS 1-2 injuries for occupants ejected through side windows in rollovers.

Table I-3
Occupant Injury and Fatality Counts by Ejection Route in Rollovers

Ejection Route	MAIS 1-2		MAIS 3+		Fatal	
Row 1 Window	10,618	87%	3,660	89%	3,470	84%
Row 2 Window	1,589	13%	421	10%	620	15%
Row 3 Window	22	<1%	14	1%	38	1%
total	12,229	100%	4,095	100%	4,128	100%

Proliferation of Vehicles with Rollover Sensors: The availability of vehicles that offer inflatable side curtains that deploy in a rollover has increased since they first became available (Figure I-7). For the 2007 model year, rollover sensors are available on approximately 95 models with the system being standard equipment on about half. Rollover sensors are available predominantly on SUVs.

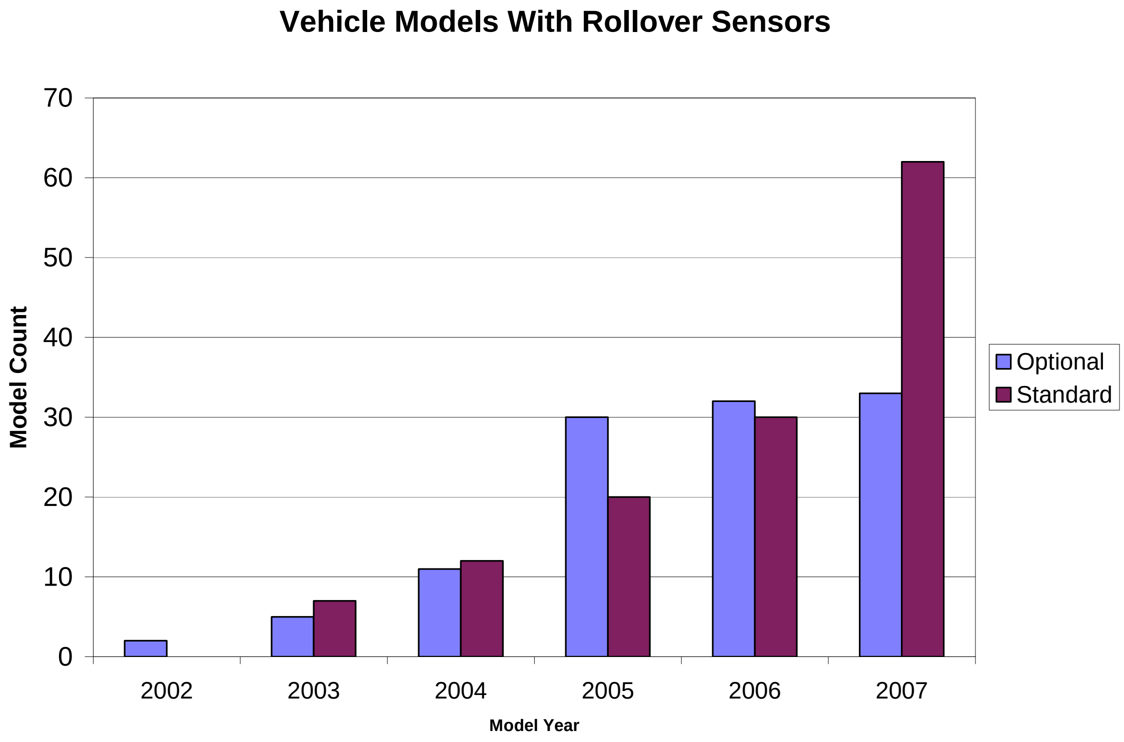

Figure I-7 Vehicles with Rollover Sensors

Current State and Future Direction of Ejection Countermeasures: The first generation of roof mounted inflatable curtain air bags were introduced in the U.S. in the late 1990s (1998 Volvo S80, Figure I-8). These inflatable curtains were designed to deploy in the event of a side impact crash to reduce the chance of head injury. During the 2002 MY, Ford introduced the first generation of side curtain air bag that were designed to deploy in the event of a rollover crash

(Figure I-9). Ford introduced this rollover air bag curtain system as an option on the Explorer and Mercury Mountaineer and marketed it as the "Safety Canopy."

There are three important design differences between air bag curtains designed for rollover ejection mitigation as opposed to side impact protection. The first difference is longer inflation duration. The portion of a side impact crash when the air bag curtain can provide protection is less than a 0.1 seconds. By contrast, rollover with multiple full vehicle rotations can last many seconds. Ford claims that their "Safety Canopy" stay inflated for six seconds. GM claims that their side curtain air bags designed for rollover protection maintain 80% inflation pressure for 5 seconds. The side curtains on the 2005 and later Honda Odyssey stay inflated for 3 seconds.

Figure I-8 1999 Volvo S80

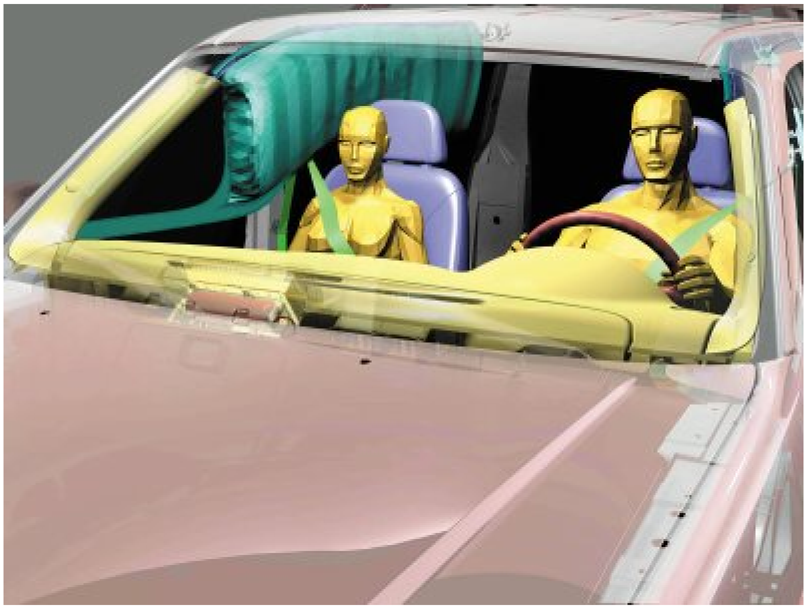

Figure I-9 2002 Ford Explorer/Mercury Mountaineer

The second important air bag curtain design difference between side impact and rollover protection is the size or coverage of the air bag curtain. GM claims that their curtains designed for rollover protection are larger than non-rollover curtains. One of the most obvious trends in newer vehicles is the increasing area of coverage for rollover curtains. Third, the rollover curtain must be tethered tightly the lower part of the air bag to vehicles' A- and C-pillars.

Figure I-10 shows the side curtain for the 2006 Ford Expedition/Navigator. For the 2003 to 2006 models this was optional on the Expedition and standard on the Navigator. It is not much different from that of the original 2002 Explorer/Mountaineer. Ford claimed that these systems covered two-thirds to 80% of the first two rows of windows. Compare this to the 2007 Ford Expedition/Navigator system shown in Figure I-11, the coverage is much more complete in the new vehicles and extends to the third row. However, it still appears as if the second rollover curtain does not extend to the sill. The 2007 Chevrolet Tahoe has extensive coverage as well (Figure I-12).

Figure I-10   2006 Ford Expedition/Navigator

Figure I-11   2007 Ford Expedition/Navigator

Figure I-12   2007 Chevrolet Tahoe

In the minivan vehicle category, the Honda Odyssey has been offering standard rollover protection with full three rows of coverage since 2005. Figure I-13 shows the second and third occupant seating rows. Note that the lower edge of the curtain extends beyond the sill. Figure I-14 shows the three row coverage of the standard equipment rollover curtain in the 2006 Mercury Monterey.

Figure I-13   2005 Honda Odyssey

II BACKGROUND

Previous Agency Efforts on Rollover Mitigation:

NHTSA has been active in rollover[8] crash rulemaking and research for 30 years. The NHTSA Authorization Act of 1991 (part of the Intermodal Surface Transportation Efficiency Act) required the agency to address several vehicle safety subjects through rulemaking, including protection against unreasonable risk of rollovers of passenger cars and light trucks. In January 1992, NHTSA published an ANPRM and a Technical Assessment Paper (57 FR 242). The ANPRM soliciting information concerning rollover crashes, to assist the agency in planning a course of action on several rulemaking alternatives, supplementing the ANPRM. The Technical Assessment Paper discussed testing activities, testing results, crash data collection, and analysis of the data.

During the development of the ANPRM and after receiving and analyzing comments to the ANPRM, it became obvious that no single type of rulemaking could solve all, or even a majority of, the problems associated with rollover. Subsequently, a Rulemaking Plan titled "Planning Document for Rollover Prevention and Injury Mitigation Docket 91-68 No. 1" was published for public review on September 29, 1992, (57 FR 44721). The Planning Document gave an overview of the rollover problem and a list of alternative actions that NHTSA was examining to address the problem. Activities described in that document were:

1) Crash avoidance research on vehicle measures for rollover resistance;

2) Research on antilock brake effectiveness;

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[8] As used in this document rollover refers to a lateral rollover or a vehicle rotation about its longitudinal axis.

3) Rulemaking on upper interior padding to prevent head injury;

4) Research into improved roof crush resistance to prevent head and spinal injury;

5) Research on improved side window glazing and door latches to prevent occupant ejection; and

6) Consumer information to alert people to the severity of rollover crashes and the benefits of safety belt use in this type of crash.

In 1994, NHTSA terminated rulemaking to establish a minimum standard. In May 1996, NHTSA issued the "Status Report for Rollover Prevention and Injury Mitigation." This document updated the progress of the programs discussed in the Planning Document.

Side Window Area Ejection Mitigation by Glazing Use:

NHTSA published two ANPRMs in 1988 announcing that the agency was considering the proposal of requirements for passenger vehicles intended to reduce the risk of ejections in crashes where the side protection of the vehicle was a relevant factor. One notice (53 FR 31712) dealt with passenger cars. The other notice (53 FR 31716) dealt with light trucks.

The agency reported at the time, based on the 1982-1985 Fatality Analysis Reporting System (FARS), each year 19.5 percent of the occupant fatalities were the result of complete ejection through glazing and 4.3 percent were the result of partial ejection through glazing. Data presented indicated that a large percentage of these ejections were through the side windows and that ejected occupants were at greater risk of fatality or serious injury.

NHTSA believed that new side window designs, incorporating different glazing/frames, had the potential to reduce the risk of ejections. At that time, NHTSA suggested that one performance approach would be to use an 18 kg (40 lb) glazing impact device, requiring that it not penetrate the plastic layer of a side window at 32 km/h (20 mph), an estimated typical contact speed. Numerous comments were received on the 1988 ANPRM. Major issues were raised concerning the proposal, primarily that the safety benefits were not quantified. Others were that the injury criteria were not specified for side impact, the practicability of glazing designs were questioned and had never been demonstrated, the cost was high, and there was no objective and repeatable test procedure proposed. Finally, the comments questioned what effect ejection mitigating glazing would have on overall occupant injuries and fatalities, and whether this material would actually increase injuries to belted occupants.

As mentioned above, as a result of the NHTSA Authorization Act of 1991, a planning document was created containing a research plan for ejection mitigation through the use of glazing. Public comments on the glazing program questioned design practicability, the lack of standardized testing, and the potential for additional contact injuries.

In November 1995, NHTSA issued a report titled “Ejection Mitigation Using Advanced Glazings: A Status Report.”[9] This report documented the size of the problem of vehicle occupants being ejected through first row side glazing. The report also described testing NHTSA had done with a prototype glazing system using modified door and glazing materials.

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[9] “Ejection Mitigation Using Advanced Glazings: A Status Report,” November 1995, Docket No. NHTSA-1996-1782-3.

Based on this testing, NHTSA developed some estimates of potential benefits that could be associated with advanced side glazing.

NHTSA followed this with another report in August 1999 titled "Ejection Mitigation Using Advanced Glazings: Status Report II."[10] This report updated several aspects of the previous research. First, a more current door/glazing system was evaluated. Second, a series of sled tests were conducted to attempt to evaluate the potential for neck injury from the use of advanced glazing systems. Third, additional tests were conducted to evaluate the feasibility of using some impactor component tests. Fourth, the benefit-analysis was updated to include more recent data and to respond to comments received on the 1995 report.

In NHTSA's fiscal year 2001 Appropriations, Congress noted that NHTSA had been looking at advanced side glazing since 1991, and directed NHTSA to complete and issue a final report on advanced side glazing. That report was published in August 2001 and titled "Ejection Mitigation Using Advanced Glazing: Final Report."[11]

The report concluded that advanced side glazing has the potential to yield significant safety benefits by reducing partial and complete ejections through side windows, particularly in rollover crashes. Further, it found that the safety benefits are not unique to advanced glazing systems; other safety countermeasures can also prevent ejections. Finally, it was decided that glazing systems should be evaluated as one component of a comprehensive ejection prevention

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[10] "Ejection Mitigation Using Advanced Glazings: Status Report II," August 1999, Docket No. NHTSA-1996-1782-21.

[11] 4 "Ejection Mitigation Using Advanced Glazings: Final Report," August 2001, Docket No. NHTSA-1996-1782-22.

and mitigation strategy that includes alternate ejection countermeasures such as the more recent developments in inflatable head protection and/or rollover protection systems.

Recent and Current Activities: Rollover NCAP, Rollover IPT, and R/OPCT

In 2002-2003 timeframe, NHTSA began the sponsorship of five Integrated Project Teams (IPT) targeting the Administration's priority areas. In June 2003, the rollover IPT[12] published its final report (68 FR 36534). The crashworthiness topics specifically addressed in the rollover IPT Report were ejection mitigation and roof crush. The ejection mitigation program was further divided into three phases. Phase I was the then-ongoing FMVSS No. 214 upgrade implementing an oblique pole test, Phase II was development of an occupant containment countermeasure test and Phase III was development of test(s) for sensor systems to detect rollover crashes.

The Relationship between the FMVSS No. 214 Pole Test and Ejection Mitigation

On December 4, 2003, the Alliance of Automobile Manufacturers (Alliance) and the Insurance Institute for Highway Safety (IIHS) announced a new voluntary commitment to enhance occupant protection in front-to-side and front-to-front crashes. The industry initiative consisted of improvements and research in several phases, focusing on, among other things, accelerating the installation of side impact air bags (SIAB). As part of the agreement the manufacturers may choose to install inflatable curtains. The voluntary commitment will therefore increase the offering of the inflatable curtain as standard equipment. According to the agreement, SIAB will be installed on widespread basis (at least 50%) by 2007 with full implementation by 2009.

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[12] See: http://www-nrd.nhtsa.dot.gov/vrtc/ca/capubs/IPTRolloverMitigationReport and Docket NHTSA-2003-14622

On September 11, 2007, NHTSA published a final rule to upgrade FMVSS No. 214, 72 FR 51908, Docket NHTSA-29134; Petitions for reconsideration, 3 FR 32473, Docket NHTSA-2008-0104. Part of the proposal introduced a pole impact for the front seating positions. The pole impacts the vehicle at 75 degrees from the longitudinal plane and is positioned to strike the test dummy's head. The test is performed with a 5th percentile female dummy in a full forward position and a 50th percentile male dummy in the mid track position. The preamble stated that the regulation was the first step in the agency's goal of reducing the risk of vehicle ejection. The agency believed that the potential countermeasures, i.e., torso-head combination air bags and side curtains, would provide a certain degree of ejection mitigation through the side windows, during the side impacts in which they would deploy. The benefits estimate for that regulation included reduction of partial side window ejected occupants in side impacts. However, the benefits estimate did not include complete ejections. Any impact where a rollover was the first event was excluded from the analysis. Crashes where a rollover was a subsequent event were included, but only for fatalities. Benefits were only assumed for side impact crashes with ΔV between 19.2 and 40.2 km/h and impact directions from 2 to 3 o'clock and 9 to 10 o'clock.

III. TEST DATA AND ANALYSIS OF LINEAR IMPACTOR HEADFORM TEST DATA

This chapter presents test data available to the agency on the guided linear impactor headform test.

The agency is proposing that the occupant containment countermeasure be tested by impact from a guided 18 kg featureless headform traveling from the inside the vehicle towards the outside, laterally and horizontally. The proposed test requires that each side window, for up to three vehicle rows, be impacted at any of four locations referenced to the edges of the window opening. Two impact velocities (16 and 24 km/h) are used in the test: the 16 km/h impact will occur 6 seconds after air bag deployment and the 24 km/h impact will occur 1.5 seconds after air bag deployment.

As part of the agency's research effort, a series of linear impactor headform tests were performed with OEM and prototype ejection mitigation air bags. The test results and the proposed test procedure used are discussed in the following section.

A. Impactor

Dimensional Characteristics: The featureless head form (headform) was developed to be a free-motion head form for use in interior impact testing. The width and height dimensions as well as the contour of the head form face were chosen based on biomechanical data from mid-sized adult males. The impacting face of the head form is intended to have dimensions which are the average of the front and side of a human head.

The head form outer surface dimensions are given in Figure III-1. The curvature of the upper right quadrant of the outer surface is given by the equation:

(Y/88.4 mm)2 + (Z/113.0 mm)2 = 1 [Y/3.48 in.)2 + (Z/4.45 in.)2] = 1

This equation is valid in the first quadrant only (top half), but the bottom half is symmetric about the X-axis. The rest of the shell is generated by rotating the curve ± 90 degrees about the Z-axis. For the inner shell (drawing not shown), the curvature of the upper right quadrant is given by the equation:

(Y/77.0 mm)2 + (Z/101.6 mm)2 = 1 [(Y/3.03 in.)2 + (Z/4.0 in.)2 = 1]

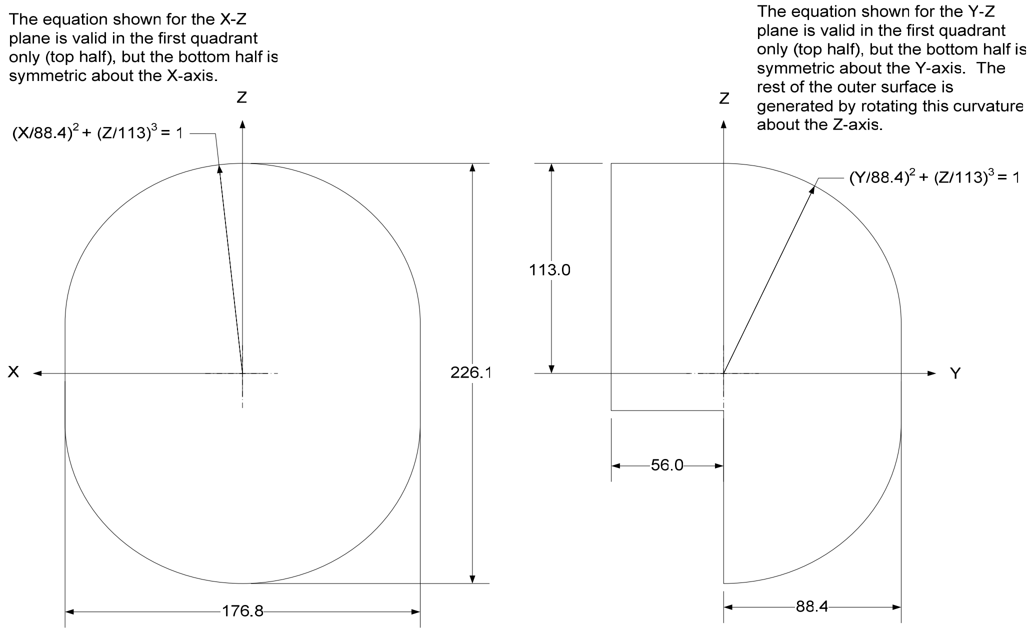

Figure III-1. Front and Side View of Headform Outer Surface (right) with Dimensions given in Millimeters.

Mass Characteristics: The 18 kg mass of the guided impactor was developed through a series of pendulum tests, sled tests and computer modeling. The head form also has the moment of inertia characteristics of the front and side of the head. However, these characteristics do not come into play when it is used as the leading face of a guided impactor.

A series of pendulum impact tests were conducted on a BioSID Anthropomorphic Test Device to measure effective mass of the head and shoulder. The BioSID was chosen because it is configured for side impact, unlike the Hybrid-III dummy, and has a shoulder which is not present in the SID test dummy used for FMVSS No. 214 – Side Impact Protection. A linear impact pendulum weighing 23.4 kg (51.5 lb) was used in all pendulum tests. The head and shoulder were struck laterally (perpendicular to the midsagittal plane) in separate tests, using two impact speeds (9.7 and 12.9 km/h) and four impact surfaces. In addition to the rigid impactor face, three types of padding were added to the impactor face to increase the contact time representative of advanced glazing impacts. Example plots are shown in Figure III-2.

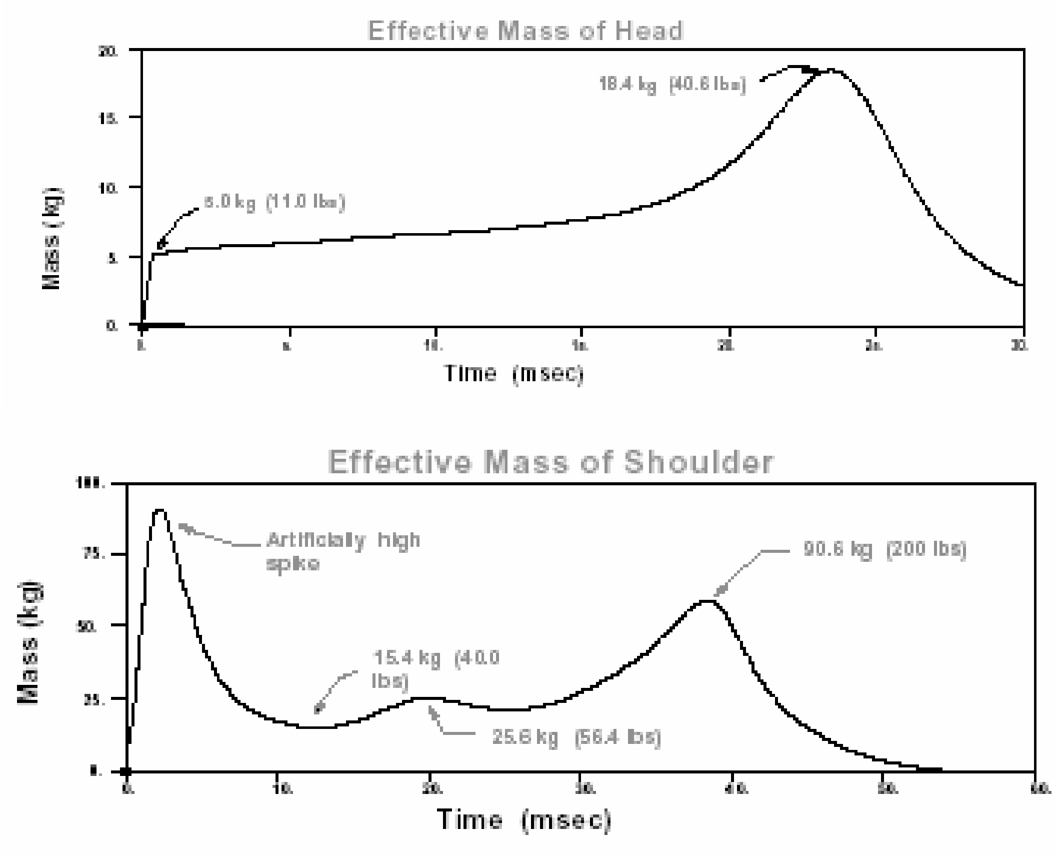

Figure III-2. Example plots of effective mass for 9.7 km/h velocity foam covered pendulum impacts with the dummy head and shoulder.

Effective mass was calculated by dividing the force time history calculated from the pendulum accelerometers and dividing this by the acceleration time history from the dummy sensors. In general, higher speed impacts and impacts with softer surfaces generated higher effective mass. The graphs for the effective mass of the head impact show an immediate rise to 5 kg in less than 5 ms, when only the head is interacting with the pendulum, followed by a slow rise to values between 10 and 18 kg as the torso becomes affected prior to 20 ms. The shoulder impacts showed artificially high values of calculated effective mass prior to about 5 ms because of a lag between the force measured in the pendulum and the acceleration measured at the upper spine. After the spike the effective mass was 16 to 18 kg, followed by a rise to 25 to 27 kg at 20 ms after impact. Finally, there is a more rapid rise to values around 90 kg by 40 ms when, presumably, a more substantial percentage of the torso and lower body were affected. Based on these tests a range for the effective mass of the head and shoulders was estimated to be 16 to 27 kg.

In summary, the impactor mass was based on the determination of an effective mass calculated through both pendulum and sled test impacts. Sled tests designed to represent both side impacts and rollover impacts gave similar energies and two equivalent mass estimates. The 18 kg equivalent mass was seen during the test intended to be more representative of a rollover event. This was also the equivalent mass calculated from pendulum impact into the dummy shoulder. Thus, the 18 kg equivalent mass is considered a reasonable representation of an occupants head and a portion of the torso. An equivalent mass more representative of just the head would be substantially smaller and an equivalent mass accounting for more torso and lower body mass would be substantially more. The 18 kg mass is well within the effective mass GM estimated from vehicle rollover tests. Both GM and Ford indicated that their internal test procedures used to evaluate side curtains utilizes an 18 kg guided impactor.[13] In a meeting held with the Alliance, they also indicated a potential test procedure might utilize an 18 kg impactor.[14]

B. Number and Locations of Impactor Test Targets

Number of Target Locations per Glazing Area: In examining current side window designs, four targets seem sufficient to assure side window coverage for the vast majority of designs. The number of targets can be less than four if the window area is small enough to create significant overlap in the target locations.

Side Window Opening: The target locations are defined in reference to the side window opening, with a 25 mm offset from that opening.[15] We will use the definition of "daylight opening" found in FMVSS No. 201.[16] In addition, we propose to exclude any flexible gasket material or weather striping used to create a waterproof seal between the glazing and the vehicle interior, from this definition.[17]

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[13] Ford presentation at SAE Government/Industry Meeting, Washington, D.C., May 9, 2006.

[14] Alliance presentation to NHTSA, Washington, D.C., January 25, 2006. [Docket NHTSA-2006-26467]

[15] The rationale for the 25 mm offset for the head form edge relates to the potential inaccuracy of the linear impactor. Although the impactor is guided, it is not possible to always have it strike exactly where intended. As will be discussed later, we will allow a ± 10 mm tolerance on the impact location as well as ± 2 mm for locating the offset line and ± 2 mm for locating the target tangent to the offset line. Thus, a 25 mm offset from the window daylight opening (minus gasket) gives us 11 mm of buffer to assure that the impactor will not be restrained by the window frame structure.

[16] FMVSS No. 201 defines "daylight opening" as: Other than a door opening, the locus of all points where a horizontal line, perpendicular to the vehicle longitudinal centerline, is tangent to the periphery of the opening, including the area 50 mm inboard of the window glazing, but excluding any flexible gasket material or weather striping used to create a waterproof seal between the glazing and the vehicle interior.

[17] The rationale for the exclusion of this flexible material is that the targeting strategy already allows for a 25 mm boundary between the window opening edge and the head form edge. Adding to this additional flexible edge material would move the impactor target even further inward from the potential ejection opening. In addition, we have placed a limit on how close the target location can be before one of the target locations is eliminated, so there is a desire to keep the target locations close to the window edge. Finally, it is not likely that flexible waterproofing would provide ejection mitigation.

Rearward Limit on Target Area: The agency is limiting the impact testing to the side window daylight openings adjacent to no more than three rows of occupant seating. Furthermore, within the first three seating rows, we are proposing that for any side window opening that extends rearward of the rearmost forward-facing designated seating position, the rearward edge of the side window opening is defined by a vertical lateral vehicle plane 600 mm behind the (Seating Reference Point (SgRP) of the last row or 3rd row of seats. We note that, as far as the number of rows of coverage, all light vehicle rollover occupants in the target population for this proposal were ejected through the first three side window rows.[18]

Method for Determining Impactor Target Locations: The target locations were selected to ensure the procedure is objective and repeatable in assessing full window coverage. In addition, the targeting method/procedure is simple and straight forward. The following procedure is used for determining impactor target locations: The first step in determining the impactor target locations is to find the corners of the window opening. For example, Figure III-2 shows the side window daylight opening for the front and rear windows of a typical vehicle. The offset line is 25 millimeters inside the daylight opening. The projection of the head form in the vehicle vertical longitudinal plane represents the outline of the impactor target. A corner is defined as any location within the daylight opening where the impactor target outline is tangent to the offset line at two points. Figure III-2 shows target outlines placed in the corners of the opening.

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[18] Third and higher row window are not specifically coded as ejection routes in NASS, so the other window category was reviewed. This category contained only a limited number of 3rd row window ejections (about 1% of fatalities and MAIS 3+ injuries).

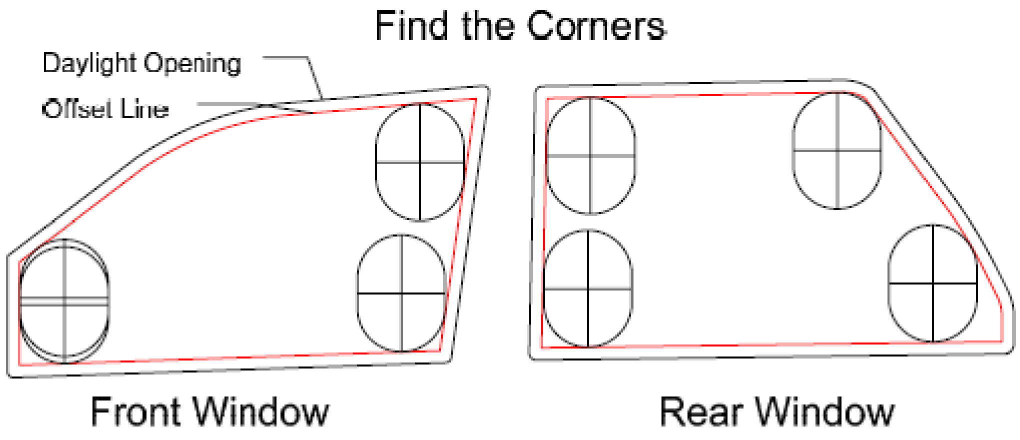

Figure III-3. Target Outlines Placed in Corners of Opening.

The next step in the target location process requires that the geometric center of the daylight opening be identified. This is then used to separate the opening into four quadrants, e.g., lower-front, lower-rear, upper-front and upper-rear. Third, determine the quadrant that each target outline center is located within. For the front window, eliminate any target whose center is not within (inclusive of the border between quadrants) the lower-front and upper-rear quadrants. For all rear window openings, eliminate any target whose center is not within the upper-front and lower-rear quadrants (inclusive of the border). If there is more than one target left in the primary target quadrants, maintain the lowest target in the lower quadrants and the highest targets in the upper quadrants. If there are no target centers within the quadrant, use the target whose center is closest to the quadrant. This process leaves the targets shown in Figure III-3.

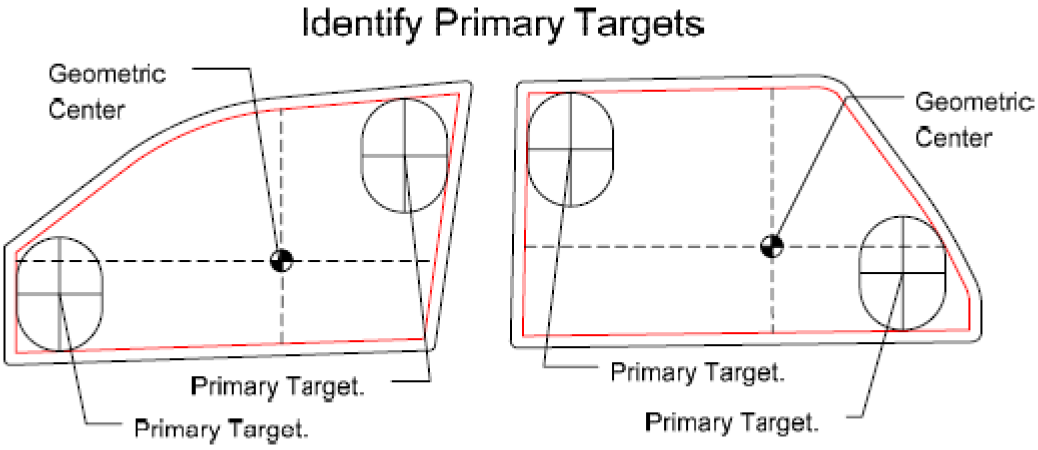

Figure III-3. Target Whose Center Is Closest to Quadrant

The final step is to locate additional targets for each daylight opening positioned in reference to the primary targets. To locate the additional targets, the horizontal distance between the centers of the primary targets is measured. These distances are shown as A and B for the front and rear window in Figure III-4, respectively. Vertical lines are drawn at horizontal distances A/3 and B/3 from the primary target locations. For the front window area, a secondary target is centered at a rearward horizontal distance A/3 from the lower-front primary target and moved vertically upward until contact is made with the offset line. Another secondary target is centered at a forward horizontal distance A/3 from the upper-rear primary target and moved vertically downward until contact is made with the offset line. For all other windows except the front, a secondary target is centered at a rearward horizontal distance B/3 from the upper-front primary target and moved vertically downward until contact is made with the offset line. Another secondary target is centered at a forward horizontal distance B/3 from the lower-rear primary target and moved vertically upward until contact is made with the offset line.

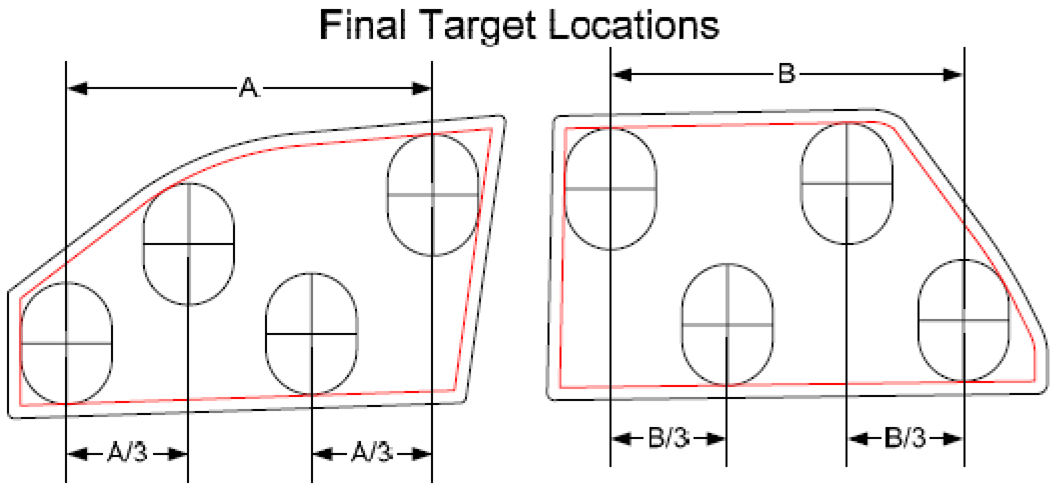

Figure III-4 Locate Corners Identify Primary Targets Final Target Locations

<u>Method for Target Reduction for Small Windows</u>: Figure III-7 represents the daylight opening of a 2006 MY Toyota Camry. Note that there is a small window area to the rear of a larger rear window area often referred to as a sail panel. This is typical of many two door passenger cars. For many of these cars this window area is too small to accommodate an impactor. However, for two door passenger cars these sail panels can be large enough to be impacted. Many SUVs also have relatively small oddly shaped window areas, which are large enough to fit an impactor.

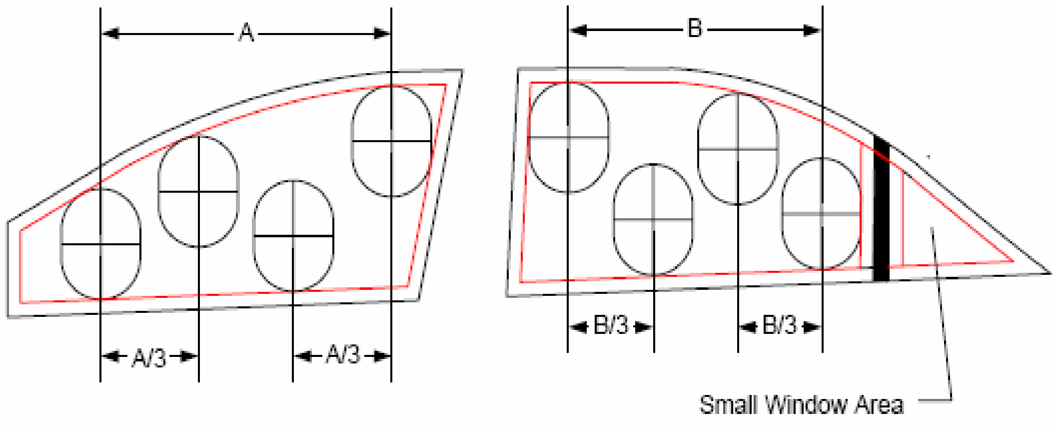

Figure III-5 Small Window Area

Figure III-5 shows how a relatively small triangular daylight opening would be targeted. It is clear that as a window gets smaller it is not necessary to have 4 impact locations. We are proposing a strategy that uses the horizontal (x-axis) and vertical (z-axis) distances between target centers to determine their elimination. The strategy is as follows:

(1) The four target locations are determined as described above, with two of the targets being primary and two being secondary, as shown in Figure III-7.

(2) Determine the horizontal and vertical distance between the centers of the secondary targets.

(3) If the horizontal distance is less than 135 mm and the vertical distance is less than 170 mm, eliminate the upper secondary target.

<u>Reconstitution of Targets</u>: For many passenger cars the target locations will be such that the vertical separation of the targets will be smaller than the 170 mm limit required for target elimination. Accordingly, if the primary targets are closer horizontally than 405 mm [3x135], the two secondary targets will be eliminated. As a result, the window drops from having four crowded targets, to having only two with a relatively substantial separation between them. Therefore, we are proposing that if after the target elimination scheme is used, only two targets remain and they are more than 360 mm apart, one target be added back. This added target will be centered such that it bisects a line connecting the centers of the two remaining targets.

C. Window Position and Condition

<u>Window Position</u>: Under the proposed test procedure, it is allowed to put windows in position ("up" position), but pre-broken. That is, if a manufacturer incorporated advanced laminated glazing into their window, the window is allowed to be in place, but the glazing will be broken

without deforming the laminate.[19] Typically this advanced glazing is a three layer construction with a plastic laminate sandwiched between two pieces of tempered glass.[20]

D. Testing OEM and Developmental Systems

Testing Description: For several years, NHTSA has been testing side window curtain air bags and advanced glazing according to the proposed test procedure, except for some differences in the target locations. Early on, prototype systems were evaluated. The inflatable device known as the Advanced Head Protection System (AHPS) developed by Zodiac Automotive US (formerly Simula Automotive Safety Devices, Inc.) was modified to provide more window coverage and was not vented. It is essentially an inflatable tubular structure in combination with a woven material that extends over the window opening. The TRW prototype is more akin to a typical air bag curtain and was fixed to the A- and B-pillars at its end points and along the roof rail, but not tethered. Figure III-6 shows these prototypes on the Chevrolet CK pickup. The advanced glazing used on the CK pickup was a bi-laminate glazing, consisting of standard CK tempered glass with a plastic film bonded to inner surface, and a laminate construction, similar to windshields. The entire window edge was encapsulated.

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[19] . The target population data showed that 69% of occupants were ejected through a front row window that was up prior to the crash. .The test procedure for pre-breaking advanced glazing has been developed by the agency and is part of the NPRM. The agency is proposing a 50 mm spacing breakage pattern through the use of a spring-loaded center punch with a 5 ± 2 mm diameter prior to the tip, adjusted to an activation load of 150 ± 25 N load..

[20] We analyzed field data to determine the pre and post-crash window condition. One data set consisted of the window adjacent to an occupant in a rollover. This data set had 2.9 million weighted entries. Another data set consisted of the window through which an occupant was ejected in the target population for the proposed standard. This was a much smaller data set, with only about 21,000 weighted entries. The larger data set indicated that 86% of front windows were up prior to a crash. The target population data showed that 69% of occupants were ejected through a front row window that was up prior to the crash. For the larger data set, of the front windows that were up before the crash, 45% were broken after the crash. For the target population, nearly all the pre-crash closed windows were broken after the crash.

Figure III-6 Prototype Zodiac (left) and TRW (right) air bag curtains on CK pickup.

The OEM curtain systems tested had either standard or optional rollover sensors. All OEM air bag curtains were top mounted. Any laminates tested were marketed as theft protection and not as a form of ejection mitigation.[21]

The target locations shown in Figure III-6 were determined by the proposed method. As stated above, exclusive of the Honda Odyssey, for all tests of prototype systems and OEM system through the 2005 model year (MY05), the method for determining the target location was slightly different than currently being proposed. We will refer to this as the research target method as opposed to the proposed target method. Below we will briefly explain the differences between the methods. Although not quantified, we believe that the target shifts were small

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[21] Mark P. Gold, Manager, Applications Development Solutia Inc. stated "Laminated glass has been shown to provide up to 10 times the penetration resistance of standard tempered glass, and enhanced versions, such as that used in the GM-610 van, can resist up to 2 minutes of aggressive attack by an intended intruder or thief. The FBI's Uniform Crime Report (http://www.fbi.gov/ucr/05cius/data/table_23.html) shows that in 2005 over 1.3 million thefts were reported from vehicles in the United States, with losses valued nearly $900 million from these thefts (average loss $691 per occurrence). Additionally 500,000 losses of motor vehicle accessories valued at over $235 million and the theft of over 973,000 motor vehicles valued at over $6 billion were tallied in this report. Although police documentation shows that almost 50% of vehicle thefts and break-ins occur through the vehicle's side windows we leave it to your judgment as to how to account for this $7,143,000,000 annual security benefit that would result from the use of laminated side glazing," May 8, 2007, via e-mail.

enough that data using the research target method can be reasonably compared to the proposed target method. The MY05 Odyssey was targeted by the proposed method.

The difference in determining the target location had the most effect on A2, A3, B1 and B4. The resulting shift in target location was a function of the window shape. The primary difference in the research target method was that A3 was found by the bisecting the angle produced by the intersection of a line parallel to the A-pillar and roof rail, which in the case of the window in Figure III-6, would shift A3 rearward and upward. Since A2 is located horizontally midway between A3 and A4 in both the research and proposed target methods, A2 in the research method would be rearward of the A2 position shown in Figure III-6.

The rear window data for prototype and OEM system through MY05 is, for the most part, limited to B1 and B4. Under the research method used to find the target locations, B1 was at the lower sill, in the middle of the window and B4 was in the upper rear corner. Again, under the research method, B1 and B4 would likely be shifted forward from the location shown in Figure III-7. For the test of the Zodiac prototype on the Navigator, extra targets were impacted. For only this vehicle, Tables III-1 through III-3 present an average result from two impacts that were on either side of the proposed targets B1 and B4.

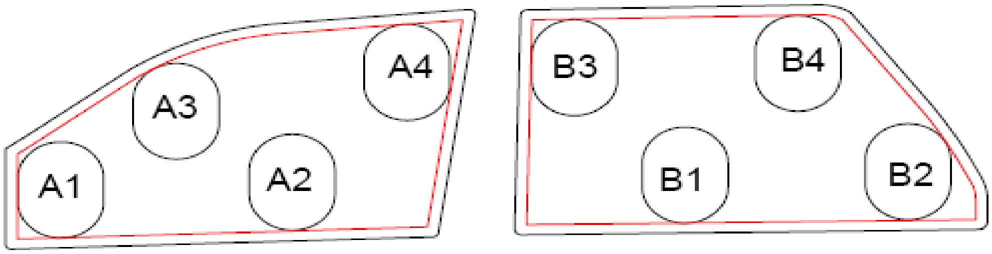

Figure III-7 Target Location Determined by Proposed Method

Test Results: The results of the testing are given in Tables III-1 through III-7. The results are given in columns, by target location. The tabulated results are shade/color coded. Any values exceeding the proposed 100 mm limit on impactor displacement is in (purple or) the darkest shading. Results from 80 to 100 mm are (gold or) medium shading. Results which are less than 80 mm are in (green or) the lightest shading.

Although the agency is proposing a 24 km/h impact at 1.5 seconds after air bag deployment, research data was acquired at 20 km/h and also 16 km/h to determine the sensitivity to impact speed. Several ejection mitigation systems were not tested at 24 km/h at every target location because the 20 km/h results indicated displacements in excess of 100 mm at that location. The cell shading (purple/dark) assumes the 24 km/h impact would also have exceeded 100 mm. Similarly, some target locations were not tested at 20 km/h, but the cell is shaded (green/light) indicating a value below 80 mm of displacement because the 24 km/h impact was less than 80 mm.

Tables III-1 through III-3 show the results for vehicle front windows. For all three sets of tests, A1 (front lower corner) was the most challenging target and A4 (upper rear corner) was the least challenging. For the 24 km/h test the only system that did not exceed the 100 mm criterion at A1 was the Zodiac Prototype on the CK pickup. At 20 km/h, the MY05 Infinity had one test result of 99 mm and another of 106 mm at A1. For the 16 km/h - 6 second delay test, two OEM systems and two prototype systems had displacements slightly above or less than 100 mm at A1. No displacement at A4 exceeded 76, 73 or 67 mm at 24, 20 and 16 km/h, respectively. Taken as a whole, A2 and A3 showed similar results to each other for all three test conditions. The trends for severity by target location are the same for the 16 km/h - 6 second delay impacts.

Table III-1
Front Row Window, 24 km/h Impact, 1.5 second Delay

Vehicle	**Position A1**	**Position A2**	**Position A3**	**Position A4**
03 Ford Navigator	No Data	(20km/h)	(20km/h)	-22
03 Ford Navigator w/lam.	No Data	35	No Data	No Data
04 Volvo XC90	(20 km/h)	193	130	18
04 Volvo w/lam.	(20 km/h)	44	118	15
05 Nissan Pathfinder	(20 km/h)	161	(20 km/h)	76/76
05 Toyota Highlander	(20 km/h)	202	137	67
05 Infinity FX35	124	83 96 112	89/89 108	53
05 Chevy Trailblazer	138	168	159	No Data
05 Chevy Trailblazer w/lam.	No Data	No Data	(20 km/h)	No Data
05 Honda Odyssey	No Cover	119	107	No Data
06 Dodge Durango	174	156	(20 km/h)	54
06 Dodge Durango w/lam.	No Data	(20 km/h)	No Data	No Data
Zodiac Prot. on CK	12	19	No Data	No Data
Zodiac Prot. on Navigator	150/143	54	96 102	21/24
Zodiac Prot. on Nav. w/lam.	No Data	No Data	91/97	No Data
TRW Prot. on CK	No Cover	82/82 102	2/6	-13/-8
TRW Prot. on CK w/ lam.	180/182	21	-26/-26	-33/-25

Color Key:

Exceeded 100 mm	80 to 100 mm	Less than 80 mm

Table III-2
Front Row Window, 20 km/h Impact, 1.5 second Delay

Vehicle	Position A1	Position A2	Position A3	Position A4
03 Ford Navigator	No Data	186/196	229	-37
03 Ford Navigator w/theft lam.	No Data	6	No Data	No Data
04 Volvo XC90	163	84 107	107/131	-3
04 Volvo w/ theft lam.	102/151	27	97	(24 km/h)
05 Nissan Pathfinder	181	133	240	58
05 Toyota Highlander	159/164	113/150	106/113	73
05 Infinity FX35	99 106	58	70	29
05 Chevy Trailblazer	112	121	127	No Data
05 Chevy Trailblazer w/lam.	90	80	109	No Data
05 Honda Odyssey	No Cover	96	57	-45
06 Dodge Durango	160	140	180	18
06 Dodge Durango w/lam.	No Data	101	No Data	No Data
Zodiac Prot. on CK	-12	-9	No Data	No Data
Zodiac Prot. on Navigator	122	38	76 81	-9/-0.9
Zodiac Prot. on Nav. w/lam.	No Data	No Data	No Data	No Data
TRW Prot. on CK	No Cover	75	-29	-52
TRW Prot. On CK w/ lam.	104	0	-54	-60/-63

Table III-3
Front Row Window, 16 km/h Impact, 6 second Delay

Vehicle	Position A1	Position A2	Position A3	Position A4
03 Ford Navigator	243	74	211	-30
03 Ford Navigator w/theft lam.	157	-14	137	No Data
04 Volvo XC90	154/167	52 93	78	-22
04 Volvo w/ theft lam.	86 105	26	59	No Data
05 Nissan Pathfinder	108/120	93 106	188	37/46
05 Toyota Highlander	198	132	147	67
05 Infinity FX35	85	21	39	9
05 Chevy Trailblazer	121	192	No Data	No Data
05 Chevy Trailblazer w/lam.	No Data	102	No Data	No Data
05 Honda Odyssey	No Cover	77	69	-4
06 Dodge Durango	138	135	167	13
06 Dodge Durango w/lam.	No Data	No Data	142	No Data
Zodiac Prot. on CK	0	0	No Data	No Data
Zodiac Prot. on Navigator	135	49	78 81	-0.2
Zodiac Prot. on Nav. w/lam.	104	No Data	70	No Data
TRW Prot. on CK	No Cover	99/97	-36	-41
TRW Prot. On CK w/ lam.	80	-3	-44	-67

The 2nd row window data in Tables III-4 through III-7 are much more limited, with nearly all the data at B1 and B4. In general, these data indicate target location B1 is more challenging than B4. The exception to this is the Dodge Durango, which performed well at all 2nd row targets. For the 24 km/h test at B1, three of the ejection mitigation systems tested had displacements that did not exceed 100 mm. For the 20 and 16 km/h test at B1, a total of 3 systems did not exceed 100 mm. We expect that the Durango would not have exceeded 100 mm at this speed, since it did not exceed 100 mm at 24 km/h. At B4, three systems had displacements that exceeded 100 mm. This was reduced to one system for the 20 and 16 km/h impacts.

Table III-4
Second Row Window, 24 km/h Impact, 1.5 second Delay

Vehicle	Position B1	Position B2	Position B3	Position B4
03 Ford Navigator	To Stops[22]	No Data	No Data	-40
04 Volvo XC90	(20 km/h)	No Data	No Data	69
04 Volvo w/ theft lam.	91/93	No Data	No Data	62
05 Nissan Pathfinder	161	No Data	No Data	128
05 Toyota Highlander	146	No Data	No Data	149
05 Infinity FX35	143	No Data	No Data	45
05 Honda Odyssey	71	152	80	193
06 Dodge Durango	76	86	91	82
Zodiac Prot. on Navigator	98$_{\text{avg. (96 to 100)†}}$	99	No Data	104$_{\text{avg. (32 to 176)†}}$

†Combined data from two impact location closest to the defined target location.

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[22] Note that any cell listed as "To Stops" indicates a displacement of the impactor to the point were the mechanical stops of the device keep it from further movement. This occurred for the MY03 Navigator at B1 at 24 and 20 km/h. This indicates the bag has a very little coverage at this location.

Table III-5
Second Row Window, 20 km/h Impact, 1.5 second Delay

Vehicle	Position B1	Position B2	Position B3	Position B4
03 Ford Navigator	To Stops	No Data	No Data	-14
04 Volvo XC90	183	No Data	No Data	(24 km/h)
04 Volvo w/ theft lam.	94	No Data	No Data	(24 km/h)
05 Nissan Pathfinder	126/150	No Data	No Data	99
05 Toyota Highlander	107	No Data	No Data	102
05 Infinity FX35	79 94	No Data	No Data	21
05 Honda Odyssey	42	134	34	84
06 Dodge Durango	(24 km/h)	No Data	No Data	No Data
Zodiac Prot. on Navigator	70 Avg. (67 to 72)†	70	No Data	77 Avg. (9 to 144)†

†Combined data from two impact location closest to the defined target location.

Table III-6
Second Row Window, 16 km/h Impact, 6 second Delay

Vehicle	Position B1	Position B2	Position B3	Position B4
03 Ford Navigator	126	No Data	No Data	-27
04 Volvo XC90	189	No Data	No Data	29
04 Volvo w/ theft lam.	63	No Data	No Data	9
05 Nissan Pathfinder	104	No Data	No Data	75
05 Toyota Highlander	138	No Data	No Data	107
05 Infinity FX35	61	No Data	No Data	19
05 Honda Odyssey	12	121	55	28
06 Dodge Durango	3	36	71	18
Zodiac Prot. on Navigator	81 Avg. = (73 to 89)†	98	No Data	67 Avg. = (16 to 117)†

†Combines data from two impact location closest to the defined target location.

Table III-7 shows very limited 3rd row window data for the Odyssey and Durango at all test conditions. For this system, C4 is much more challenging than C1.

Table III-7
Third Row Window, All Impact Speeds and Time Delays

Vehicle	Position C1	Position C2	Position C3	Position C4
24 km/h – 1.5 s				
05 Honda Odyssey	No Data	No Data	175	(20 km/h)
06 Dodge Durango	No Data	No Data	No Data	(20 km/h)
20 km/h – 1.5 s				
05 Honda Odyssey	58	No Data	122	To Stops
06 Dodge Durango	66	No Data	No Data	283
16 km/h – 6 s				
05 Honda Odyssey	44	To Stops	80	331
06 Dodge Durango	52	No Data	No Data	No Data

Figure III-8 summarizes the displacement data at each target location, by test type. The data at each target has been averaged. However, test results from a target location were excluded from the average if the test was not done at each impact speed. For example, the average at A1 is derived from only four ejection mitigation systems. This graph reinforces trends seen in the tabulated data for the system evaluated to date, i.e., the 24 km/h - 1.5 second delay test is the most stringent. For all except target locations B2 and B3, the 16 km/h - 6 second delay test had the least average impactor displacement. However, the comparative data for targets B2 and B3 had only two and one vehicle, respectively.

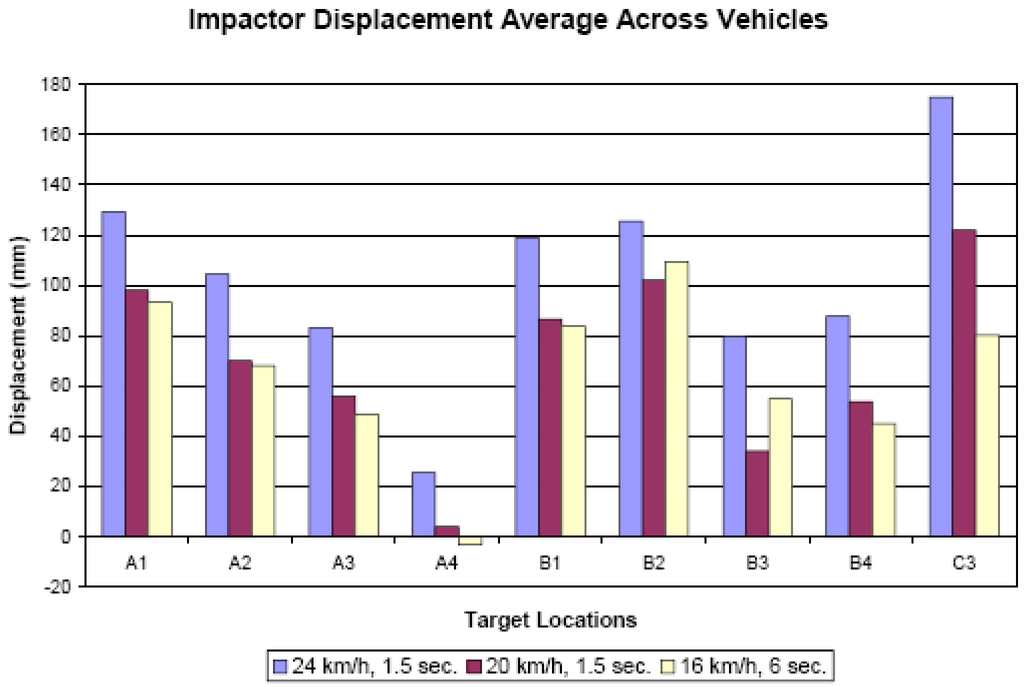

Figure III-8 Impactor Displacement Average across Vehicles

In summary, the headform test results show that almost all the curtain systems met the requirement in the 16 km/h at 6 second delay test. However, the data show that meeting the 100 mm displacement requirement at 24 km/h is more challenging especially at targets A1, B1 and B2. When the opening is covered, the results indicate that most of currently available rollover curtain air bags are capable of retaining the headform within 120 mm.[23]

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[23] We do not have data to fully analyze the effects of increasing the displacement limit from 100 mm to 120 mm. Hypothetically, if a bag is long enough to provide a tension load just above the headform such that its reaction force aligns with the direction of the headform, as illustrated in Figure IV-4, the proposed 100 mm requirement would result in a 182 mm (7.2 inches) potential gap under the curtain (below the tension line). When the 100 mm displacement increases to 120 mm, the potential gap would increase to 194 mm (7.6 inches).

IV. BENEFITS

This chapter estimates the potential benefits of the proposed occupant retention requirements. These benefits would be achieved from providing window curtains or other countermeasures that would meet the required guided linear impactor test. The benefit calculations are based on limited laboratory tests and real world crash data. The process and theory are presented in the method section.

The benefit analysis is categorized into two groups: (1) benefits from fatality reduction, and (2) benefits from non-fatal MAIS 3-5 injury mitigation.[24] The general procedure is to first identify the baseline target population and then to estimate the fatal or injury reduction rate. Real world crash data, laboratory test results and other relevant test data are used to calculate fatal and serious non-fatal injury reduction rates. The injury reduction rates are applied to the corresponding target population, which results in fatality or injury reduction benefits.

<u>Overview of fatal and non-fatal injuries in real world crashes</u>: The agency's annualized injury data from 1997 to 2005 NASS CDS and fatality counts adjusted to 2005 FARS levels show that ejection through side windows makes up the greatest part of the ejection problem.[25] There are 6,174 fatalities, 5,271 MAIS 3+ non-fatal injuries, and 18,353 MAIS 1-2 injuries for occupants

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[24] We believe that rollover curtain bags are effective in preventing MAIS 1 & 2 injuries. However, the oblique pole and our moving barrier test results show that some of serious and fatal injuries prevented would result in AIS 1 or 2 injuries. For example, at 18 mph occupant delta-V (which would be observed in the 20 mph vehicle delta-V oblique pole test), the resulting HIC was about 550 with a canopy (curtain) bag. At this HIC level, there are 39% and 30% risk of receiving AIS 1 and 2 head injuries, respectively. In that analysis, due to limited data, we did not consider these "trickled-down" dis-benefits. Some of these "trickled-down" disbenefits would offset the MAIS 1 & 2 potential benefits. Neither have we considered these trickled-down disbenfits for this ejection mitigation

[25] In the benefit analysis, we used annualized injury data from 1997 to 2005 NASS CDS and fatality counts adjusted to 2005 FARS levels to analyze ejection routes. All unknowns have been distributed, and all crashes types were included. However, the counts are restricted to ejection occupants that were injured. In addition the final target population included only crashes where the curtain air bag would be expected to deploy.

ejected through side windows. These make up 61%, 47% and 68% of all ejected fatalities, MAIS 3+ non-fatal and MAIS 1-2 injuries, respectively, as shown in Tables IV-1 and IV-2.

Table IV-1
Occupant Injury and Fatality County by Ejection Route in All Crash Types
(1997-2005 NASS, 2005 FARS)

Ejection Route	MAIS 1, 2	MAIS 3, 4, 5	Fatal
Row 1 Window	15,797	4,607	5,209
Row 2 Window	2,533	621	906
Row 3 Window	23	43	59
Windshield	1,923	1,565	1,155
Backlight	1,625	1,677	515
Sunroof	1,127	305	237
Other Window	1	51	0
Not Window	3,870	2,411	2,068
Subtotal			
All Side Windows	18,353	5,271	6,174
Total	26,899	11,280	10,149

Table IV-2
Occupant Injury and Fatality Percentages by Ejection Route in All Crash Types
(1997-2005 NASS, 2005 FARS)

Ejection Route	MAIS 1, 2	MAIS 3, 4, 5	Fatal
Row 1 Window	58.7%	40.8%	51.3%
Row 2 Window	9.4%	5.5%	8.9%
Row 3 Window	0.1%	0.4%	0.6%
Windshield	7.1%	13.9%	11.4%
Backlight	6.0%	14.9%	5.1%
Sunroof	4.2%	2.7%	2.3%
Other Window	0.0%	0.5%	0.0%
Not Window	14.4%	21.4%	20.4%
Subtotal			
All Side Windows	68.2%	46.7%	60.8%
Total	100.0%	100.0%	100.0%

Tables IV-1 and IV-2 show that side windows are the most common ejection routes.[26] In particular, real world crash data show that ejection is the largest safety problem for occupant

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[26] In addition, the crash data showed that the front row window through which an occupant was ejected was closed or fixed prior to the crash 69% of the time.

protection in rollover crashes.[27] Among the 6,174 occupants who were killed when they were ejected from vehicles through side windows,[28] 3,668 were occupants who were ejected through the side window opening in rollover crashes, 462 were from side impacts followed by rollover, and 1,568 were side impacts without subsequent rollover (planar-only).[29] The remaining 476 were from front and rear planar-only crashes and other rollovers.

If ejection is eliminated in these crashes, a substantial number of lives would be saved. Winnicki reported that the relative risk of fatalities of ejected to non-ejected drivers in all ejection crashes is 3.55 for drivers and 3.15 for front seat passengers.[30] This translated into 72 percent and 68 percent reductions in fatalities when ejection is eliminated, respectively. An analysis by vehicle type shows that a particularly large ejection risk for drivers of light trucks, which have a 5.62 relative risk or an 82 percent reduction in fatalities for non-ejected drivers.

The hypothetical ejection mitigation system used for the analysis is based on current and potential curtain air bag technologies. The hypothetical system would prevent occupants in front and rear seating positions[31] from ejection in some rollover and side crashes,[32] as most curtain air

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[27] J. Winnicki, "Estimating the Injury-Reducing Benefits of Ejection Mitigation Glazing," February 1996, Docket Number NHTSA-1996-1782-18, DOT HS 808 369.

[28] Among these fatalities, 6,115 were from occupants in the 1st and 2nd rows and the remaining 59 fatalities were from the 3rd row.

[29] For the fatal and non-fatal serious injuries in side crashes, we included both near-side and far-side occupants.

[30] DOT HS 808 369.

[31] For vehicles with third row seats, the analysis assumes that the system provides the same protection for occupants in the front and the rear rows. However, for third row windows, a laminated glass could be used for these non-removable windows, as the laminated glass is bonded to the frame of the window using urethane. The urethane bonding is also being used by manufacturers for the front windshield. Although the agency does not have sufficient data to determine its effectiveness, we believe that a laminate glass would provide an equivalent safety protection for third row windows based on the material and design used. Although laminated glazing would be effective for non-removable 2nd or 3rd row windows, it would be far less effective for removable windows. In a SAE technical report titled "A Comparative Study of Automotive Side Window Occupant Containment Characteristics for Tempered and Laminated Glass," No. 2006-01-1492, one of the conclusions made was that both tempered side glass and laminate side glass could vacate the window opening such that an unrestrained occupant (and, possibly, portions

bags are designed to deploy from vehicle's roof rail. Similar to the approaches used in the FMVSS Nos. 208 and 214[33], we did not consider AIS 1& 2 (non-serious) injuries for the target population. Accordingly, we limited our target population to fatal and serious non-fatal injuries in these crashes.

The rest of this chapter is organized as follows: The first section establishes the baseline target population; the second section discusses the methodology used for deriving the reduction in fatal and serious injuries; the third section estimates benefits for improving occupant protection results from the proposed linear guided headform test. The benefit summary section provides overall benefits in a table format; finally, the last section discusses any related issues that would affect the benefit estimate.

<u>Target population</u>: A pre-2006 baseline target population was used to estimate benefits. The target population is based on annualized injury data from 1997 to 2005 NASS CDS and fatality counts adjusted to 2005 FARS levels. However, the counts are restricted to ejection occupants that were injured.[34] Even though some proportion of these vehicles had side impact air bags, very few had rollover sensors. The majority of these vehicles were not equipped with rollover

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of a restrained occupant) could pass through the opening in rollovers. According to the report, less than 11% of MY 2006 vehicles are equipped with laminated side glass (27 models out of 251 models available).

[32] For the analysis, we assumed that vehicle manufacturers will install a single curtain system to cover the front and rear window opening areas, although it would be feasible to install two separate curtains to cover the openings.

[33] Docket's: NHTSA-1997-3111 and NHTSA-2007-29134

[34] In NASS CDS, the ejection route for side windows is only explicitly coded for the front (Row 1 Window) and rear (Row 2 Window). The third and higher row side window ejections should be coded as "other glazing." This is because there are specific codes available for coding roof glazing, windshield and backlight. However, when extracting NASS cases of known ejections through "other glazing," we observed 17 unweighted occupants. A hard copy review of these cases showed that 9 were known 3rd row side window ejections, but five (5) cases were miscoded. Four (4) were actually backlight ejections and one (1) was a sunroof ejection. The known 3rd row ejections were recoded as "Row 3 Window" ejections.

mitigation systems.[35] The NHTSA linear headform test[36] results show that these vehicles would not consistently meet the proposed 100 mm headform displacement requirement at all test positions. For the analysis, the target population is defined as occupants who were ejected through the window openings and sustained MAIS 3+ (including fatalities) injuries in both rollovers and non-rollover side crashes. For rollover crashes, complete and partial ejections were considered, whereas only complete ejections were considered in non-rollover 12-25 mph delta-V side crashes.[37] We note that vehicles that are required to meet the proposed linear headform displacement requirement would also meet FMVSS No. 214 oblique pole test requirements. In 12-25 mph delta-V side crashes, vehicle's side impact sensor would deploy the curtain. Although the majority of vehicles in the target population (pre-2006) were not equipped with an ejection mitigation system, several recent vehicle models (MY 2007, for example) have countermeasures designed to prevent occupants from ejection in rollover crashes. Vehicle manufacturers plan to continuously increase the number of vehicles equipped with rollover air bags. According to projected air bag sales, about 55% of all MY 2011 light vehicles will be equipped with rollover air bags when the phase-in of the proposed rule begins in September 1, 2013.[38] For the benefit analysis, we used the projected MY 2011 vehicle sales as a baseline.

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[35] Accordingly, we didn't adjust the target population for the current effectiveness of rollover bags since there are so few of them on the road for the pre-2006 target population.

[36] The headform consists of a guided 18 kg mass. Since it is a guided impactor, only uni-axial motion is measured during an impact. The impactor is designed to be placed inside a vehicle for testing the side window areas and can be positioned to strike different locations on those areas.

[37] Potential benefits for protecting occupants who were partially ejected in non-rollover, 12-25 mph side crashes were included in the new FMVSS 214 benefit estimate (i.e., adding oblique pole test).

[38] The agency is proposing to phase-in the new ejection mitigation requirements starting the first September 1 three years from the date of publication of a final rule. Assuming that a final rule would be issued prior to September 1, 2010, the effective date would be September 1, 2013. Although the agency prefers to use MY 2014 vehicle sales data as a baseline, the sales data were not available for this analysis. As a result, we used the MY 2011 data.

Potential benefits from these countermeasure systems were excluded from the incremental benefit estimate.[39]

Subcategories of target population: There are four major crash categories: *Planar* (non-rollover crash), *Rollover* (crash were rotation about the vehicle longitudinal axis occurred during the crash sequence, regardless of whether or not a planar impact or rotation about some other vehicle axis occurred), *End-Over-End* (rotation about the vehicle lateral axis) and all *Other* (non-rollover crash). These major crash types can be subcategorized further. Planar crashes are *Side*, *Front* or *Rear*. For our purposes, planar crashes were defined by using primary or first area of damage as a surrogate for impact direction. As will be explained later, in order to prevent any overlap with the injury population used for the FMVSS No. 214 pole impact upgrade, it is also necessary for rollover crashes to be divided into those that were preceded by a side impact and all others.

We expect ejection mitigation systems to deploy an ejection countermeasure in a rollover crash.[40] If the ejection countermeasure is a side air bag curtain, we expect that this will deploy on the impact side in a side crash. Therefore, at its most basic level, the target population for this proposal is derived from any crash involving a rollover or a side planar crash. However it is necessary to make adjustments to this population. The main reason for these adjustments is to account for benefits already attributed to the FMVSS No. 214 upgrade.

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[39] In the analysis we assumed that the performance of rollover bags remains unchanged in the future without the proposed ejection mitigation requirements. Since some of the air bags would not meet the proposed requirements, the benefits and costs associated with these bags to meet the requirements were considered in the analysis, as discussed in the additional benefits section. According to the MY 2011 vehicle sales data, about 94% of light vehicles will be equipped with curtain bags. Among these curtain bag systems, approximately 58% will be equipped with rollover sensors. (94% x 58% = 55%).

[40] A typical ejection mitigation system consists of a rollover sensor and two curtain air bags (one on each side). As discussed in the system effectiveness section in this chapter, the senor would not be 100% effective in all rollover crashes. In other words, we do not expect the sensor to detect all rollovers. However, when the sensor detects a roll, we expect that it deploys an ejection countermeasure in a rollover crash.

The benefits estimate for the new FMVSS No. 214 standard included partially ejected adult (13+ years) occupants in side impacts. However, the benefits estimate did not include complete ejections. Any impact where a rollover was the first event was excluded from the analysis. Crashes where a rollover was a subsequent event were included, but only for fatalities. Benefits were only assumed for side impact crashes with ΔV between 19.2 and 40.2 km/h (12 and 25 mph) and impact directions from 2 to 3 o'clock and 9 to 10 o'clock.

To make sure our target population does not overlap with the one used for the FMVSS No. 214 pole impact upgrade, we subcategorized our rollover crashes. As indicated above, the two subcategories are rollovers proceeded by a side impact and all other rollovers. These subcategories are then divided into impact delta-V (ΔV) ranges where appropriate. Both the subcategories of side impact and rollover proceeded by side impact are separated into side impacts with delta-V between 19 to 40 km/h and all other side impacts. No attempt is made to separate the data by direction of side impact as this is not necessary for the accurate determination of the target population of this proposed standard. Next, the fatal and non-fatal serious injuries were discriminated, where necessary, by the ejected occupant's age (0 – 12 or 13+ years), ejection degree (partial or complete) and injury level (non-fatal or fatal).

The FMVSS No. 214 upgrade accounted for partial ejections in side impacts with ΔV between 19 and 40 km/h for all 13+ year occupants. The Ejection Mitigation population covers all other ejected occupants in this side impact category. The FMVSS No. 214 upgrade accounted for partial fatal ejections in side impacts with delat-V between 19 and 40 km/h that precede a rollover. Thus, the non-fatal partial ejections and all complete ejections represented in this group are part of the Ejection Mitigation population. All injuries and fatalities at other side impact delta-Vs that precede a rollover are also part of the Ejection Mitigation population. Finally, any other crash with a rollover[41] is counted in the Ejection Mitigation population. The breakdown of the target population is shown in Table IV-3.

Table IV-3
Breakdown of Crash Categories and Occupant Characteristics/Outcomes for Side Window Ejection Occupants for Ejection Mitigation Target Population Identification

Major Category	Subcategory	Impact Delta-V (mph)	Occupant Age	Ejection Degree	Injury Outcome	MAIS 3-5	Fatality
Planar-Only	Side	12-25 (19-40 km/h)	0 – 12 yrs	All	All	44	61
			13 & older	Complete[42]	All	81	293
Rollover about Longitudinal Axis	Rollover preceded by side impact	12-25	All	All	Non-fatal	334	0
				Complete	Fatal	0	89
		All other delta-V	All	All	All	227	284
	All other rollovers	All delta-V for planar component	All	All	All	3,564	3,668
					total	4,250	4,395

The results in Table IV-3 show that the target population for the ejection mitigation standard is 4,395 fatalities and 4,250 MAIS 3-5 injuries. In addition, when the target population was categorized by ejection row and belt use (Table IV-4), it shows that the majority of serious and fatal injuries were from completely ejected unbelted occupants in the first seating row. According to the 1997 – 2005 NASS and 2005 FARS data, about 53% of all serious injuries (2,243 MAIS 3-5) and 56%[43] of all fatalities (2,459) in the target population were from completely ejected unbelted occupants in the first seating row:

Table IV-4

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[41] We will refer to this part of the target population as rollover crashes for simplicity. However, it includes any crash where the vehicle was coded as having rolled over in the crash sequence, except those preceded by a side impact.

[42] In the FMVSS No. 214 oblique-pole benefit analysis, any fatal and non-fatal injuries resulting from complete ejection were not included in the target population, whether the crashes were followed by rollovers or not.

[43] 2,459/4,395 = 0.5595, 56%

Distribution of Target Population by Ejection Row and
Injury Level by Ejection Degree and Belt Use (Annualized 1997 – 2005 NASS, 2005 FARS)

Ejection Degree	Belted	Row 1			Row 2			Row 3		
		MAIS 1-2	MAIS 3-5	Fatal	MAIS 1-2	MAIS 3-5	Fatal	MAIS 1-2	MAIS 3-5	Fatal
Complete	Yes	92	16	69	12	40	0	0	30	0
Complete	No	3,968	2,243	2,459	1,484	324	588	22	7	38
Partial	Yes	4,464	1,086	526	58	42	45	0	7	0
Partial	No	2,492	391	617	119	64	53	0	0	0
	Total	11,016	3,736	3,671	1,673	470	686	22	44	38

For occupants who were ejected in rollover crashes not preceded by a side impact, there were a total of 3,668 fatalities and 3,564 MAIS 3+ non-fatal serious injuries in the target population. The crash data show that the majority of fatal and non-fatal serious injuries were from unbelted occupants who were completely ejected (4,652 out of 7,232), as shown below:

Table IV-5
Target Population Fatalities and MAIS 3-5 Serious Injuries in
Rollover not Preceded by Side Impacts (Annualized 1997 – 2005 NASS, 2005 FARS)

	Fatality			Serious Injury		
Occupant	Partial	Complete	Total	Partial	Complete	Total
Belted	538	57	595	1,078	56	1,134
Unbelted	515	2,558	3,073	336	2,094	2,430
total	1,053	2,615	3,668	1,414	2,150	3,564

For occupants who were ejected in side crashes, as discussed, the side target population was categorized into three subgroups: (a) side impacts followed by rollover for all delta-V's, excluding 12-25 mph delta-V's (19 and 40 km/h); (b) side impacts followed by rollover for delta-V's between 12 mph and 25 mph;[44] and (c) side impacts without subsequent rollover for delta-V's between 12 mph and 25 mph. Each sub-target population is further discussed in the following section.

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[44] For side impacts followed by rollovers at delta-V's lower than 12 mph, vehicle's side impact sensors may not deploy the bag. In this delta-V range, we assumed that rollover sensors would detect vehicle's roll motion in time for crashes that would result in more than one-1/4 turn. For non-rollover side crashes at delta-V's higher than 25 mph, we assumed that the structure of the vehicle would not withstand the impact, although rollover bags would be capable of preventing occupants from ejection. In the 214 NPRM, the agency estimated that side head bags are not effective for lateral delta-V's higher than 25 mph.

(a) Side impacts followed by rollover for all but 12-25 mph delta-V's: The crash data show that there were 155 partially ejected and 129 completely ejected occupant fatalities when all delta-V's are considered (a total of 284).[45] The 155 were from unbelted occupants who were partially ejected, and the remaining 129 fatalities were from unbelted occupants who were completely ejected from vehicles.[46] For MAIS 3-5 serious non-fatal injuries, there were 53 partially ejected and 174 completely ejected occupant injuries, a total of 227 serious injuries. Among the 227 serious injuries, about 37% (83) were from belted occupants and the others were from unbelted occupants. The fatal and non-fatal serious injuries are shown below:

Table IV-6
Target Population Fatalities and MAIS 3-5 Serious Injuries in Side Impacts Followed by Rollovers for
All Delta-V's except 12-25 mph Delta-V's[47]

	Fatal			Serious Injury		
Occupant	Partial	Complete	Total	Partial	Complete	total
Belted	0	0	0	53	30	83
Unbelted	155	129	284	0	144	144
total	155	129	284	53	174	227

(b) Side impacts followed by rollover for delta-V's between 12 and 25 mph: We estimated a total of 89 complete fatal ejections: 12 from belted occupants and 77 from unbelted occupants.[48] For serious injuries, a total of 334 MAIS 3-5 injuries occurred: 116 partially ejected and 218 completely ejected occupants, as shown below:

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[45] As discussed above, we excluded belted occupant fatalities from the target population. In addition, according to agency's 2000-2004 CDS, 2004 FARS and 2004 GES data, approximately 29.1% of all AIS injuries were from a delta-V range of 12 -25 mph in side crashes.

[46] As discussed, belted partial ejection fatalities were included in the 214 oblique pole target population but belted complete ejection fatalities were excluded from the target population.

[47] The injury numbers were rounded to the nearest integer.

[48] There were 87 partial and 89 complete fatal ejections in a delta-V range of 12-25 mph in side impacts followed by rollovers. The 87 partial fatal ejections were considered in the 214-benefit estimate and were excluded from the analysis. However, complete ejections (whether fatal or non-fatal serious injuries) were not considered in the 214-benefit analysis. Accordingly, only the 89 fatal complete ejections are considered in the analysis.

Table IV-7
Fatalities and Serious Injuries in Side Impacts Followed by Rollovers for Delta-V's between 12 mph and 25 mph

	Fatal			Serious Injury		
Occupant	Partial	Complete	total	Partial[49]	Complete	total
Belted	0	12	12	4	0	4
Unbelted	0	77	77	112	218	330
total	0	89	89	116	218	334

(c) Side impacts without subsequent rollover for delta-V's between 12 mph and 25 mph: This subgroup was further divided by occupant age. For adults (13+ years), there were 293 fatalities and 81 serious injuries in the subgroup, as shown in Tables IV-8 and -9.

Table IV-8
Fatalities and Serious Injuries in Side Impacts without Subsequent Rollovers for Delta-V's between 12 mph and 25 mph for 13+ Year Occupants

	Fatal			Serious Injury		
Occupant	Partial	Complete	total	Partial[50]	Complete	total
Belted	0	0	0	0	0	0
Unbelted	0	293	293	0	81	81
total	0	293	293	0	81	81

We note that there were 562 fatalities from partially ejected occupants in the side crashes.[51] As discussed, the benefits estimate for the new FMVSS No. 214 standard included reduction of partial side window ejected adult (13+ years) occupants in side impacts. Accordingly, these fatalities were excluded from the ejection mitigation benefit analysis. However, the FMVSS No 214 benefits estimate did not include complete ejections, so they are included here.

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[49] The FMVSS No. 214-benefit analysis did not include seriously injured occupants who were partially ejected in side crashes (12 -25 mph delta-V's) followed by rollovers. These injuries were included in this analysis.

[50] The FMVSS No. 214-benefit analysis did not include seriously injured occupants who were partially ejected in side crashes (12 -25 mph delta-V's) followed by rollovers. These injuries were included in this analysis.

[51] There were 187 fatalities from belted and 375 fatalities from unbelted adult occupants who were partially ejected through side windows in side impacts without any subsequent rollover in a lateral delta-V range of 19.3 to 40.2 km/h. These fatalities were included in the 214-target population and, as a result, were not considered in the ejection mitigation benefits.

In addition, children (0-12 years old) were previously excluded from the FMVSS No. 214-benefit analysis because the majority of air bags that are in compliance with the 214 requirements would not span either forward or low enough, specially the air chambers (although the webbing span forward in the window opening), to provide a sufficient contact surface with the head and other body regions. Unlike the FMVSS No. 214-air bag, curtain air bags that are designed to meet the proposed linear headform test requirements would cover the entire window opening area in side impacts. Therefore, the hypothetical rollover air bag would be effective in protecting children who are partially or completely ejected in side impacts in a delta-V range of 12-25 mph. There were a total of 61 fatalities and 44 serious injuries for children under 13 years old (0-12 years old), as shown in Table IV-9 and Figure IV-1.

Table IV-9
Fatalities and MAIS 3-5 Serious Injuries in Side Impacts without Subsequent Rollovers for Delta-V's between 12 mph and 25 mph, Children (0-12 years old)*

	Fatal			Serious Injury		
Occupant	Partial	Complete	Total[52]	Partial	Complete	total
Belted	33	0	33	0	0	0
Unbelted	0	28	28	7	37	44
total	33	28	61	7	37	44

* The belted children include adult belts used with a child safety seat.

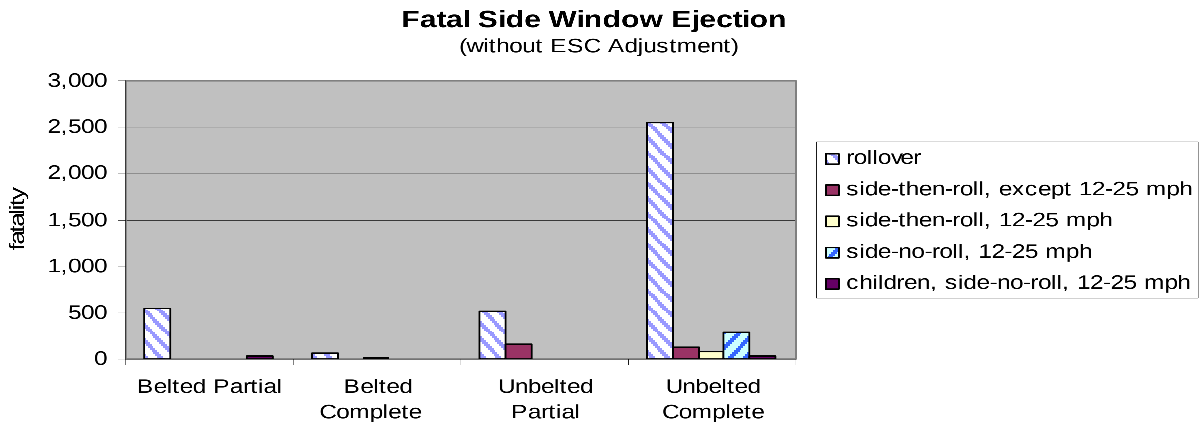

Figure IV-1 Target Population Fatalities and Serious Injuries through Window Opening

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[52] The injury numbers were rounded to the nearest integer.

Additional adjustments made to target population: In addition to the FMVSS No. 214-target population adjustment, several additional adjustments were made to the target population, as discussed below:

1. Completely Ejected Belted Occupants: Although the ejection mitigation system could be effective in protecting belted occupants who are completely ejected in rollover crashes, these are typically very violent rollovers and we assumed that the structure would not withstand such crashes. Accordingly, completely ejected belted occupants in rollover crashes were not considered for the benefit analysis.[53] There were 69 fatally injured completely ejected belted occupants in rollover crashes, as shown in Table IV-4.[54]

2. Electronic Stability Control (ESC) System: The agency's real world crash data show that the ESC system is highly effective in preventing single vehicle side crashes and rollovers. A statistical analysis of 1997-2004 FARS data and state data from calendar years 1997-2003 show that ESC is about 79% effective in preventing rollovers,[55] as shown below:

Table IV-10
ESC Effectiveness in Rollovers

Vehicle Type	PCs	LTVs
Fatal Single-vehicle rollovers (FARS)	69%	88%
MY 2011 Projected Percent Sales	46%	54%
Weighted ESC Effectiveness	79%	

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[53] Potential occupant mitigation benefits for adult occupants who were partially ejected in side crashes were analyzed in the 214-FRIA. The potential benefits of the 214 rulemaking were excluded from the ejection mitigation benefits in the analysis.

[54] Among the 69 fatalities, 12 were from the side impact with subsequent rollover in a 19 to 40 km/h delta-V range (see Table IV-7) and the other 57 were from rollovers without side crashes (see Table IV-5). For unbelted occupants, similar to the belted occupants, we excluded fatalities resulting from catastrophic rollover crashes. The methodology used for the exclusion is discussed in the method section in this chapter.

[55] Note that (1) all the reductions are statistically significant at the 0.05 level, (2) the control group included crash involvements in which a vehicle: (i) was stopped, parked, backing up, or entering/leaving a parking space prior to the crash (ii) traveled at a speed less than 10 mph, (iii) was struck in the rear by another vehicle, or (iv) was a non-culpable party in a multi-vehicle crash on a dry road.

Based on the recently proposed ESC rulemaking, for the analysis, we assumed that all applicable new vehicles will be equipped with ESC before this rule is effective.[56] When the target population from Table IV-5 is adjusted with the 79% effectiveness and the expected 100% installation rate, a total of 761 fatalities would occur in rollovers without any side crashes. Among the 761 fatalities, 218 would be from partial ejections and the remaining 542 would be from complete ejections, as shown below:

Table IV-11
ESC Adjusted Fatalities for
Occupants Ejected through Side Windows
In Rollover without Side Impacts

Occupant	Partial	Complete*	Total
Belted	112	12	123
Unbelted	107	[57]531	637
total	218	542	761

* The numbers were rounded to the nearest integer.

For side crashes with and without rollover target population, similar to the method used for the rollover target population, we adjusted the target population with potential ESC benefits. In the FMVSS No. 214 FRIA, we estimated that ESC is about 41% and 6% effective for single vehicle crashes and multiple vehicle crashes, respectively, when both passenger cars and light trucks/SUVs are combined in fatal side crashes. Since the combined target population from Tables IV-6 through IV-10 are not categorized by SVCs & MVCs, for the analysis, we weighted the effectiveness rates with the number of single and multiple side crashes used in the FMVSS No. 214 analysis. According to the FMVSS No. 214 crash data, 16% of the fatal side crashes

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[56] Based on manufacturers' product plans submitted to the agency, 71 percent of the MY 2011 light vehicles will be equipped with ESC. However, under the FMVSS No. 126, "Electronic Stability Control Systems," we expect all MY 2011 vehicles will be equipped with ESC. In addition, since all 2012 and later model year (MY) light vehicles are required to meet the ESC requirements, 100% of all light vehicles would be equipped with ESC when the phase-in of the proposed ejection mitigation rule begins in September 2013.

[57] When the unbelted complete ejection fatalities from catastrophic rollover crashes were excluded from the 531 unbelted complete ejection fatalities, it resulted in 519 fatalities. The methodology used for the adjustment is discussed in the method section in this chapter.

were from single and the remaining 84% were from multiple vehicle crashes. Based on the weighted data, we assumed that ESC is 12% effective in preventing side crashes. [58] The ESC adjusted side impact sub-target populations are shown below:

Table IV-12
ESC Adjusted Fatal Side Impacts Followed by Rollovers for
All Delta-V's except 12-25 mph

Occupant	Partial	Complete	Total
Belted	0	0	0
Unbelted	137	114	251
total	137	114	251

Table IV-13
ESC Adjusted Fatal Side Impacts Followed by Rollovers, 12-25 mph Delta-V

Occupant	Partial	Complete	total
Belted	0	11	11
Unbelted	0	68	68
total	0	79	79

Table IV-14
ESC Adjusted Fatal Side Impacts without Subsequent Rollovers, 12-25 mph Delta-V

Occupant	Partial	Complete	total
Belted	0	0	0
Unbelted	0	259	259
total	0	259	259

The ESC adjusted target population is summarized in the following table:

Table IV-15. Keys to Table IV-16

Crash & Injury Population	Rollover Alone	Side Impact Alone	Side impact w/ Rollover
12-25 mph delta-V	A	N/A	C
Exclude 12-25 delta-V	A	N/A	B
Children	A	E	B & C
Adults	A	D	B & C

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[58] By applying the ESC effectiveness to the side impacts whether followed by rollovers or not, we are assuming that preventing the side impact would prevent subsequent rollovers. However, we expect some of the subsequent rollovers could occur even if the side impact is prevented. Therefore, by not including these un-prevented rollovers in the target population, we would slightly underestimate the potential benefits. There were 2,311 near-side front occupant fatalities. Among the 2,311 fatalities, 372 (16%) were from vehicle-to-narrow object and the remaining 1,939 (84%) were front vehicle-to-vehicle/others in side crashes, in a delta-V range of 12 -25 mph (12% weighted ESC: 41%x16% + 6%x84% = 12%)

Table IV-16. ESC adjusted fatal target population

Crash	Occupant	W/o ESC	With ESC	% reduction
A. rollover, no side impacts	Belted Partial	538	112	79%
	Belted Complete	57	12	
	Unbelted Partial	515	107	
	Unbelted Complete	2,558	519	
B. side impacts followed by rollovers, excludes delta-V 12-25 mph	Belted Partial	0	0	12%
	Belted Complete	0	0	
	Unbelted Partial	155	137	
	Unbelted Complete	129	114	
C. side impacts, w/ subsequent rollovers, 12-25 mph:	Belted Partial	0	0	12%
	Belted Complete	12	11	
	Unbelted Partial	0	0	
	Unbelted Complete	77	68	
D. side impacts, no rollovers, 12-25 mph, no children	Belted Partial	0	0	12%
	Belted Complete	0	0	
	Unbelted Partial	0	0	
	Unbelted Complete	293	259	
E. side impact, no rollover, children (0-12 YO), include both partial and complete ejections, 12- 25 mph	Belted Partial	33	29	12%
	Belted Complete	0	0	
	Unbelted Partial	0	0	
	Unbelted Complete	28	25	
	Total	4,395	1,392	68%

3. Vehicle Type: For the analysis, we did not separate occupant injuries by vehicle type. The fatal and non-fatal serious injuries in the target population are from all light vehicle crashes, involving passenger cars, vans, SUVs, pickups, and utility vehicles, as shown below:

Table IV-17
Side Window Ejections by Vehicle Type, Towaway Crashes
Annual Average for 1997-2005 NASS, Fatalities Adjusted to 2005 FARS

Vehicle Type	Fatalities through:			All Occupants in Crashes	Side Window Ejection per 1,000 Occupants
	Row 1	Row 2	Row 3		
Passenger cars	2,438	272	17	3,332,723	0.82
SUVs	835	198	30	596,303	1.78
Vans	241	114	0	404,264	0.87
Pickups	883	47	0	517,002	1.80
Others/unknown	17	0	0	6,631	2.61
Total	4,414	631	47	4,856,923	1.05

The results in Table IV-17 show that occupants in passenger cars have a lower probability of partial or complete fatal ejections through side windows (0.82 per 1,000) when compared to SUVs (1.78 per 1,000), vans (0.87 per 1,000), and pickup trucks (1.80 per 1,000). Similar findings were reported by Winnicki. He found that, in general, occupants in passenger cars have a lower relative risk of fatality when compared to front occupants in light trucks.[59] By combining injuries from different vehicle types, we are assuming that the proportion of passenger cars or light trucks on the road remains unchanged when the proposed ejection mitigation requirement is fully implemented.

4. Safety Belt Use: Safety belts are highly effective in preventing occupants from complete ejection. According to 2003 crash data, 74 percent of passenger vehicle occupants who were completely ejected from the vehicle were killed.[60] The data show that virtually all completely ejected occupants were unbelted. Among completely ejected occupants, only one (1) percent of the occupants were reported to have been using safety belts. For the analysis, we assumed that the safety belt use rate remains unchanged. We expect that impacts of this assumption on the benefit estimate would not be significant since the belt use rate was relatively high when the fatal crash data were collected (82% in 2005) and the number of adjusted fatalities (1,392) was relatively small. Even if the belt use rate increases two or three percentage points in the future

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[59] All Ejections – Light Trucks:

Front Occupant	Relative Risk of Fatality	Fractional Reduction in Fatality	Relative Risk of Incapacitating Injury	Fractional Reduction in Incapacitating Injury
Driver	5.62	82.19%	2.76	63.76%
Passenger	4.66	78.55%	2.22	54.87%

All Ejections – Passenger Cars:

Front Occupant	Relative Risk of Fatality	Fractional Reduction in Fatality	Relative Risk of Incapacitating Injury	Fractional Reduction in Incapacitating Injury
Driver	2.94	66.06%	2.37	57.83%
Passenger	2.66	62.46%	1.88	46.79%

[60] Traffic Safety Facts, 2003 Data, NHTSA, DOT HS 809 765.

(MY 2011), the number of additional lives saved by the increase in belt use would be a small percentage of the overall benefits.[61]

5. Occupants in Near and Far Side Seating Positions in Side Impacts: In a study titled "The Effect of Side Air Bags on Fatalities and Ejection in Side Impact," Kahane found that having an air bag for the torso and head reduced the fatality risk in all side impacts, except far side impacts to belted occupants, by about 20 percent for drivers and right-front passengers. In particular, the report indicates that curtain air bags are equally effective in preventing partial and complete ejections for both near- and far-side occupants, excluding belted far-side occupants. Although the agency does not have real world crash data for occupants in different seating positions, based on the performance of side air bags in real world crashes, rollover curtain air bags would provide a similar level of protections for occupants in both near-side and far-side seating positions in side impacts. For the analysis, therefore, we assumed that rollover curtain air bags are equally

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[61] In a report titled "Fatality reduction by Safety Belts for Front-Seat Occupants of Cars and Light Trucks," DOT HS 809 199, Kahane found that 3-point belts are 74% and 80% effective in reducing fatalities for occupants in cars and light trucks, respectively, in rollovers (primary). When the target population was separated by vehicle type, it showed that 41% of the side window ejection fatalities were from occupants in passenger cars and the remaining 59% were from light trucks (see Appendix G). Therefore, safety belts are about 78% effective in preventing side window ejection fatalities in rollovers. If we assume that the belt use rate increases from 82% in 2005 to 85% in 2010 we can calculate the change in benefits as follows. Potential Fatality = (Current fatalities)/(1-UPFCxEffectiveness); where UPFC = the belt use rate among fatalities in potential fatal crashes. Assume UPFC = 68% with the 82% use rate and 71% with the 85% use rate. With the 1,392 observed fatalities, the potential fatalities would be 2,927 with 68% UPFC and 78% effectiveness. Thus, safety belts with 82% use rate would save 1,535 lives. With the 85% use rate and 71% UPFC, safety belts would save 1,618 lives. Therefore, lives saved by the higher belt use rate would be 83 (lives). When the 83 lives are subtracted from the target population, it results in 1,309 fatalities. In the benefits chapter, we estimated that 402 lives out of 1,392 fatalities would be saved by the ejection mitigation system. Thus, the overall effectiveness would 29% (402/1,392 =.29, 29%). When the 29% overall effectiveness is applied to the 1,309 fatalities, it results in 378 lives saved. Therefore, impacts of the higher use rate on the benefit estimate would be about 24 lives (6% reduction in the estimated benefits). The model used for the UPFC: UPFC = 0.43751 x (average use rate) + 0.47249 x (average use rate)^2]. "The basis for the use of a curvilinear model is the probability that the least risk-averse drivers are both more likely to get involved in fatal crashes and are less likely to use their seat belts. This is reflected in the relatively low belt use rates among drivers involved in potentially fatal crashes. As usage approaches 100%, those involved in fatal crashes will make up a greater portion of non-users, and an increasing portion of new users as well. A complete discussion of the basis for selecting a curvilinear model is included on pages 9-11 of the source document." We seek comment on this approach. For additional information, see "Belt Use Regression Model – 2003 Update," by J. Wang and L. Blincoe, The Office of Planning, Evaluation, and Budget, Department of Transportation.

effective in preventing both near- and far-side occupants from ejection in side impacts including side impacts followed by a rollover, excluding belted far-side occupants.

Summary of Target Population: The target population was initially categorized into two groups: (1) complete and partial ejections in rollovers not preceded by a side impact and (2) ejections in side impacts with and without subsequent rollovers. The ejections in side impacts were further categorized into four subgroups: (a) followed by rollovers all but 12-25 mph, (b) followed by rollovers in a delta-V range of 12-25 mph, (c) adults in side impacts without any subsequent rollover in a 12-25 mph vehicle delta-V range, and (d) children in side impacts without any subsequent rollovers in a vehicle delta-V range of 12-25 mph.

For the complete and partial ejections in rollovers not preceded by side impacts, the ESC adjusted target population show that 218 partial and 531 complete fatal ejections would occur, annually.[62] Among these fatalities, 123 would be from belted occupants and the remaining 626 would be from unbelted occupants. For MAIS 3-5 injuries, we estimated that 311 and 449 serious injuries would occur from partial and complete ejections, respectively, in rollover crashes. Among these injuries, 249 would be from belted and the other 510 would be from unbelted occupants. The injury data (MAIS 3-5) show that unrestrained occupants are more vulnerable than belted occupants: about 67% would be from unbelted and the remaining 33% would be from belted occupants. The fatality data showed the same tendency, 15% from belted and 85% from unbelted.

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[62] As discussed in the benefit derivation section, we estimated the number of fatal and serious injuries resulting from very severe rollover crashes. We assumed that the hypothetical ejection mitigation system would not be effective in preventing these injuries. Accordingly, these fatal and serious injuries were excluded from the benefit analysis.

In addition, the crash data show that about 88% (3,735) of the serious injuries occurred when occupants were ejected through the first row window opening, whereas 84% (3,671) of the fatalities were from ejections through the first row window opening. The injury data show that a total of 4,249 serious injuries occurred when occupants were ejected through side window openings. Among these serious injuries on average 63%, 26% and 11% were MAIS 3, MAIS 4 and MAIS 5, respectively, as shown below[63]:

Table IV-17
Fatal and MAIS 3-5 Injuries
Ejection through First Row Side Window

Occupant	Partial Ejection				Complete Ejection				Total*	
	MAIS			Fatal	MAIS			Fatal		
	3	4	5		3	4	5		Injury	Fatal
Belted	735	323	27	526	11	5	0	69	1,101	595
Unbelted	336	37	18	617	1,252	636	355	2,459	2,634	3,076
Total	1,071	360	45	1,143	1,263	641	355	2,528	3,735	3,671

* The injury numbers were rounded to the nearest integer

Table IV-18
Fatal and MAIS 3-5 Injuries
Ejection through Second Row Side Window

Occupant	Partial Ejection				Complete Ejection				Total*	
	MAIS			Fatal	MAIS			Fatal		
	3	4	5		3	4	5		Injury	Fatal
Belted	42	0	0	45	40	0	0	0	82	45
Unbelted	0	64	0	53	263	30	30	588	388	641
Total	42	64	0	98	303	30	30	588	471	686

* The injury numbers were rounded to the nearest integer

Table IV-19
Fatal and MAIS 3-5 Injuries
Ejection through Third Row Side Window

Occupant	Partial Ejection				Complete Ejection				Total*	
	MAIS			Fatal	MAIS			Fatal		
	3	4	5		3	4	5		Injury	Fatal
Belted	0	7	0	0	0	0	30	0	37	0
Unbelted	0	0	0	0	0	7	0	38	7	38
Total	0	7	0	0	0	7	30	38	43	38

* The injury numbers were rounded to the nearest integer

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[63] For the cost per equivalent life saved calculation, each injury level was converted to the corresponding (i.e., equivalent) life saved with a different weight factors.

<u>Benefits Derivation</u>:

The assumptions and methods used for the benefit estimate are presented in the following section.

A. Assumptions

For the benefit analysis, the following assumptions were made:

- Rollover sensors are capable of detecting any lateral rollovers that result in more than one quarter-turn.
- Vehicles that have rollover sensors also have separate side impact sensors and are equipped with ESC.
- Side impact sensors are effective in detecting impacts in a lateral vehicle delta-V range of 12 mph and higher.
- Rollover air bags are not effective in preventing occupants from either complete or partial ejections in the window opening area that failed to meet the 100 mm headform displacement requirement.[64]
- We assumed that all ejections would be contained by the hypothetical ejection mitigation curtain air bag system if the system meets the headform displacement requirement.[65]
- Side head air bags (that are designed to meet the FMVSS No. 214-oblique pole requirements) are not effective in preventing occupants from <u>complete</u> ejection in side crashes.

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[64] The assumption implies that a particular ejection mitigation system is not effective when it fails to meet the proposed 100 mm displacement requirement. However, a bag that fails to meet the proposed displacement requirement could protect some occupants in certain crashes. Therefore, the assumption would underestimate the potential benefits.

[65] Although the performance of a curtain air bag is measured by the headform displacement, the analysis considered all partial and complete ejections through the window opening whether ejections are head-leading or not.

- When ejection is eliminated, vehicle occupants who were originally ejected through the window opening areas would be exposed to the same risk of fatal and serious injuries as those occupants who were not ejected in similar crashes.
- The seat belt use rate remains unchanged; same as the rate observed in the baseline calendar year.
- Rollover air bags are assumed to be equally effective in preventing occupants from ejection in side crashes, whether they are in near-side, mid or far-side seating positions.[66]
- Risk of ejection through the window opening area:
    - The risk of ejection through a particular area in the window opening is proportional to the likelihood of impacts with areas surrounding the window opening in rollovers.[67] Alternatively,
    - The risk of ejection through a particular area in the window opening is identical regardless of the location.[68]

The assumptions used for the analysis and justifications for the assumptions are further discussed in the following method section.

B. Method

For the benefit analysis, the basic estimation procedure consists of four steps: B.1 group fatal and serious injuries (MAIS 3-5) by crash type (rollover or side impacts), ejection type (partial or

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[66] For additional information, see a report titled "The Effect of Side Air Bags on Fatalities and Ejection in Side Impacts " by Charles Kahane

[67] The assumption is based on dummy ejections in rollover tests. However, we do not know how ejections are distributed in the opening area when such ejections occur in real world rollover crashes. We note that in the sensitivity chapter in this PRIA.

[68] Under this assumption, when the window opening area is divided into four quadrants, the risk of ejection through each quadrant would be same.

complete) and belt use; B.2 calculate performance of the ejection mitigation air bag system; B.3 calculate overall percentage reduction rates; and B.4 derive benefits. The following is a detailed description of these steps.

<u>B.1 Group Fatal and Serious Injuries</u>: The fatal and serious injuries in the target population were categorized by crash mode, ejection type and belt use. We considered four different <u>crash types</u> in the analysis: rollovers without side impacts, side impacts followed by rollovers excluding 12-25 mph delta-V's, side impacts with subsequent rollovers in a vehicle delta-V range of 12-25 mph, and finally, side impacts without subsequent rollovers in a vehicle delta-V range of 12-25 mph. In addition, four occupant ejection types (belted partial, belted complete, unbelted partial and unbelted complete) and children (0-12 years) were considered for the analysis.

<u>B.2 Calculate Performance of Ejection Mitigation System</u>: We assumed that the performance of an ejection mitigation system is directly related to the following three factors: sensor effectiveness, air bag containment effectiveness, and reduction in injury risk when an occupant remains inside a vehicle in crashes.[69]

<u>B.2.1. Sensor Effectiveness</u>:

Although the agency is not proposing any requirements for the sensor, as discussed below, we assumed that a rollover sensor will be provided as an integral part of the system and have accounted for its cost in our cost/benefits analysis. To date, none of the field data examined

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[69] Rollover crashes are complex events and, as a result, many different factors would affect the outcomes. Some of the factors are related to the vehicle (such as sensors, type of ejection mitigation systems, occupant protection in interior impacts, and structural integrity) and others are related to an occupant (such as belt use, seating position, size of the occupants). For the vehicle related factors, sensors, containment systems and occupant protection in interior impacts/contacts would be most critical to the outcomes.

(SCI, EWR and NASS) indicate that a problem exists with the deployment of air bag curtains in rollover crashes.[70] In combination with this fact, as indicated above, the agency has not done any independent research on the characteristics of rollover sensors and at this point, is not able to set performance thresholds that optimize performance of a sensor in the field. The fact that there is no apparent safety problem with respect to rollover sensors leads us to believe that it is reasonable to assume that vehicles with ejection mitigation curtain air bags would be equipped with a rollover sensor. In other words, all manufacturers will provide rollover sensors, even though there will be no regulatory requirement to do so. On the other hand, one might argue that the field data that we have seen to date is much too limited to conclude that sensors are performing adequately and no improvements are needed.[71]

Although agency's limited Special Crash Investigation (SCI) data and reports from industry indicate that current rollover sensors are performing well even in low severity rolls, we do not have statistically significant real world or laboratory data to determine how effective the sensors are in very low severity rolls. For the analysis, therefore, we assumed that rollover sensors are

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[70] The agency's SCI division conducted a detailed analysis of seven real-world rollover crashes on Ford vehicles where the subject vehicles contained a rollover sensor and curtain air bags, as shown below:

Case	Make	Model	MY	No. of ¼-turn	Deployment			
					Deploy	Angle	Time (ms)	Rate (deg/s)
CA01-059	Mercury	Mountaineer	2002	1	Yes	17	No data	17 to 25
CA04-010	Ford	Explorer	2003	1	Yes	43	20	75
IN-02-010	Ford	Expedition	2003	2	Yes	45	146	111
2004-003-04009	Ford	Expedition	2003	5	Yes	unknown	unknown	unknown
DS04-016	Ford	Expedition	2003	5	Yes	unknown	unknown	unknown
DS04-017	Ford	Expedition	2004	12	Yes	unknown	unknown	unknown
2003-079-057	Volvo	XC90	2003	6	Yes	unknown	unknown	unknown

In each case, the rollover sensor deployed the side curtain air bag. Note that the CA01-059 and CA04-010 cases show that current rollover sensors are capable of detecting quarter-turn rolls.

[71] Between October of 2005 and February of 2006 the agency met with four major supplier of rollover sensors (Autoliv, Delphi, Siemens, and TRW) and representatives of the Automotive Occupant Restraints Council (AORC). (Docket NHTSA-2006-26467.) One of the inputs provided by the suppliers was that future ejection mitigation systems will be integrated in the vehicle electronic stability control (ESC), which will provide many other sensor inputs such as yaw, pitch, steering angle, wheel speed, longitudinal velocity and lateral velocity. With these additional inputs, the system will be more robust, reducing the chance of unnecessary deployment and allowing for earlier deployment in rollovers.

not effective in low-energy (slow) rolls, which result in a single quarter turn. (Since some sensors would be effective in low-energy rolls, the assumption would underestimate the potential benefits by underestimating sensor effectiveness.) In addition, Knapton observed that the dominant factors determining vehicle impact velocities in rollovers appears to be those retarding the vehicle motion, and not those resulting from the vehicle motion.[72] In other words, some quarter-turn rolls may have a high initial roll rate when the roll motion is interrupted by an external object at its quarter-turn. Therefore, the assumption would further underestimate the effectiveness by excluding high energy (i.e., high initial roll rate) quarter-turn rolls. For example, in a report titled "An Invetigation of Occupant Injury in Rollover: NASS-CDS Analysis of Injury Severity and Source By rollover Attributes," Paul Bedewi found that about 23% of all fatal injuries were from one-quarter rollover crashes. As defined in this analysis, these rolls were considered as "slow" rolls. Under the assumption, the sensor is not capable of detecting these "slow" rolls. However, we suspect that the majority of fatal one-quarter rolls may have a high initial roll rate, such that the sensor could detect the roll. Unfortunately, the agency does not have data to quantify the percent of fatal one-quarter rolls that had a high initial roll rate.[73] P. Bedewi found that about 80% of all rolls are 2+ quarter turns (i.e., including 2 quarter turns) in real world rollover crashes. The data show that about 77% of all MAIS 6 in rollover crashes were from 2+ quarter turns.[74] Accordingly, for fatal injuries, we assumed that

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[72] A report titles "Rollover Crash Test Film Analysis," Report No. DOT-TSC-HS476-PM-83-25, July 1983.

[73] We note that not all fatal "slow" rolls as defined in the analysis have a slow initial roll rate. In fact, we believe that the majority of these fatal "slow" rolls had a high initial roll rate. However, as we discussed, we do not have information on the number of occupants who were fatally injuries in quarter-turn rolls with a high initial roll rate.

[74] See "An Investigation of Occupant Injury in rollover: NASS-CDS Analysis of Injury Severity and Source by Rollover Attributes," Paul Bedewi, FHWA/NHTSA National Crash Analysis Center, George Washington University, Table 19 in the report, un-weighted MAIS injury distribution for rollover exposed occupants with MAIS 3+.

Injury	1-1/4 turn		2, 3, 4 - 1/4 turn		> 4 -1/4 turn		2+ ¼ turn
Severity	count	%	count	%	Count	%	% of total
MAIS 3	73	54%	196	49%	117	44%	81%
MAIS 4	20	15%	86	21%	71	27%	89%

rollover sensors are 77% effective in detecting rolls in fatal rollover crashes. For serious injuries, similar to the method used for fatal injuries, we estimated rollover sensors are 84% effective in detecting rolls, which result in serious injuries.[75]

For side impacts, as discussed in the FMVSS No. 214 final rule, we assumed that side impact sensors are effective in any side crashes that have delta-V's equal to or higher than 12 mph.[76] The side impact target population was categorized into three subgroups: (1) side impacts followed by rollover all but 19-40 km/h (12-25 mph) vehicle delta-V's, (2) side impacts followed by rollover with 12-25 mph, and (3) side impacts without any rollover in a lateral delta-V range of 12-25 mph.

Since both side impact and rollover sensors are capable of deploying the air bag, we established a hierarchy of the sensors for the three sub groups. For the first side impact case above, as discussed in the FMVSS No.214 final rule, side impact sensors would not detect side impacts when the impacts occur at vehicle delta-V's lower than 12 mph. In other words, when a vehicle

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MAIS 5	27	20%	86	21%	62	23%	85%
MAIS 6	14	10%	34	8%	14	5%	**77%**
Total	134	100%	402	100%	264	100%	

According to Bedewi, Table 14 in the report, weighted distribution of MAIS injuries by vehicle type

Injury Severity	Car	Light turcks	Total
MAIS 3	47%	53%	100%
MAIS 4	53%	47%	100%
MAIS 5	37%	63%	100%
MAIS 6	57%	43%	100%

[75] According to the un-weighted MAIS injury distribution above, there were 738 MAIS 3-5 injuries (highlighted in the table). Among these injuries, 618 were from 2+ ¼ turns: (368+250)/(120+368+250) = 84%. We note that suppliers estimate their rollover sensors will work between 90% and 95% of rollovers. If the claim is indeed true, the assumption would underestimate the sensor effectiveness by 7% - 12% for non-fatal serious injuries and 14% - 19% for fatal injuries. Note that in the sensitivity chapter in this PRIA, we estimated the potential benefits with both 90% and 95% sensor effectiveness.

[76] Although side sensors would be effective in this delta-V's (12+ mph), we estimated that the countermeasures and/or vehicle structure would not be effective in delta-V's higher than 25 mph in side crashes.

rolls more than one-quarter turn after a side impact, which occurs at a vehicle lateral delta-V of 12 mph or lower, its rollover sensor would deploy the air bags.[77] As for side impacts followed by rollover at delta-V's higher than 25 mph, the crashes were not coded by impact objects. Therefore, we did not know whether these crashes are vehicle-to-vehicle, vehicle-to-narrow object or other roadside objects. We suspect that the majority of these objects were relatively close to the ground since these objects most likely tripped the vehicle into rollover. Therefore, for delta-V's higher than 25 mph in both single and multiple vehicle side impacts with subsequent rollover, we assumed that vehicle's rollover sensor, not side impact sensors, deploys the air bag.[78] For the second and third side impact cases mentioned above, we assumed that side impact sensors detect impacts and trigger the deployment in a vehicle delta-V range of 12-25 mph, as assumed in the FMVSS No. 214-side impact analysis, whether subsequent rolls occur or not.

B.2.2. Containment Effectiveness:

As briefly discussed in the assumption section, we do not know how ejections are distributed in the window opening area when such ejections occur in real world rollover crashes. For the containment effectiveness, two different approaches were initially considered. One is based on kinetic energy that the air bag can absorb in its deployment (i.e. inflation stage), and the other is

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[77] Previously, we estimated that rollover sensors are about 77% effective in fatal crashes, whereas side impact sensors are 100% effective in 12+ mph lateral delta-V crashes. The 77% roll sensor estimate was made based on an assumption that rollover sensors are not capable of detecting one-quarter rolls.

[78] In the 214-benefit analysis, we assumed that side impact sensors are capable of detecting all side impacts (as defined in the 214-benfit analysis) at a vehicle lateral delta-V of 12 mph and higher. We do not have crash data to determine whether vehicle's side impact or rollover sensors trigger the bag. When a vehicle rolls after a high lateral impact, most of these rolls would result in multiple ¼-turns due to high kinetic energy associated with the lateral impacts speed. However, not all these rolls would result in multiple ¼-turns. As assumed, vehicle's rollover sensor is not capable of detecting these single quarter turn rolls. Consequently, by assuming its rollover sensor triggers the bag at these delta-V's, we would underestimate the potential ejection mitigation benefits.

based on the likelihood of occupant ejection through a particular area of the window opening in a rollover, as discussed below:

B.2.2.1 Effectiveness based on kinetic energy: For this approach, we examined dummy ejection velocities in rollovers with respect to the number of rolls. It may be intuitive that the number of rolls can be seen as a measure of rollover crash severity. Accordingly, one would expect an increase in dummy (to vehicle) impact velocity as the number of rolls increases. If we assume that the ejection velocity increases as the number of roll increases, the air bag becomes ineffective when the number of rolls reaches a certain threshold. In other words, since the air bag would be designed to withstand a finite kinetic energy level, under the assumption, as the number of rolls increases, the kinetic energy associated with the dummy would become greater than the air bag can withstand (i.e., reaches the threshold). To validate the conjecture that the energy level is proportional to the number of rolls, we examined how test dummies behave during roll. In a report titled “Rollover Crash Test Film Analysis,” D. Knapton studied test films obtained from the Federal Highway Administration to determine dummy & vehicle motion during vehicle rollover. Contrary to the expectation, Knapton reports in his film analysis that there was a trend toward lower dummy impact velocities as the number of rolls increased, as shown below:

Table IV-20
Summary of Dummy Ejection and Dummy/Vehicle Impact Velocities

No. of Rolls	No. of Tests	Restrained Dummy		Unrestrained Dummy	
		Avg. Max.(1)	Max. Vel.(2)	Avg. Max.(1)	Max. Vel.(2)
1	2	25.8	38	23.7	23.7
1 ½	1	No data	No data	16.8	20.6
2	2	18.2	18.2	17.1	18.0
3	1	12.4	15.8	No data	No data

(1) Average for all the maximum velocities at specified number of rolls (ft/sec)
(2) Maximum of all the maximum velocities at specified number of rolls (ft/sec)

According to Knapton, the dominant factor determining dummy/vehicles impact velocities in the 6 tests examined appears to be those retarding the vehicle motion, and not those resulting from the vehicle motion. He found that the vertical motion of a rolling vehicle appeared to be a significant factor in reducing the amount of vehicle rolling (i.e., the number of rolls). This dummy test data did not show a direct relationship between interior impact and ejection velocity and the number of rolls. We concluded that insufficient data exist to derive a relationship between the number of rolls and occupant-to-interior impact velocity. Therefore, we are unable to use an energy method/approach that relies on this relationship to determine the containment effectiveness.

B.2.2.2 Effectiveness based on risk of ejection: Alternatively, we examined the risk of ejection through a particular area in the window opening in rollover crashes to determine the containment effectiveness. Two assumptions for the risk ejection were examined and used for the benefit analysis. One is to assume that the risk of ejections through a particular opening area in the window opening is proportional to the likelihood of impacts around the opening area in rollover crashes (i.e., weighted risk of ejection). The other is to assume that the risk of ejections through the opening is evenly distributed in the window opening area (i.e., uniform risk of ejection). These two methods are discussed below:

B.2.2.2.1 Weighted risk of ejection: Although vehicle rolls are complex events and neither a translation nor a rotation about a fixed axis, one could reason that there is a higher impact frequency of the head at areas above the window opening compared to areas below the opening since the axis of rotation is often below the CG of an occupant and the distance between the head and the header (upper portion of the window opening) is shorter than the distance between the head and the window sill.[79] In the report, D. Knapton reports a total of 10 impacts above and below the window opening area during the rolls: three (3) at window header, four (4) upper door frame, and three (3) at window sill: 7 were above the opening and the remaining 3 were below the window opening area. A similar impact tendency was observed in real world rollover crashes. According to Digges, a NASS sample count shows that there were 10 brain/neck injuries (nine brain injuries and one spine injury) that occurred as a result of impacts with vehicle's rail/header (above the window opening) and 7 brain injuries resulting from impacts with upper side interior (below the opening, such as window sill) for belted occupants in rollovers.[80] It appears that the real world rollover crash and laboratory test data support the conjecture that there is a higher impact frequency at areas above the window opening compared to areas below the opening. Furthermore, a series of rollover tests performed by GM suggest that there is a higher risk of ejection through the upper portion of the window opening area when compared to the lower portion of the opening.[81] For the analysis, therefore, we assumed that

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[79] Real world crash data show that the majority of rollovers are considered as "tripped" rollovers. In tripped rollovers, a vehicle moves laterally until it reaches a tipping point and rolls. Initially, the vehicles would rotate about an axis formed by two contact points between the wheels and the ground. Occupants in the near-side outboard seating positions initially move laterally toward the window opening area as the vehicle rotates. As a result, the head of the occupant often impacts with the upper portion of the window opening area. During subsequent rolls, forces generated during the rolls often keep the initially displaced occupant in a particular location in the vehicle, such as vehicle's window headliner.

[80] According to K. Digges, "Summary Report of Rollover Crashes," June 2002, FHWA/NHTSA National Analysis Center, NASS sample counts of head impacts with rail/header (upper portion of the window opening area, a total of 10) are about 40% higher than head impacts with upper side components (lower portion of the window opening area, a total of 7) for belted occupants in rollover crashes.

[81] In a briefing, "Ejection Mitigation Component Test Development," GM reports peak resultant membrane corner load measurements made by a load cell installed at each window opening corner. The data indicate that the number of impacts at the upper front portion of the window opening is greater than the number of impacts at the lower front portion of the window opening in the tests. However, the peak resultant force data indicate that the impacts are more evenly distributed when impacts at the front and rear portions of the window opening area are compared. According to their test data, 43% of the maximum resultant membrane attachment loads occurred at the upper rear corner and 33% occurred at the lower rear corner (see Figure 30 in the report). The upper front and lower front had

the risk of ejections through a particular area in the window opening is proportional to the likelihood of impacts around the opening area in rollover crashes. In other words, the risk of ejection through the upper portion of the window opening would be higher than the risk of ejection through lower portion of the opening, when such ejections occur.

While the majority of vehicle occupants would be contained by rollover air bags, the current design indicate that some occupants could be ejected through <u>potential gaps</u> around the bottom and front lower portion of the air bag. [82] To determine the effectiveness, we derived a likelihood of ejections through a particular area in the window opening for a typical curtain air bag, which is anchored at A- and C-pillars and attached to the window header, as illustrated in Figure IV-2.[83]

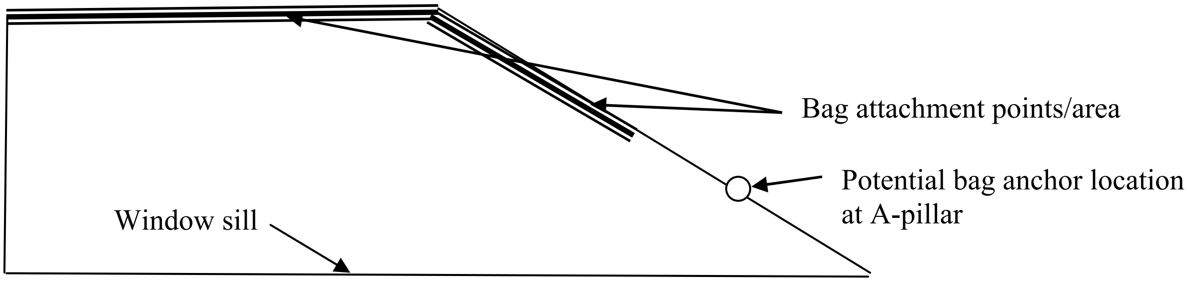

Figure IV-2. Illustration of Front Window Opening & Bag Attachment

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15% and 9%, respectively. (O'Brian-Mitchell, Bridget M., Lange, Robert C., "Ejection Mitigation in Rollover Events – Component Test Development," SAE 2007-01-0374.)

[82] The real world crash data and very limited laboratory test data may suggest that the risk of ejection through the upper portion of the window opening would be higher than the risk of ejection through lower portion of the opening. Therefore, if we assume that ejections are evenly distributed in the window opening area, it would overestimate the risk of ejection through the potential gaps around the bottom and front lower portion of the bag. Mathematically, therefore, the containment effectiveness derived based on the "even distribution" assumption could be considered as a minimum effectiveness. We note that occupants could move around inside a vehicle during a rollover event. Therefore, some occupants could have multiple impacts with the air bag, especially in severe complex rollovers. In some cases, an occupant could move to the potential opening after the occupant initially impacts the curtain area without the potential opening. However, we do not have a direct knowledge of these movements in rollovers and, consequently, the influence of these movements were not included in the analysis.

[83] As discussed later in this section, occupants who are initially contained by air bags could find another ejection portal when a sufficient roll time is given. Thus, the risk of ejection would increases when the number of rolls increases. However, we do not know the exact effect of the number of rolls or the duration of crashes on occupant movement. Due to limited data the effect was not considered in the analysis.

Risk of ejection through window opening:

Knapton reports that dummy motion during a rollover sequence normally starts with an initial movement caused by an initial impact with an exterior object and that in most rollovers involving window ejections the head of a dummy leads the ejection. One of observations he made was that the test dummies impacted multiple times with vehicle's interior components during a roll sequence whether restrained or not. [84, 85] The review of the motion pictures taken inside seven vehicles during rollover crashes are summarized below:[86]

(1) Belted and Unbelted Test Dummies Together:

	No. of Impacts by Dummy Body Part				
Impact Object	Head	Shoulder	Chest	Back	Total
Window Header	3	0	0	0	3
Upper Door Frame	4	0	0	0	4
Window Sill	2	1	0	0	3

(2) Unbelted Test Dummy with Interior Impact Objects around Window Opening:

	No. of Impacts by Dummy Body Part				
Impact Object	Head	Shoulder	Chest	Back	Total
Window Header	0	0	0	0	0
Upper Door Frame	1	0	0	0	1
Window Sill	0	0	0	0	0

(3) Belted Test Dummy with Interior Impact Objects around Window Opening:

	No. of Impacts by Dummy Body Part				
Impact Object	Head	Shoulder	Chest	Back	Total
Window Header	3	0	0	0	3
Upper Door Frame	3	0	0	0	3
Window Sill	2	1	0	0	3

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[84] Report No. DOT-TSC-HS476-PM-83-25.

[85] The dummy impact sequence data show that most of the dummies initially impacted vehicle interior components (seven (7) out of the nine (9) rollover tests) rather than the window opening area. The data show that some of window ejections occurred after the dummy impacts with vehicle interior (surface) components such as window sill or A-pillar.

[86] Detailed crash data are found in Appendices A and B.

Table IV-21
Belted dummy impacts above and below window opening area

Impact Object	No. of Impacts		Impact Area	% of total
Window header	3		Impacts above window opening area	67%
Upper door frame	3			
Window sill	3		Impacts above window opening area	33%
Total	9		Total	100%

When using the areas above and below the window as proxies, the belted dummy data showed that the likelihood of impacting the upper portion of the window opening area (67%) is greater than the likelihood of impacting lower portion of the window opening area (33%).

As discussed previously, some occupants would be ejected through potential gaps around the bottom and front lower portions of the air bag, even if the air bag is in compliance with the proposed linear headform displacement requirement.[87] To determine the size and location of the potential gaps, we examined the overall dimension of the headform and its relative positions with respect to the window frame. The headform has a height of approximately 10 inches (250 mm) and a width of about 6 inches (150 mm). The CG of the headform is about the geometric center of the head: approximately 5 inches from the bottom surface of the headform. When positioned at the impact points, A1 and A2 in the front window opening, the CG of the headform would be

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[87] Based on the headform impact points with respect to the window frame, we believe that most of ejections through the gap would be partial ejections and that these ejections may or may not result in serious injuries. However, under the methodology, by limiting the target population to serious injuries, we are assuming that any ejections through these potential gaps would result in serious injuries.

approximately 6 inches from the window sill, as shown below:

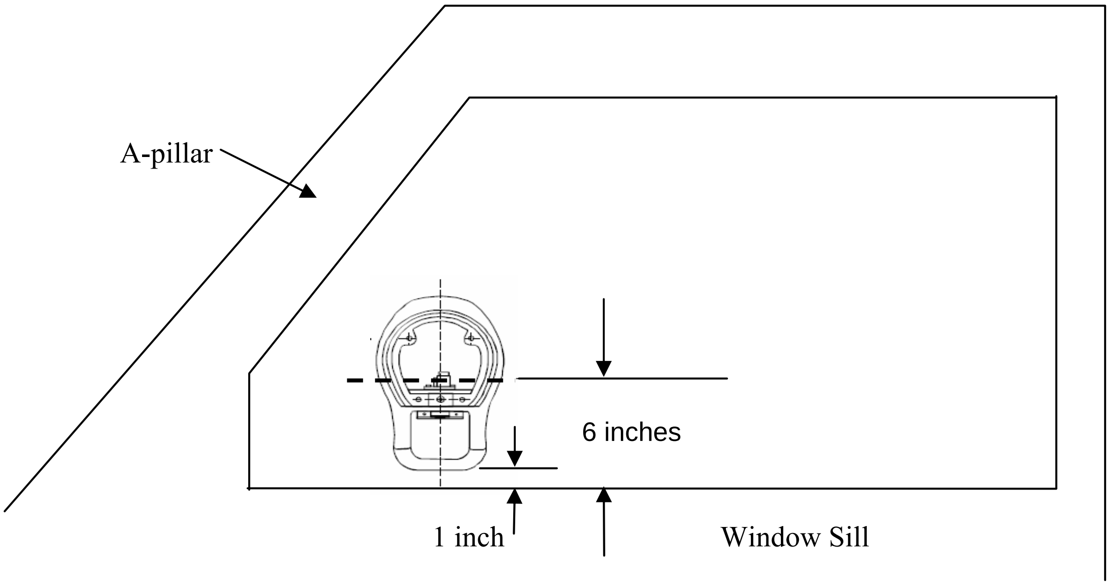

Figure IV-3. Position of Impactor (headform) with respect to Window Sill

When the head of an occupant impacts with these impact points, A1 and A2, hypothetically, the air bag would contain the head and, as a result, prevent the occupant from ejection. However, for areas below these impact points, toward the window sill, the air bag may or may not contain the occupant when such impacts/ejections occur in rollover crashes since the linear headform test cannot be performed in this narrow area. Accordingly, we assumed that rollover bags are not effective in preventing ejection if the CG of the head of an occupant is lower than the CG of the headform measured at the two lower impact points, A1 and A2 in the linear headform test.[88]

For example, the window opening of a 2003 model year Toyota Camry has a height of about 18 inches. When the headform is positioned at A1 or A2, the distance between the CG of the headform and the window sill would be about six (6) inches (as shown in Figure IV-3). If the

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[88] The assumption implies that all occupant impacts below the 6-inch line would result in partial or complete ejections. However, we suspect that not all occupant impacts at these areas would result in partial or complete ejections since the lower portion of the bag would interfere with the movement in some ejections. Thus, an ejection under this assumption could be considered a “worst case scenario”.

window area is divided into three equal lengths vertically, the lower 1/3 portion of the window opening would be below the CG of the headform. The window opening of the Camry has a height of 46 cm (18 inches) and a width of 99 cm (39 inches) at the top and 191 cm (75 inches) at the bottom (at the window sill). Thus, the lower 1/3 window opening area would be 2,675 cm^2, which is 40% of the total window area.[89] Since there are many different shapes of the window opening, for simplicity, we assumed a rectangle for all side window openings in the analysis. Under the assumption, about 33% (6"/18" = 33%, 1/3) of the window opening area would be below the CG of the headform (i.e., the difference between the CG of the headform and the window sill). Under the assumption, the bottom 1/3 of the window opening would be considered as a potential gap that the head of an occupant can get through[90] in rollover crashes, even if rollover air bags meet the headform displacement requirement at the two lower impact points.

Previously, for belted occupants, we estimated that the likelihood of impacting areas above the window opening is 67% and the likelihood of impacting areas below the opening is 33%. As discussed in the assumption section, 67% of belted occupants who were either partially or completely ejected through the window opening would be ejected through the upper portion of the window opening and the remaining 33% would be through the lower portion. In other words, the risk of ejection through the upper portion of the window area would be 2 times higher than the risk of ejection through the lower portion of the opening (67%/33% = 2 times).

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[89] Total area = 6,619 cm^2; upper 2/3 area = (1/2)(99+x)(2/3)(46) cm^2; lower 1/3 area = (1/2)(x+191)(1/3)(46) cm^2.

[90] As discussed in this chapter, when the head-form has a displacement of 100 mm at the lower impact points, theoretically, it could result in a 182 mm gap between the window sill and the bottom of the bag (see Figure IV-4), assuming the bag is just long/tall enough to retain the headform. If the curtain were rigid structure, hypothetically, any body parts that are larger than the 182 mm gap would not go through the gap. However, when the head hits the 182 mm gap, the curtain can be pushed upward creating a wider gap. However, we do not know whether the gap is wide enough (wider than 182 mm) to allow a head or other body parts to get through.

The derivation above shows that if air bags are not effective in preventing ejection through the lower 1/3 of the opening, the containment effectiveness (not overall effectiveness) would be at least 67% for belted occupants[91] in certain rollover crashes.[92] (We note that occupants who were initially contained by the bag might find an ejection portal when a sufficient roll time is given. However, agency's 208-dolly test results indicate that many adult occupants would get stuck in one section of the car with inflated curtain air bags (most often up against the B-pillar) and would not transverse from one side of the vehicle to another each time the vehicle rolls.[93] The test results lead us to believe that the majority of adult belted occupants who are initially contained by inflated rollover bags would not find another portal in severe rolls. However, we note that almost all of the dolly tests had belted test dummies and would not show how unbelted occupants behave in rolls. We suspect that unbelted occupants would have a higher degree of movement along an area of contact in the air bag. As of today, we do not know how the number and duration of rolls affect the bag's containment capability in real world crashes. Accordingly, these effects were not considered in the analysis.[94] Note that, as discussed in the target

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[91] In other words, if the ejections were evenly distributed in the opening, the hypothetical rollover curtain bag would prevent 67% of the ejections. However, since the risk of ejection through the upper portion of the window opening would be higher than the risk of ejection through the lower portion of the opening, the containment effectiveness would be higher than 67%.

[92] The 6 inch potential gap would be large enough to allow upper extremities (hands, arms and shoulders) to contact exterior objects in rolls. For belted occupants, we speculate that the majority of upper extremity injuries would occur when these body parts are ejected through areas near the window sill. In a report titled "An Investigation of Occupant Injury In Rollover: NASS-CDS Analysis of Injury Severity and Sources by Rollover Attibutes," ESV Paper No. 419, Paul G. Bedewi, found that upper extremities account for 14% of AIS 3+ injuries for belted occupants. The upper extremity ejection through the potential gap is further referenced in the discussion section in this chapter.

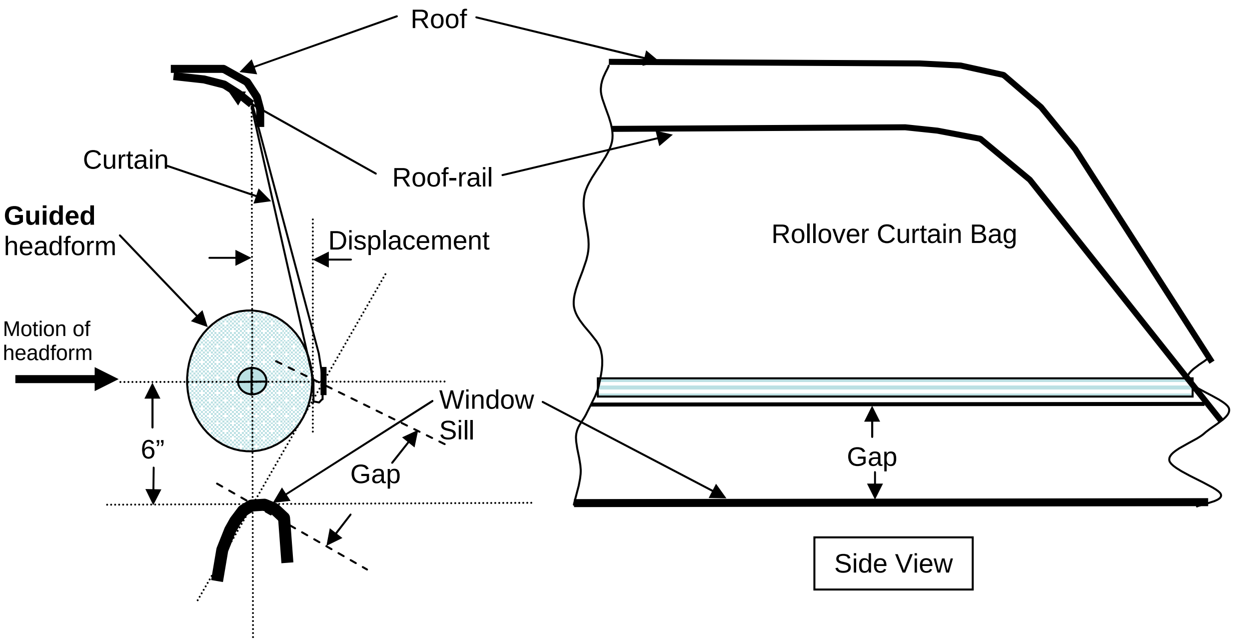
[93] In a study titled "Timing of Head to vehicle Perimeter Contacts in Rollovers" (SAE 2007-01-0370), the motion of the occupants prior to an upper vehicle structure-to-ground impact in rollovers was analyzed. One of the conclusions made by the study is that occupants approach the roof rail area and remain there. It said "Restrained occupants very quickly approached the roof rail and remained there until there were additional external forces due to vehicle-to-ground impacts." In addition, it found that the trajectories of near-side occupants were similar for both restrained and unrestrained occupants. The authors also noted that unrestraint occupant motion was more variable and chaotic, particularly for far side occupants.

[94] The film analysis shows that the dummies, whether restrained or not, impacted multiple times with vehicle's interior components during a roll sequence, when vehicles are not equipped with air bags. In some cases, the dummy was propelled several times in different directions and partially ejected more than once during a vehicle roll.

population section (see Table IV-3), we limited our target population to planar-only side crashes and lateral rollovers (i.e., vehicle rolls about its longitudinal axis).

In summary, although we do not have real world crash data to show occupant ejection paths in the window opening area in rollover crashes, we have anecdotal test data that suggest (i) that the number of ejections through the upper portion of the window opening may be greater than the number of ejections through the lower portion and (ii) that rollover air bags might not be effective in preventing the head or arms of an occupant from ejection through a potential gap between the curtain and the window sill, even if the air bags are in compliance with the displacement requirement.

For example, the head of the unbelted driver dummy in the '76 Honda ejected twice during a very severe eight (8) quarter-turn rollover. If we assume that an unbelted occupant impacts twice the window opening area covered with a rollover curtain during an 8 quarter-turn rollover and that the bag is 71% effective in containing an occupant whenever the occupant impacts with the opening area. Hypothetically, under the assumptions, the system would have an overall containment effective of 50% (71%x71% = 50%).



Displacement	100 mm	150 mm	200 mm
Gap	182 mm	214 mm	251 mm

Figure IV-4. Potential gap between curtain and window sill

Occupant containment effectiveness for the weighted risk of ejection method:

The test dummy and real world crash data show that belted and unbelted occupants would have different impact characteristics in rollover crashes. For the analysis, therefore, we considered belted and unbelted occupants separately.

Risk of ejection with respect to the upper and lower portions of the window:

(1) Belted Occupants for Vertical Impact Distribution in Rollovers:

For belted test dummies, similar to the approach used for the combined (belted and unbelted), the likelihood of impacts in the window opening area was derived, as shown below:

Table IV-23
Belted Test Dummy Interior Impacts*

Impact Component	Test No. (Knapton, DOT HS 476)					Total
	263	293	35412-12	287	1336-22C81	
Window header	2	0	0	0	1	3
Upper door frame	1	0	0	1	1	3
Window sill	1	0	0	2	0	3
Total						9

Table IV-24
Likelihood of Impact Above and Below Window Opening

Impact Area	No.	% of
Impacts above window opening area	6	67%
Impacts below window opening area	3	33%
total	9	100%

The results in the tables above show that 33% of the ejections would occur through the lower portion of the window (i.e., lower 50% of the window opening). If bags are not effective in preventing ejection through the potential gap (between the curtain and the window sill), we estimated that 22% of the ejections would occur through the potential gap in the lower portion of the window opening. [For simplicity of calculation, we assumed that ejections are evenly distributed in the lower portion of the opening. Under the assumption, 22% (21.8%) of the ejections would occur through lower 1/3 (33%) of the opening, 33%* (.33/.50) = 22%.] Therefore, it would be reasonable to assume that the risk of ejection through the upper 2/3 of the uncovered window opening area would be at least 78% (100%-22% = 78%). In other words, even if a rollover curtain air bag meets the requirements 22% of the ejections would occur through the potential gap between the curtain and the window sill. For the analysis, therefore, we assume that the containment effectiveness for a curtain air bag meeting the proposed requirements would be 78% for belted occupants in rollover crashes, <u>if there were no other potential gaps</u> in the opening. [95,96]

We note that the standard would use a guided impactor component test to assess the ability of the countermeasure (e.g., a curtain system) to mitigate ejections in different types of rollover and side impact crashes involving different occupant kinematics. The test has been carefully designed to represent the dynamic rollover event. Due to limited data, we assumed that any ejections resulting AIS 3+ injuries, including fatalities, would be represented by the headform test in the analysis. In other words, we assumed that when a curtain air bag meets the proposed headform test requirements, it would prevent any ejections through the side window opening.[97] There are two rationales for the assumption. First, the impact mass is based on the mass imposed by a 50th percentile male's upper torso on the window opening during an occupant ejection. The mass of the impactor, 18 kilograms (kg) (40 lbs), in combination with the impact speed discussed below, has sufficient kinetic energy to assure that the ejection mitigation countermeasure is able to protect a far-reaching population of people in real world crashes. The component test involves

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[95] If the ejections were evenly distributed in the lower portion of the window, about 22% [(33%* (.33/.50) = 22%,] of the ejections would occur through the potential gap in the lower portion of the window opening. As discussed, the risk of ejection would decrease as the impact point moves toward the window sill. Therefore, it would be reasonable to assume that the risk of ejection through the lower portion would not be higher than 22%. In other words, the risk of ejection through the upper 2/3 of the window opening area would be at least 78%% (100%-22% = 78%). Accordingly, we assumed that the containment system would be 78% effective in preventing occupant ejections through the window opening area. Note that the assumption would underestimate the containment effectiveness since the ejection through the upper portion would be higher than 78%.

[96] With the estimated 78% containment effectiveness for <u>belted occupants</u>, rollover bags would allow 22% of ejections through a potential gap above the window sill. We suspect that the majority of these ejections would be upper extremities. As discussed, according to Paul G. Bedewi, 2003, ESV Paper No. 419, upper extremities account for 14% of AIS 3+ injuries for <u>belted occupants</u> in rollovers. Previously, we estimated that when <u>both</u> belted and unbelted occupants are considered, about 20% of injuries would occur through the potential gap (when both belted and unbelted were considered, 30% through the lower portion, 30% x (.33/.50) = 20%). The estimated 22% risk of ejection through the gap for <u>belted occupants</u> shows that unbelted occupant would have a higher risk of ejections through the upper portion of the window opening area (with less than 20% risk of ejection through the potential gap) when compared to belted occupants, when such ejections occur.

[97] As discussed in the target population section, there are some exceptions to this assumption. For catastrophic rollovers crashes, we assumed that the ejection mitigation system would not be effective even if it meets the proposed headform requirements.

use of a guided linear impactor designed to replicate the loading of a 50th percentile male occupant's head and upper torso during ejection situations. The mass of the guided impactor was developed through pendulum tests, side impact sled tests, and modeling conducted to determine the mass imposed on the window opening by a 50th percentile adult male's upper torso and head during an occupant ejection ("effective mass").[98] The final part of the analysis involved computer modeling of an 18 kg impactor and 50th percentile Hybrid III dummy impacting simulated glazing (foam). The comparison found that the total energy transferred by the 18 kg impactor was within the range of the total energy transferred by the entire dummy. For a 16.1 km/h dummy model impact with the foam, the effective mass that came in contact with the foam was between 12.5 kg and 27 kg. Second, although we do know the number of ejections that are head-heading in real world rollovers, we believe that the majority of ejections in rollovers are either head-leading or shoulder-leading ejections. According to the film analysis by Knapton, there were 52 dummy-to-vehicle interior impacts and 13 dummy ejections were observed. Among the 13 dummy ejections, 8 were head-leading, 4 were shoulder-leading and the remaining one was back-leading ejections.[99]

(2) Unbelted Occupants for <u>Vertical</u> Impact Distribution in Rollovers:

When the unbelted dummy impact data were considered separately, there is only one case of dummy impacting the area surrounding the window opening, as shown previously. Therefore, we determined that the number of dummy impacts were too small to derive an impact distribution with respect to the window opening area. Therefore, for unbelted occupants who

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[98] For additional discussion see "Technical Analysis in Support of a Notice of Proposed Rulemaking for Ejection Mitigation."

[99] For additional discussion, see a report titled "Rollover Crash Test Film Analysis" by D. Knapton, DOT-TSC-HS476-PM-83-25, Table 3.

were ejected through the side window opening, the dummy data were not utilized for the vertical impact distribution. Instead, we analyzed real world crash data to qualitatively determine whether it is reasonable to use the belted occupant containment effectiveness rate as a proxy for unbelted occupants. According to Digges, unrestrained occupants have a higher risk of contacting the upper portion of the window opening area (about 1.3 times) when compared to restrained occupants in real world rollover crashes, as shown below:[100]

Table IV-25
Occupant Impacts on Upper Portion of Window Opening Area, 1988-1990 NASS/GES

Impact Area	Risk of Total Impacts		Relative Frequency[101]
	Restrained	Unrestrained	
Rail/Headers	1.9%	2.5%	1.3

In addition, the NASS data show that belted and unbelted occupants would have a similar frequency (risk) of impacts with vehicle's interior <u>side components</u>, as shown below:

Table IV-26
Total Side Interior Impact NASS Sample Count, 1988-1990 NASS/GES

Impact Area	Restrained	Unrestrained
Side interior impacts	30	50
All interior impacts	521	838
% of total	5.8%	6.0%

The results in Table IV-26 show that 5.8% of interior impacts occurred with side interior components for restrained occupants and 6.0% for unrestrained occupants. (Although the NASS sample count shows that belted and unbelted occupants would have a similar risk of striking interior <u>side components</u>, the dummy test data and real world injuries suggest that unbelted occupants would more freely bounce around in rollover crashes. As a result, unbelted occupants would have a higher exposure of receiving serious injuries when compared to belted occupants in rollover crashes.) The field data show that it would be reasonable to assume that both

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[100] These are injury inducing contacts as reported in real world crashes. We do not know how non-injurious contacts are distributed in the area surrounding the opening in real world crashes.

[101] 2.5%/1.9% = 1.3

unrestrained and restrained occupants have the same risk of striking interior side components as they do of any other injurious impact and that unrestrained occupants have a 1.3 times higher chance of striking the upper portion of the window opening, when such impacts occur, as shown below:

Table IV-27
Risk of Impact with Upper and Lower Portions of Window Opening Area
By Belt Use, 1988-1990 NASS/GES

Impact Area	Restrained	Unrestrained
Upper portion (above window)	67%	73%[102]
Lower portion (below window)	33%	27%
Total	100%	100%

Table IV-27 shows that 73% and 27% of unbelted occupants would collide with the upper portion and the lower portion of the window opening area, respectively. The analysis of real world data strongly suggested that unbelted occupants would have a higher risk of ejection through the upper portion of the window opening when compared to belted occupants.[103] Therefore, unbelted occupants would have a lower risk of ejection through the potential gap above the window sill, when such ejections occurred. As a result, the bag would have a higher containment effectiveness rate for unbelted occupants when compared to belted occupants. However, we are uncertain that the real world crash data are statistically sufficient to quantify the estimated risk of ejection for unbelted occupants. For unbelted occupants, therefore, we used the 78% containment effectiveness rate that was derived for belted occupants as a proxy. (Consequently, the use of the containment effectiveness rate derived for belted occupants, as a proxy, for unbelted occupants would underestimate the potential benefits.) In summary, the real

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[102] [(67/33)x1.3]/[(67/33)x(1.3) + 1] = 0.725, 73%

[103] The ejections include both partial and complete ejections in rollovers. We suspect that lap and shoulder belts would reduce the vertical movement of an occupant in rollovers and, as a result, reduce the risk of ejection through the upper portion of window opening, when compared to unbelted occupants. Note that belted occupants have a lower risk of complete ejection compared to unbelted occupants. As discussed in a section titled “injury risk associated with remaining inside the vehicle section,” preventing belted occupants from ejection would result in a different overall system effectiveness value when compared to unbelted occupants.

world crash data suggest that unbelted occupants would have a higher risk of ejection through the upper portion of the window opening and that assuming both belted and unbelted occupants would have the same risk of ejection through a particular area in the window opening would not over estimate the potential benefits.

Risk of ejection through area between curtain air bag and A-pillar:

Previously, we estimated the risk of ejection with respect to the upper and lower areas of the window opening. Since the impact points spread across the window opening area, we also examined the likelihood of ejection through a particular area in the window opening with respect to the front- and rear-portion of the opening (i.e., lateral distribution).

<u>Belted Occupants (lateral distribution)</u>: For belted test dummies, the impact data show that the majority of the impacts occurred at the B-pillar, as shown below:

Table IV-28
Belted Dummy Impacts with A- and B-Pillars

Impact Component	Test No. (Knapton)					Total
	263	293	35412-12	287	1336-22C81	
A-pillar	0	1	0	0	0	1
B-pillar	2	1	1	1	0	5
Total						6

The results in Table IV-28 show that the belted dummies had a total of six (6) impacts with the A- or B-pillars. Among the six (6) impacts, five (5) were at the B-pillar and the remaining one (1) was at the A-pillar. The results indicate that belted occupants would have a lower risk of hitting the front-portion of the window opening area when compared to the rear portion, as shown below:

Table IV-29
Belted Dummy Impact Points, with respect to Front and Rear of Window Opening

Impact Area	No. of	% of
Rearward of window opening area	5	83%
Forward of window opening area	1	17%
Total	6	100%

However, the belted dummies used in the vehicle tests were restrained with lap belts, not 3-point lap & shoulder belts. Since the shoulder belt would restrict the dummy movements toward the A-pillar compared to 2-point lap belts, we expect the number of impacts with the B-pillar would be higher if the 3-point belts were used in the test.

Similar to the approach used for the vertical impact distribution in the window opening area, we assumed that the likelihood of impacting with the B-pillar (which is rearward of the window opening) and the A-pillar are 83% and 17%, respectively, for belted occupants when only the longitudinal distribution of the impacts was considered, as shown below:

Table IV-31a
Likelihood of Impacting Rear and Front of Window Opening
Belted Occupants, Ejection through Front Window Opening

Impact Area	% of	Segment of Window Opening	% of
Rear of window opening	83%	Rear of window opening	83%
Front of window opening	17%	Front of window opening	17%

Similar to the method used for the vertical impact distribution, we assumed that ejections are evenly distributed in the front half of the window opening. Under the assumption, therefore, 8.5% of the impacts would be in the front ¼ of the window opening area.[104] Typically, a curtain bag is attached to the roof rail and anchored at the A- and C-pillars as the air bag is designed to deploy from the vehicle's roof rail. The rear end of most current air bags is attached to the lower

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[104] Being consistent with the method used for the risk of vertical ejection, we assumed that ejections were evenly distributed in the front ½ of the window opening area with respect to the A- and B-pillars. If the ejections were evenly distributed in the front ½ of the window opening area, the risk of ejection through the front ¼ area would be 8% (17%/2 = 8%).

part of the C-pillar near the window sill (C-pillar anchor), whereas the front end is attached to the middle of the A-pillar (A-pillar anchor). In this air bag configuration, the portion below the line drawn between the C-pillar and A-pillar anchors is not attached to the vehicle structure, although it covers the window opening area. When the A-pillar attachment is too far from the window sill (i.e., near the roof rail), therefore, the front lower portion of the air bag (the portion that is below the line drawn between the A- and C-pillar anchors) would not meet the displacement requirement when tested with the headform. To provide a sufficient tension without excessive gas pressure in the air chambers, manufacturers would lower the A-pillar anchorage close to the window sill. Likewise, to meet the proposed linear headform displacement requirement at the front lower point (A1), vehicle manufacturers would position the A-pillar anchor close to the CG of the headform positioned at A1 (i.e., close to the horizontal plane passing through the CG).[105] The CG of the headform positioned at A1 would be near the midpoint of the front window opening.[106] Therefore, we believe that manufacturers would design the air bag system such that the front of the air bag is anchored at a point that is lower than the midpoint of the A-pillar. In addition, the upper front part of the air bag would be securely attached to the pillar. As a result, the upper front of the area between the air bag and the A-pillar would be completely covered and, hypothetically, would not create any gap in rollover crashes (that are considered in the benefit analysis). Accordingly, for occupants who impact the front ¼ of the window opening area, we <u>assumed</u> that only the bottom ½ of the area (that is, the area between the bag and A-pillar) would allow (partial) ejection,[107] as shown in Figure IV-5.

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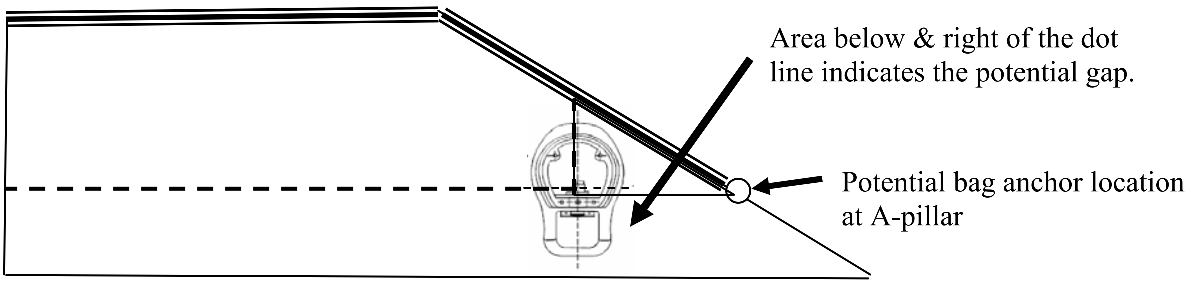
[105] If the A-pillar anchor is positioned above A1, it would be difficult to provide sufficient tension in the bag to withstand forces generated during the headform impact at the impact point (A1).

[106] The front window of a 2003 Toyota Camry has a height of 18 inches. When the headform is position in the A1, the CG of the headform would be 6 inches from the window sill, below the midpoint of the front window opening.

[107] As shown in Figure IV-5, since the front corner would be too narrow to position the headform, manufacturers may or may not cover this area with loomed air bag cloth. When the area is not covered with loomed air bag cloth,



Area below & right of the dot line indicates the potential gap.

Potential bag anchor location at A-pillar

Figure IV-5. Illustration of Front Window Opening & Potential Ejection Area

The majority of current single-piece curtain air bags are designed to continuously cover the front and rear window openings, as it is anchored at the A-and C-pillars. Therefore, for occupants who strike the rear-portion of the front window opening area, we assumed that the curtain bag would prevent them from ejection in rollover crashes.[108] Under the assumptions, approximately 5% of belted occupants would be ejected through the front lower <u>corner potential</u> opening (between A-pillar and the window sill) if the bag is not effective in preventing occupants from ejection through the lower 1/3 of the front ¼ of the window opening area.[109] (The estimated 5% ejection rate is based on the risk of ejection, the anchor location, headform impact points and current curtain air bag designs. However, we note that a typical passenger car has a very narrow opening area between window sill and the lower portion of the A-pillar, as illustrated in Figure IV-5. Therefore, we suspect that the head of an <u>adult occupant</u> in a passenger car is too large to go through this narrow opening area. As a result, it would underestimate the air bag containment since the majority of ejected occupants were adults. On the other hand, upper extremities (such

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partial ejections could occur in rollovers. For the analysis, we assumed that this area is not covered with air bag cloth although it would slightly underestimate the containment effectiveness.

[108] As discussed in the target population section, we determined that not all fatal and non-fatal injuries would be prevented by curtain bags even if the bags initially prevent ejections through the window opening.

[109] Previously, when only vertical ejections are considered, we estimated that 22% of ejections would occur through the lower 1/3 portion of the window opening area (i.e., potential gap). Whereas, when only lateral ejections are considered, we estimated that 8% of the ejections would occur through the front ¼ of the window opening area. We assumed that the upper portion of the front window opening would be covered by a curtain bag that is securely attached to the A-pillar. Therefore, assuming ejections are evenly distributed, the risk of ejection through the lower portion of the front window opening area would be 5% ((8%x22%)+(8%x77%)/2 = 5%).

as arms and shoulders) of an adult occupant and the head of a small child could be ejected through the gap.)

We note that passenger cars and light trucks have many different shapes and sizes of the window opening. Some are more slanted than others (especially passenger cars). To simplify the calculation for air bag containment effectiveness, as shown in the calculation above, we assumed that window openings are rectangular in shape with a height of 46 cm (18 inches) and an opening area of 6,619 cm^2 (1,026 in^2) of the Camry. One of the consequences of assuming "rectangle" for the window opening is that it reduces the potential gap (area) above the window sill since most window openings have a relatively larger area moving toward the window sill. In the uniform risk distribution method section, following the weighted risk distribution section here, we assumed that the risk of ejection is evenly distributed regardless of belt use and shape of the window opening. Potential benefits derived from these two methods were compared and presented in this PRIA.

<u>Unbelted Occupants (lateral distribution):</u> For unbelted dummies, as shown previously, we have very limited data. According to the Knapton report, there were two impacts at the front and rear portions of the window opening area, one at the A-pillar and the other at the B-pillar. Although the number of impacts at the A- and B-pillars was small, it showed a distinctive difference when compared to the impact pattern observed with belted test dummies. Table IV-29 showed that the majority of belted dummy impacts occurred at the B-pillar (83%, at the rear portion of the opening), whereas unbelted impacts were evenly distributed between the A-and B-pillars. Due to the distinctive difference in distribution, we have decided to use the unbelted dummy impact

data for the lateral distribution for unbelted occupants. The interior side impact data show that the impacts were more evenly distributed between the A- and B-pillars when compared to belted dummies, as shown below:

Table IV-32
Unbelted Dummy Impacts with A and B Pillars

Impact Component	Test No. (Knapton)				Total
	1336-C81	3541-12	45-5	1336-22C81	
A Pillar	1	0	0	0	1
B Pillar	1	0	0	0	1
Total					2

Table VI-33
Estimated Risk of Impact with A- and B-pillars

Impact Area	No. Impact	% of
B-pillar	1	50%
A-Pillar	1	50%
Total	2	100%

Similar to the approach used for the belted occupants, the likelihood of ejecting through a potential gap between A-pillar and the bag was derived, as shown below:

Table VI-34
Likelihood of Ejecting through Potential Gap between A-pillar and Bag, Unbelted Occupants

Impact Area	% of	Segment	% of
Rear of window opening	50%	Rear of window opening	50%
Front of window opening	50%	Front-rearward of window opening	50%

The results in Table VI-34 show that 50% of unbelted occupants would be ejected through the front ½ portion of the window opening area. Similar to the method used for belted occupants, when the area is divided into four sections with the same width, 25% of unbelted occupants would be ejected through the front ½ portion of the window opening. Similar to the method used for belted occupants, we assumed that unbelted occupants have 13% (25%/2 = 13%) chance of ejection through the front lower portion of the window opening area.

Overall risk of ejection through front window opening:

(A) Belted occupants: The analysis shows that there is a higher risk of ejection through the upper and rear portion of the front window opening. When the opening is divided into three equal vertical areas, we estimated that the risk of ejection through the lower 1/3 of the opening would be 22%. For each vertical section, we estimated that there are 83% (83.3%) risk of ejection through the rear half of the area and, 8% (8.3%) risk of ejection through the front ¼ of the window opening, as shown below:

Table IV-35
Risk of Ejection through Front Window Opening
Belted Occupants <u>without</u> Considering Ejection through Sunroof

Vertical	% of	Lateral			Total
		Rear half	Front mid 1/4	Front 1/4	
		83%	8%	8%	100%*
Upper 2/3	78%	65%	6%	6%	78%*
Lower 1/3	22%	18%	2%	2%	22%*
Total:	100%				

* Rounded to the nearest integer.

The results in Table IV-35 show the risk of ejection through the front side window opening, which was based on the relative position of the headform and also rollover tests performed with selected vehicles.[110] Due to limited data, we assumed that all AIS 3+ injuries, including fatalities, were all head-lead ejections in the analysis. With the potential gaps in the front and bottom of the curtain air bag, we estimated that the hypothetical ejection mitigation curtain air bag would be 75% effective in preventing <u>belted</u> occupants from ejection through the front side window opening in rollover crashes.[111]

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[110] Previously, we discussed that the mass of the impactor in combination with the impact speed has sufficient kinetic energy to assure that the ejection mitigation countermeasure is able to protect a far-reaching population of people in real world crashes.

[111] The numbers were rounded to the nearest integer. As shown in Figure IV-5, vehicle manufacturers may or may not cover the area between the front lower impact point (A1) and the A-pillar. If the area is not covered, the containment effectiveness would be 71% (65% + 6% = 71%). If the area is fully covered by attaching it to the A-

In the weighted risk containment method, we derived containment effectiveness values for belted and unbelted occupants. However, we note that the degree of ejection (i.e., partial and complete) was not considered in the analysis. In other words, the containment effectiveness (calculated with the potential gaps) would not tell whether the ejected occupants with a system that meets the proposed requirements have partial or complete ejections. Although we do not have either laboratory or real world data, we suspect that the hypothetical ejection mitigation air bag (that is capable of meeting the requirements) would not allow complete ejections even with the potential gaps in most rollovers.

(B) Unbelted occupants: The analysis shows that unbelted occupants would have a higher risk of ejection through the upper portion of the front window opening, when compared to belted occupants. However, due to limited data, we used the effectiveness derived for belted occupants as a proxy: 78% for the upper 2/3 and 22% for the lower 1/3 portion of the window opening area. The lateral ejection distribution shows that the unbelted (occupant) ejections are more evenly distributed than belted occupants: assuming 25% risk of ejection through the opening, as shown below:

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pillar, the containment effectiveness would be 78% (65% + 6% +6% =78%). For the analysis, we assumed that the bag would contain ½ of the ejection through the front upper 2/3 portion of the opening area (the shaded area in Figure IV-5). Under the assumption, the containment effectiveness would be 75% (65% + 6% +6%x (1/2) = 75%, rounded to the nearest integer).

Table IV-36
Risk of Ejection through Front Window Opening
Unbelted Occupants without Considering Ejection through Sunroof

Vertical	% of	Lateral				Total
		Rear 1/4	Rear mid 1/4	Front mid 1/4	Front 1/4	
		25%	25%	25%	25%	100%
Upper 2/3	78%	19.4%	19.4%	19.4%	19.4%	78%
Lower 1/3	22%	5.6%	5.6%	5.6%	5.6%	22%*
Total	100%					

* The numbers were rounded to the nearest integer

Table IV-36 shows that, with the potential gaps in the front and bottom of the curtain, the hypothetical ejection mitigation curtain air bag would be about 68% effective in preventing <u>unbelted</u> occupants from ejection through the front window opening in rollover crashes.[112]

Ejection through Sunroof for Belted Occupants:

In real world rollover crashes, some occupants are ejected through the sunroof (either partially or completely). According to K. Digges, "Summary Report of Rollover Crashes," FHWA/NHTSA National Crash Analysis Center, June 2002, about 17% of ejections occurred through the sunroof, as shown below:[113]

Table IV-37
Ejection Paths in Rollover Crashes

Ejection Path	Ejectees	Harm
Closed Glazing	50%	52%
Open Glazing	16%	15%
Sunroof	17%	15%
Windshield	8%	5%
Doors	9%	13%
Total	100%	100%

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[112] The numbers were rounded to the nearest integer. 19.4%+19.4%+19.4%+19.4%*(1/2) = 68%, rounded to the nearest integer.

[113] According to a briefing provide by Kennerly Digges, "Sources of Injury Harm in Rollover Crashes, The George Washington University, April 12, 2001, unrestrained occupants have 12% and 63% harm distributions for ejections through the sunroof and the side windows, respectively.

Although we do not have data to show the number of seriously injured occupants who were ejected through the sunroof in lateral rollovers, we suspected the majority of sunroof ejections occurred during lateral rollover crashes.[114] As shown in Tables IV-1 and IV-2, the agency's real world crash data show that about 3% of serious and 2% of fatal injuries (5% of MAIS 3+) occurred when occupants were ejected through the sunroof. During lateral rollover events, our analysis shows that side windows and the sunroof would be most likely ejections routes. When ejections through side windows and the sunroof are considered, the crash data show that not more than 5% of the ejections occurred through the sunroof.[115]

The rollover crash data show that some occupants would bounce off the interior components before ejecting through an opening (including sunroof) in certain rollovers. However, when vehicles are equipped with window curtain bags, only a small number of adult occupants would rebound when they impact with a curtain bag in rollovers. Therefore, we suspect that the actual percentage would be higher than the 5% estimated ejection rate, when vehicles have a curtain ejection mitigation system.[116] Although a small number of adult occupants would rebound, we do not have data to quantify the number of these occupants. Due to limited data, therefore, we assumed that 5% of all AIS 3+ (induced) ejections occur through the sunroof in rollovers and

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[114] Note that Knapton analyzed how test dummies impacted with the roof by body region and the number of quarter-turns. Unfortunately, the data do not include actual dummy impact points in the roof area. As a result, we do not have laboratory data to estimate the risk of ejections through the sunroof.

[115] There were 5,271 serious (46.1%) and 6,174 fatal (53.9%) ejection injuries, a total of 11,445. Among these injuries, 305 serious (5.5%) and 237 fatal (3.7%) injuries were from sunroof ejections. Thus, (46.1%x5.5%) + (53.9%x3.7%) = 5%.

[116] The 5% ejection rate includes occupants who bounce off the interior component and also deployed air bag. When ejection curtains are in place, the total number of side ejection will decrease. Therefore, we believe that the actual ejection rate through the sunroof would be higher than 5% when all vehicles are equipped with (rollover curtain bags). However, we were unable to quantify the percentage of ejections through the sunroof with a curtain air bag meeting the proposed requirements.

that (roof) glazing is not effective in preventing an occupant from ejection.[117] (Note that the 5% sunroof ejection rate is based on 1997-2005 NASS and 2005 FARS. We believe that a small number of these vehicles would be equipped with a sunroof since the majority of these vehicles are older model vehicles. However, the number of vehicles equipped with the sunroof has increased steadily since MY 1997. For example, the percentage of U.S. domestic passenger cars with a sunroof increased from 20.3% in MY 1999 to 25.3% in MY 2005.[118] We expect that the sunroof ejection rate (estimated 5%) would also increase as the number of vehicles with a sunroof increases. The sunroof and its effects on occupant safety are further discussed in Chapters VII.) With the 5% ejection through the sunroof, the containment effectiveness would decrease from 75% to 71% for belted occupants and from 68% to 65% for unbelted occupants.[119]

Overall Air Bag Containment Effectiveness in Rollovers: In the previous section, we analyzed the likelihood of ejection through potential gaps around the air bag for both belted and unbelted occupants in rollover crashes. In addition, the risk of ejection through the sunroof was also considered in the analysis, as shown below:

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[117] We are not aware of any strength or impact requirements for roof glazing. Although some roof glazing would be as strong as advanced glazing used in the side window opening, we do not have data on the strength of roof glazing. Therefore, we assumed that roof glazing is not effective in preventing ejection. Since not all sunroof ejections occurred in lateral rollovers, the assumption would overestimate the risk of ejection through the sunroof in lateral rollovers (i.e., when ejection through side windows and the sunroof are considered). Consequently, the assumption would underestimate the containment effectiveness.

[118] The percentages are based on Ward's 2000 & 2006. In addition, as part of the ejection mitigation rulemaking effort, the agency performed a field survey of current vehicles. The survey showed that about 37% of MY 2007 were equipped with the sunroof.

[119] Previously we estimated that bags are 75% effective in preventing belted occupants from ejection through the window opening area. With 5% ejection through the sunroof, the effectiveness would decrease from 75% to 71% ($75\%_{\text{effectiveness}} \text{x} 95\%_{\text{window}} + 0\%_{\text{effectiveness}} \text{x} 5\%_{\text{sunroof}} = 71\%$, for unbelted: 68%x95% + 0%x5% = 65%), as shown in Table IV-38. As discussed, the actual sunroof ejection rate would be lower than 5% when all vehicles are equipped with a curtain ejection mitigation system, with the existing sunroof installation rate.

Table IV-38
Overall Air Bag Containment Effectiveness Rates
Fatally Injured Occupants

Belt Use	Fatality (% of total)	Containment Effectiveness, (Vertical)	Loss of Containment Effectiveness, (Lateral)	Combined	Loss of Containment Effectiveness, (Sunroof)	Overall
Belted	15%	78%	3%	75%	4%	71%
Unbelted	85%	78%	10%	68%	3%	65%

The vertical containment rates show that when the front window opening area is completely covered by a rollover air bag (i.e., meet the 100 mm headform displacement requirement) the air bag would prevent 78% of both belted and unbelted occupants from ejection.[120] However, among these occupants, a small number of occupants (3% of belted and 10% of unbelted) could be ejected through the front-bottom corner of the opening. When they are combined, the analysis shows that the hypothetical ejection mitigation curtain air bag would be 75% effective for belted and 68% effective for unbelted occupants in preventing ejection through the front window opening in lateral rollover crashes[121] when the air bag meets the proposed headform displacement requirement.[122] The 75% and 68% containment effective rates were then adjusted with the 5% sunroof ejection rate for both belted and unbelted occupants, respectively, to derive the 71% and 65% overall containment effectiveness rates for belted and unbelted occupants, respectively.[123]

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[120] As discussed previously, due to limited data, we used the belted ejection rate for unbelted occupants, as a proxy.

[121] The term "lateral roll" is used to describe rollovers that occur about vehicle's longitudinal axis.

[122] As discussed previously, we assumed that some occupants who are initially contained by the bag would be ejected through the sunroof.

[123] The derived effectiveness rates are based on the likelihood of partial and complete head ejections in rollover crashes. Therefore, one would argue that the effectiveness rates should be applied exclusively to head/face injuries and, consequently, other body injuries should not be included in the target population. On the other hand, real world crashes data show that the majority of serious injuries are head/face injuries in rollover crashes. According to Digges, in a report titled "Summary Report of Rollover Crashes," June 2002, about 45% of all Harms were from

B.2.2.2.2 Uniform risk of ejection: Previously, we discussed the risk of ejection through a particular area in the window opening under the assumption that the risk of ejection is proportional to the likelihood of impacts with areas surrounding the window opening in rollovers. As discussed, the agency does not have direct knowledge of actual ejection route through the window opening in rollovers. As an alternative to the weighted risk of ejection, we examined how potential benefits differ when the risk of ejection through the window opening is assumed to be uniformly distributed.

Although we do not have a direct knowledge of occupant ejection paths in the opening, laboratory and real world crash data indicate that the ejections may not uniformly distributed in the opening and the risk of ejection through the upper portion of the opening may be higher than the risk of ejection through the lower portion of the opening, particularly in the first few quarter turns of a rollover. How such an assumption would hold in the more sever rollovers that make up the majority of the benefits of the proposed rule is not well understood.[124] In other words, if we assume that ejections are uniformly distributed in the window opening, the risk of ejection through the potential gaps (below the curtain) would be greater than the estimated risk that was used in the weighted risk method.

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head related injuries. Based on the observation, we believe that a bag that is capable of preventing the head of an occupant from ejection would be effective in preventing other body injuries in most crashes (i.e., injuries would have occurred if an occupant had been ejected through the window opening).

[124] As discussed in the benefit chapter, a study performed by GM found that the majority of maximum resultant membrane attachment loads occur at the rear attachments with 43% of the maximum loads occurring at the upper rear corner and 33% occurring at the lower rear corner. The GM test data indicate that the risk of ejection through the lower portion of the window opening is lower than the risk of ejection through the upper portion of window opening. We note that this study is not representative of the majority of the target population of the proposed rule since about half of the tests were restricted to less than one quarter turn and no test was more than 2 quarter turns.

The uniform risk of ejection method is simpler and easier to understand than the weighted risk of ejection method. In addition, as mentioned previously, the "uniform" method does not require any laboratory or real world data and would not distinguish belted and unbelted occupant ejections for the containment effectiveness.

Previously, we estimated that rollover curtain bags may not be effective in preventing ejection when such ejection occur through the lower 1/3 portion of the opening, even if these bags meet the displacement requirement. If we assume that all ejections are uniformly distributed in the window opening, the bag would allow 1/3 of ejections through the potential gap in rollover crashes (resulting in a 67% containment effectiveness rate). When the 67% containment rate is adjusted with the 5% ejection rate through the sunroof, it would result in a 63% overall containment rate ($67\%_{\text{containment, uniform risk}} - 67\% \text{x} 5\%_{\text{ejection through sunroof}} = 63\%$).[125]

Since the risk of ejection through the upper portion of the window opening would be greater than the risk of ejection through the lower portion, the containment effectiveness based on an assumption that ejections are evenly distributed would be regarded as a minimum containment effectiveness (assuming that the hypothetical ejection mitigation system is not effective in preventing ejection through a potential gap between the curtain and the window sill).

We note that the use of the minimum containment effectiveness would not significantly affect the benefits estimate. One of the reasons for the insensitivity is that about 38% of the lives saved

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[125] As discussed later in the chapter, when the 63% containment effectiveness rate is used, the overall system effectiveness rate decreases from $45\%_{\text{weight, belted and unbelted}}$ to 43% for rollover crashes. Previously we estimated that 248 and 154 additional lives would be saved in rollover and side crashes, respectively. When the uniform risk is used, we expect that 390 additional lives would be saved. Among the 390 lives, 237 were from the rollover population and the remaining 152 were from the side impact. See Appendix E for additional information

were from occupants who were ejected in side crashes that were considered in the target population (154/402 = 38%). As discussed in the benefit chapter, these fatalities would not be affected by the "uniformly distributed" ejections in the window opening in rollovers.[126]

3. Injury risks associated with remaining inside the vehicle:

As part of the Advanced Glazing Project of NHTSA,[127] which was to reduce the number of fatalities and serious injuries in motor vehicle crashes due to ejection, Winnicki estimated the number of lives saved and serious injuries prevented when ejection is eliminated. His analysis utilized state data files maintained by NCSA, NHTSA.[128] It employs the double-pair comparison methodology to compare the injury rates in various severity levels among the ejected and the non-ejected vehicle occupants. Since complete ejection is rare among occupants of motor vehicle using the safety belts, his analysis was restricted to the unrestrained occupants. Due to limited data, the reduction rates based on the unrestrained occupants were used in the analysis.

Although we do not have statistically significant crash data, we believe that belted occupants would have a higher percent injury reduction rate when compared to unbelted occupants (when they remain inside the vehicle). According to Digges (in a report titled "Summary Report of Rollover Crashes"), brain/head are the most injured body regions (9.8% for brain and 13.3% for

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[126] Under the uniform risk assumption, the curtain system would prevent 296 serious injuries, annually. When the equivalent life saved was discounted by 3% and 7%, it resulted in 359 and 285 equivalent fatalities. With the $583M incremental total cost, the cost per equivalent life saved would be $1.63M and $2.04M, respectively. The net-benefit would be $1,605M and $1,158M at 3% and 7% discount rates, respectively.

[127] The study is for advanced glazing, which is a passive device in preventing occupants from ejection. Technically, there is no "sensor" in the passive containment system. However, for the discussion, we could say the system (glazing) is 100% effective in detecting crash events since the system is always "on" when windows are in "up" position.

[128] For additional information, see a report titled "Estimating the Injury-Reducing Benefits of Ejection-Mitigating Glazing," John Winnicki, DOT HS 808 369, February 1996.

head). He reports that a small number of the head/face injuries would occur as a result of impacts with the interior components, as shown below:

Table IV-39
Percent Distribution of Brain/Head Injuries by Injuring Source in Rollovers, Digges

Injury Source	Injured Body Region	Restrained NASS Sample Count	Injured %	Injury Source	Injured Body Region	Unrestrained NASS Sample Count	Injured %
Lower Side Intr	Abdomen	3	0.6%	Exterior	All	117	14.0%
Seatbelt	Abdomen	6	1.2%	All Other	All	516	61.6%
Exterior	All	12	2.3%	Roof	Brain	42	5.0%
All Other	All	331	63.5%	A & B Pillars	Brain	7	0.8%
Roof	Brain	22	4.2%	Rail/Headers	Brain	16	1.9%
Rail/Headers	Brain	9	1.7%	Windshield Edges	Brain	6	0.7%
Upper Side Intr	Brain	7	1.3%	Windshield	Brain	28	3.3%
A & B Pillars	Brain	2	0.4%	Lower Side Intr	Chest	16	1.9%
Noncontact	Brain	2	0.4%	Steering Assemble	Chest	21	2.5%
Loose Objects	Brain	5	1.0%	Rail/Headers	Head, other	5	0.6%
Lower Side Intr	Chest	8	1.5%	A & B Pillars	Head, other	6	0.7%
Steering Assemble	Chest	12	2.3%	Dash	Lower Xtr	34	4.1%
Seat Belt	Chest	16	3.1%	Seatback	Pelvis	2	0.2%
Dash	Lower Xtr	27	5.2%	Roof	Spine	3	0.4%
Roof	Neck, other	10	1.9%	Flying Glass	Upper Xtr	19	2.3%
Windshield Edges	Neck, other	2	0.4%				
Noncontact	Neck, other	27	5.2%				
Rail/Headers	Spine	1	0.2%				
Armrests	Upper Xtr	6	1.2%				
Dash	Upper Xtr	5	1.0%				
Seatback	Upper Xtr	2	0.4%				
Steering Assembl	Upper Xtr	6	1.2%				
	total	521	100.0%			838	100.0%
Total Head/Brain w/Interior Components			4.4%				13.1%

Table IV-39 shows that about 4% and 13% of the brain/head injuries were from impacts with the interior components for belted and unbelted, respectively. Since most brain injuries would be serious injuries,[129] one could conclude that unbelted occupants would have a higher risk of injury even if they remain inside of the vehicle. The data suggest that unbelted occupants would move

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[129] In a report titled "Summary Report of Rollover Crashes," Digges found that 23% of injuries were head/face injuries but accounting for about 55% of the comprehensive Harm.

around and the head of an unbelted occupant impacts interior objects much more than belted occupants in rollover. For example, we assumed there is an occupant who had a head injury as a result from contacting the ground in rollover (assume a chance of injury is "1"). When the ejection is prevented and occupant is belted, the data suggested that the belted occupant would move less freely around inside the vehicle and have a lower chance of head contacts with the interior components (with a "x" chance of injury) compared to when the occupant is not belted (with a "y" chance of injury, with "y" > "x"). If occupants are contained inside a vehicle, belted occupants would have a higher percent reduction rate when compared to unbelted occupants.[130] In other words, belted occupants would have a higher percent reduction rate when compared to unrestrained occupants when they remain inside the vehicle. Therefore, the use of the reduction rates (i.e., Winnicki's) based on the unrestrained occupants for both belted and unbelted occupants would underestimate the overall effectiveness.

<u>Ejections Occurred in Rollovers</u>: In the Winnicki report, an analysis by crash type shows that the greatest benefits of ejection prevention occur in rollover crashes (86% reduction in fatalities for driver and 90% reduction in fatalities for passenger). When partial and complete ejections are considered separately, it reports that the relative risk of fatality is reduced by 85.6% for partially ejected drivers and 87.1% for completely ejected drivers when ejection is eliminated in rollover crashes. For passengers, the relative risk of fatality is reduced by 90.1% for partially ejected drivers and 89.7% for completely ejected drivers.

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[130] As discussed in the target population section, we excluded fatalities from catastrophic rollovers. In other words, we only considered non-catastrophic rollovers where the structure of a vehicle remains intact.

For the benefit analysis, we utilized the reduction rates derived by Winnicki by averaging (i.e., simple average, not weighted) the driver's and passenger's relative risk reduction rates, as shown below:

Table IV-40
Average Fatal Injury Risk Reduction Rates in Rollovers

Occupant	Partial Ejection	Complete Ejection
Driver:	86%	87%
Passenger:	90%	90%
Avg. (rounded):	88%	88%
Difference between driver and passenger:	4%	3%

The results in Table IV-40 show that both partially and completely ejected occupants in rollover crashes would have a similar fatal injury reduction rate (88%). One of the assumptions used in Winnicki's analysis is that the effect of being prevented from ejection by the advanced glazing is the same as the effect of being prevented from ejection by other elements of vehicle interior components. By utilizing the reduction rates, we are assuming that the effect of being prevented from ejection by air bags is the same as the effect of being prevented from ejection by other elements of vehicle interior components.

Ejections Occurred in Side Impacts: According to Winnicki, on average, the relative risk of fatality would be reduced by 49% for partially ejected occupants and 41% for completely ejected occupants in side crashes when ejection is eliminated, as shown below:

Table IV-41
Average Fatal Injury Risk Reduction Rates in Near Side Crashes

Occupant	Partial Ejection	Complete Ejection
Driver:	57%	37%
Passenger:	40%	45%
Avg.	49%	41%

For left side impacts, the rates are 37% for drivers (near-side) and 68% for front passengers (far-side) in complete ejection side crashes; for right side impacts 79% for drivers (far-side) and 45% for front passengers (near-side) in complete ejection side crashes, as shown below:

Table IV-42
Percent Reduction Rate, Complete Ejection Left Side Impact

Occupant	Fatalities	Incapacitating Injuries
Driver:	**37%**	54%
Passenger:	68%	37%

Table IV-43
Percent Reduction Rate, Complete Ejection Right Side Impact

Occupant	Fatalities	Incapacitating Injuries
Driver:	79%	49%
Passenger:	**45%**	21%

The fatal reduction rates show that near-side occupants are more vulnerable to fatal injuries and would have a higher fatal risk even if they are contained inside vehicles in side crashes when compared to far-side occupants.

For the analysis, we used the reduction rates derived for near-side occupants: drivers for left side impacts and front passengers for right side impacts.[131] Accordingly, the hypothetical curtain (rollover) bag would be 37% and 45% effective in protecting drivers and front passenger who are

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[131] The rates would be minimum reduction rates, and the use of these rates would underestimate the potential benefits. We could use a simple average or weighted average of near and far side for the Final Regulatory Impact Analysis (FRIA).

completely ejected in fatal side crashes, respectively. For partially ejected front occupants, the rates are 57% for drivers and 40% for front passengers, as shown below:

Table IV-44
Reduction in Fatal and Serious Injury Risks in Side Impacts
Partially and Completely Ejected Occupants When Ejection is Eliminated

Occupants	Fatalities		Incapacitating Injuries	
	Partial Ejection	Complete Ejection	Partial Ejection	Complete Ejection
Driver	57%	37%	53%	54%
Passenger	40%	45%	45%	21%
Avg.	49%	41%	49%	38%

In the method section in this chapter, we said that the basic estimation procedure consists of four steps: B.1 group fatal and serious injuries (MAIS 3-5) by crash type (rollover or side impacts), ejection type (partial or complete) and belt use; B.2 calculate performance of the ejection mitigation air bag system; B.3 calculate overall percentage reduction rates; and B.4 derive benefits. The following section B.3 discusses the methodology used to calculate overall percent reduction rates for each subgroup.

B.3 Overall Percent Reduction Rate: Rollover crashes are complex events. As a result, the effectiveness of an occupant ejection mitigation system depends on several factors, such as sensitivity of its sensor, size of the curtain, deployment time, operation/inflation duration, and chamber gas pressure, etc. For the benefit analysis, we assumed that its effectiveness is directly and solely related to three factors: its sensor, containment effectiveness, and the risk of receiving injuries when occupants are contained inside vehicles in crashes. Our analysis shows that many crash conditions (crash mode, belt use, partial/complete ejection, etc.) would affect the effectiveness of these factors (sensor, containment & risk of remaining in the vehicle). The overall system effectiveness shows that rollover air bags would be reasonably effective in preventing occupant ejection in most fatal rollover crashes (about 45%[132] as presented in Table IV-45). However, for belted occupants who were completely ejected through the opening, we believe that these occupants were involved in very severe rollover crashes such that the containment system may not be capable of preventing these occupants from ejection and/or the structure cannot withstand the impact forces in such severe crashes. Accordingly, for the benefit analysis, we assumed that the system is not effective in protecting completely ejected belted occupants in rollover crashes. For unbelted occupants who were completely ejected through the opening, we believe that some of these occupants were involved in very severe crashes that the vehicle's structure cannot withstand the crash loads. However, we do not have data to quantify these occupants. According to our rollover crash data (as shown in Table IV-5), there were 595 belted occupant fatalities. Among the 595 belted occupant fatalities, 538 were partial and the remaining 57 were from complete ejections. Since belted occupants would remain in the vehicle as long as the structure withstands the loads, we reasoned that the vehicle's structure did not withstand the loads for the 57 fatal belted occupants. The assumption implies that all partially ejected belted occupants who were fatally injured were not from catastrophic rollover crashes. Under the assumption, the risk of non-catastrophic fatal crashes (that the structure of a vehicle can withstand the loads) would be about 9 times higher than the risk of catastrophic fatal crashes (538/57 = 9.4 times, or 9.58% of all belted fatalities would be from catastrophic crashes, 57/595 = 9.58%). In other words, the number of fatalities in catastrophic crashes would be 9.4 times smaller than the number of fatalities resulting from partial ejections. For unbelted occupants, there were 3,073 fatalities in rollovers. Among the 3,073 unbelted fatalities, 515 were from partial ejections and the remaining 2,558 were from unbelted complete ejections. Note that for

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[132] The target population shows that 15% of the fatalities were belted and the remaining 85% were unbelted occupants. In the following section, we estimated that the ejection mitigation system has an overall effectiveness of 48% for partially ejected belted occupants and 44% for unbelted occupants: (15% x 48%) + (85% x 44%) = 45%.

the fatally injured belted occupants, we assumed that all completely ejected occupants were from catastrophic rollovers. However, it would not be reasonable to make such assumption for unbelted occupants since the risk of ejection of unbelted occupants would be much higher than that of belted occupants in rollovers. In other words, some of completely ejected occupants would be from none catastrophic rollovers. If we assume that the occurrence of catastrophic fatal crashes is independent of belt use, as discussed above, the number of fatalities in catastrophic crashes would be 9.4 times smaller than the number of fatalities resulting from partial ejections. Therefore, 55 fatalities out of the 2,558 complete-unbelted ejections (515$_{\text{partial ejection}}$/9.4) = 55) would be from catastrophic fatal crashes. Similar to the methodology used for the belted complete fatalities, we assumed that crashes were too severe for the mitigation system to be effective for the 55 unbelted complete fatalities in rollovers (i.e., 55 fatalities out of the 2,558 unbelted complete ejections were from catastrophic rollover crashes, i.e., 2.13% of the 2,558 of the complete unbelted fatalities). Accordingly, these unbelted partial ejection fatalities were not considered in the target population.[133] For side impacts, the overall effectiveness ranges from 21% to as high as 49%. The complete list of overall system effectiveness rates for fatally injured occupants is shown below:

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[133] As discussed, we do not know the number of fatalities resulting from catastrophic rollover crashes. Since it is unlikely that all belted complete ejection fatalities were from catastrophic rollover crashes, the assumption (that the ejection mitigation system is not effective in these fatal crashes) would underestimate the benefit. On the other hand, some fatal partial ejections (whether belted or not) could be from catastrophic rollover crashes.

Table IV-45a
Overall System Effectiveness for Fatalities, Weighted Distribution Method

Crashes		Sensor	Containment	Winnicki's	System
Rollover, no side impacts:					
Belted	Partial	77%	71%	88%(1)	48%
Belted	Complete	77%	0%(2)	88%(1)	0%
Unbelted	Partial	77%	65%	88%	44%
Unbelted	Complete(3)	77%	65%	88%	44%
Side impacts followed by rollovers, excluding 12-25 mph:					
Belted	Partial	77%	71%	49%	27%
Belted	Complete	77%	0%	41%	0%
Unbelted	Partial	77%	65%	49%	25%
Unbelted	Complete	77%	65%	41%	21%
Side impacts, w/ subsequent rollovers, 12-25 mph:					
Belted	Partial	100%	71%	49%	35%
Belted	Complete	100%	0%	41%	0%
Unbelted	Partial	100%	65%	49%	32%
Unbelted	Complete	100%	65%	41%	27%
Side impacts, no rollovers, 12-25 mph:					
Belted	Partial	100%	100%	49%	49%
Belted	Complete	100%	0%	41%	0%
Unbelted	Partial	100%	100%	49%	49%
Unbelted	Complete	100%	100%	41%	41%
Side impacts, no rollovers, children (0-12 yrs), partial & complete, 12-25 mph:					
Belted	Partial	100%	100%	49%	49%
Belted	Complete	100%	0%	41%	0%
Unbelted	Partial	100%	100%	49%	49%
Unbelted	Complete	100%	100%	41%	41%

(1) As discussed, the actual percent reduction rate would be higher than 88% for belted occupants. Consequently, the overall system effectiveness would be higher.

(2) We assumed that the structure would not withstand the impact loads in rollovers (i.e., catastrophic crashes) that result in complete ejection for belted occupants.

(3) Similar to the complete belted occupants, the target population was adjusted to account for complete partial unbelted occupants in catastrophic rollover crashes.

Table IV-45b
Overall System Effectiveness for Fatalities, Uniform Distribution Method

Crashes			Sensor	Containment	Winnicki's	System
Rollover, no side impacts:						
	Belted	Partial	77%	63%	88%	43%
	Belted	Complete	77%	0%	88%	0%
	Unbelted	Partial	77%	63%	88%	43%
	Unbelted	Complete	77%	63%	88%	43%
Side impacts followed by rollovers, excluding 12-25 mph:						
	Belted	Partial	77%	63%	49%	24%
	Belted	Complete	77%	0%	41%	0%
	Unbelted	Partial	77%	63%	49%	24%
	Unbelted	Complete	77%	63%	41%	20%
Side impacts, w/ subsequent rollovers, 12-25 mph:						
	Belted	Partial	100%	63%	49%	31%
	Belted	Complete	100%	0%	41%	0%
	Unbelted	Partial	100%	63%	49%	31%
	Unbelted	Complete	100%	63%	41%	26%
Side impacts, no rollovers, 12-25 mph:						
	Belted	Partial	100%	100%	49%	49%
	Belted	Complete	100%	0%	41%	0%
	Unbelted	Partial	100%	100%	49%	49%
	Unbelted	Complete	100%	100%	41%	41%
Side impacts, no rollovers, children (0-12 yrs), partial & complete, 12-25 mph:						
	Belted	Partial	100%	100%	49%	49%
	Belted	Complete	100%	0%	41%	0%
	Unbelted	Partial	100%	100%	49%	49%
	Unbelted	Complete	100%	100%	41%	41%

In the previous section, we analyzed the likelihood of ejection through potential gaps around the air bag in rollover crashes. Two methods namely “weighted risk of ejection” and “uniform risk of ejection” were used to derive the containment effectiveness. First, for the weighted risk of ejection method, the impact distribution was based on laboratory and real world crash data. Containment effectiveness was then derived from assumptions about window area coverage (71% for belted and 65% for unbelted occupants). For the uniform risk method, we assumed that ejections are evenly distributed in the opening area (63% for both belted and unbelted). As shown tables above, the weighted risk of ejection method and the uniform risk of ejection method produced similar effectiveness estimates, but the weighted risk had a slightly lower overall effectiveness value for rollovers.

For side crashes, however, we did not have laboratory dummy impact distribution data to derive the containment effectiveness rate. Rather, we assumed that a rollover curtain air bag is effective in preventing complete ejection in a very narrow delta-V range. In the FMVSS No. 214 Final Regulatory Impact Analysis (FRIA) for the oblique pole, we estimated that the FMVSS No. 214-curtain air bag system would be effective in a lateral delta-V range of 12-25 mph. In addition, the oblique pole test results showed that the head of a test dummy must be in contact with the curtain to be effective in the delta-V range.

In the FMVSS No. 214 FRIA, the agency determined that the FMVSS No. 214 curtain air bag system could prevent some complete ejections in side crashes. However, we could not quantify the effectiveness for this crash mode and ejection status. Consequently, we assumed that the FMVSS No. 214 curtain air bag would not be effective in preventing occupants from complete ejection in side crashes. The agency believes that a curtain air bag that is capable of meeting both the FMVSS No. 214-oblique and the proposed linear headform test requirements would be effective in preventing occupant ejection through the window opening in a lateral delta-V range of 12-25 mph. In the FMVSS No. 214 FRIA for the oblique pole, the agency determined a total of 9,270 fatalities would occur in side impact crashes (passenger vehicles, based on 2004 FARS). Among the 9,270 fatalities, 306 were from side crashes preceded by rollovers and the remaining 8,963 were from non-rollover side crashes. When the 8,963 were categorized by occupant seating position, it showed that 2,877 were from far-side adult occupants and 5,591 were from near-side adult occupants. Among the 5,591 near-side occupants, 2,551 were from side crashes occurred in a delta-V range of 12-25 mph (i.e., 46% of the 5,591 fatalities, and the remaining 3,040 were from other delta-V's). Among the 2,551 fatalities, 207 were from completely ejected adult occupants (8.1% of the 2,551 fatalities) in a delta-V range of 12-25 mph. If we assume that near-side occupants have the same risk of complete ejection in all vehicle delta-V's, there would be 246 completely ejected adult fatalities in the other delta-V's (i.e., not 12-25 mph, 3,040 x 8.1% = 246). Therefore, a total of 453 fatalities would be from completely ejected near-side adult occupants in side crashes (in all delta-V's, 207 + 246 = 453). According to Kahane, head curtains reduce the risk of fatal occupant ejection in side impacts by a statistically significant 30 percent.[134] Therefore, about 136 lives could be saved among the 453 fatal complete ejections (453 x 30% = 136). In the ejection mitigation analysis, we estimated that the curtain ejection mitigation curtain air bag would be 49% and 41% effective for belted and unbelted, respectively, in a narrow delta-V range of 12 -25 mph fatal side crashes (as shown in Table IV-45). When the effectiveness rates were applied to the 207 completely ejected adult occupants in a delta-V range of 12-25 mph, about 90 lives would be saved in the side crashes (207 x $46\%_{\text{if all belted}}$ = 95 and 207x $41\%_{\text{if all unbelted}}$ = 85). The above calculation illustrates that the assumption (that the hypothetical ejection mitigation system is only effective in a delta-V range of 12-25 mph in side crashes) would somewhat underestimate the benefits. In summary, it appears that the derived 49% and 41% system effectiveness rates would be reasonable when compared to the estimate made with real world crash data.

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[134] Kahane, C.J. *An Evaluation of Side Impact Protection – FMVSS 214 TTI(d) Improvements and Side Air Bags.* NHTSA Technical Report No. DOT HS 810 748, Washington, 2007

For serious injuries, the derivation shows that the ejection mitigation system would be less effective when compared to fatal injuries. The effectiveness ranges from 20% for unbelted completely ejected occupants in side-then-roll crashes to 49% for belted ejections in side crashes.[135] The complete list of overall system effectiveness rates for serious injuries is shown below:

Table IV-46a
Overall System Effectiveness for Serious Injuries Weighted Distribution Method

Crashes			Sensor	Containment	Winnicki's	System
Rollover, no side impacts:						
	Belted	Partial	84%	71%	67%	40%
	Belted	Complete	84%	0%	52%	0%
	Unbelted	Partial	84%	65%	67%	36%
	Unbelted	Complete	84%	65%	52%	28%
Side impacts followed by rollovers, excluding 12-25 mph:						
	Belted	Partial	84%	71%	49%	29%
	Belted	Complete	84%	0%	38%	0%
	Unbelted	Partial	84%	65%	49%	27%
	Unbelted	Complete	84%	65%	38%	20%
Side impacts, w/ subsequent rollovers, 12-25 mph:						
	Belted	Partial	100%	71%	49%	35%
	Belted	Complete	100%	0%	38%	0%
	Unbelted	Partial	100%	65%	49%	32%
	Unbelted	Complete	100%	65%	38%	24%
Side impacts, no rollovers, 12-25 mph:						
	Belted	Partial	100%	100%	49%	49%
	Belted	Complete	100%	0%	38%	0%
	Unbelted	Partial	100%	100%	49%	49%
	Unbelted	Complete	100%	100%	38%	38%
Side impacts, no rollovers, children (0-12 yrs), partial & complete, 12-25 mph:						
	Belted	Partial	100%	100%	49%	49%
	Belted	Complete	100%	0%	38%	0%
	Unbelted	Partial	100%	100%	49%	49%
	Unbelted	Complete	100%	100%	38%	38%

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[135] For the containment effectiveness for seriously injured occupants, we assumed that the bag is equally effective for both fatally and seriously injured occupants, when such ejections occur.

Table IV-46b

Overall System Effectiveness for Serious Injuries, Uniform Distribution Method

Crashes			Sensor	Containment	Winnicki's	System
Rollover, no side impacts:						
	Belted	Partial	84%	63%	67%	35%
	Belted	Complete	84%	0%	52%	0%
	Unbelted	Partial	84%	63%	67%	35%
	Unbelted	Complete	84%	63%	52%	28%
Side impacts followed by rollovers, excluding 12-25 mph:						
	Belted	Partial	84%	63%	49%	26%
	Belted	Complete	84%	0%	38%	0%
	Unbelted	Partial	84%	63%	49%	26%
	Unbelted	Complete	84%	63%	38%	20%
Side impacts, w/ subsequent rollovers, 12-25 mph:						
	Belted	Partial	100%	63%	49%	31%
	Belted	Complete	100%	0%	38%	0%
	Unbelted	Partial	100%	63%	49%	31%
	Unbelted	Complete	100%	63%	38%	24%
Side impacts, no rollovers, 12-25 mph:						
	Belted	Partial	100%	100%	49%	49%
	Belted	Complete	100%	0%	38%	0%
	Unbelted	Partial	100%	100%	49%	49%
	Unbelted	Complete	100%	100%	38%	38%
Side impacts, no rollovers, children (0-12 yrs), partial & complete, 12-25 mph:						
	Belted	Partial	100%	100%	49%	49%
	Belted	Complete	100%	0%	38%	0%
	Unbelted	Partial	100%	100%	49%	49%
	Unbelted	Complete	100%	100%	38%	38%

B.4 Derive Benefit:

B.4.1 Lives saved and injuries prevented by ejection mitigation system. To comply with the proposed ejection mitigation requirements, vehicle manufacturers would most likely install rollover curtain air bag systems in their vehicles. Although the agency has limited real world crash data, the agency's DRF and linear headform test data show that rollover air bags would be very effective in preventing occupants from ejection in rollover and certain side crashes.[136] For

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[136] During agency's DRF tests, TRW and Simula AHPS curtains contained the torso, head, and neck of the dummy, so complete ejection did not occur in a simulated rollover crash environment. The test devices/curtains (TRW air

potential benefits, separate analyses were performed for five sub-target population groups: (A) rollover crashes without side impacts; (B) side impacts followed by rollovers, excluding 12-25 vehicle delta-V's; (C) side impacts followed by rollovers in a vehicle delta-V range of 12-25 mph; (D) side impacts without rollover crashes in a vehicle delta-V range of 12-25 mph; (E) Children in side impacts without rollover crashes in a vehicle delta-V range of 12-25 mph.

A. Rollover Crashes without Side Impacts

Lives Saved: When all light vehicles are equipped with the ESC system, we estimated a total of 749 fatalities would occur in rollover crashes, annually. Among the 749 fatalities, 218 would be from partial ejections and the remaining 531 would be from complete ejections. Among the 531 complete fatal ejections, 519 were from unbelted occupants. Previously we estimated that about 2.13% of the complete unbelted fatalities would be from catastrophic crashes where the structure would not withstand the crash loads. Accordingly, these fatalities were excluded from the target population. The system effectiveness for these crashes ranges from zero percent for completely ejected belted occupants to 48% for partially ejected belted occupants. When the system is fully implemented, we expect a total of 332 lives would be saved, annually, in rollover crashes, as shown below:

Table IV-47
Lives Saved in Rollover Crashes without Side Impacts

Occupant		Fatalities adj. w/ ESC(1)	System effectiveness	Benefits (lives)
Belted	Partial	112	48%	54
Belted	Complete	12	0%	0
Unbelted	Partial	107	44%	47
Unbelted	Complete	519	44%	231
			Total	332

(1) We assumed that all applicable vehicles are equipped with ESC.

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curtain and Simular AHPS) allowed the shoulder and arm to escape below the bags. See a report titled "Status of NHTSA's Ejection Mitigation Research Program" for additional discussion.

Injuries prevented: We estimated a total of 783 serious injuries (MAIS 3-5) would occur in rollover crashes, annually. Among the 783 serious injuries, 311 would be from partial ejections and the remaining 472 would be from complete ejections. When the catastrophic crashes were excluded, it resulted in 449 completely ejected seriously injured occupants in the target population.[137] The system effectiveness rate ranges from zero percent for completely ejected belted to 40% for partially ejected belted occupants. When the system is fully implemented, we expect a total of 245 serious injuries would be prevented, annually, in rollover crashes, as shown below:

Table IV-48
Serious Injuries Prevented(1) in Rollover Crashes without Side Impacts

Occupant		Injuries adj. w/ ESC	System effectiveness	Benefits (MAIS 3-5)
Belted	Partial	237	40%	94
Belted	Complete	12	0%	0
Unbelted	Partial	74	36%	27
Unbelted	Complete	436	28%	124
	Total	759		245

(1) The numbers were rounded to the nearest integer.

B. Side Impacts Followed by Rollovers, Excluding 12-25 mph Vehicle Delta-V

Lives saved: We estimated a total of 251 fatalities would be in the target population of ejections for side impacts followed by rollovers at all but 12 -25 mph vehicle delta-V's, annually.[138] Among the 251 fatalities, 137 would be from partially ejected unbelted occupants and the remaining 114 would be from completely ejected unbelted occupants. When the system is fully implemented, we expect a total of 57 lives would be saved, annually, as shown below:

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[137] There were 56 completely ejected and 1,078 partially ejected serious injuries: 56/1,078 = 5.2%. We assumed that 5.2% of the 2,094 unbelted complete ejection injuries would be from catastrophic crashes. Similar to the methodology used for the fatalities, these crashes were excluded from the target population.

[138] As discussed in the target population section, we have a separate benefit analysis for the 12-25 mph side crashes followed by rollovers.

Table IV-49
Lives Saved in Side Impacts Followed by Rollovers
Excluding 12-25 Vehicle Delta-V's

Occupant		Fatalities adj. w/ ESC	System effectiveness	Benefits (lives)*
Belted	Partial	0	27%	0
Belted	Complete	0	0%	0
Unbelted	Partial	137	25%	34
Unbelted	Complete	114	21%	24
			Total	57

* The numbers were rounded to the nearest integer.

Injuries prevented: For the target population, we estimated a total of 210 serious injuries would occur in the crashes, annually. Among the 210 seriously injured occupants, 49 would be from partial ejections and the remaining 161 would be from complete ejections. When the system is fully implemented, we expect a total of 42 serious injuries would be prevented, annually, as shown below:

Table IV-50
Injuries Prevented in Side Impacts Followed by Rollovers
Excluding 12-25 Vehicle Delta-V's

Occupant		Injuries adj. w/ ESC	System effectiveness	Benefits (MAIS 3+)†
Belted	Partial	49	29%	14
Belted	Complete	28	0%	0
Unbelted	Partial	0	27%	0
Unbelted	Complete	134	20%	27
			Total	42

† The numbers were rounded to the nearest integer.

Note that the number of serious injuries prevented in this side impact case shows that a relatively small number of serious injuries would be prevented in side crashes when compared to the potential benefits in rollovers. The relatively low potential benefits are mainly due to the smaller target population.

C. Side Impacts Followed by Rollovers in Vehicle Delta-V Range of 12-25 mph

Lives saved: We estimated a total of 79 fatalities would occur in the target population of ejections for side impacts followed by rollover crashes, annually. Among the 79 fatalities, 11 would be from completely ejected belted occupants and the remaining 68 would be from completely ejected unbelted occupants. Note that the FMVSS No. 214-benefit assessment included potential benefits for belted and unbelted occupants who were partially ejected in fatal side impacts in a delta-V range of 12-25 mph. Accordingly, the FMVSS No. 214-fatal benefits were excluded from the ejection mitigation benefit estimate. We estimated that the system would save 18 lives, annually, as summarized below:

Table IV-51
Lives Saved in Side Impacts Followed by Rollovers in Vehicle Delta-V Range of 12-25 mph

Occupant		Fatalities adj. w/ ESC	System effectiveness	Benefits (lives)
Belted	Partial	0	35%	0
Belted	Complete	11	0%	0
Unbelted	Partial	0	32%	0
Unbelted	Complete	68	27%	18

Injuries prevented: We estimated a total of 310 serious injuries would occur in side impacts followed by rollover crashes, annually: 108 from partial and 202 from complete ejections. As discussed, we included potential benefits for both partially and completely ejected occupants who were seriously injured in a delta-V range of 12-25 mph. When fully implemented, we expect a total of 84 serious injuries would be prevented by the ejection mitigation system, annually. The estimated benefits are shown below:

Table IV-52
Injuries Prevented in Side Impacts Followed by Rollovers in
Vehicle Delta-V Range of 12-25 mph

Occupant		Injuries adj. w/ ESC	System effectiveness	Benefits (MAIS 3+)
Belted	Partial	4	35%	1
Belted	Complete	0	0%	0
Unbelted	Partial	104	32%	33
Unbelted	Complete	202	24%	49

D. Side Impacts without Rollover Crashes in Vehicle Delta-V Range of 12-25 mph:

Lives saved: Similar to the side impacts with subsequent rollovers in a delta-V range of 12-25 mph, only unbelted occupants who were completely ejected in fatal side impacts in the delta-V range were considered. For the target population, we estimated a total of 259 fatalities would occur in side impacts without rollover crashes, annually. When the system is fully implemented, we expect a total of 106 lives would be saved, annually, in non-rollover side impacts, as shown below:

Table IV-53
Lives Saved in Side Impacts without Rollover Crashes in
Vehicle Delta-V Range of 12-25 mph

Occupant		Fatalities adj. w/ ESC	System effectiveness	Benefits (lives)
Belted	Partial	0	49%	0
Belted	Complete	0	0%	0
Unbelted	Partial	0	49%	0
Unbelted	Complete	259	41%	106

Injuries prevented: For the benefit analysis, only occupants who were completely ejected in side impacts in the delta-V range (12 – 25 mph) were considered. We estimated a total of 75 serious injuries would occur in side impacts without rollover crashes, annually. These 75 seriously injures would be from completely ejected unbelted occupants. When the system is fully implemented, we expect a total of 28 serious injuries would be prevented in non-rollover 12-25 mph side impacts, annually, as shown below:

Table IV-54
Injuries Prevented in Side Impacts without Rollover Crashes in
Vehicle Delta-V Range of 12-25 mph

Occupant		Injuries adj. w/ ESC	System effectiveness	Benefits (MAIS 3+)
Belted	Partial	0	49%	0
Belted	Complete	0	0%	0
Unbelted	Partial	0	49%	0
Unbelted	Complete	75	38%	28

We note that the benefit estimates are based on assumptions that side impacts sensors are effective in detecting crashes in the delta-V range and that air bags designed to solely meet the FMVSS No. 214-pole test requirements are not capable of preventing unbelted occupants from complete ejection in 12-25 mph side crashes.

E. Children (0-12 years) in Side Impact with No Rollover in Delta-V of 12 -25 mph:

Lives saved: For children in side impacts without subsequent rollovers in a delta-V range of 12-25 mph, both partially and completely ejected children were considered in the delta-V range. We estimated that a total of 54 child fatalities would occur in 12-25 mph side impacts without rollover crashes, annually, when all applicable vehicles are equipped with ESC. Among the 54 fatalities (rounded to the nearest integer), 25 were from completely ejected unbelted children and the remaining 29 were from partially ejected belted children. When the system is fully implemented, we expect a total of 24 lives would be saved, annually, in non-rollover side impacts, as shown below:

Table IV-55
Lives Saved in Side Impacts without Rollover Crashes in
Vehicle Delta-V Range of 12-25 mph, Children

Occupant		Fatalities adj. w/ ESC	System effectiveness	Benefits (lives)
Belted	Partial	29	49%	14
Belted	Complete	0	0%	0
Unbelted	Partial	0	49%	0
Unbelted	Complete	25	41%	10

Injuries prevented: We estimated a total of 41 serious injuries would occur in side impacts without rollover crashes, annually. These 41 seriously injures would be from both partially and completely ejected unbelted children. When the system is fully implemented, we expect a total of 16 serious injuries would be prevented, annually, in non-rollover 12-25 mph side impacts, as shown below:

Table IV-56
Injuries Prevented in Side Impacts without Rollover Crashes in
Vehicle Delta-V Range of 12-25 mph, Children

Occupant		Injuries adj. w/ ESC	System effectiveness	Benefits (MAIS 3+)
Belted	Partial	0	49%	0
Belted	Complete	0	0%	0
Unbelted	Partial	6*	49%	3
Unbelted	Complete	34*	38%	13

* The numbers were rounded to the nearest integer.

Figure IV-6 Lives Saved by Window Ejection Mitigation System, with 100% ESC

In summary, as shown in Figure IV-6, the hypothetical ejection mitigation system would save 538 lives and prevent 414 serious injuries, annually, when the system is fully implemented. The majority of the potential benefits would be from protecting occupants in rollover crashes. About 62 % of the fatal and 59% of the serious injury benefits would be from the rollover protection.[139]

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[139] The agency's crash data show that the majority of serious injuries were AIS 3 injuries, as shown below:

Belt use	Ejection	MAIS 3	MAIS 4	MAIS 5	Total
Belted	Partial	69%	29%	2%	100%
Belted	Complete	59%	6%	35%	100%
Unbelted	Partial	74%	22%	4%	100%
Unbelted	Complete	59%	26%	15%	100%

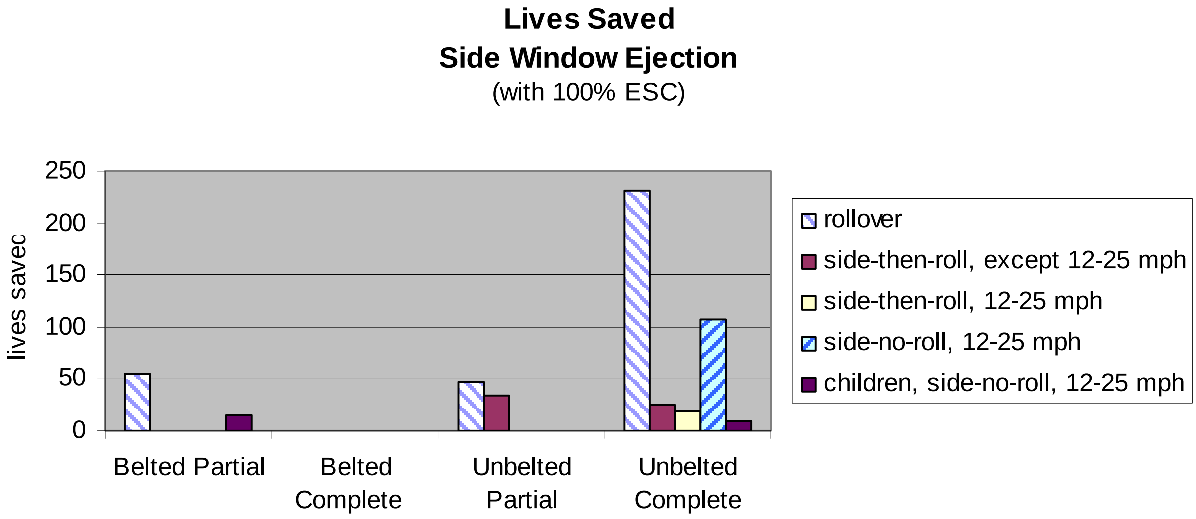

Figure IV-6. Number of Lives Saved with Ejection Mitigation Air Bag

B.4.2 Incremental benefits over MY 2011 voluntary installations: The benefit estimate was based on an assumption that the vehicles (involved in the rollover and side crashes) were not equipped with ejection mitigation air bags, as shown in Table IV-57.

Table IV-57
Benefits of Ejection Mitigation Air Bag, AIS 3-5 and Fatal
Assuming None of Vehicles are Equipped with Bag

Crash	AIS 3	AIS 4	AIS 5	Fatalities
Rollover, no side impact:	157	66	22	332
Side impacts followed by rollover, not 12-25 mph:	26	11	4	57
Side impact with subsequent rollover, 12-25 mph:	54	21	9	18
Side impacts, no rollover, 12-25 mph:	17	7	4	106
Side impacts, no rollover, Children, 12-25 mph:	10	4	2	24
Total:	264	109	41	538

However, vehicle sales data submitted by manufacturers show that about 55% of MY 2011 vehicles will be equipped with a rollover ejection mitigation system (i.e., typically, consist of two curtain air bags and a rollover sensor per vehicle). Based on our linear headform test results, we believe that some of the systems would be effective in preventing occupants from ejection in certain crashes. Accordingly, the estimated benefits (in terms of lives saved and injuries prevented) were adjusted with the potential benefits of these air bags: the number of MY 2011 vehicles that are equipped with rollover air bags and also the compliance rate.[140] For the adjustment, individual air bag type was not considered; rather it was assumed that vehicles are equipped with production curtain rollover bags regardless of vehicle model or type. For the compliance rate (i.e., passing rate for the proposed linear guided headform test requirements), each impact point was considered separately and the linear headform tests performed at an impact speed of 24 km/h at 1.5 second delay were used[141], as shown in Table IV-58

Table IV-58
Linear Headform Test Compliance Rate
24 km/h at 1.5 second delay

Vehicle	MY	Front (1st row)			
		A1	A2	A3	A4
Ford Navigator	2003	N/A	Fail	Fail	-22
Ford Navigator w/ theft lam.	2003	N/A	35	N/A	N/A
Volvo XC90	2004	Fail	193	130	18
Volvo w/ theft lam.	2004	Fail	44	118	15
Nissan Pathfinder	2005	Fail	161	Fail	76/76
Toyota Highlander	2005	Fail	202	137	67
Infinity FX35	2005	124	83/96/112	89/89/108	53

Table IV-59
Linear Headform Test Compliance/Passing Rate
At Given Impact Point

Opening	Front Window (1st row)			
Impact Point	A1	A2	A3	A4
Passing Rate	0%	30%	22%	100%

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[140] The compliance rate is based on pre-MY 2007 vehicles. By applying the pre-MY 2007 vehicle compliance rate, we are assuming that the performance of the MY 2007 bags remains unchanged.

[141] The use of the 24 km/h (with 1.5 second delay) headform data does not imply that air bags that meet the deflection requirement in this test condition would be in compliance with the proposed requirements. In other words, we expect that not all bags that meet the 24 km/h impact requirement will be in compliance with the proposed requirements at 6 second delay. Accordingly, the use of the 24 km/h performance data, as a proxy, would underestimate the (overall) additional benefits by overestimating their passing rates.

The linear headform test results show that none of the curtain air bags met the displacement requirement at A1, whether laminated glazing is used or not.[142] In contrast, none of the vehicles failed the requirement at A4.[143]

Risk of ejection at each impact point: In the containment effectiveness analysis section, we derived the risk of ejection through a particular area in the window opening. Similar to the approach used in the containment analysis, the window opening was divided into four areas (i.e., quadrant). To determine the risk of ejection through each quadrant in the window opening area, we assumed that any ejection through a particular quadrant is represented by the impact point at that quadrant. In other words, if the air bag meets the headform displacement requirement at a particular impact point, we assumed that the air bag would be effective in preventing occupants from ejection through that quadrant.[144] The risk of ejection through each quadrant for both belted and unbelted occupants are shown below:

Table IV-60
Risk of Ejection With Respect To Window Opening Area[145]
Ejection through Front Window Opening with 5% Ejection through Sunroof

Occupant Restraint	Headform Impact Point			
	A1	A2	A3	A4
Belted	5%	26%	11%	53%
Unbelted	16%	16%	32%	32%

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[142] The laminated glazing is primarily designed for theft protection, not ejection mitigation.

[143] For additional discussion, see Chapter III, "Test Data."

[144] For the compliance rate, we assumed that a curtain bag would be effective in preventing occupants from ejection through a particular quadrant if the bag meets the headform displacement requirement at that impact point. However, as discussed in the containment estimation section, the bag would allow certain ejections through the potential gaps even if it meets the displacement requirement at a given impact point in the window opening area. Therefore, the use of the assumption would underestimate the (overall) additional benefits by overestimating the containment effectiveness rate of current bags.

[145] We note that the percentages do not add up to 100% since we assumed that about 5% of occupants would be ejected through the sunroof when such ejections occur. For example, previously we estimated that belted occupants would have 67% chance of ejection through the upper portion and 83% chance of ejection through the rear portion of the window opening. With the 95% window ejection rate, we estimated that about 56% of ejections would occur through this quadrant (67%x83%x95% = 53%).

The results in Table VI -60 show that the majority of belted occupants would be ejected through the rear portion of the window opening (53%), whereas most unbelted occupants would be ejected through the upper portion of the opening. For both belted and unbelted occupants, with the weighted risk of ejection methodology, the risk of ejection through the front lower corner (of the window opening) would be relatively low. However, as mentioned previously, the movement of an occupant after he/she contacts the air bag was not considered in the weighted risk of ejection method. In other words, although the weighted risk of ejection method showed that the initial risk of ejection through the front lower corner is low, the risk of ejection through the area could increase when the occupant movement is considered. In addition, we note that the risk of ejection through the area would be the same as any other areas in the window opening when the uniform risk of ejection method/assumption is used.

For the risk of ejection through each quadrant, we considered belted and unbelted occupants together. The agency's real world crash data show that 15% of all fatal window ejections were from belted occupant and the remaining 85% were from unbelted occupants.[146] These belt use rates for fatally ejected occupants (15% and 85%) were used to derive a weighted risk of ejection at a given quadrant in the window opening, as shown below:

Table IV-61
Weighted Risk of Ejection through Front Window Opening Area
(Combined both Belted and Unbelted Occupants)[147]

Headform Impact Point	A1	A2	A3	A4
Risk of ejection	14%	17%	29%	35%

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[146] As shown previously in the target population section, there were 640 belted and 3,755 unbelted fatalities (a total of 4,395) when occupants were ejected through side window openings. Among the 640 belted fatalities, 595 were from the 1st row window opening and the remaining 45 were from the 2nd row window opening. For unbelted occupants, 3,076 were from the 1st row window opening, 641were from 2nd and the remaining 38 were from the 3rd row window opening.

[147] As discussed in Footnote 152, we assumed that 5% of the ejections would occur through the sunroof.

Table IV-61 shows that the risk of ejection through each quadrant ranges from 14% at the lower forward section to 35% at the upper rear portion of the front window (near the B-pillar) when both belted and unbelted are considered. The results show that the majority of ejections would be through the upper portion of the opening (64%[148]). To derive the percent of ejections that could be prevented (if all applicable vehicles are equipped with <u>currently</u> available air bag systems), the passing rate (i.e., compliance rate) was applied to the weighted risk of ejection for each impact point, as shown below:

Table IV-62
Probability of Ejection Prevented with Current Rollover Air Bags
Front Window Opening Area
(Both belted and unbelted occupants)

Impact Point	A1	A2	A3	A4	Total
Passing rate	0%	30%	22%	100%	
Weighted risk of ejection	14%	17%	29%	35%	
% of ejection prevented	0%	5%	6%	35%	46%

The results in Table IV-62 show that currently available ejection mitigation air bags would be most effective in preventing occupants from ejection through the upper rear portion of the window opening (near B-pillar); the majority of ejections would occur through this upper portion of the opening area. When the risk of ejection and the passing rate are combined, the results show that the current rollover curtain air bags would prevent about 46% of front window ejections when both belted and unbelted occupants are considered.

<u>Potential benefits result from voluntarily installed rollover air bags</u>: The percent of ejection prevented was applied to the number of vehicles that will be equipped with currently available

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[148] 29% at the A3 and 35% at the A4 = 64%, when both belted and unbelted fatalities were considered.

rollover air bags. For the baseline air bags sales, we utilized MY 2011 vehicles[149] that will be equipped with rollover air bags, as shown below:

Table IV-63
Percent of Vehicles Equipped with Rollover Ejection Bag
Passenger Cars and Light Trucks (All Body Types, MY 2011, Sales in Millions)

Model Year (MY)	Total Sales	Vehicles with Curtain Air Bag	Curtain Air Bag with Rollover Sensor	% Installation Rate
2011	17M	15M	8.7M	55%

When the weighted risk of ejection is adjusted with the MY 2011 rollover air bag installation rate, it resulted in a 25% adjustment factor (46% $_{\text{effectiveness, currently available air bag systems}}$ x 55%$_{\text{installation rate}}$ = 25% (25.27%)). In other words, if we assume that (1) all vehicles are equipped with ESC, (2) the performance of current rollover bags remains unchanged, and (3) future rollover bag sales are same as the projected sales in MY 2011 vehicles, about 25% of the total potential benefits would be realized by these bag systems. When the 25% adjustment factor was applied to the previously derived potential benefits[150], it resulted in 402 additional lives saved and 310 serious injuries prevented,[151] as shown below:

Table IV-64
Incremental Benefits* of Ejection Mitigation Air Bag

Crash	AIS 3	AIS 4	AIS 5	Fatalities
Rollover, no side impact:	118	49	16	248
Side impacts followed by rollover, not 12-25 mph:	19	8	3	43
Side impact with subsequent rollover, 12-25 mph:	41	15	7	14
Side impacts, no rollover, 12-25 mph:	12	6	3	80
Side impacts, no rollover, Children, 12-25 mph:	7	3	2	18
Total:	197	82	31	402

* The numbers were rounded to the nearest integer.

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[149] Although the phase-in begins in MY 2014, the MY 2011 vehicle data is most current data we have.

[150] Additional benefit = potential benefit x (1-25%). If the performance of current ejection mitigation curtain air bag remains unchanged, 55% of the 46% of MY 2011 vehicles would be meet the proposed displacement requirement. Therefore, without the proposed rule, 25% of MY 2011 vehicles would meet the displacement requirement. The potential benefits from the 25% complying vehicles were subtracted from the potential benefits.

[151] The methodology implies that curtain bags do not have any beneficial effects in reducing injury severity when an occupant impacts with a particular window opening area that failed the headform displacement requirement. We suspect that certain bags would provide some benefits even if they failed to meet the displacement. However, we do not have data to substantiate the speculation. Accordingly, these potential benefits were not considered in the analysis.

Summary of Benefits:

When vehicles are fully equipped with Electronic Stability Control (ESC) system, a total of 1,392 fatalities would occur when occupants are ejected through the side window opening areas in vehicle crashes.[152] Among these fatalities, about 54% are from rollovers not preceded by a side impact and the remaining 46% are from side impacts that may or may not result in a subsequent rollover. For the weighted risk of ejection method, the benefit analysis shows that when passenger cars and light trucks, including SUVs and minivans, are equipped with the hypothetical rollover curtain air bag[153], a total of 538 lives would be saved and 414 AIS 3+ serious injuries would be prevented, annually. The majority of the benefits would result from preventing occupants from ejection in rollovers crashes (62% of fatalities and 59% of serious injuries). It shows that a relatively small percentage of the benefits would be from protecting belted occupants (about 13% of fatalities and 26% of serious injuries), whether they are completely or partially ejected, when compared to unbelted occupants. When the estimated benefits are adjusted with the projected rollover bag sales (MY 2011) and the performance of current rollover bags, the benefit analysis shows that the ejection mitigation system would save 402 additional lives and prevent 310 additional serious injuries (MAIS 3-5), annually. The estimated potential and additional benefits are summarized below:

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[152] In the analysis, we estimated that some fatally injured occupants who were completely ejected in catastrophic rollover crashes would not be saved by the hypothetical ejection mitigation system. These fatalities are not included in the 1,392 fatalities.

[153] In other words, bags that are capable of meeting the proposed headform deflection requirement.

Table IV-65
Incremental Benefits

Crash Type, Belt Use, Ejection Type		Target adj. w/ 100% ESC		Benefits		Incremental Benefits		Total Incremental Benefits	
		Fatality	Injuries	Fatality	Injuries	Fatality	Injuries	Fatality	Injuries
Rollover, no side impacts:									
Belted	Partial	112	237	54	94	40	70		
Belted	Complete	12	12	0	0	0	0		
Unbelted	Partial	107	74	47	27	35	20		
Unbelted	Complete	519	436	231	124	173	93	248	183
Side impacts followed by rollovers, exclude 12-25 mph:									
Belted	Partial	0	49	0	14	0	11		
Belted	Complete	0	28	0	0	0	0		
Unbelted	Partial	137	0	34	0	25	0		
Unbelted	Complete	114	134	24	27	18	20	43	31
Side impacts, w/ subsequent rollovers, 12-25 mph:									
Belted	Partial	0	4	0	1	0	1		
Belted	Complete	11	0	0	0	0	0		
Unbelted	Partial	0	104	0	33	0	25		
Unbelted	Complete	68	202	18	49	14	37	14	62
Side impacts, no rollovers, 12-25 mph:									
Belted	Partial	0	0	0	0	0	0		
Belted	Complete	0	0	0	0	0	0		
Unbelted	Partial	0	0	0	0	0	0		
Unbelted	Complete	259	75	106	28	80	21	80	21
Side impact, no rollover, Children, 12-25 mph									
Belted	Partial	29	0	14	0	11	0		
Belted	Complete	0	0	0	0	0	0		
Unbelted	Partial	0	6	0	3	0	2		
Unbelted	Complete	25	34	10	13	8	10	18	12
	Total[154]	1,392	1,396	538	414	402	310	402	310

When the risk of ejection through the window opening is assumed to be uniform, we estimated that 390 additional lives would be saved and 296 additional serious injuries would be prevented, as shown below:

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[154] The fatal and non-fatal benefit numbers were rounded to the nearest integer.

Table IV-66
Incremental Benefits with Uniform distribution method

Crash Type, Belt Use, Ejection Type		Target adj. w/ 100% ESC		Benefits		Incremental Benefits		Total Incremental Benefits	
		Fatality	Injuries	Fatality	Injuries	Fatality	Injuries	Fatality	Injuries
Rollover, no side impacts:									
Belted	Partial	112	237	48	84	36	62		
Belted	Complete	12	12	0	0	0	0		
Unbelted	Partial	107	74	46	26	34	19		
Unbelted	Complete	519	436	224	121	167	91		
Side impacts followed by rollovers, exclude 12-25 mph:								237	173
Belted	Partial	0	49	0	13	0	10		
Belted	Complete	0	28	0	0	0	0		
Unbelted	Partial	137	0	33	0	24	0		
Unbelted	Complete	114	134	23	27	17	20		
Side impacts, w/ subsequent rollovers, 12-25 mph:								41	29
Belted	Partial	0	4	0	1	0	1		
Belted	Complete	11	0	0	0	0	0		
Unbelted	Partial	0	104	0	32	0	24		
Unbelted	Complete	68	202	18	48	13	36		
Side impacts, no rollovers, 12-25 mph:								13	61
Belted	Partial	0	0	0	0	0	0		
Belted	Complete	0	0	0	0	0	0		
Unbelted	Partial	0	0	0	0	0	0		
Unbelted	Complete	259	75	106	28	80	21		
Side impact, no rollover, Children, 12-25 mph								80	21
Belted	Partial	29	0	14	0	11	0		
Belted	Complete	0	0	0	0	0	0		
Unbelted	Partial	0	6	0	3	0	2		
Unbelted	Complete	25	34	10	13	8	10		
								18	12
	Total[155]	1,392	1,396			390	296	390	296

Discussion:

1. Advanced glazing: The benefits analysis assumes that all side windows are made out of tempered/safety glass and, consequently, advanced/laminated glazing was not considered. Although very few vehicles are currently equipped with advanced/laminated glazing for the side windows, this technology could be effective in preventing occupants from ejection with and without curtain air bags. Advanced glazing in combination with a side curtain has been found to

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[155] The fatal and non-fatal benefit numbers were rounded to the nearest integer.

be effective and complementary; glazing may be protective to the curtain and provide retention in the event of for late curtain deployments. Current field and laboratory data suggest that even partially shattered advanced glazing would be effective in preventing occupant ejection through the potential gaps in certain crashes when rollover curtain air bags are used. [156] For the target population of the PRIA, the front row window through which an occupant was ejected was closed or fixed prior to the crash 69 percent of the time. Broader population of occupants exposed to rollovers show a higher percentage of window closed or fixed. When crashes were restricted to rollover crashes where an occupant was seated next to the window opening, our 1997 – 2005 NASS CDS data show that a higher percentage, 86 percent, of front windows are closed or fixed prior to a rollover. For the rear rows, the percentage increases from 86 percent to 98 percent.[157] For all rollover exposed occupants, the front and rear percentages were 88 and 98 percent, respectively. The PRIA we assumed that the front row window was closed or fixed prior to the crash 69 percent of the time, since this was the value for the target population.

The agency is aware of advanced glazing technologies being developed for vehicle's side windows. Some of these technologies, such as three-layered s polymer and tempered glass, could be used to prevent ejection through the potential gap above the window sill when the window is up. Note that unlike curtain air bags, as the glass comes up from the window sill, advanced glazing would be stronger near the window sill to withstand the impact load from an occupant. Hypothetically, if the window is up 100% of the time and the advanced glazing

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[156] As discussed, potential gaps can be formed over the window sill and front lower corner of the window opening.

[157] The crash data show that the second and third row ejection route windows were closed or fixed about 94 and 100 percent of the time, respectively. Combining all of the data, the ejection route windows were closed or fixed 72 percent of the time before the crash. In addition, when all rollover crashes with adjacent occupants were considered, 87 percent of the ejections occurred through the previously closed or fixed window opening in rollovers.

prevents partial and complete ejections through the gap,[158] the glazing-bag combined system would be 95% effective in preventing ejections through the window opening areas, whereas rollover bags that are meeting the headform test requirements are about 69% effective in preventing ejections through side window without the glazing.[159] (If we assume that side windows are up 69% of the time before side window ejection, the effectiveness of the curtain plus advanced glazing system would be about 87%.) As shown above, since rollover bags would be highly effective in preventing occupants from ejection with and without the advanced glazing and a relatively small number of vehicles are equipped with the advanced glazing, the exclusion of the advanced glazing from the analysis would not have significant effects on the benefit estimate.[160]

In the analysis, we assumed that vehicle manufacturers can meet the proposed headform displacement requirement with curtain air bags. However, the agency's test data indicate that target location A1 is much more challenging than other impact points in the front widow

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[158] We do not have data to estimate the effectiveness of advanced glazing.

[159] According to our field data, 16% (595) of all fatalities (3,668) in rollover crashes with no side impact were from belted occupants and the other 84% were from unbelted occupants, as shown below:

Fatalities in Rollover Crashes

Restraint	Partial	Complete	Total	% of
Belted	538	57	595	16%
Unbelted	515	2,558	3,073	84%
Total			3,668	100%

In the analysis, we assumed that 5% of occupants who were retained by rollover air bags would be ejected through the sunroof. When adjusted with the real world injury data, the glazing & bag combination would be 95% effective if the window is up 100% of the time and the advanced glazing prevents ejection through the potential gaps. Whereas, rollover bags without the advanced glazing would be about 69% effective when ejections through the sunroof are considered , as shown below:

Occupant	% of	Containment Effectiveness	Weighted
Belted	16%	71%	11%
Unbelted	84%	65%	58%
			69%

With the 69% window up and the 69% combined containment effectiveness in rollovers, the effectiveness of a bag plus advanced glazing system would be 87% ($95\%\text{x}.69_{\text{windwo-up}} + 69\%\text{x}.31_{\text{windwo-down}}$) = 87%), if the advanced glazing prevents ejection through the potential gaps.

[160] In the sensitivity chapter we estimated potential benefits for the glazing + air bags system.

opening. As discussed above, if manufacturers utilize advanced/laminated glazing in the front window opening, we expected the containment effectiveness would increase from $69\%_{\text{weighted}}$ to 87%, assuming all ejections through the potential gaps would be prevented by the glazing. In the benefit analysis, we estimated that the overall rollover air bag system would be about $45\%_{\text{weighted overall}}$ effective in reducing fatal injuries.[161] When the 87% improved containment effectiveness is used, the overall effectiveness would increase from 45% to 59% ($77\%_{\text{sensor}}$ x $81\%_{\text{containment w/ glazing}}$ x $88\%_{\text{Winnick's}}$ = $59\%_{\text{overall system effectiveness, fatal injuries}}$).

The agency's 2nd row window data in Chapter III are much more limited when compared to the 1st row window data. In general, the data indicate that target location B1 is more challenging than B4. The exception to this is the Dodge Durango, which performed well at all 2nd row targets.[162] The Durango test data show that, unlike the front window opening, currently available air bag systems can be used to comply with the displacement requirement when the test is conducted in the 2nd row window opening area. Therefore, we expect that vehicle manufacturers may not need to install the advanced glazing in the 2nd row and possibly 3rd row window openings. Note that the Durango is a 3 row vehicle. One might expect that the 2nd row in a 3 row vehicle might perform well due to support from the B and C pillars. The 3rd row window in many vehicles is fixed. This fixed window might be a natural application of advanced glazing in that good edge capture may be achieved and the window is never rolled down.

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[161] We estimated that the ejection system would have an overall effectiveness of 48% and 44% for belted and unbelted occupants, respectively, in rollover crashes. The weighted effectiveness would be 45%, $(16\%\text{x}48\%)_{\text{belted}} + (84\%\text{x}44\%)_{\text{unbelted}} = 45\%_{\text{weighted}}$

[162] The Dodge Durango 2nd window data show 76 mm at B1, 86 mm at B2, 91 mm at B3, and 82 mm at B4, when tested at 24 km/h with a 1.5 second delay.

2. Minor (AIS 1-2) injuries prevented by rollover curtain bags in side crashes: Based on the 1997-2006 NASS CDS, we determined that on average 74,098 injuries occurred from flying glass involving 46,789 occupants in side crashes, annually. The majority of these injuries were to the head or face, and most were rated as AIS 1. Among the 46,789 injured occupants, 30,015 had face/head injuries from flying glass. Among the 30,015 occupants with head/facial injuries, 11% (3,237) were children under 13 years. It shows that many occupants injured by flying glass received multiple injuries of this type. The injuries from flying glass in side impacts are shown below:

Table IV-69
Injuries from flying glass by body region and AIS, 1997-2006 NASS CDS

Body region	AIS 1	Ais 2	AIS 3	Adjusted annual*
Torso	1,215	9	0	1,224
Face/head	46,733	14	0	46,747
Neck	1,395	9	9	1,413
Arm & hand	21,269	0	0	21,269
Leg & foot	2,862	0	0	2,862
Unknown	586	0	0	586
Total	74,060	32	9	74,098

* The numbers were rounded to the nearest integer.

The NASS crash data showed that side air bags deployed at a median lateral delta-V of 11 mph. Thus, we assumed that side curtain air bags would not prevent injuries from flying glass below a lateral delta-V of 11 mph. In addition, as discussed in the FMVSS No. 214 FRIA, we believe that side air bags would not be effective when side impacts occur at lateral delta-V's higher than 25 mph. When head/face, arm/hand injuries from flying glass were considered, the crash data showed that 49% of the injuries occurred in a lateral delta-V range of 11-25 mph.

Regarding curtain air bag effectiveness in preventing injuries from flying glass, an analysis of the crash data showed that 2.60% of occupants were injured by flying glass without side curtain air bags and 0.32% with curtain air bags. The 0.32% was based on five sampled injured occupants. Although the differences are statistically significant, the standard errors were very large relative to the estimate.

In summary, when the window opening area is fully covered with the ejection mitigation curtain air bag, it would substantial reduce minor facial injuries resulting from shattered glazing in side crashes. However, as discussed, the NASS sample size is too small to derive the effectiveness of curtain air bags in preventing injuries from flying glass. The agency plans to re-examine the potential benefits when additional data are available.

V. TECHNICAL COSTS AND LEADTIME

In this chapter, we discuss the cost of different technologies that could be used to comply with the linear headform test and estimate the compliance test costs. There are a variety of potential ways for manufacturers to meet the test requirements. To meet the proposed displacement requirement, vehicle manufacturers could utilize several different design approaches, such as a one-piece curtain air bag that covers the front and rear window opening areas, a separate window curtain air bag for each window opening area or utilizing advanced glazing combined with a curtain air bag for movable windows and advanced glazing alone for fixed windows. Among the potential design approaches, we believe the one-piece curtain design would be most cost effective in meeting the requirement. The agency believes that current (one-piece) curtain air bags designed for head protection in side impacts will have to be wider, larger and stiffer to meet the proposed headform requirements. In addition to the increase in size, manufacturers would need to modify other air bag characteristics, such as operating gas pressure, duration, and location of bag tether attachments. For the analysis, we assumed that vehicle manufacturers utilize the one-piece design to comply with the displacement requirement.[163]

Installing a wider and stiffer curtain air bag on the side roof rail will cause some models to be redesigned. The normal redesign cycle for passenger car models is 4-5 years, while pickup trucks and some vans (including SUVs) have longer design cycles of 6-7 years. The costs to

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[163] We believe that some vehicle manufacturers would install laminated/advanced glazing along with curtain air bags to meet the displacement requirement at removable windows. As discussed in the benefit chapter, advanced glazing in combination with a side curtain has been found to be effective and complementary. In addition to the retention benefit, the glazing can provide other benefits, such as reducing noise in the occupant compartment, increasing theft protection, and even reducing harmful rays by blocking a certain spectrum of light. The agency does not have data to quantify these secondary benefits and, as a result, these benefits were not considered in the benefit estimate. Rather, the benefits and costs associated with advanced glazing were discussed in the sensitivity analysis chapter in this Preliminary Regulatory Impact Analysis (PRIA).

design a model to install a wider and stiffer window curtain are small if it is done at the time of a normal redesign. We believe, therefore, the most cost-effective way to accomplish the redesign task is to allow sufficient leadtime to redesign vehicles during their normal redesign cycle. Since we are providing sufficient leadtime, we have not addressed costs for redesigning models.

A. Current Side Air Bag Technology Costs (in 2007 Dollars)

We believe that all of the assembly costs of a wider curtain air bag (i.e., wider than curtain air bags that are capable of meeting the FMVSS No. 214-oblique pole requirements) would remain the same. The only difference would be in the direct material costs for the air bag and possibly for the inflator. Since the materials used for air bags are similar in characteristics regardless of air bag types, it would be reasonable to assume that the material cost is only affected by the amount of material used in the system. In addition, based on the previous FMVSS No. 214-head air bag cost analysis, we believe that the size of the air bag and the inflator are the most critical cost items for the system, as discussed in the following section.

1. Costs Associated with Wider/larger Bag Size.

<u>Air Bag</u>: In the FMVSS No. 214 Final Regulatory Impact Analysis (FRIA), we estimated costs of curtain air bags that are designed to meet the FMVSS No. 214 oblique pole requirements. The estimated costs were based on two NHTSA contractor teardown studies of side/head air bags. Based on the studies, we determined an average cost of $130.87 per vehicle for currently available window curtain air bags including inflators and $134.02 for the FMVSS No. 214-curtain bag.[164] The estimated $134.02 is based on the <u>minimum coverage</u> of the window

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[164] The estimated $134.02 air bag cost is for modifying bags and inflators. Other costs such as sensors and wiring are not included in the $134.02. The total cost to a vehicle for two current separate thorax side air bags and head

opening to meet the FMVSS No. 214-oblique pole requirement. However, it is unlikely that vehicle manufacturers design head/side air bags to <u>just cover</u> the pole impact area to comply with the proposed requirements. For example, although we found that a small number of currently available head air bags will have to be widened to meet the oblique pole impact test, the majority of current curtain air bags are wider than the hypothetical FMVSS No. 214-curtain air bag. In other words, most of currently available wider curtain air bags cover more than the FMVSS No. 214-minimum coverage area in the window opening. Therefore, we believe that manufacturers would install curtain air bags that are wider than the hypothetical FMVSS No. 214-bag (which provides the minimum coverage) to meet the oblique pole requirements. For the cost estimate, therefore, we did not use the estimated FMVSS No. 214-curtain air bag cost (i.e., $134.02 per vehicle) for the baseline. Rather, we will analyze actual costs associated with current <u>side</u> curtain air bags that are capable of meeting the FMVSS No. 214-oblique pole requirements. These costs will be used as a baseline to estimate incremental costs associated with (wider) <u>rollover</u> curtain air bags.

A recent oblique pole and MDB tests performed by the agency show that a MY 2004 Honda Accord equipped with window curtain bags met the head injury requirement with both 50th percentile male and 5th percentile female test dummies. The HIC$_{36}$ scores were 567 and 446 for the 5th and 50th dummies, respectively.[165] The head air bag installed in the Accord has a height of 16 inches (41 cm) and a width of 62 inches (157 cm) measured at the bottom.[166] The Accord

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window curtains is estimated to be $234.93 ($63.83 for the thorax bags, $130.87 for the window curtains, $36.67 for the sensors and $3.56 to connect to the already existing electronic control module, in 2004 dollars).

[165] In addition, the bag would provide a good head protection in vehicle-to-vehicle side crashes based on the HIC scores measured in the NHTSA 214-MDB tests. The test results from the Accord are shown below:

Measurement	Pole, 5th	Pole 50th	MDB, front, 5th	MDB, front, 50th
HIC	567	446	104	109

[166] The length of the bottom portion of a typical curtain bag is longer than the upper portion.

test results, including a high speed video analysis, show that curtain air bags that are similar in size and construction would be wide enough to retain the head of a test dummy in the oblique and also MDB tests. In other words, curtain air bags that are similar to the Accord curtain air bag would produce HIC scores that are below the required 1,000 with both the 50th percentile male and 5th percentile female test dummies, as demonstrated in the Accord oblique pole test.

According to a report titled "Perform Cost and Weight Analysis, Head Protection Air Bag Systems, FMVSS 201," DOT HS 809 842, a curtain air bag installed in a MY 2003 Toyota Camry has a height of about 16 inches and a width of about 61 inches measured at the bottom, with a total coverage area of 800 in^2 (5,161 cm^2). A visual inspection shows that the Camry and the Accord have curtain air bags that are similar in construction and size[167]. As discussed, the Accord's oblique pole test results indicate that the curtain installed in the Camry could meet the FMVSS No. 214-oblique pole test requirements without widening the air bag. For the cost analysis, we used the Camry curtain bag as a baseline (FMVSS No. 214-curtian bag[168]) to derive the incremental material costs associated with a rollover curtain air bag[169].

The side window opening area of a MY 2003 Toyota Camry has a height of 18 inches (46 cm) and a width of 39 inches (99 cm) at the top and 75 inches (191 cm) at the bottom (at the widow sill), with a total opening area of 1,026 in^2 (6,619 cm^2). To fully cover the window opening area, therefore, the 214-curtian bag must be widened by 1,458 cm^2 (6,619$_{\text{window opening}}$ -5,161$_{\text{size of 214-}}$

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[167] The Camry is about 3% larger than the Accord.

[168] Assuming that a final rule would be issued in October 2009, NHTSA proposes that the phase-in would start in September 1, 2013. Accordingly, we expect that the majority of vehicles will be installed with the 214-curtain bag before the effective date of the ejection mitigation final rule.

[169] According to a report titled "Perform Cost and Weight Analysis, Head Protection Air Bag Systems, FMVSS 201," DOT HS 809 842, the majority of the head bags were rectangular in shape.

curtain = 1,458 cm^2), as shown in Figure V-1.

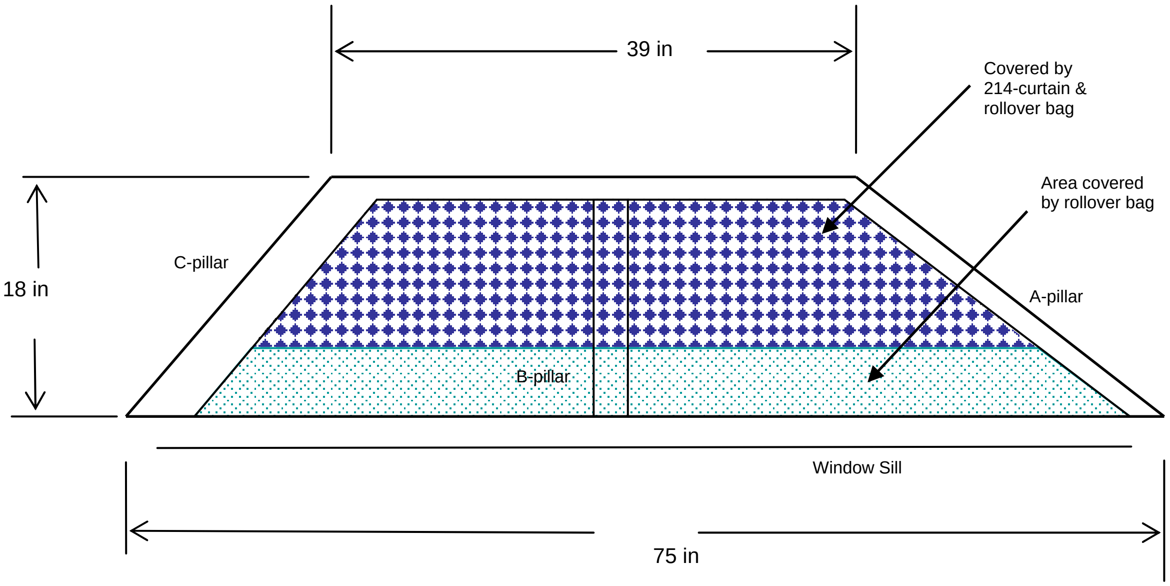

Figure V-1 Air Bag Coverage Area with respect to MY 2003 Toyota Camry Front and Second Side Window Opening (not to scale)

In the teardown study of curtain air bags, DOT HS 809 842, we estimated that material (i.e., loomed cloth used for the air bag) costs associated with the Camry curtain bag would be $103.75 per vehicle in 2003 economics, as shown below:[170]

Table V-1
Variable Manufacturer and End User Costs for
MY 2003 Toyota Camry Curtain Air Bag per Vehicle (in 2003 costs)

Air Bag Item	Material ($)	Direct Labor ($)	Variable Mfg. ($)	End User ($)
Installation	0.00	2.10	2.86	4.32
Bag – Loomed Cloth	19.84	11.56	68.73	103.75
Inflator	7.61	6.88	30.69	46.33
Total	27.45	20.54	102.28	154.40

When the $19.84 cloth material cost was adjusted with a 1.51 end-user adjustment factor, it resulted in $29.96 end user cost per vehicle in 2003 economics. When the $29.96 end user cost is adjusted with the implicit GDP price deflator, it resulted in $33.73 per vehicle ($16.87 per air

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[170] Additional discussion, see a report titled "Perform Cost and Weight Analysis, Head Protection Air Bag Systems, FMVSS 201," DOT HS 809 842.

bag) end user cost in 2007 economics.[171] The unit material cost was estimated to be \$0.00327 per cm^2 based on the 5,161 cm^2 air bag coverage area and the \$16.87 estimated material cost per air bag [(\$16.87 per bag)/5,161 cm^2 = \$0.00327/cm^2]. As discussed previously, the Camry has a window opening area of 6,619 cm^2. Thus, the air bag (5,161 cm^2) must be widened by 1,458 cm^2 to fully cover the window opening area (6,619 cm^2). With the \$0.00327 unit cost (per cm^2) and the additional coverage area (1,458 cm^2), we estimated that material costs associated with widening the air bag would be \$ 9.53 per vehicle (1,458 cm^2 x \$0.00327/cm^2 = \$4.77/curtain, $\$4.77_{\text{per curtain}}$ x 2_{sides} = \$9.53 per vehicle in 2007 economics).[172]

In summary, for the incremental costs associated with the hypothetical rollover air bag, we assumed that vehicle manufacturers need to spend \$9.53 per vehicle to widen the FMVSS No. 214-curtain bag to meet the proposed headform displacement requirement (in 2007 costs) at the front and second row window openings. The incremental costs associated with the wider curtain air bag (i.e., rollover air bag) are relatively small when compared to the overall system cost. For vehicles equipped with combo air bags that are designed to comply with the FMVSS No. 214-oblique pole requirements, the costs would be higher since the combo system must be replaced with a curtain (rollover air bag) system. We estimated a cost of \$91.14 for the wider FMVSS No. 214-combo air bag[173] and \$183.39 for the hypothetical rollover curtain air bag per vehicle (including inflator but without rollover sensor, in 2007 costs). Therefore, material costs for

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[171] \$19.84 x $1.51_{\text{end-user}}$ = \$29.96 end-user cost per vehicle. According to the implicit GDP price deflator all urban consumers, 2007 = 119.816, 2003 = 106.404, the multiplier = 119.816/106.404 = 1.1260, \$33.73, (\$29.96 x 1.1260 = \$33.73) for two bags per vehicle. Thus, for each bag, \$16.87

Year	2003	2005	2007
implicit GDP price deflator	106.404	113.034	119.816
Loomed Cloth, end user cost	\$29.96	\$31.83	\$33.73

[172] The teardown study shows that the loomed cloth used for the Toyota curtain bags weighs about 2.59 lbs. per vehicle. The window opening area and the bag coverage indicate that the increase in weight would be insignificant.

[173] In the 214 FRIA, we estimated that two combo bags would be \$85.98 (two per vehicle) in 2005 economics. When adjusted with implicit GDP price deflator, it results in \$91.14.

replacing the FMVSS No. 214-comb bag would be about \$92.25 (\$183.39 - \$91.14 = \$92.25), excluding rollover sensor[174], as summarized in Table V-2.

Inflator: A typical inflator consists of an electrical initiator unit, a casing and propellant. The cost teardown study (DOT HS 809 842) shows the cost ranges from \$30 to as high as \$57 per unit.

(A) Costs associated with electrical initiator: The inflators are designed such that an increase in propellant would not require a larger more powerful electrical initiator. Thus, it is reasonable to assume that the same type of initiator would be used for both the FMVSS No. 214-curtain and larger rollover curtain air bag designs.

(B) Propellant and casing: Current curtain head air bags are typically designed to provide head protections by incorporating gas chambers in the air bag. To comply with the proposed headform displacement requirements in the opening area, the majority of air bag manufacturers would not have to incorporate additional gas chambers in the extended air bag area. However, in some cases, vehicle manufacturers may need to enlarge the chambers. In the cost and weight analysis report, we estimated that material costs associated with the inflators installed in a 2003 Toyota Camry would be about \$7.61 in 2003 economics, which was designed to inflate to cover the 5,161 cm^2 area in the window opening. If we assume that the ratio between the area covered with the chamber and the overall air bag coverage area remain unchanged, the 28% increase in coverage area [(6,619-5,161)/5,161(cm^2) = 28.25%] would increase the cost by \$2.42 ($\$7.61 \times 0.2825_{\text{28\% increase}} \times (119.816/106.404)_{\text{Ratio of implicit GDP price inflator}} = \$2.42$ incremental cost in 2007 economics).

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[174] $\$183.39_{\text{rollover curtain}} + \$38.02_{\text{rollover sensor}} - \$91.14_{\text{wider combo}} = \$130.28_{\text{incremental cost.}}$ In addition, for the overall incremental costs, we assumed that manufacturers would install thorax bags when combo bags are replaced by rollover curtain bags.

Tether: In the benefit chapter, we determined that some of the tether anchors (to the A- and C-pillars) need to be strengthen to withstand the loads at the lower impact points, A1 and A2. In addition, the tether may be lowered to provide more window coverage. Unlike the tethers in a curtain bag design, the tethers in a rollover air bag would be designed to provide a sufficient tension in the bag to meet the 100 mm displacement requirement. In some cases, manufacturers would shorten the length of the side curtain tethers to provide the required tension (to meet the displacement requirement). Based on the geometry of the opening, therefore, we assumed that there are no incremental costs associated with the tethers.

2. Costs Associated with Rollover Sensor

The electronic components used in a typical curtain bag system consist of several (side) impact sensors, wiring harness and a central electronic module. Unlike side impact sensor systems, rollover detection systems do not have satellite sensors or wiring harness. Instead, rollovers sensors are most likely integrated into a central control, which is designed to detect rolls and deploy countermeasure(s). In addition, we anticipate that all light vehicles will be equipped with Electronic Stability Control (ESC) system when vehicles are designed to meet the proposed ejection mitigation requirements. ESC is capable of detecting several vehicle inputs that could be used in detecting rollovers, such as lateral acceleration and yaw rate. With ESC, therefore, we believe that vehicle manufacturers would utilize these inputs and only need a roll rate sensor as an additional component for the rollover mitigation system. However, as of today, the agency has not performed any detailed teardown studies on rollover systems and, as a result, does not have refined cost estimates for rollover sensors. Based on information provided by sensor suppliers and the cost information obtained during agency's teardown studies on Electronic Stability Control system, we estimated that the price of the sensor would be the same as the cost estimate used for yaw sensors in the ESC Final Regulatory Impact Analysis (FRIA). Accordingly, we estimated each rollover sensor would be $38.02 (in 2007 dollars) per vehicle.[175]

3. Costs Associated with Vehicle Modification: The one-piece curtain system is designed to cover the front and rear side window opening areas with a single curtain bag. The top of the bag would be attached to vehicle's roof line and the sides would be attached to vehicle's pillars (A-pillar and either C- or D-pillars in large SUV's or mini vans).[176] Although we expect vehicle manufacturers will modify the current air bag designs, any modifications to the structure would not be significant, especially if the redesign is done at the time of a normal design cycle.

Estimated Vehicle Costs for Meeting Headform Test

To determine the number of vehicles with rollover air bags, we obtained information on MY 2011 vehicle models equipped with rollover air bags from manufacturer's estimated sales. The combined results of this effort to estimate the percent of sales are shown in Tables V-2 and V-3.

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[175] The cost of the sensor is $38.02 in 2007 economics and $35.87 in 2005 economics. The $35.87 average cost is based on costs of five vehicle makes/models. The cost ranges from $22.06 to as high as $50.47 per vehicle.

[176] We note that convertibles will have a different curtain air bag design. Perhaps, it would be designed to deploy from the window sill.

Table V-2
MY 2011 Estimated Bag Sales
(These are based on manufacturer sales projections/plans prior to FMVSS 214 requirements)

Bag Type	% of total
No air bag	4.99%
Curtain + Thorax	73.82%
Curtain	19.75%
Combo	1.34%
Thorax	0.07%
ITS + Thorax	0.03%
total	100%

Table V-3
Vehicles Equipped with
Curtain and Combination Bags[177]

System	Percent of MY 2011 Sales	Weighted Sales Percent
Curtain with rollover sensor	55%	55%
Curtain without rollover sensor	39%	44%
Combination (Combo)	1%	1%
total	95%*	100%

* We assumed that the remaining 5% (100%-95% = 5%) include other types of air bag systems (such as the tube, thorax air bag only) and also "no air bag."

The results in Table V-3 show that an estimated 95 percent of the passenger cars and SUVs & light trucks will voluntarily be equipped with head air bags in MY 2011 vehicles. The majority of these head air bags will be curtain air bags and 55% of these curtain bags will be equipped with rollover sensors. It is assumed that 100% of vehicles will meet the FMVSS 214 requirements, and 1% would meet the 214 requirements with a combination bag.

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[177] The "curtain" includes both "curtain + thorax" and "curtain only." The ITS may be utilized to meet the 214-oblique pole requirements. The percent of the ITS is relatively small (less than 1% for MY 2007 vehicles) and the system would not be capable of meeting the headform displacement requirement. The numbers were rounded to the nearest integer.

Compliance Rate of Current Rollover Curtain Bags

The linear headform test results indicate that the majority of current curtain bags (whether they are designed as head bags or rollover bags) would not meet the proposed 100 mm deflection requirement at all four (4) impact points in the front window opening.

The headform test results showed that some of currently available curtain bags are capable of meeting the displacement requirement at impact points A2, A3 and A4. However, as mentioned, none of the air bags met the requirement at all impact points. For the cost estimate, therefore, we assumed that all current curtain air bags will be modified whether they meet the displacement requirement at a particular impact point or not. In addition, when current air bags are redesigned to meet the headform displacement requirement in the front widow opening area, we believe that manufacturers will design the air bags such that they meet the deflection requirement at both front and rear window opening areas. On the other hand, even if current bags meet the displacement requirement in the rear opening area, they must be redesigned since none of the current air bags met the displacement requirement at all impact points in the front window opening area. Thus, we did not consider headform impact tests performed in the rear opening area since the test results show that all currently available systems need to be redesigned.

Table V-4 shows our range of current technology cost estimates, although these technologies may or may not actually go into production. For this analysis, we estimated the costs based on a wider curtain air bag.[178] We considered two approaches that vehicle manufacturers may take to meet the proposed requirements: (1) modify current curtain head air bags to the one-piece

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[178] These rollover bags would be wider than the hypothetical 214-curtain bag.

rollover curtain air bag[179] and (2) replace the FMVSS No. 214-combination bag with the one-piece rollover curtain air bag and a thorax air bag. In addition, although the headform test does not require manufacturers to install rollover sensors, we believe that manufacturers will provide rollover sensors as part of the system. Accordingly, costs associated with rollover sensors are included in the cost estimate, as shown in Table V-4A and V-4B.[180]

Table V-4A
Estimated Technology Cost Summary for Covering 1st and 2nd Row Window Openings
(in 2007 dollars)

Systems	Costs ($ in 2007)	Estimated percentage of MY 2011 baseline
Combination Bag (w/ 2 sensors)	$91.14	1.34%
Window Curtain System (w/ 2 sensors):		44.08%
214-curtain bags	$173.86	
thorax bags	$75.61 [181]	
Total	$249.47	
Window Curtain System (w/ 2 side and one roll sensors):		54.59%
214-curtain bags	$173.86	
thorax bags	$75.61	
roll sensor	$38.02	
Total	$287.49	
Weighted average cost[182]:	$268.11	(per MY 2011 manufacturers' plans)

Table V-4B. Ejection Mitigation System (2 side and one roll sensors)

Components	Cost
curtain bags (w/ 2 side sensors)	$183.39
thorax bags	$75.61
roll sensor	$38.02
Increase in inflator cost	$2.42
Total	$299.44

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[179] For the analysis, we assumed that manufacturers would install thorax bags when vehicles are equipped with curtain bags to meet the 214-oblique pole requirements.

[180] The MY 2011 vehicle baseline sales were based on vehicle manufacturers' projected sales, prior to the issuance of the NPRM. It is possible that the projected percentage of MY 2011 vehicles with ejection mitigation systems would increase when the NPRM is issued.

[181] The wide 214-throax bag: $69.08 per vehicle in 2004 economics. Adjusted with the implicit GDP price inflator, $69.08x(119.816/109.462) = $75.61 per vehicle

[182] Some vehicles may need four (4) sensors for side impacts to meet the 214-oblique pole requirements. However, the ejection mitigation rule would not affect the side impact sensors needs. Therefore, the incremental costs would remain the same.

The results in Table V-4 showed that the incremental cost per vehicle would be $31.33, based on MY 2011 sales.

Costs Associated with 3rd Row Window Curtain

Previously, we estimated that vehicle manufacturers need to spend $11.95 ($9.53 for curtain and $2.42 for inflator) per vehicle for covering 1st and 2nd row windows. Accordingly, these costs do not include costs associated with covering 3rd row windows. For the FMVSS No. 214 rulemaking, vehicle manufacturers provided their projected sales thru MY2011. The sales data show that 25% of MY 2011 light vehicles have a third row seat. As part of the ejection mitigation rulemaking effort, a series of field surveys were performed to determine the size of side windows. Our survey data show that the majority of SUVs and vans, if not all, have 3rd row windows. For example, a MY 2007 Nissan Pathfinder has three row windows (two movable and one fixed in the 3rd row). The third row side window has a height of 46 cm (18 inches) and a width of 48 cm (19 inches), a total area of 2,206 cm^2. Previously the air bag material cost was estimated to be $0.00327 per cm^2 and the inflator cost was estimated to be $0.00166 per cm^2 ($8.57/5,161 cm^2 = $0.00166 in 2007 economics). When the 3rd row side window opening is covered with a curtain air bag, therefore, it would incur $21.74 incremental cost per vehicle, ($\$0.00327_{\text{air bag cloth}} + \$0.00166_{\text{inflator}}) \times 2{,}206\ cm^2 = \$10.87_{\text{per side}}$, $21.74 per vehicle. If we assume that these light trucks will have two side windows in the 3rd row, the total incremental costs associated with the air bag would be about $92 million (17 million vehicles x 25% x $21.74 = $92.4 million). Note that, for the estimated $92 million for the 3rd row windows, we assumed that all curtain air bags installed in MY 2011 light trucks (including SUVs and minivans) only cover the front and 2nd row window openings. However, when curtain air bags are installed in SUVs and vans to meet the FMVSS No. 214-oblique pole requirements, for example, we believe that the air bag will be tethered to the A-and D-pillars, rather than being attached the A- and C-pillars, since the D-pillar would have a higher structural strength and larger space for the anchor and tethers, as shown in Figure V-2.

Figure V-2. Ejection Mitigation Curtain Air Bag (Canopy) Installed in MY 2004 Mercury Monterey Minivan

In other words, when manufacturers install a curtain air bag to meet the FMVSS No. 214-oblique pole requirements in the front row of SUVs and vans, the curtain air bag would be anchored to the A-and D-pillars and cover not only the front but also the second and third row window openings. Accordingly, for incremental costs over manufacturers' plans, we assumed that SUVs and vans would have a similar cost for both front and rear windows. Therefore, under the voluntary compliance agreement in the second and third rows, we estimated that the total incremental costs associated with 3rd row bags would be about \$51 million (17 million vehicles x 25% $_{\text{w/ 3rd row seat}}$ x \$11.95 = \$50.8 million).

Total Incremental Costs

Table V-6 shows estimated incremental costs to meet the proposed requirements for the baseline curtain and 214-combination bags.

Table V-5
Average Incremental Vehicle Costs for 1st and 2nd Rows (in 2006 costs)

Existing System	Assumed 214 Weighted Sales (%)	Need		Roll rate sensor	214-curtain minus combo bag(1)	Increased $ in inflator	Widen curtain	Per vehicle
		Bag	sensor	$38.02	$167.87	$2.42	$9.53	
Curtain w/ roll sensor	55%	Wider curtain	None	$0	$0	$2.42	$9.53	$11.95
Curtain w/o roll sensor	44%	Wider curtain	Roll sensor	$38.02	$0	$2.42	$9.53	$49.97
Combo[183]	1%	Rollover curtain	Roll sensor	$38.02	$167.87	$2.42	$0	$208.31 (2)
total	100%							

(1) $\$183.39_{\text{Rollover curtain}} - \$91.14_{\text{combo}} + \$75.61_{\text{thorax bag}} = \$167.87$
(2) $38.02 + $167.87 + $2.42 = $208.31 per vehicle.

Table V-6
Total Incremental Costs
(MY 2011 as baseline, in 2006 dollars,
Based on 17 million sales of passenger vehicles under 10,000 GVWR)

Baseline 214-bag System	Weighted Sales	Per Vehicle	Weighted Incremental Cost	Total Cost
Curtain w/ roll sensor	55%	$11.95	$6.52	
Curtain w/o roll sensor	44%	$49.97	$22.03	
Combo[184]	1%	$208.31	$2.78	
Weighted incremental cost per vehicle			$31.33	
Total incremental cost for 1st and 2nd rows for 17 million vehicles				$533million
Total 3rd row for SUVs and Vans				$51 million
Total incremental cost for 1st, 2nd and 3rd rows for 17 million vehicles				$583 million[185]

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[183] For the 214-combination baseline system (1.41% of total sales in MY 2011), we assumed that the combination system will be replaced with the rollover curtain system. Accordingly, the costs associated with the 214-combination system were subtracted from the costs of the rollover curtain system.

[184] For the analysis, we used the 214-bags as a baseline. As part of the 214 rulemaking effort, the agency determined that the majority of vehicles will be equipped with either curtain bag or head-thorax combination (combo) bags. If vehicles are equipped with these bags, the MY 2011 sales data indicate that combo bags would be about 1.3% of the total sales (54.59% curtain with a roll sensor, 38.98% curtain without roll sensor, 1.34% combo and 5.10% others). The estimated costs are based on assumption that all vehicles are equipped with either curtain or combo bags: 1.4% $\text{combo}_{\text{weighted}}$ and 98.6% $\text{curtain}_{\text{weighted}}$ (1.4% + 98.6% = 100%).

The results in Table V-6 show that the total annual net cost for meeting the requirements with a curtain air bag with rollover sensors. We assumed that the projected MY 2011 vehicle market share (of different head bag systems) remains unchanged when the costs were adjusted with the weighted 2011 vehicle sales, it resulted in \$31.33 per vehicle if 1st and 2nd row windows are covered with a curtain air bag.[186] When the 3rd row windows are covered with a curtain bag, the total incremental cost would be \$583 million (\$532.7M + \$50.8M = \$583 million, as shown in Table V-6).

With estimated 17 million light vehicles and assuming no compliance, the total incremental cost for the 1st and 2nd row windows would be \$533 (\$532.7) million in 2007 dollars. For the \$533 million incremental cost, we estimated that vehicle manufacturers need to spend \$11.95 for FMVSS No. 214-curtain bags with rollover sensor and \$49.97 for 214-curtain bags without rollover sensor for each vehicle. Although some convertibles could be equipped with head air bags that are designed to come upward from the door window sill, the ability of such a design to meet the proposed ejection mitigation test is not known. Agency discussions with convertible manufacturers have also indicated that they are exploring the use of advanced glazing. The NPRM requests comments on the feasibility of installing ejection mitigation countermeasures to convertibles. Below we explore the effect on incremental costs of exempting convertibles from the requirement. If this is the case, we believe that the majority of convertibles will be equipped with combo air bags when the final rule is issued. The MY 2011 sales show that 1.3% of

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[185] The numbers were rounded to the nearest integer, \$532.7 + \$50.8 = \$583.4 million. When all light vehicles (17 million) are combined, the incremental unit cost would be \$34.32 per vehicle.

[186] (55% curtain with roll sensor x \$11.95) + (44% curtain without roll sensor x \$49.97) + (1% combo bags x \$208.31) = \$31.33 for 1st and 2nd row windows in 2006 economics.

vehicles are convertibles (FMVSS No. 214-vehicles: 54.59% curtain with a roll sensor, 38.98% curtain without roll sensor, 1.34% combo and 5.1% others. Previously, we assumed that vehicles that are not currently equipped with head air bags would be equipped with curtain bags (without a rollover sensor). Accordingly, we expect that 44.08% of MY 2011 vehicles would be equipped with curtain air bags without a roll sensor.) If convertibles are exempted, about 0.04% of MY 2011 vehicle would be equipped with combo air bags (1.34% - 1.3% - 0.04%).[187] Therefore, the weighted incremental cost would be $28.63 for 16.8 million vehicles ($59.59\%\text{x}\$11.95_{\text{curtain w/ roll sensor}} + 44.08\%\text{x}\$49.97_{\text{curtain w/o roll sensor}} + 0.04\%\text{x}\$208.31_{\text{combo}} = \$28.63$, 17Mx(1-1.3% = 16.8M vehicles)[188]. Thus, the total incremental cost <u>without convertibles</u> would be $487 million (17 million x ($1\text{-}0.013_{\%\text{ of convertibles}}$) x $\$28.63_{\text{weighted}} = \$486.6$ million) for covering 1st and 2nd row windows. Previously, we estimated that the total incremental costs associated with 3rd row air bags would be $51 million. Therefore, if convertibles are excluded from the final rule, the total incremental cost would be $537 million to cover all three row windows.[189]

It should be noted that the costs above do not reflect costs associated with vehicle modifications and compliance tests. Currently, curtain air bags are installed in the roof rail/headliner and are anchored to the vehicle structure. The weight and shape of these systems are specifically designed for the roof rail/headliner. When manufacturers decide to install the system as a countermeasure, we believe that the required additional material for the roof rail headliner

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[187] We assumed that all MY 2011 light vehicles would be equipped with either curtain or combo bags to comply with the 214-oblique pole requirements. In addition, we assumed that all convertibles would be equipped with combo air bags.

[188] Additional information, see Table V-6, last column.

[189] When convertibles are excluded from meeting the headform test requirements, the total incremental cost would decrease from $583 million to $537 million dollars. We note that by applying the $11.95 and $49.97 incremental costs (estimated for 214-curtains with and without rollover sensors), we are assuming that all non-convertibles are equipped with curtain bags (no combo bags).

modification on a per-vehicle cost would be insignificant. Costs associated with vehicle compliance tests are discussed below in section C.

B. Other Potential Technology Costs

Separate air bag for each window opening area: Although the majority of the manufacturers will install one-piece curtain air bags to comply with the linear impactor headform test requirements, other technologies could be used to comply with the requirements. For example, vehicle manufacturers may install a separate air bag for each window opening (that is, separate air bags to cover multiple window openings) to overcome design difficulties such as potential interference with the shoulder belt or large coverage areas in vans with multi-seating rows. However, due to limited data, these potential costs were not estimated in the analysis.

Vehicle with advanced glazing installed: We believe that the majority of vehicle manufacturers will install window curtain air bags to comply with the proposed impactor headform test requirements. However, although it is not believed to be likely for laminated glazing to be used as a standalone system for movable windows to meet the displacement requirement, laminated glazing could be installed on certain vehicles, such as passenger vans with a long 3rd row side windows, as a supplement to curtain air bags. These laminated side window glazing would provide a reaction surface for the curtain air bag. The agency is proposing that windows with advanced laminated glazing are fully raised and pre-broken prior to the test. The test results showed that the pre-broken glazing in combination with side curtain have been found to be effective and complementary. In particular, the combination could be effective in meeting the displacement requirement at the lower target points, A1 and A2 in the front window openings.[190]

In a November 1995 report,[191] an estimate was made of the cost and weight of side glazing for a 1995 Ford Taurus. Existing tempered glass was estimated to cost $8.01 and "trilaminate" glass was estimated to cost $32.01 per unit (per side window) as the price to consumers (in 1995 dollars). The weight of the two windows was identical at 8.82 lbs. Trilaminate glass was defined as 0.762 mm Polyvinyl Butyral (PVB) core sandwiched between two layers of 1.85 mm annealed glass. This is the same glazing being used today in laminate side windows. The PVB is good for energy absorption. In discussions with glass representatives, it was found that the current cost of the glazing is slightly less today (in $2007 dollars) than were estimated in 1995. However, the difference in cost between tempered glass and laminate glass is about the same today as was developed by our contractors in 1995. That is, $24 (in 2007 dollars) is about the incremental difference in costs for going from a tempered glass to a laminate glass for standard size front or rear seat window. If anything, the incremental cost may decrease slightly with increasing sales of laminated glass.

One of the important features for utilizing laminated glass for side window ejection is the extent of edge capture around the edge of the glass. For a front windshield, the laminated glass (similar to what will be used for side windows) is bonded to the frame of the window using urethane. The urethane bonding is also being used by manufacturers for third seat side windows that are

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[190] As discussed in the benefit chapter, none of the vehicles met the displacement requirement at A1 whether laminated glazing is used or not. The laminated glazing installed in the vehicles was primarily designed for theft protection, not ejection mitigation. We believe that laminated glazing can be designed for ejection mitigation.

[191] "Ejection Mitigation Using Advanced Glazing, A Status Report, November 1995", NHTSA Advanced Glazing Research Team.

not moveable. We note that there is no difference in how the laminated glass will be held in the door channel, as compared to tempered glass. It might have to be offset slightly, but no difference in costs.

In addition to advanced glazing, some vehicle manufacturers are considering other advanced materials, such as polycarbonate, to use for the side openings in the rear. Based on information from suppliers, we believe that the cost for the plastic window is about the same as laminated glass but it weighs about half as much. However, the agency has not performed any evaluation on these advanced materials and how they behave in rollovers. We note that the pre-break test procedure was developed based on an assumption that either tempered or laminated glazing will be used for the windows. We do not believe that the current glass breaking procedure would do much to the polycarbonate, other than scratch or chip the surface a bit. On the other hand, the procedure could be relevant to a polycarbonate window since the window would not shatter as easily as a tempered or laminate glass window in rollovers, so it would be much more likely to be in place to help contain an occupant.

C. Compliance Test Costs

This section discusses the estimated costs for the agency to perform compliance tests or potentially for a manufacturer to perform certification tests. Costs are in 2007 dollars.

The proposed linear guided headform impact test is similar to the 201-head form test specified in FMVSS No. 201 “Occupant Protection in Interior Impact.” The 201-headform test is designed to provide occupant protection in interior impacts by impacting a 6.8 kg, 165 mm diameter headform at a relative velocity of 24 km/h. Unlike the proposed linear headform test, the 201-headform test is not guided test. Since the 201-headform test is already run by vehicle manufacturers, tests like the 201-headform may not be incremental costs for them. In other words, the difference between these two headform tests would be insignificant in terms of compliance test costs.

The labor cost of running a head form test (either the FMVSS No. 201 free motion or the proposed guided) is around $100 (not including the cost of the vehicle). The number of proposed test ranges from a minimum of 8 to a maximum of 24, depending upon the number of window openings.[192] The average cost of a vehicle is $28,000. For each vehicle, we estimated that the testing costs are $300 for the air bag, $400 for the laminated glazing and $100 for labor/engineering. Thus the average cost for running a proposed headform test is less than one dollar per vehicle.[193]

The vehicle cost estimates for NHTSA may not reflect the vehicle cost estimates for manufacturers. While the average new vehicle price is around $30,000, manufacturers developing all new models may decide to use a few prototype vehicles for development testing

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[192] Assumptions used for the weighted test cost are shown below:
217 make/models, 16.9 million annual vehicle production, 78,000 average annual make/model production (16.9M/217 = 78,000), 5 year production cycle, air bag cost = $300, laminated glazing cost = $400, labor per test = $100, for 16 tests, the cost would be $12,800, vehicle cost $28,000, the total cost would be $40,800. 40,800/78,000 = $0.52/veh/ design cycle, $0.52/5 = $.10 per/vehicle.

[193] The number of actual head form tests performed in a vehicle depends on the number of window openings. For two door passenger cars or light trucks, a total of eight (8) tests are likely required, although vehicle with small windows could require fewer. For large minivan or SUVs with three separate window openings for each side, a total of 24 tests are required. On average, we estimate a total of 16 tests per vehicle. The estimation is based on an assumption that all passenger vehicles (under 10,000 GVWR) have two medium or large side window openings for each side. However, we expect that about 50% of the fleet will be light trucks, including SUVs and mini vans. In general, SUVs and minivans have more than two side windows in each side. Therefore, the estimated 16 test per vehicle would somewhat underestimate the required number of tests (per vehicle). However, the increase in cost would be relatively small. If we assume that 50% of light vehicles have four side windows and the remaining vehicles have six side windows, the test cost would be about $.11per vehicle, with less than one cent difference.

purposes. Although a prototype vehicle can cost much more than a production vehicle, a developmental vehicle for the proposed test requirements would be less than the production vehicle since incomplete vehicles could be used for the curtain air bag installation and the head form test.

D. Leadtime

The longest design issue, in terms of time, is installing a window curtain (which would be wider than the FMVSS No. 214-curtain) on the side roof rail. This is most easily accomplished when the model is being redesigned. Most passenger car models are redesigned in about a four years period, while pickup trucks and some vans have longer redesign cycles of about 7 years. NHTSA believes the most cost-effective way to accomplish this redesign task is to allow a phase-in of the requirements. This accomplishes two objects. First, the new makes and models can be designed with the new requirements efficiently. Second, all of the make/models don't have to be redesigned at one time. The agency is proposing to phase-in the new ejection mitigation requirements starting the first September 1 three years from the date of publication of a final rule. Assuming that a final rule would be issued in after September 1, 2009, NHTSA proposes that the phase-in would be implemented in accordance with the following schedule:

September 1, 2013 for 20 percent of a manufacturer's light vehicles,
September 1, 2014 for 40 percent of a manufacturer's light vehicles,
September 1, 2015 for 75 percent of a manufacturer's light vehicles, and
September 1, 2016 for all light vehicles.

Advanced credits earned prior to the phase-in would be allowed during the phase-in period.

E. Summary of Costs and Lead-time:

We believe that the ejection mitigation rulemaking generally poses no design conflicts for vehicles and presents relatively few synchronization issues and could comfortably follow the 214 rulemaking without significant redesign problems. We believe that the design changes will primarily involve component level modification by suppliers rather than vehicle structural modification. In reality, we expect that vehicle manufacturers will design a system one time to meet both the 214 and head form test requirements. We expect that cost savings resulting from the "one time" design would not be substantial with respect to the total cost.[194] The estimated incremental costs in 2007 economics are shown below:

Table V-7
Total Cost and Weighted Average Cost Per Vehicle
(Assuming all 214-head bags are either curtain or comb bags, in 2007 economics)

Baseline 214-Head Bags, MY 2011			Assuming No Compliance[195]		
Bag Type	Sales (%)	Estimated Weighted Sales (%)	Total Sales: 17,000,000	Avg. Incremental Cost per Vehicle	Total Cost (in Millions)
214-Curtain w/ roll sensor	55%	55%	4,979,300	$11.95	$111
214-Curtain w/o roll sensor	39%	[196]44%	10,910,600	$49.97	$374
214-Combo	1%	1%	1,110,100	$208.31	$47
Total	95%	100%	17,000,000	N/A	$533*
Weighted Average Cost per Vehicle					$31.33
Total Weighted Incremental Cost for 1st and 2nd Row Windows					$533M
3rd Row windows					$51M
Total Weighted Incremental Cost for 1st, 2nd and 3rd Row Windows[197]					$583M*

* If all applicable light vehicles are considered, the incremental average unit cost would be $34.32.

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[194] The costs in 2007 dollars were achieved by applying the implicit gross domestic (GDP) price deflector to the 2005 economics: 113.034 in 2005, 119.816 in 2007, the ratio = 1.06.

[195] Agency's linear headform test results show that none of the bags tested met the deflection requirement when tested at all impact points. Thus, we believe that all currently available bags need be redesigned to be in compliance with the proposed requirements.

[196] When all light vehicles are equipped with head air bags to meet the 214-oblique pole requirements, we assumed that vehicles without any head air bags would be equipped with 214-curtain bags (without rollover sensors) to comply with the 214-oblique pole requirements. As a result, the percentage of curtain without rollover sensors would increase from 38.98% to 44.08%.

[197] As discussed, the total incremental cost would decrease from $583M to $537M if convertibles are excluded from meeting the headform deflection requirement.

VI. COST-EFFECTIVENESS AND BENEFIT-COST ANALYSES

A. Cost –Effectiveness Analysis

The intent of the rulemaking is to minimize deaths and injuries by preventing occupants from side window ejection in motor vehicle crashes. To achieve this goal, NHTSA is requiring a linear impactor headform test, to ensure that occupants are provided whole body protection by mitigating partial and complete ejections in crash environments. In previous chapters, a countermeasure system based on curtain air bag technologies was examined for costs and benefits.

As a primary measure of the effect of the linear headform test, this analysis will measure the cost per equivalent life saved. In order to calculate a cost per equivalent fatality, nonfatal injuries must be expressed in terms of fatalities. This is done by comparing the value of preventing nonfatal injuries to the value of preventing a fatality. Comprehensive values, which include both economic impacts and lost quality (or value) of life considerations will be used to determine the relative value of fatalities and nonfatal injuries. These values were taken from the most recent study by NHTSA. In Table VI-1, the process of converting nonfatal injuries to its fatal equivalent is shown.[198] The third column of Table VI-1 shows the comprehensive values used for each injury severity level, as well as the relative incident-based weights for nonfatal serious injuries, AIS 3-5.

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[198] In valuing reductions in premature fatalities, we used a value of $5.8 million per statistical life and $6.1 million comprehensive cost. The $5.8 million statistical life is based on the most recent DOT guidance, Revised Departmental Guidance, treatment of Value of Preventing Fatalities and Injuries in Preparing Economic Analysis," Memorandum from D. J. Gribbin, General Counsel and Tyler D. Duval, Assistant Secretary for Transportation Policy, February 5, 2008.

In Chapter IV, ejection mitigation benefits were derived for the curtain air bag countermeasure, as shown in Table VI-1.

Table VI-1
Process of Converting Nonfatal Injuries to Equivalent Fatalities
(Resulting from curtain ejection mitigation air bag countermeasure)

Injury Severity	No. of Fatalities and Injuries	Conversion Factor	Equivalent Fatalities (Undiscounted)
Fatalities	402	1.0000	402
AIS-5	31	0.6656	21
AIS-4	82	0.1998	16
AIS-3	197	0.0804	16
Total			455

The results in Table VI-1 show that the curtain ejection mitigation air bag would save 455 equivalent fatalities.

In Table VI-2, the safety benefits from Table VI-1 have been discounted at 3% and 7% rates to express their present value over the lifetime of one model year's production. Although passenger cars and light trucks have different adjustment factors at a given percent discount rate, the average of these adjustment factors was used for the discount based on the assumption that future sales will be approximately 50 percent passenger cars and 50 percent light trucks. The discount factors and the discounted fatal equivalents are summarized in Table VI-2.

Table VI-2
Present Discounted Value of Lives Saved

Fatal Equivalent	Discount Rate	Discounted Fatal Equivalent
455	0.8155 at 3%	371
455	0.6489 at 7%	295

The discounted fatal equivalents in Table VI-2 show that curtain ejection mitigation curtain air bags would save 371 and 295 equivalent lives when discounted at 3% and 7%, respectively.

The total annual costs[199] from Table V-8 for vehicles with ejection mitigation air bags were divided by the discounted fatal equivalent from Table VI-2 to produce estimates of the cost per equivalent life saved, as shown in Table VI-3.

Table VI-3
Range of Costs[200] per Equivalent Life Saved

Ejection Mitigation System	Cost (in millions)	Equivalent Lives Saved		Costs Per Equivalent Life Saved (in millions)	
		at 3%	at 7%	at 3%	at 7%
Curtain Air Bag	$583	371	295	$1.6	$2.0

The results in Table VI-3 show that the cost per equivalent life saved for the curtain ejection mitigation air bag system ranges from $1.6 million to $2.0 million at 3% and 7% discount rates, respectively.

B. Benefit-Cost Analysis

Effective January 1, 2004, OMB Circular A-4 requires that analyses performed in support of rules must include both cost effectiveness and benefit-cost analysis. Benefit-cost analysis differs from cost effectiveness analysis in that it requires that benefits be assigned a monetary value, and that this value be compared to the monetary value of costs to derive a net benefit. In valuing

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[199] Previously, we estimated a total incremental cost of 583 million when the expected bag sales remain unchanged. See the cost chapter for additional discussion.

[200] In the benefit analysis, we used an array of 214-side bags to estimate increased costs for the ejection mitigation system because we could not accurately predict the precise methods that vehicle manufacturers would use to upgrade the 214 side air bag systems to meet the headform displacement requirement. However, if the market share of different types of head bags in MY 2011 vehicles remains unchanged, we could estimate costs associated with the probable outcome of rollover bags under the proposed rule. The sales data indicate that 58%, 41% and 1% of side bags are curtain with rollover sensors, curtain without rollover sensor and finally combo bags, respectively.

reductions in premature fatalities, we used a value of $5.8 million per statistical life (in 2007 economics).[201]

When accounting for the benefits of safety measures, cost savings not included in value of life measurements must also be accounted for. Value of life measurements inherently include a value for lost quality of life plus a valuation of lost material consumption that is represented by measuring consumer's after-tax lost productivity. In addition to these factors, preventing a motor vehicle fatality will reduce costs for medical care, emergency services, insurance administrative costs, workplace costs, and legal costs. If the countermeasure is one that also prevents a crash from occurring, property damage and travel delay would be prevented as well. The sum of both value of life and economic cost impacts is referred to as the comprehensive cost savings from reducing fatalities.

The countermeasures that result from FMVSS No. 226, "Ejection mitigation" affect vehicle crashworthiness and thus do not involve property damage or travel delay. The agency is conducting a study to establish the comprehensive cost saving from preventing a fatality for crashworthiness countermeasures. The preliminary results indicate that the comprehensive cost would be $6.1 million per life in 2007 economics. The $6.1 million comprehensive cost saving was used for the benefit-cost analysis. The costs used to derive the $6.1 million comprehensive cost saving and the relative value factors reflecting $5.8 million statistical life are shown in Appendix F.

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[201] "Revised Departmental Guidance, Treatment of Value of Preventing Fatalities and Injuries in Preparing Regulatory Evaluations", Memorandum from D. J. Gribbin, General Counsel and Tyler D. Duval, Assistant Secretary for Transportation Policy, February 5, 2008.

Total benefits are derived by multiplying the value of life by the equivalent lives saved. The net benefits are derived by subtracting total costs from the total benefits, as shown in Table VI-4.

Table VI-4
Net Benefits with a Value of $6.1M Comprehensive Cost per Equivalent Life

Ejection Mitigation System	Benefits ($M)		Net Benefit ($M)	
	3%	7%	3%	7%
Rollover Curtain Air Bag	$2,263	$1,801	$1,680	$1,217

The results in Table VI-4 show that ejection mitigation air bags would result in net benefits of $1,680 million and $1,217 million at 3% and 7% discount rates, respectively.[202]

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[202] Although it would be unrealistic, we could calculate the net benefits if all <u>baseline</u> vehicles (i.e., MY 2011) are equipped with a same (baseline) air bag type. Nat benefits ($M) at 7%: (a) curtain w/ rollover sensor: $1,598 with $203M cost; (b) curtain but no rollover sensor: $951 with $850M cost; (c) combo without rollover sensor: -$1,278 with $3,541M cost.

VII. SENSITIVITY ANALYSES

A. Introduction

This section discusses the change in costs and benefits that result from different assumptions used in the analysis. When inputs that affect the analysis are uncertain, the agency makes its best judgment about the probable values or range of values that will occur. This analysis will examine alternatives to these selections to illustrate how sensitive the results are to the values initially selected.

The factors that will be examined include: (1) the cost and (2) effectiveness of rollover sensors, (3) the use of laminated glazing including laminated glazing in the roof, (4) ejection through the second and third row window openings, (5) excluding A1 from the test requirements, (6) 100% belt use rate, and (7) crashes involving alcohol.

B. Sensitivity Factors

(1) Cost of rollover sensor. In the cost chapter, we estimated that each vehicle needs one rollover sensor at an average cost of \$38.02 (in 2007 economics). The average cost is based on NHTSA contractor teardown studies of five vehicle makes/models. The rollover sensor cost ranged from \$23.38 to \$53.50 per vehicle (in 2007 economics). The unit costs of these sensors are significantly different among different models and manufacturers. If the \$53.50 sensor cost is used, the cost for each ejection mitigation system would increase greatly, as shown below:

Table VII-1
Costs for Air Bag System[203] with $53.50 Rollover Sensor (in 2007 dollars)

Baseline 214-Air Bag System	Estimated Sales	Average Incremental Cost Per Vehicle
Curtain with Roll Sensor	55%	$11.95
Curtain without Roll Sensor	44%	$65.45
Combo	1%	$223.79

With the $53.50 sensor cost (in 2007 dollars), the weighted total incremental cost would be $703 million ($652 $_{\text{1st and 2nd rows w/ \$53.50 sensor}}$ + $50.8 $_{\text{3rd row curtain}}$ = $703) and the cost per equivalent life saved would increase to $2.5 million (with 7% discount and $2.0 million at 3%). When the $23.38 (lower end) was used, it would result in a weighted total incremental cost of $470 million ($419 $_{\text{1st and 2nd rows w/ \$23.38 sensor}}$ + $50.8 $_{\text{3rd row curtain}}$ = $470 million, $1.7 million per equivalent life saved at 7% discount and $1.3 million at 3%).

(2) Effectiveness of rollover sensor. In the benefits chapter, we assumed that each vehicle will be provided with a rollover sensor as an integral part of the system. Although the agency has not done any independent research to estimate the effectiveness of rollover sensors, we believe that it would be more difficult for the sensor to detect low-energy rolls that would result in a low number of quarter-turns in lateral rollovers. Accordingly, we assumed that rollover sensors are not effective in quarter-turn rolls. However, some sensor suppliers estimate that their sensors will work in between 90% and 95% of rollovers, which is much higher than the 77% effectiveness rate used in our analysis. If the claim is indeed true, the assumption used for the

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[203] A combination bag is designed to protect both head and thorax of an occupant in side crashes. When a combination bag is replaced by a curtain system, we assumed that the vehicle will be equipped with two curtain and two thorax bags. $53.50 $_{\text{roll sensor}}$ + $183.39 $_{\text{roll curtain bag}}$ + $2.42 $_{\text{incr. inflator}}$ - $91.14 $_{\text{combo}}$ + $75.61 $_{\text{thorax}}$ = $223.79.

sensor effectiveness would underestimate the sensor effectiveness by 7% - 12% for non-fatal serious injuries (AIS 3-5) and 14% - 19% for fatal injuries[204], as shown below:

Table VII-2
Difference in Rollover Sensor Effectiveness between
Assumptions in the Analysis and Suppliers' Estimates

Estimate	Non-fatal serious injury	Fatal
Agency estimate	84%	77%
Supplier estimate – lower range	90%	90%
Supplier estimate – upper range	95%	95%

When the 90% (supplier estimated) sensor effectiveness rate is used, the overall system effectiveness increases from 48% and 44% to about 56% and 52% for belted and unbelted occupants, respectively, in rollovers. With the use of the 90% effectiveness rate, the number of overall additional lives saved would increase from 402 to 449 lives, annually. For the 95% sensor effectiveness rate, the number of overall additional lives saved increases from 402 to 468 lives, annually, as shown in Table VII-3 and also Appendix E.

Table VII-3
Summary of Expected Incremental Lives Saved[205]
With Different Rollover Sensor Effectiveness Rates

Estimate	Effectiveness (in fatal)	Overall Additional Lives Saved
Agency estimate	77%	402
Supplier estimate – lower range	90%	449
Supplier estimate – upper range	95%	468

(3) Use of laminated glazing:

In the benefit analysis, we assumed that all side windows are made of tempered/safety glass and, consequently, advanced/laminated glazing was not considered. However, the agency's test data indicate target location A1 (see Figure III-6) is much more challenging than other impact points in the front window opening. Current field and laboratory data suggest that even partially

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[204] The numbers were rounded to the nearest integer.
[205] For the fatal benefits in the table, we assumed that all side windows would be made out of tempered glass.

shattered advanced glazing could be effective in preventing occupant ejection through the potential gaps in certain crashes when rollover curtain bags are used.[206]

(3.1) Benefits: As discussed in the benefit chapter, if manufacturers utilize advanced/laminated glazing in the front window opening as a supplement to air bag curtains, we expected the containment effectiveness would increase from 71% to 88% for belted and 65% to 86% for unbelted (weighted with the 69% window-up percentage)[207], assuming all ejections through the potential gaps would be prevented by the glazing.[208] The use of laminated glazing would moderately increase the overall system effectiveness. For example, in the benefit analysis, we estimated that the overall rollover air bag system would be about 48% effective in reducing belted partial fatal injuries in rollover crashes. When the 88% improved containment effectiveness is used, the overall effectiveness would increase from 48% to 59% ($77\%_{\text{sensor}}$ x $88\%_{\text{containment}}$ x $88\%_{\text{Winnick's}}$ = 59%) for belted, assuming side windows are up 69% of the time before side window ejection. With the $59\%_{\text{with glazing}}$ system effectiveness for belted and 58% for unbelted, we expect the number of additional lives saved would increase from 248 to 322 (lives)

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[206] Although we do not have laboratory or real world crash data, we suspect that advanced glazing may have a limited effectiveness in preventing occupants from partial or complete ejection in vehicle-to-pole/tree side crashes.

[207] The agency's 1997-2005 NASS CDS data showed that, for the target population of the proposed rule, the front row window through which an occupant was ejected was closed or fixed prior to the crash 69 percent of the time. As discussed in the benefit chapter, we assumed that advanced glazing would contain 95% of ejections through the window opening (with the 5% ejection through the sunroof) when the window is up (69%). When the window is down (31%), we assumed that the containment effectiveness values are the same as values derived for the full-curtain bag.

[208] With the 5% sunroof ejection rate, we estimated that the curtain+glazing system would be 95% effective in preventing occupant ejection. Previously, we estimated that the curtain system would be 71% and 65% effective for belted and unbelted occupant, respectively, in rollovers. These containment rates were adjusted with the 69% window-up rate to derive the 92% combined effectiveness (95% x $\%69\%_{\text{window up}}$ + 71% x $(100\%\text{-}69\%)_{\text{window down}}$ = 88% for belted, 95% x 69% + 65% x (100%-69%) = 86% for unbelted. The weighted combined containment effectiveness would be 86%: 16.5% were belted and 83.5% were unbelted in fatal rollovers. 16.5% x .88 + 83.5% x .86 = 86%.

in rollover crashes. With the glazing, the overall number of additional lives saved in rollover and side crashes would increase from 402 to 494 (lives)[209].

The agency's test data on the 2nd window are much more limited when compared to the 1st window data. There were only two vehicles, MY 2005 Honda Odyssey and MY 2006 Dodge Durango, that were tested for the 2nd window.

Table VIII-4

Headform Impact Test for 2nd Window, lower and upper impact points, 24 km/h

Lower impact area	A1	A2	B1	B2	C1	C2
Honda Odyssey	No cover	119	71	152	58*	No data
Dodge Durango	174	156	76	86	66*	No data
Upper impact area	A3	A4	B3	B4	C3	C4
Honda Odyssey	107	No data	80	193	175	To stops
Dodge Durango	140*	54	91	82	No data	283

* At 20 km/h

In general, the data indicate target location B1 is more challenging than B4. The exception to this is the three-row Dodge Durango, which performed well at all 2nd row targets. When the displacement data for the lower impact areas of target A2 and B1 were compared, it showed a substantial decrease in displacement, from 119 mm (failed) to 71 mm for the Odyssey and from 156 mm (failed) to 76 for Durango. The test results suggested that the B-pillar would provide a load bearing area (such as advanced glazing would) for the 2nd row. Although the 2nd row data were from three-row vehicles, the test data show that, unlike the front window opening, currently available air bag systems could be used to comply with the displacement requirement when the test is conducted in the 2nd row window opening area.[210]

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[209] In the benefit chapter, we used both "weighted risk" and "uniform risk" approaches for the containment effectiveness. The fatal benefits are based on the "weighted risk" method.

[210] The Durango test data indicated that manufacturers may not need to install laminated glazing combined with air bags in the 2nd window opening. Accordingly, we do not expect that laminated glazing will be used in the 2nd row opening.

Real world crash data show that a sizable number of occupants were ejected through the sunroof. Based on currently available data, we believe that laminated glazing may be useful as a countermeasure to prevent occupants from ejection through the sunroof. At this time, however, we do not know whether manufacturers would utilize laminated glazing for the sunroof for their vehicles, although current retention technologies indicate that laminated glazing may be feasible. In addition, the agency has not developed any test procedures to evaluate sunroof glazing performance in rollovers. Accordingly, we do not have a specific method to estimate potential benefits of using laminated glazing for the sunroof.

If we assume that the sunroof glazing is as effective in containing occupants[211] as the advanced side window glazing (as discussed in this chapter) and that the sunroof has the same 86% window-up (i.e., closed-window) percentage as front windows in rollovers,[212] the containment effectiveness would be about 86% ($100\%_{\text{containment thru sunroof}}$ x $86\%_{\text{closed sunroof}} = 86\%_{\text{containment effectiveness}}$) for the target population.[213] Under the assumption, the laminated sunroof would be about 58% effective in reducing a fatality ($86\%_{\text{containmnet effectiveness}}$ x $77\%_{\text{sensor effectiveness}}$ x $88\%_{\text{Winnicki's risk}} = 58\%$). Previously, we estimated a total of 737 fatalities in the rollover target population (excluding fatalities from catastrophic crashes). With the 5% ejection rate, the laminated sunroof glazing would save about 21 additional lives, annually, in rollover crashes [($112_{\text{belted partial}} + 107_{\text{unbelted partial}} + 519_{\text{unbelted complete}}$) x $5\% = 37_{\text{occupants ejected through the sunroof.}}$

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[211] In the benefit chapter, we used two methods to derive the containment effectiveness. We note that these methods are not based on occupant injury levels but the likelihood of ejection through a particular area in the window opening.

[212] The agency's 1997-2005 NASS CDS data showed that 86 percent of front window were closed (or fixed) prior to a rollover.

[213] As discussed, some rollover crashes were excluded from the target population. In addition, we do not have data to show whether the sunroof can contain all ejected occupants (i.e., 100%) when it is in closed-position in roll crashes. Therefore, we believe that the actual rate would be lower than the estimated 86% containment rate.

$37_{\text{occupants}}$ x $58\%_{\text{ sunroof ejection effectiveness}}$ = 21_{lives}].[214] However, we do not know the number of vehicles currently equipped with laminated sunroof glazing (or will be equipped in MY 2011). As a result, we are unable to estimate what percentage of the 21 fatal benefits would result in additional benefits (i.e., adjusted with the installation rate in MY 2011).

<u>(3.2) Costs</u>: In the cost chapter, we estimated that if vehicle manufacturers replace a tempered glass with a laminated glass for standard size front window or rear seat window, the associated unit cost would be about $24 (in 2007 dollars). We expect that the incremental cost may decrease slightly with increasing sales of laminated glass. If all light vehicles are equipped with laminated glazing in the <u>front window</u>, the expected incremental total cost associated with the glazing would be about $816 million (17 million $_{\text{No. of vehicles}}$ x $\$24_{\text{incremental unit cost}}$ x $2_{\text{No. of windows}}$ = $816 million). The agency expects that about 40% of all light vehicles would have fixed (non-removable) windows in the rear passenger (i.e., 3rd row) or cargo compartment.[215] If both the front and the 3rd row windows are equipped with laminated glazing, the total incremental cost would be more than one billion dollars ($\$352\text{M}_{\text{ Curtain}}$ + $\$1{,}142\text{M}_{\text{ Advanced glazing}}$ = $1,494M. See Chapter VIII for detailed cost analysis on the partial curtain that could be used with laminated glazing).[216]

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[214] In the rollover target population, there are 12 belted-complete fatalities. As discussed, we excluded these fatalities from the benefit analysis.

[215] Six manufacturers (comprising 87 percent of light vehicles sales) responded confidentially to a NHTSA request for planned side air bag installation and projected sales through model year (MY) 2011. According to the sales data, 25% of MY 2011 light vehicles have a third <u>seat</u>.

[216] Since 100% of vehicles have 1st row windows and 40% of vehicles have a 3rd row seat or rear cargo bay with side windows, the total cost would be $1,142 million, as shown below:

	Unit cost	No. of veh.	No./veh.	% of total	Cost	
1st row	$24	17M	2	100%	$816M	
3rd row	$24	17M	2	40%	$326M	Total: $1,142M

The $1,142M is based on an assumption that laminated glazing would be installed in the rear window opening (i.e., windows behind the 2nd row). According to the sales data, 25% of MY 2011 light vehicles have a third row <u>seat</u>. If we assume that laminated glazing would be installed only in the 3rd row <u>seat</u> (not for cargo bay), the cost would be $1,020M. In addition, in Chapter VIII, we estimated that manufacturers need a total incremental cost of $352M to

<u>(3.3) Cost per Equivalent life Saved</u>: With the glazing, the number of additional lives saved in rollover and side crashes would increase from 402 to 494 (lives) over and above window curtains, assuming the headform requirement at the A1 cannot be met with a window curtain. Similar to the method used for the fatalities, we estimated that a total of 391 AIS 3-5 injuries would be saved (39+103+249 = 391), as shown in Table VII-5.

Table VII-5
Process of Converting Nonfatal Injuries to Equivalent Fatalities
(Resulting from curtain + glazing)

Injury Severity	*Fatalities and Injuries, with Curtain*		Fatalities and Injuries, w/ Curtain and Glazing[217]	Conversion Factor[218]	Equivalent Fatalities
Fatalities	*402*		494	1.0000	494
AIS-5	*31*		39	0.6656	26
AIS-4	*82*		103	0.1998	21
AIS-3	*197*		249	0.0804	20
				Total	560

The results in Table VII-4 show that the curtain+glazing ejection mitigation system would save 560 equivalent fatalities.

The discount factors and the discounted fatal equivalents are summarized in Table VII-6.

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convert the 214-bag system to meet the single-impact headform requirement, by adding rollover sensors to the 214-curtain and converting the 214-combo bag. We used the $352M as a baseline for the incremental cost for the partial curtain (see Table VIII-4).

[217] For the analysis, we assumed that the window openings are covered with a partial curtain (i.e., excluding A1) for the curtain + glazing system.
A total of 391 additional AIS 3-5 injuries would be prevented by the "curtain + glazing" ejection mitigation system (see Appendix E for details), whereas 310 AIS 3-5 injuries were prevented by the curtain (only) system (i.e., "full curtain"). Among the 310 injuries prevented, 63.6%, 26.2% and 10.2 % were from AIS 3, AIS 4 and AIS 5, respectively. These percentages were applied to the 391 injuries prevented with the "curtain + glazing" system, resulting 249 AIS 3, 103 AIS 4 and 39 AIS 5 injuries.

[218] In valuing reductions in premature fatalities, we used a value of $5.8 million per statistical life based on the most current DOT guidance on valuing fatalities. The relative value factors (i.e., conversion factors in the table) are reflecting the $5.8 million value of a statistical life (VSL). Additional discussion is found in the Cost Effectiveness & Benefit-Cost Analysis chapter.

Table VII-6
Present Discounted Value of Lives Saved for Curtain+Glazing

Fatal Equivalent	Discount Rate	Discounted Fatal Equivalent
560	0.8155 at 3%	457
560	0.6489 at 7%	363

The discounted fatal equivalents in Table VII-5 show that curtain + glazing system would save 457 and 363 equivalent lives when discounted at 3% and 7%, respectively.

Previously we estimated that a total incremental cost of $352 million for covering 1st, 2nd and 3rd row window openings with a partial curtain. With the $1,142 million glazing cost, the total incremental cost increase from $583 million to $1,494 million ($352M + $1,142M = $1,494M,). The $1,494 million total annual cost was divided by the discounted fatal equivalent from Table VII-5 to produce estimates of the cost per equivalent life saved, as shown in Table VII-7.

Table VII-7
Range of Costs per Equivalent Life Saved[219]

Ejection Mitigation System	Cost (in millions)	Equivalent Lives Saved		Costs Per Equivalent Life Saved (in millions)	
		at 3%	At 7%	at 3%	at 7%
Curtain Bag + glazing	$1,494	457	363	$3.3	$4.1

The results in Table VII-6 show that the cost per equivalent life saved for the curtain + glazing system ranges from $3.3 million to $4.1 million at 3% and 7% discount rates, respectively.

(4) <u>Ejections through the 2nd and 3rd row window openings (with uniform distribution)</u>: In the <u>target population</u>, there are 4,041 side window ejection fatalities in rollover crashes. Among the 4,041 fatalities, 3,383 (<u>84%</u>) were from the first row, 620 (15%) were from the second and the remaining 38 (1%) were from the third row window, as shown in Table VII-8.

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[219] The $3.3M and $4.1M costs for equivalent life saved were based on a partially covered curtain (214-curtain) plus glazing.

Table VII-8
Fatalities in Target Population by Window Row in Rollover Crashes*

Crash	Row 1	Row 2	Row 3	Total	(Ref. Table)
Rollover, no side impacts	3,115	515	38	3,668	(Table IV-5)
Side impacts followed by rollovers, all but 12-25 mph	214	70	0	284	(Table IV-6)
Side impacts with subsequent rollovers, 12-25 mph	54	35	0	89	(Table IV-7)
total	3,383	620	38	4,041	▨

* There were 87 partial ejection fatalities in this side crash group. As discussed, these fatalities were included in the FMVSS No. 214-benefits and excluded from the target population.

For the remaining two sub-groups in the target population, “side impacts without rollovers in a delta-V of 12-25 mph” and “side impacts without rollovers for children 0-12 years in a delta-V of 12-25 mph”, we estimated that a total of 42 fatalities would be from the 2nd and 3rd row window opening ejections, as shown in Table VII-8.

Table VII-8
Fatalities in Target Population by Window Row in Side Impacts, 12-25 mph

Crash	Row 1	Row 2	Row 3	Total
Side impact, no rollovers	288	5	0	293
Side impacts, no rollovers, children (0-12 yrs)	0	37	0	37
total	288	42	0	330

(4.1) Reduction in Benefit: In the benefit chapter, we determined the risk of ejection through a particular area in the side window opening. The determination was based on test dummies in the front seating row in rollover crashes. Due to limited data, we assumed that all ejections in the target population occurred through the first row window opening. As mentioned, we do not know the risk of ejection at a given area in the second and third row window openings. If we assume that the risk of ejection is evenly distributed in the 2nd and 3rd row window opening areas, as discussed in the benefit chapter, the risk of ejection through the potential gap would be 33%, as shown in Figure VII-1.

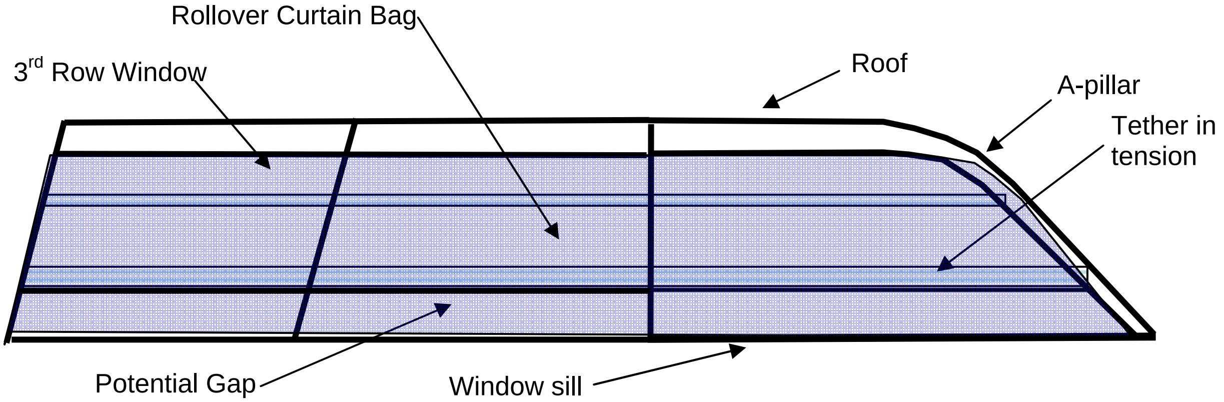

Figure VII-1. Potential Gap in 1st, 2nd and 3rd Row Window Openings

In other words, with the 5% ejection rate through the sunroof, a rollover curtain air bag would be about 63% effective in preventing occupant ejections (100% -33% = 67% (66.67%). 67% x (1-0.05) = 63%) in the 2nd and 3rd row side windows. With the 77% sensor effectiveness and 88% Winnick's survival rate, we estimated that a curtain ejection mitigation system would be 43% effective in reducing fatalities for occupants who are ejected through the 2nd and 3rd row side window openings in rollover crashes. For the side crashes followed by rollovers, we estimated that the overall system effectiveness would be about 24% for partially ejected and 20% for completely ejected occupants (as shown in Appendix E). With these system effectiveness rates, we estimated that a rollover curtain air bag system would save 51 incremental lives for occupants ejected through the 2nd and 3rd row side window openings, as shown below:[220]

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[220] For the potential benefits, we assumed that advanced glazing is equally effective for all rollovers including ones with preceding side impacts. For side impacts without rollovers in the target population, we assumed that advanced glazing would not be effective since some of the side impact include vehicle-to-narrow object (such as tree or pole).

Table VII-9
Lives Saved through 2nd and 3rd Window Openings

Crash	Fatalities	ESC adjusted	Lives Saved	Incremental Lives Saved
Rollover, no side impacts	[221]553	113	48	36
Side impacts followed by rollovers, all but 12-25 mph	70	62	12	9
Side impacts with subsequent rollovers, 12-25 mph	35	31	8	6
Total	658	205	69	51

For the side impacts, we estimated that a rollover curtain air bag system would save 9 incremental lives for occupants ejected through the 2nd and 3rd row side window openings, as shown below:

Table VII-10
Lives Saved through 2nd and 3rd Window Openings

Crash	Fatalities	ESC adjusted	Lives Saved	Incremental Lives Saved
Side impact, no rollovers	5	4	2	1
Side impacts, no rollovers, children (0-12 yrs)	61	25	10	8
total	66	29	12	9

In summary, previously we estimated that a rollover ejection system would save 402 incremental (additional) lives, annually. Among the 402 incremental fatal benefits, 337 (84% of the window ejections were from the 1st row, 402_{lives} x 84% $_{\text{1st row}}$ = 337 lives, see discussion above) would be from occupants who were ejected through the first row side windows.[222] For the remaining 65 lives saved (402 – 337 $_{\text{first row}}$ = 65), we assumed that the risk of ejection through a particular area in the 2nd and 3rd row window openings is same as the risk of ejection through a certain area in

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[221] For example, in Table VII-7, 515 fatalities were from the 2nd row ejections and 38 were from the 3rd row ejections in rollovers without side impacts, a total of 553 ejections through the 2nd and 3rd row window openings.

[222] In the target population, we estimated that 3,383 fatalities out of the total 4,041 fatalities in rollover (whether with and without side impacts) were from the first row window opening ejection, 3,383/4,041 = 84% of the total window opening ejections (see Table VII-8). In addition, it showed that 15% and 1% of the ejections were through the 2nd and the 3rd row windows. See Tables IV-5, -6 and -7 for additional information.

the front window opening. However, we do not have test or real world crash data to estimate the risk of ejection through a particular area in the 2nd and 3rd row windows. When we used the most conservative method (i.e., assuming ejections are evenly distributed in the 2nd and also 3rd row window openings), it showed that at least 60 lives (51+9 = 60) can be saved when the rear window openings are completely covered. In other words, when the 2nd and 3rd row windows are considered separately, it would result in 397 incremental lives saved (337 lives from the 1st row and 60 from the 2nd and 3rd rows). (Mathematically we could estimate that 58 lives saved would be through the 2nd row windows and 3 lives saved would be through the 3rd row windows.) Without a curtain air bag, the rollover test data show that unbelted occupants can move around in a lateral roll and find open portals to be ejected through. However, we don't know how unbelted dummies or vehicle occupants in the rear seating rows behave in a lateral roll. If the 3rd row window openings are not covered by a window curtain in crashes, due to their relatively large window sizes, when compared to the 2nd and 1st row windows, and the proximity of the 2nd and 3rd row windows, there may be many more than 3 fatalities being ejected out the 3rd row window openings.

(4.2) Increase in Cost: As discussed in the cost chapter, when the 3rd row side window opening is covered with a curtain air bag, it would incur $11.95 incremental cost per vehicle. As part of the FMVSS 214 rulemaking, vehicle manufacturers provided their projected sales. According to the sales data, 25% of MY 2011 light vehicles have a third row seat. If we assume that these SUVs and Vans will have two side windows in the 3rd row, the total incremental costs associated with the air bag would be about $51 million (17 million vehicles x 25% x $11.95 = $50.8 million).

In summary, when the 2nd and 3rd row window openings are covered with a rollover curtain air bag, it would result in 60 lives saved, annually. Mathematically we could estimate that 3 lives saved would be through the 3rd row window openings. However, the total incremental cost to cover the 3rd row windows would be relatively high. The total incremental cost was estimated to be $51 million.

(5) Excluding A1 from the test requirements: In the benefits chapter, the potential benefits were estimated based on an assumption that vehicle manufacturers would meet the requirements at the A1 impact point. Although the headform test results used in the PRIA showed that none of the vehicles we had tested met all the requirements at A1, we believe that it will be feasible and practicable for A1 to meet the proposed test requirements. An air bag supplier, Takata, has a curtain designed specifically to perform well when tested to the proposed impact test. Takata has indicated the design will meet a displacement limit of 100 mm at all target locations, including A1 (Docket NHTSA-2006-26467-19).

We believe that based on the evidence available to us, complete window coverage is critical to the effective performance of the ejection countermeasure. Testing done with a rollover fixture showed that sometimes the dummy migrates to and can find an opening in the ejection mitigation curtain.[223] As shown in Figure VII-2, excluding A1 as a target point will allow curtains to have

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[223] Section IV. B. of the NPRM explains the agency's position (see pages 16-20 of the preamble): "NHTSA undertook several research programs using a dynamic rollover fixture (DRF), which produced full-dummy ejection kinematics in an open window condition, to assess the potential effectiveness of ejection mitigation countermeasures in a rollover. These countermeasures included several designs of inflatable curtain air bags, advanced laminated glazing, and combinations of curtains and advanced glazing. The results showed, however, that not all ejection mitigation air bag curtains work the same way. Full window opening coverage is key to the effectiveness of the curtain in preventing ejection."

an opening in the window coverage at that target location. In addition, it will allow a potential gap around this opening. (In this chapter the term "potential gap" is assumed to mean a portion of the window that is covered but only by material that does not retain the headform to the proposed deflection limit. It can be thought of as an area of inadequate or insufficient coverage. The term "partial curtain" refers to a curtain that has an opening at A1.) Nevertheless, we examined the potential safety impact of a headform test without testing the point A1 in the front window opening area. However, trying to determine the benefits derived from a partial curtain and how that may impact individual manufacturer's designs was difficult, since we do not fully understand how occupants eject through a particular point in the window opening area.

One way of estimating the incremental benefits of a rollover curtain bag, which is designed to meet the displacement requirement at all four impact points, over a bag that is designed to meet only three impact points (A2 through A4) is to analyze the risk of ejection through the front low corner (A1).

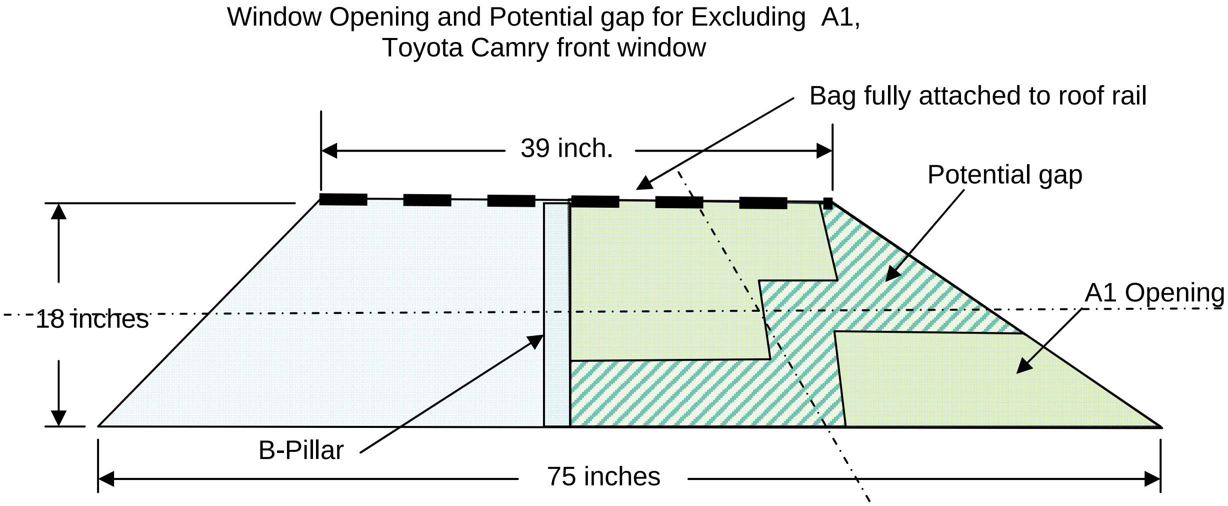

Figure VII-2. Potential gap/opening and A1

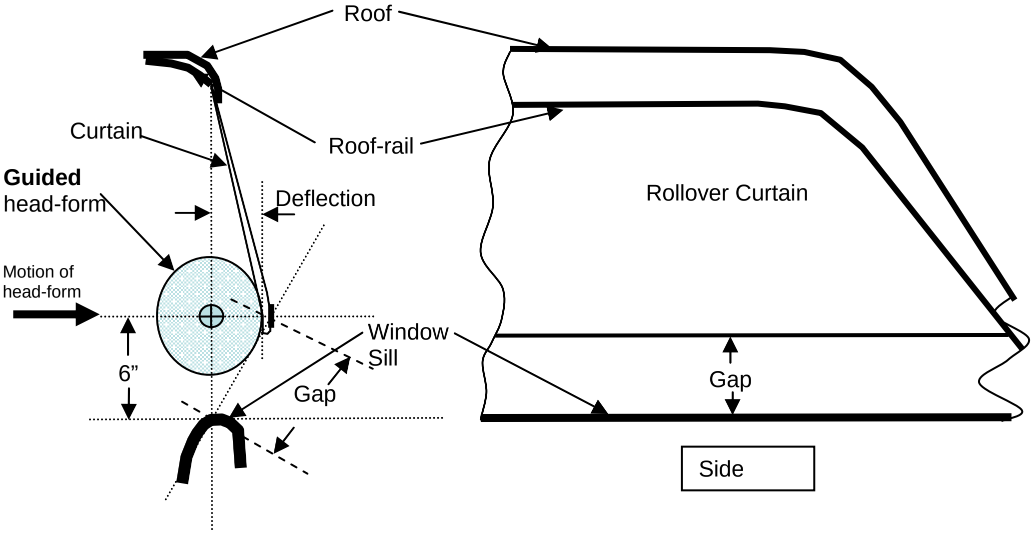

Figure VII-3 Potential Gap in Front Window

In the benefit analysis, we estimated that the risk of ejection through a potential gap between the window sill and the bottom of a rollover curtain bag (see Figure VII-3) is relatively small. If the opening area is divided into four quadrants and ejections through each quadrant is represented by the linear headform impact in that area, the risk of ejection through the lower forward quadrant (A1, between the A-pillar and the window sill) would be 5%[224] for belted occupants and 16% for unbelted occupants, as shown in Figures VII-4 and VII-5.

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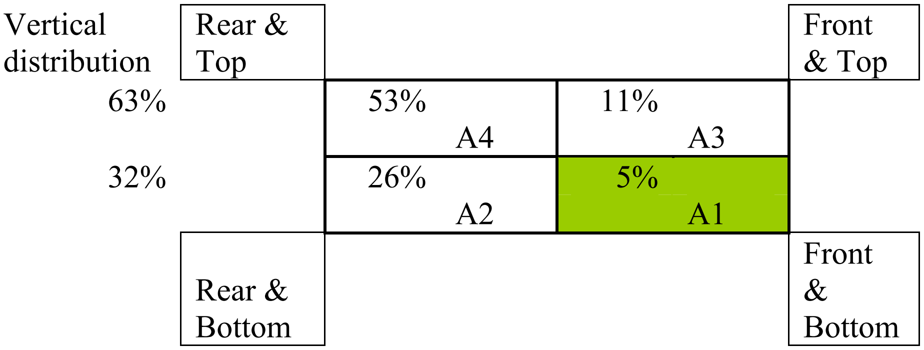
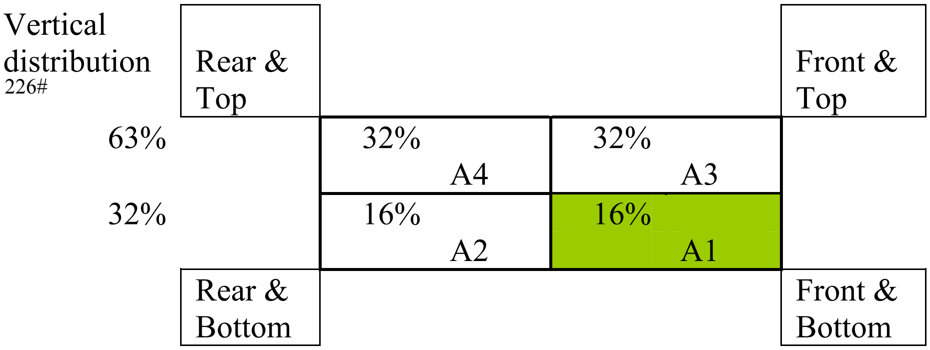
[224] For example, in the benefit chapter, we estimated that belted occupants have a 33% risk of ejection through the lower portion of the window opening and a 17% risk of ejection through the forward portion of the opening. With the 5% ejection risk through the sunroof, the risk of ejection through the lower quadrant would be 5% (33%x17%x95%=5%)



Total 95%[225] The numbers were rounded to the nearest integer.

Figure VII -4 Belted Occupants, Risk of Ejection through Each Quadrant



Total 95% The numbers were rounded to the nearest integer.

Figure VII -5 Unbelted Occupants, Risk of Ejection through Each Quadrant

As discussed, even if the opening area is fully covered, some ejections could occur through a potential gap between the curtain and the window sill. For example, for belted occupants, the risk of ejection through the lower rearward quadrant (which contains the A2) is about 26%. Previously, we estimated that a potential gap can be formed in the bottom 1/3 of the front window opening of a Toyota Camry (which has an opening height of approximately 18 inches). If the ejections through the quadrant were evenly distributed, the risk of ejection through the

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[225] Based on ejections in real world crashes, we assumed that 5% of ejections would occur through the sunroof.
[226] Note that, due to limited data, we used the vertical ejection distribution of belted occupants as a proxy for unbelted occupants.

potential gap in the lower rearward quadrant (A2) would be approximately 17% (17.3%).[227] Likewise, under the assumption, the risk of ejection through the potential gap in the low forward area would be about 3% (3.3%).[228] In other words, if the window opening is divided into four quadrants and each quadrant is represented by an impact point in the quadrant, the hypothetical full-covered rollover curtain bag would be 79% effective in preventing belted occupant ejections (1-(0.173+0.033) = 0.794, $79.4\%_{\text{fully covered curtain}}$.

In the benefit chapter, we determined that the curtain may or may not prevent the headform from ejection through the lower portion of the window area below the C.G. of the headform even if the opening is completely covered. Accordingly, we assumed that the air bag would not be effective in preventing ejections through the lower 1/3 portion of the window opening area (i.e., potential gap). In addition, we determined that there would be a potential gap at the front edge of the bag, adjacent to the A-pillar. Similar to the methodology used for the containment effectiveness of a full curtain bag in the benefit chapter, the partial curtain (which would not cover the front lower corner of the window opening) would not be effective in preventing occupants from ejection through the area surrounding the front lower opening (A1), even if it is covered by the air bag cloth. In other words, the partial curtain would allow ejections through the front lower opening and also the potential gap surrounding the opening. When the risk of ejections through the front opening and the potential gaps are considered, the partial curtain would be 58% effective in preventing belted occupants and 48% effective in preventing unbelted occupants in fatal rollover crashes.

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[227] 26% ejections would occur through the lower 50% of the opening. If the ejections were evenly distributed, accordingly, 17% of ejection would occur through the 1/3 of the window area [26%x(1/3)]/(1/2) = 17% (17.3%).
[228] 5% of the ejections would occur through the lower forward quadrant.

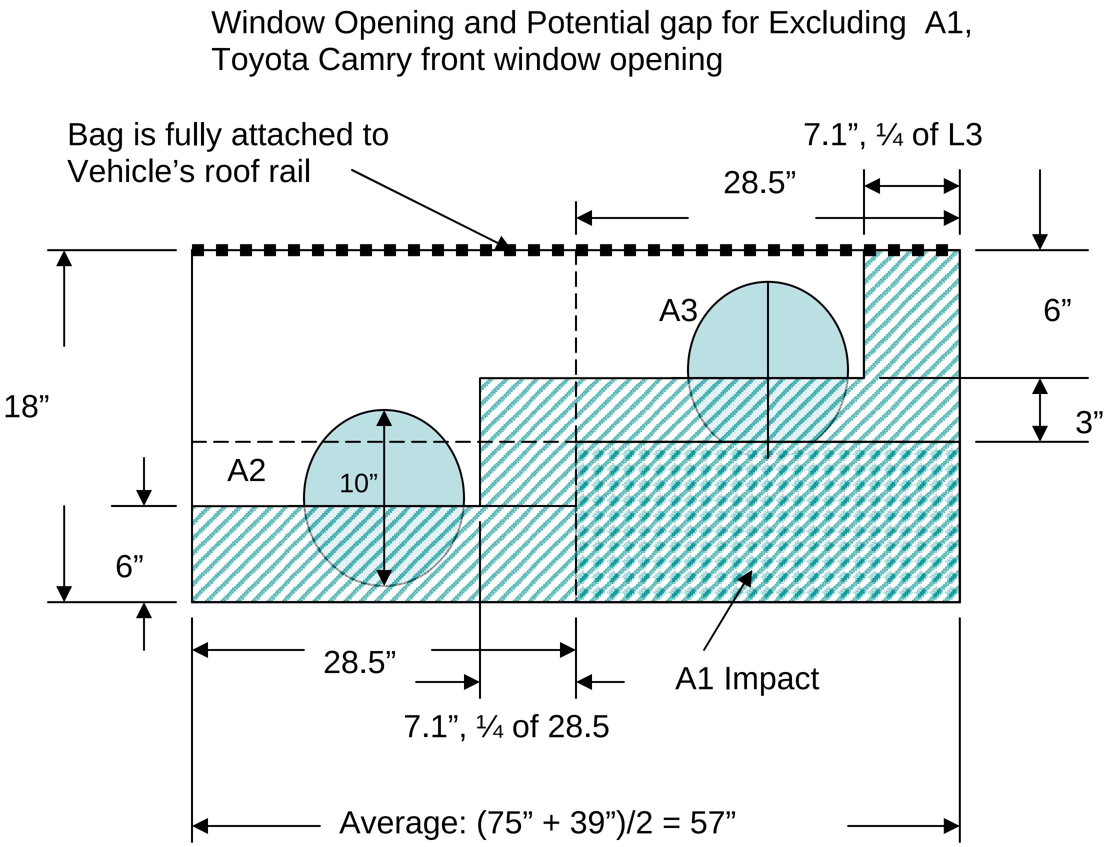

Figure VII-6. Window opening in quadrant form, 2003 MY Toyota Camry

Table VII-11 Front window opening coverage (in^2) in quadrant form for belted occupants

Quadrant:	upper rear	lower rear	upper front	lower front
Coverage area	257	257	257	257
Gap/opening area	43	171	128	257
% of opening	17%	67%	50%	100%
Full curtain containment effectiveness	53%	26%	11%	5%
Coverage without testing A1	83%	33.3%	50%	0%
Containment without testing A1	44%	9%	5%	0%
Overall belted containment:				58%

Table VII-12 Front window opening coverage (in^2) in quadrant form for unbelted occupants

Quadrant:	upper rear	lower rear	upper front	lower front
Coverage area	257	257	257	257
Gap/opening area	43	171	128	257
% of opening	17%	67%	50%	100%
Full curtain containment effectiveness	32%	16%	32%	16%
Coverage without testing A1	83%	33.3%	50%	0%
Containment without testing A1	26%	5%	16%	0%
Overall unbelted containment:				48%

We note that the derived containment effectiveness for the partial curtain system was based on several conditions and assumptions including: (a) the air bag has displacements of less than 100 mm in the other impact points, (b) the risk of ejection through a particular area in each quadrant is evenly distributed, and (c) there is a potential gap between the bag and the surrounding structure (such as window sill and A-pillar) when the bag is not completely attached to the structure.

We note that although we only tested a small number of rollover curtain bags, it appears from our tests that the vertical location of the tether anchor at the A-pillar should be lower than the center of gravity of the head-form impact point to withstand the load. Since the two lower impact points (A1 and A2) in the front window opening area are approximately at the same vertical distance from the window sill (as shown in Figure VII-7), the tether line (or lines) would go across the front forward area. We believe that these tether lines could prevent some occupant ejections through the corner gap. However, we do not have any laboratory or field data to quantify this very limited possible effectiveness (from tether lines). (Some air bag manufacturers are developing curtain bags that are not utilizing tether lines to attach the bag to the A-pillar. Instead of tether lines, the bag is attached to the A-pillar with strong load bearing fabric. The fabric would be more effective than the tether lines in preventing occupants from ejection through the front lower opening.)

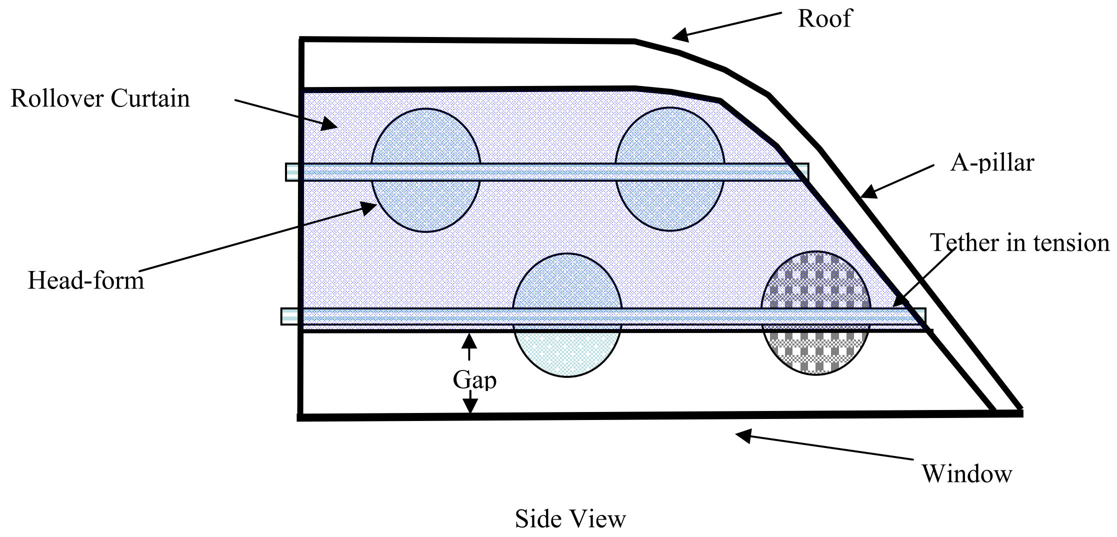

Figure VII-7. Illustration of the tether lines

In summary, we divided the window opening area into four quadrants and assumed that ejections through each area are represented by the linear head-form impact in that quadrant. We believe this analysis provides a <u>minimum</u> estimate of the potential loss in containment effectiveness if Point A1 is removed, i.e., it is an upper bound of the effectiveness of such a rollover curtain. Even at its minimum estimate, it appears that the reduction in containment by allowing an opening at Point A1 would have significant effects on the overall system effectiveness in rollovers. As explained below, for the initial impact to the curtain air bag, the overall system effectiveness would decrease from 48% to 39% for belted occupants. For unbelted occupants, the system effectiveness would reduce from 44% to 32%.

Tale VII-13
Overall Rollover System Effectiveness for Fatalities without Requiring Head-Form Test at A1 – Rollover, No Side Impact Case

Occupant	Test all four points (A1 – A4)	Exclude A1
Belted Partial	48%	39%
Belted Complete	0%	0%
Unbelted Partial[229]	44%	32%
Unbelted Complete	44%	32%

Table VII-14
Overall Rollover System Effectiveness for Fatalities without Requiring Head-Form Test at A1 – Side Impact Followed by Rollover, Excluding 12-25 mph Case

Occupant	Test all four points (A1 – A4)	Exclude A1
Belted Partial	27%	22%
Belted Complete	0%	0%
Unbelted Partial	25%	18%
Unbelted Complete	21%	15%

Table VII-15
Overall Rollover System Effectiveness for Fatalities without Requiring Head-Form Test at A1 - Side Impact Followed by Rollover, 12-25 mph Case

Occupant	Test all four points (A1 – A4)	Exclude A1
Belted Partial	35%	28%
Belted Complete	0%	0%
Unbelted Partial	32%	23%
Unbelted Complete	27%	20%

Reduction in benefit: Previously in the benefits chapter, we estimated that a total of 538 lives would be saved under the proposed test requirements (before adjustments for compliance and installation rates). When the overall system effectiveness rates as shown in Tables VII-13 thru VII-15 were applied to the fatal injury population, assuming no compliance, it would result in an upper range estimate[230] of 431 lives saved (compared to 538 lives saved with the full curtain).

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[229] As discussed in the benefit chapter, the Winnicki's reduction rates were based on unbelted occupants. Therefore, the use of unbelted occupant reduction rates would underestimate the overall system effectiveness.

[230] The upper range estimate of the benefits of a system excluding A1 assume that an occupant has only one chance of going out the area not covered by A1 (potential gap) and also the gap left by A1, regardless of severity of the rollover represented by the number of ¼-turns. As we explain below, a more reasonable estimate of the benefits of a

When A1 is excluded from the test requirements, therefore, it would result in a 20% reduction in fatal saving (108 less, 538 - 431 = 108 lives).

If we exclude A1 from meeting the test requirements, some occupants could move to the opening after impacting the curtain. By not analyzing this ejection potential, the analysis above may have overestimated the effectiveness of a countermeasure with a large gap in the window opening. That is, more occupants could be ejected through the opening at A1 than estimated in the analysis. We have found it difficult to estimate the extent to which occupants will move to openings and/or gaps in curtain coverage.

Nonetheless, we believe it is reasonable to expect that this movement, and therefore ejection potential, is related to the severity of the rollover. A metric of severity available to us is the number of ¼-turns. So as a surrogate for occupant movement to the opening, under this analysis we assume that for each complete vehicle revolution (4 ¼-turns) the occupant has an opportunity to impact the window opening. To perform this analysis we examined the agency's 1988 – 2005 NASS CDS database, as shown below in Figure VII-8.

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system excluding A1 assumes that an unbelted occupant gets multiple chances of going out the gap left by A1, depending on the rollover severity.

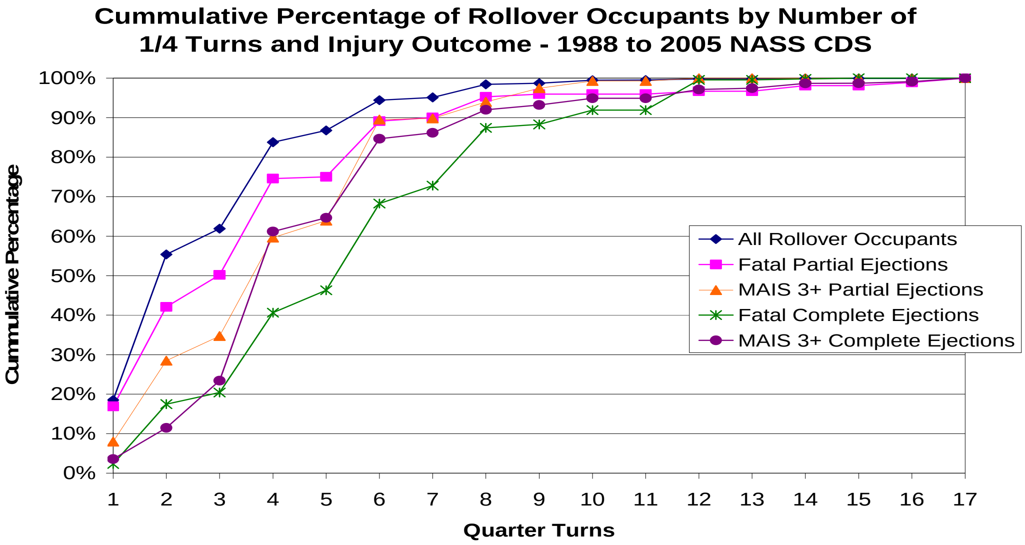

Figure VII-8 Cumulative Percentage of Rollover Occupants by Number of ¼ turns and Injury Outcome

The figure shows that the majority (50% break-point in population) of fatal completely ejected occupants exposed to rollovers crashes are in vehicles that roll more than five ¼-turns. Similarly, the 50% break-point for fatal partial ejections is about three ¼-turns. We note that these data are for all ejection portals and not just side window openings. Table VII-16 shows the population of completely ejected and partially ejected fatalities at each complete vehicle roll break-point.

Table VII-16 Fatally injured occupant ejections vs. ¼-turn

¼ turn	1 to 4	5 to 8	9+
Completely ejected	46%	42%	12%
Partially ejected	75%	21%	4%

Previously, we estimated that excluding A1 from meeting the requirements would result in 20% reduction in fatal benefits at the upper end of the range, from 538 to 431 lives (which was not yet adjusted with the current compliance rate and the expected voluntarily installed rollover bags), as shown below in Table VII-17:

Table VII-17
Lives saved after first rollover, with excluding A1 from testing (upper end of range)

Crash type, belts use and level of ejection	Sensor	Containment	Winnicki's	System	Fatalities	lives saved
rollover, no side impacts:						
Belted partial	77%	58%	88%	39%	112	44
Belted complete	77%	0%	88%	0%	12	0
Unbelted partial	77%	48%	88%	32%	107	34
Unbelted complete	77%	48%	88%	32%	519	167
side impacts followed by rollovers:						
Belted partial	77%	58%	49%	22%	0	0
Belted complete	77%	0%	41%	0%	0	0
Unbelted partial	77%	48%	49%	18%	137	24
Unbelted complete	77%	48%	41%	15%	114	17
side impacts, w/ subsequent rollovers, 12-25 mph:						
Belted partial	100%	58%	49%	28%	0	0
Belted complete	100%	0%	41%	0%	11	0
Unbelted partial	100%	48%	49%	23%	0	0
Unbelted complete	100%	48%	41%	20%	68	13
side impacts, no rollovers, 12-25 mph:						
Belted partial	100%	100%	49%	49%	0	0
Belted complete	100%	0%	41%	0%	0	0
Unbelted partial	100%	100%	49%	49%	0	0
Unbelted complete	100%	100%	41%	41%	259	106
side impact, no rollover, children (0-12 YO), include both partial and complete ejections, 12- 25 mph:						
Belted partial	100%	100%	49%	49%	29	14
Belted complete	100%	0%	41%	0%	0	0
Unbelted partial	100%	100%	49%	49%	0	0
Unbelted complete	100%	100%	41%	41%	25	10
				total	1,392	431

After the initial loading of the air bag, some unbelted occupants will move to an opening in the window coverage in lateral rollovers. To get closer to the lower end of the range of effectiveness, we assumed that occupants get another chance to be ejected through the opening at Point A1 for each complete vehicle revolution. The method assumes that an occupant impacts the air bag in each roll. (Picture a trashcan; first, cover it with a strong but elastic fabric; then, make a hole in the fabric. You drop a ball onto the fabric. Some would go through the hole and some would be retained by the fabric. This could be considered as “one-time” containment. After that, pick up the ball and drop it again, some times the ball would stay on the fabric and other times it would go through the hole. This would represent an occupant who hit the air bag in the second roll and go out.) In the previous discussion, we estimated that the partial curtain system would have a containment effectiveness of 48%. Under the assumption, the containment for the occupants would be 48%, 23% (48% * 48% = 23%), and 20% (48%*48%*48 = 20%), respectively, for the following three rolls.

As discussed above, the real world crash data showed that 46%, 42% and 12% of the completely ejected fatally injured occupants were from 1 to 4 ¼-turns, 5 to 8 ¼-turns and 9+ ¼ turns, respectively. For partially ejected occupant fatalities, 75% were from 1 to 4 ¼-turns, 21% were from 5 to 8 ¼-turns and the remaining 12% were from 9+ ¼-turns.[231] Under the assumptions of this analysis the partial curtain air bag would save 357 lives (267 additional lives saved when adjusted with the compliance and installation rates at the lower end of the range, which is discussed in the following section), as shown below in Tables VII-18a - c

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[231] We assume that these ¼-turn percentages represent both belted and unbelted partial ejections since our target population of partial ejection fatalities is about evenly split between belted and unbelted occupants.

Table VII-18a
Lives saved at lower end of range, with excluding A1 from testing, 1 to 4 ¼-turn

Crash type, belts use and level of ejection	Sensor	Containment	Winnicki's	System	Fatalities	Lives saved
rollover, no side impacts:						
Belted partial	77%	58%	88%	39%	84	33
Belted complete	77%	0%	88%	0%	4	0
Unbelted partial	77%	48%	88%	32%	80	26
Unbelted complete	77%	48%	88%	33%	239	78
side impacts followed by rollovers:						
Belted partial	77%	58%	49%	22%	0	0
Belted complete	77%	0%	41%	0%	0	0
Unbelted partial	77%	48%	49%	18%	103	18
Unbelted complete	77%	48%	41%	15%	52	8
side impacts, w/ subsequent rollovers, 12-25 mph:						
Belted partial	100%	58%	49%	28%	0	0
Belted complete	100%	0%	41%	0%	4	0
Unbelted partial	100%	48%	49%	23%	0	0
Unbelted complete	100%	48%	41%	20%	31	6
side impacts, no rollovers, 12-25 mph:						
Belted partial	100%	100%	49%	49%	0	0
Belted complete	100%	0%	41%	0%	0	0
Unbelted partial	100%	100%	49%	49%	0	0
Unbelted complete	100%	100%	41%	41%	119	49
side impact, no rollover, children (0-12 YO), include both partial and complete ejections, 12- 25 mph:						
Belted partial	100%	100%	49%	49%	22	11
Belted complete	100%	0%	41%	0%	0	0
Unbelted partial	100%	100%	49%	49%	0	0
Unbelted complete	100%	100%	41%	41%	11	5
				total	749	233

As shown in Table VII-16, Table VII-8a shows that 46% and 75% of complete and partial fatal ejections were in single roll crashes, respectively.

Table VII-18b
Lives saved at lower end of range, with excluding A1 from testing, 5 to 8 ¼-turn

Crash type, belts use and level of ejection	Sensor	Containment	Winnicki's	System	Fatalities	Lives saved
rollover, no side impacts:						
Belted partial	77%	34%	88%	23%	23	5
Belted complete	77%	0%	88%	0%	4	0
Unbelted partial	77%	23%	88%	15%	22	3
Unbelted complete	77%	23%	88%	15%	218	34
side impacts followed by rollovers:						
Belted partial	77%	34%	49%	13%	0	0
Belted complete	77%	0%	41%	0%	0	0
Unbelted partial	77%	23%	49%	8%	29	2
Unbelted complete	77%	23%	41%	7%	48	3
side impacts, w/ subsequent rollovers, 12-25 mph:						
Belted partial	100%	34%	49%	16%	0	0
Belted complete	100%	0%	41%	0%	4	0
Unbelted partial	100%	23%	49%	11%	0	0
Unbelted complete	100%	23%	41%	9%	29	3
side impacts, no rollovers, 12-25 mph:						
Belted partial	100%	100%	49%	49%	0	0
Belted complete	100%	0%	41%	0%	0	0
Unbelted partial	100%	100%	49%	49%	0	0
Unbelted complete	100%	100%	41%	41%	109	45
side impact, no rollover, children (0-12 YO), include both partial and complete ejections, 12- 25 mph:						
Belted partial	100%	100%	49%	49%	6	3
Belted complete	100%	0%	41%	0%	0	0
Unbelted partial	100%	100%	49%	49%	0	0
Unbelted complete	100%	100%	41%	41%	10	4
				total	502	103

Table VII-8b shows that 42% and 21% of complete and partial fatal ejections were in two roll crashes, respectively. Note that, for example, the containment effective decreased from 48% to 23% (48% * 48% = 23%) for unbelted partial fatalities in two roll crashes. The 23% containment effectiveness is based on an assumption that if an occupant impacts the window opening area during the first roll, the occupant would impact the window opening area again during the second roll.

Table VII-18c
Lives saved at lower end of range, with excluding A1 from testing, 9+ ¼-turn

Crash type, belts use and level of ejection	Sensor	Containment	Winnicki's	System	Fatalities	Lives saved
rollover, no side impacts:						
Belted partial	77%	20%	88%	13%	4	1
Belted complete	77%	0%	88%	0%	4	0
Unbelted partial	77%	11%	88%	7%	4	0
Unbelted complete	77%	11%	88%	7%	62	5
side impacts followed by rollovers:						
Belted partial	77%	20%	49%	7%	0	0
Belted complete	77%	0%	41%	0%	0	0
Unbelted partial	77%	11%	49%	4%	5	0
Unbelted complete	77%	11%	41%	3%	14	0
side impacts, w/ subsequent rollovers, 12-25 mph:						
Belted partial	100%	20%	49%	10%	0	0
Belted complete	100%	0%	41%	0%	4	0
Unbelted partial	100%	11%	49%	5%	0	0
Unbelted complete	100%	11%	41%	4%	8	0
side impacts, no rollovers, 12-25 mph:						
Belted partial	100%	100%	49%	49%	0	0
Belted complete	100%	0%	41%	0%	0	0
Unbelted partial	100%	100%	49%	49%	0	0
Unbelted complete	100%	100%	41%	41%	31	13
side impact, no rollover, children (0-12 YO), include both partial and complete ejections, 12- 25 mph:						
Belted partial	100%	100%	49%	49%	1	1
Belted complete	100%	0%	41%	0%	0	0
Unbelted partial	100%	100%	49%	49%	0	0
Unbelted complete	100%	100%	41%	41%	3	1
				total	141	21

The agency's headform test results show that none of the tested curtain bags met the 100 mm deflection requirement at the A1. When adjusted with the belt use rates (15% belted and 85% unbelted fatalities in rollovers), 46% of the ejections could be prevented with the currently available mitigation systems (0%+5%+6%+35% = 46%. See the benefit chapter for additional discussion), as shown in Table VII-19.

Table VII-19
Benefits of Current Ejection Mitigation Systems

Impact Point		A1	A2	A3	A4
Passing Rate		0%	30%	22%	100%
Risk of Ejection	Belted	5%	26%	11%	53%
	Unbelted	16%	16%	32%	32%
	Weighted	14%	17%	29%	35%
% of ejection prevented		0%	5%	6%	35%

With the 55% MY 2011 installation rate, we estimated that about 25% (25.27%) of the potential fatal benefits could be achieved with the curtain bag (that is in compliance with the headform test requirements, $46\%_{\text{containment}} \times 55\%_{\text{installation}} = 25\%_{\text{with current system}}$). When the 25% potential fatal benefits are subtracted from the 357 lives saved, it results in 267 incremental fatal benefits. Thus, the incremental fatal benefits decrease from 402 to 267 lives, and the injury reduction benefits decrease from 310 to 201 injuries. (See Appendix K for detailed calculation.)

Reduction in cost: In order to meet the proposed deflection requirement at the A1, manufacturers may use laminated glazing. In the cost chapter, we estimated that if vehicles manufacturers replace tempered glass with laminated glass for standard size front window, the associated unit cost would be about $24 per window (in 2006 economics). If all light vehicles are equipped with laminated glazing in the front window, the expected incremental total cost associated with the glazing would be about $816 million (17 million x $24 x 2 per vehicles = $816 million). If laminated glazing is required to meet the deflection required at the A1, the exclusion would reduce the incremental cost by $816 million.

We note that the $816 million cost saving is based on an assumption that laminated glazing is needed to comply with the proposed 100 mm deflection requirement at the A1. However, if vehicle manufacturers are able to design an ejection mitigation system to meet the proposed requirement without utilizing laminated glazing, the exclusion of the A1 from the requirement would result in a relatively small reduction in cost per vehicle. In the cost chapter, we estimated that the unit cost for the air bag cloth would be \$0.00327 per cm^2 based on the 5,161 cm^2 curtain of a Toyota Camry, which has a 6,619 cm^2 window opening area, we estimated that manufacturers would spend an additional \$9.53 per vehicle to widen the curtain bag to completely cover the window opening area.[232] When the A1 is excluded from the requirement, we estimate that 729 cm^2 of the window opening would not be covered by a bag.[233] Therefore, we estimate about \$101 million, if the low forward quadrant is not covered by a curtain bag.[234] With an estimated 17 million annual vehicle production, the exclusion of A1 would result in \$5.94 per vehicle (with total incremental cost of \$482M). In summary, we compared the incremental costs and benefits. When the low forward impact point, A1 is excluded from the impact requirements, it would result in 267 additional lives saved. The estimated benefits and costs show that excluding A1 from the test requirements would have a significant impact on the overall system effectiveness. The number of lives saved and the net savings for the full curtain and excluding A1 are shown below:

Table VII-20
Incremental Costs and Additional Lives Saved for Excluding A1 (lower estimate)

Alternatives	Lives Saved (incremental)	Costs (millions)		
		1st & 2nd rows	3rd row	total
Excluding A1 (Lower estimate)	267	\$431	\$51	\$482
Full Coverage Curtain	402	\$532	\$51	\$583

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[232] (6,619 – 5,161)x\$0.00327 $_{\text{unit}}$ x2 $_{\text{sides}}$ = \$9.53 $_{\text{per vehicle}}$

[233] 6,619-5,161 = 1,458 cm^2; if ½ of the front lower portion of the curtain is not covered by a bag, 1,458 x ½ = 729 cm^2, \$0.00327/cm^2 x 729 = \$2.38 per side. \$2.38 x 2= \$4.77 per vehicle. Previously we estimated \$2.36 for the inflator incremental cost. \$2.36 x ½ = \$1.18. Total reduction in cost = \$5.94 (\$4.77 + \$1.18 = \$5.94) per vehicles. With 17 million vehicles, 17x\$5.94 = \$101.M.

[234] The incremental cost: \$583 -\$101 = \$482 million

Table VII-21
Cost per Equivalent Life Saved (ELS) for Excluding A1 (lower estimate)

	AIS 3	AIS 4	AIS 5	Fatal	Total ELS	discounted Equivalent fatal	
Additional benefits	128	53	20	267		3%	7%
conversion factor	0.0804	0.1998	0.6656	1		0.8155	0.6489
equivalent fatal	10	11	13	267	301	246	195

Table VII-22 Net Benefits for Full Curtain and Excluding A1 (lower estimate)

Curtain	Lives Saved	Total ELS	discounted Equivalent fatal		Cost ($M)	cost per ELS ($M)		Value per ELS ($M)	Net Benefits	
			3%	7%		3%	7%	$6.10	3%	7%
Excluding A1	267	301	246	195	$482	$1.96	$2.47		$1,016	$710
Full Curtain	402	455	371	295	$583	$1.57	$1.98		$1,680	$1,217

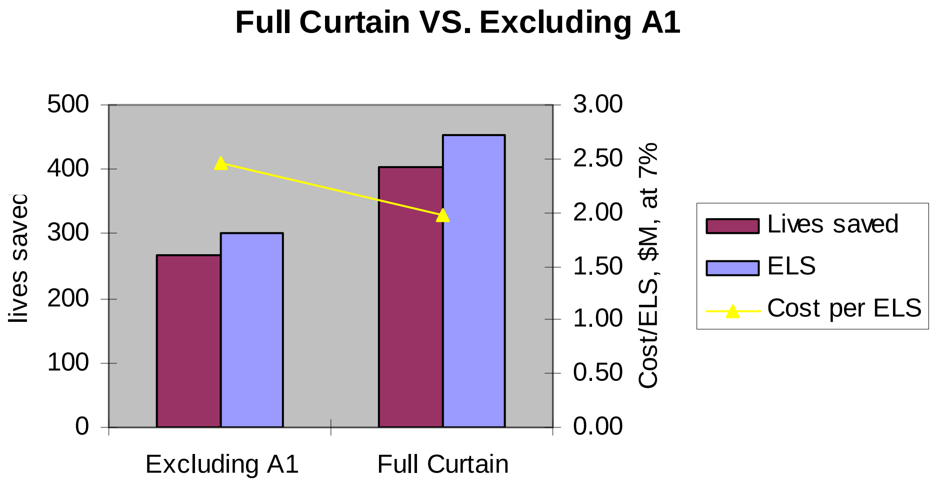

Figure VII-9. Total Lives Saved, ELS, and Cost per ELS (at 7%) for Full Curtain and Excluding A1

Table VII-23 Cost Effectiveness – Full Coverage, Excluding A1 Lower Estimate, Excluding A1 Upper Estimate

Air bag System	Lives saved	Additional lives saved	Cost per ELS	
			3% discounted	7% discounted
Full Coverage[235]	538	402	1.57	1.98
Excluding A1, upper estimate	431	322	1.63	2.05
Excluding A1, lower estimate	357	267	1.96	2.47

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[235] If the methodology used to derive the lower estimate is used for the full curtain, it would result in 333 lives saved (instead of the estimated 402 additional lives saved).

We note that the lower estimate (267 additional lives saved) is based on an assumption that occupants get only one chance to impact the window opening area for each complete vehicle revolution. However, as D. Knapton observed in his rollover film analysis,[236] occupants move inside a vehicle and could impact the window opening area more than once during a single roll. Therefore, the actual lower end of range could be lower than the estimated 267 lives saved. However, the agency does not have information to determine this minimum value when the front corner opening is excluded from the test requirements.

In the benefits chapter, we used the uniform risk of ejection as an alternative to the weighted risk of ejection. The uniform risk of ejection assumes that the risk of ejection through the window opening is uniformly distributed. When the uniform distribution method was used, it showed that the lower end of the range decreased to 245 lives saved, as shown below.

Table VII-24 Cost Effectiveness – Excluding A1 Lower Range Estimate with Uniform Risk of Ejection Method

Air Bag System	Lives saved	Additional lives saved	Cost per ELS	
			3% discounted	7% discounted
Excluding A1, lower estimate	327	245	2.14	2.69

(6) 100% belt use rate: If all <u>observed</u> occupants wear safety belts, a substantial number of fatalities in the target population would be prevented. "Observed" usage essentially means daytime usage – that is when NHTSA observes usage. However, in terms of usage in potentially fatal crashes, 100% observed usage in the daytime equates to 91% usage in all potentially fatal crashes since the agency has found that nighttime usage in fatal crashes is about 18 percentage

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[236] For detailed discussion, see the containment discussion in the benefit chapter.

points lower than daytime usage and fatalities for this group are weighted about 50% during the day and 50% during the night.

With 100% observed safety belt use, we expect that the number of fatalities would decrease from 1,392 to 862. With the 862 fatalities, the ejection mitigation system would save 249 lives. (See Appendix H for additional discussion). Hypothetically, we could assume that all occupants could wear safety belts at all times. In other words, we could assume that all fatally injured occupants used safety belts in rollovers. If unbelted occupants are turned into belted occupants, the number of rollover crashes remain the same, however, there is a higher target population of belted occupants that could have partial ejections (essentially their head going out the window and hitting the ground). So, belted benefits go up from the ejection mitigation curtains. The benefits of the ejection mitigation curtain (rather than just the side air bag curtain) for belted people would come from keeping the curtain inflated for the six seconds. Often in rollover crashes the ejection occurs at the end of the rollover sequence, as evidenced by where the body lies and the vehicle's final position. If all fatally injured occupants in the target population used safety belts, the number of fatalities would decrease from 1,392 to 658. In the target population, there were 1,392 fatalities. Among the 1,392 fatalities, 163 were belted occupants and the remaining 1,229 were unbelted. In the benefits chapter, we estimated that the ejection mitigation would save 51 belted occupants. With the 51 lives saved, the overall system effectiveness would be 31% (51/163 = 0.31). When the 31% effectiveness was applied to the 658 fatalities, it shows that 206 lives would be saved with the ejection mitigation system when all occupants in crashes used safety belts.

(7) Crashes involving alcohol: For the benefits estimate, the agency's 1997-2005 NASS Crashworthiness Data System (CDS) and fatalities counts adjusted to 2005 FARS levels were used. According to the crash data, there were 4,395 fatalities in the target population, before adjustments for electronic stability control (ESC) implementation. If we exclude from our baseline target population crashes with unknown alcohol involvement, the population is reduced to 3,138 occupants.[237] Table VII-25 shows that 58% of the fatalities in the target population are in alcohol related crashes.[238]

Table VII-25 Alcohol Used by Driver in Fatal Crashes of the Target Population

Alcohol Used in Crash	Occupant Role	Alcohol Used by Driver of this Vehicle	Sample Count	Annual Estimated	Total	% of total
yes	Driver	Yes	120	1,313	1,797	58%
yes	Driver	No	1	6		
yes	Driver	Unknown	1	11		
yes	Passenger	Yes	36	451		
yes	Passenger	Unknown	2	16		
no	Driver	No	26	159	1,341	42%
no	Driver	Unknown	25	273		
no	Passenger	No	22	557		
no	Passenger	Unknown	32	352		

The NASS data show that the seat belt use rate was much lower when drivers were under the influence of alcohol when compared to sober drivers in the target population. As shown below, 76% of drunk drivers were not wearing a seat belt in fatal crashes.

Table VII-26 Driver Belt Use versus Alcohol Use in Fatal Crashes of the Target Population

Occupant Belt Use	Vehicle Driver Used Alcohol		
	yes	no	unknown
No	76%	44%	55%
Yes	24%	56%	45%
total	100%	100%	100%

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[237] We define an alcohol involved/related crash as one where any involved driver was under the influence of alcohol.

[238] Among the occupant fatalities in crashes where there was a drunk driver, 74% were drivers, 26% were passengers.

When the baseline target population is adjusted for 100 percent ESC implementation, we estimate 1,392 fatalities. When the 58% alcohol involved fatalities were excluded from this target population, it resulted in 797 alcohol related fatalities, as shown below.

Table VII-27 shows that among the 797 alcohol related fatalities, 609 would be unbelted and the 189 would be belted occupants. The 609 unbelted and 189 belted fatalities were redistributed according to the percent frequency of belted and unbelted fatalities in the target population, as shown in Appendix I.

Table VII-27 Alcohol Related Fatalities in Target Population

ESC adjusted target population	% of alcohol involved	Fatalities related alcohol	% of Unbelted	% of Belted	Total No. of Unbelted	Total No. of belted
1,392	57.27%	797	76%	24%	609	189

As shown in Appendix I, when all drunk driver related fatalities were excluded from the target population, the fatalities in the target population decreased from 1,392 to 595. With the decrease number of fatalities in the target population, the potential benefits would decrease from 402 lives saved to 147 lives saved. When adding injuries to the 147 lives saved, there are 180 ELS with no discount. The 3% and 7% discount ELS values are 147 and 117, respectively.

<u>Summary of Sensitivity Analyses</u>: In this chapter, we discussed the change in costs and benefits that result from different assumptions used in the analysis. The factors that were examined include the cost of side impact sensors, the effectiveness of the rollover sensor, the use of laminated glazing, the use of a uniform distribution of ejection through the opening, and ejections through the 2nd and 3rd row window openings. The three factors affecting benefits (sensor effectiveness, laminated glazing and uniform distribution) showed that the ejection mitigation system could save 581 (additional) lives, annually, in the most favorable conditions

(curtain and advanced glazing in the front window and 95% sensor effectiveness). When the least favorable factors were used (77% sensor effectiveness, no advanced glazing and uniform ejection distribution in the window open area), the sensitivity analyses showed at least 390 (additional) lives would be saved, annually, as shown in Figure VII-10.[239]

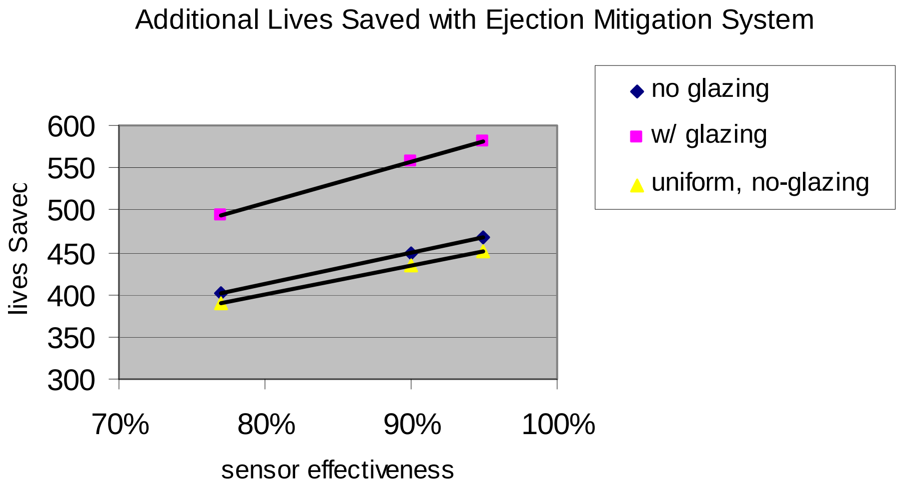

Figure VII-10. Range of estimated benefits with different assumptions used

When the sensor effectiveness decreases from 95% supplier higher estimate to 90% supplier lower estimate and 77% used in the benefit analysis for the curtain + glazing system, Figure VII-1 shows that the number of additional lives saved would decrease from 581 to 556 and 494, respectively. The middle regression line shows that 66 more lives could be saved by a curtain (only) system if the sensor effectiveness increases from 77% to 95% (468 – 402 = 66 lives). However, the upper and middle linear regression lines in Figure VII-1 show that the use of advanced glazing would result in 19 percent increase in number of lives saved.[240] The lower linear regression line shows that a curtain ejection mitigation system (without advanced glazing) could save at least 390 additional

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[239] At the time of this analysis impactor test data for the 2nd row window opening for passenger cars was not available. As a result, we are not certain whether advanced glazing is needed for the 2nd row. Nevertheless, based on the impactor test results, we believe that laminated glazing may not be needed in the 2nd opening area to meet the proposed displacement requirement.

[240] 1-(402/494) = 19% increase with 77% sensor effectiveness rate.

lives, annually, if all ejections through the widow opening area were uniformly distributed in rollover crashes. The incremental lives saved with different assumptions used are shown below:

Table VII-28

Window Condition	Sensor Effectiveness		
	77%	90%	95%
W/ glazing	494	556	581
No glazing	402	449	468
Uniform distribution	390	434	452

When the front lower area, A1 is excluded from meeting the head form requirements, the number of additional lives saved decreased substantially from 402 for the full curtain to 267 for the partial curtain. In addition, the analysis showed that the full curtain air bag system would be more cost effective than the partial curtain (i.e., the partial curtain has a 25% [(2.47-1.98)/1.98] higher cost/ELS).

VIII. ALTERNATIVES

There were a number of alternative regulatory approaches the agency considered for this rulemaking. These alternatives include:

1. Require the front lower corner of the front side window area (test point A1) to meet the deflection requirement at a lower impact speed of 20 km/h.
2. Require a single impact at the center of the side window opening area.

Each of these is discussed below:

<u>Alternative 1</u>: Test point A1 at a lower impact speed of 20 km/h.

This is a headform test run with a lower impact speed of 20 km/h at point A1 in the front window opening area. We attempted to analyze separately the effect of testing the A1 at a lower impact speed in the ejection mitigation test. However, trying to determine the benefits of these aspects and how the manufacturers might react to them individually was difficult, since we do not fully understand how occupants eject through a particular point in the window opening area.

1.A. Reduction in containment effectiveness: One way of estimating the incremental benefits of a fully covered rollover curtain bag, which designed to meet the displacement requirement at all four impact points, over a full curtain bag that is designed to meet the requirements at three impact points A2 through A4 but at a lower speed at A1 is to analyze the risk of ejection through the front low corner, A1. As discussed in the test data chapter in this PRIA, we did not find any curtain bags (whether they are deigned for side, rollover or both) that met the 100 mm displacement criteria at all impact points since most of the bags tested did not cover this area.

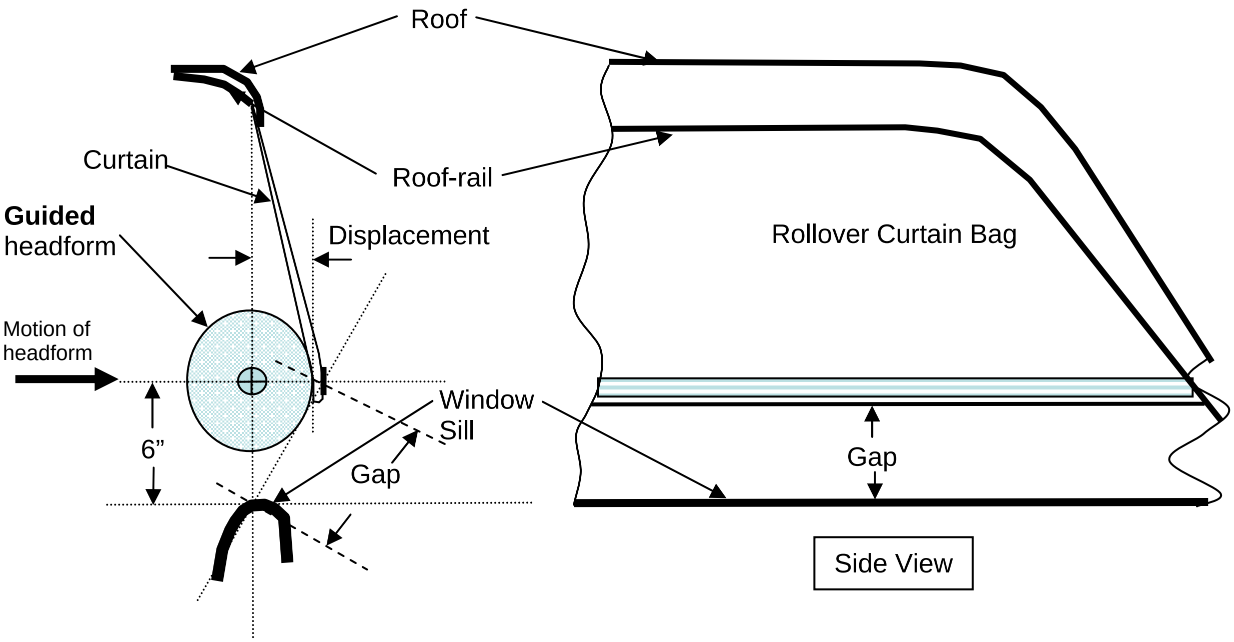
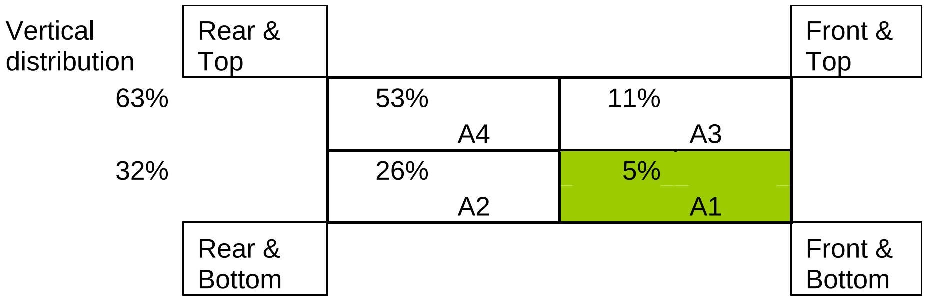


Figure VIII-1 Potential Gap in Front Window

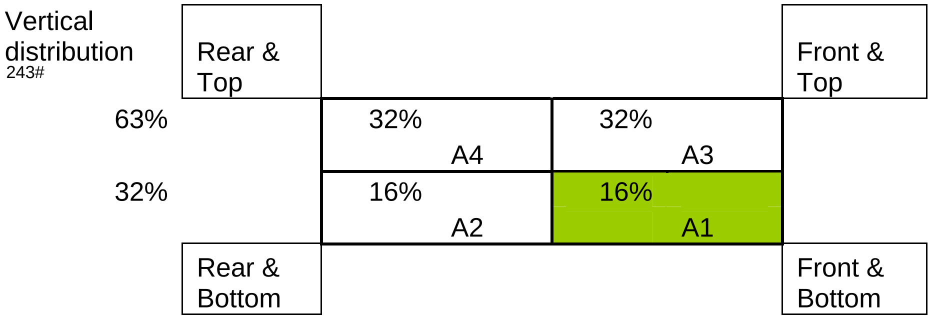
In the benefit analysis, we estimated that the risk of ejection through a potential gap between the window sill and the bottom of a rollover curtain bag is relatively small. We used two different approaches to estimate the risk of ejection through a particular area in the window opening, namely, weighted risk of ejection and uniform risk of ejection. In this section, we estimated the reduction in benefits when the A1 area is subjected to a lower impact force. In addition to the weighted and uniform risk of ejection approaches, a modified methodology was used to estimate the containment effectiveness of a fully covered curtain bag that is designed to meet the lower impact force. Unlike the method used in the benefits chapter, the opening area is divided into four quadrants and ejections through each quadrant are represented by the liners headform impact in that area.

First, with the weighted risk of ejection approach, under the assumption discussed above, the risk of ejection through the lower forward quadrant (A1, between the A-pillar and the window sill) would be 5%[241] for belted occupants and 16% for unbelted occupants, as shown in Figures VIII-2 and VIII-3.



Total: 95%[242] the numbers were rounded to the nearest integer

Figure VIII -2 Baseline for Belted Occupants, Risk of Ejection through Each Quadrant, with "Weighted Risk" Method



Total: 95%

Figure VIII -3 Baseline for Unbelted Occupants, Risk of Ejection through Each Quadrant, with "Weighted Risk" Method

As discussed in the benefits chapter, even if the opening area is fully covered, some ejections could occur through a potential gap between the curtain and the window sill. For example, for belted occupants, the risk of ejection through the lower rearward quadrant (which contains the A2) is about 26%. Previously, we estimated that a potential gap can be formed in the bottom 1/3 of the front window opening of a Toyota Camry (which has an opening height of approximately

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[241] For example, in the benefits chapter, we estimated that belted occupants have a 33% risk of ejection through the lower portion of the window opening and a 17% risk of ejection through the forward portion of the opening. With the 5% ejection risk through the sunroof, the risk of ejection through the lower quadrant would be 5% (33%x17%x95%=5%)

[242] Based on ejections in real world crashes, we assumed that 5% of ejections would occur through the sunroof.

[243] Note that, due to limited data, we used the vertical ejection distribution of belted occupants as a proxy for unbelted occupants. Additional discussion on the risk of ejection is provided in the benefits chapter.

18 inches). If the ejections through the quadrant were evenly distributed, the risk of ejection through the potential gap in the lower rearward quadrant (A2) would be approximately 17% (17.3%).[244] Likewise, under the assumption, the risk of ejection through the potential gap in the low forward gap would be about 3% (3.3%).[245] In other words, if the window opening is divided into four quadrants and each quadrant is represented by an impact point in the quadrant, the hypothetical full-covered rollover curtain bag would be 73% effective in preventing belted occupant ejections (52.8% + 8.8% + 9.7% + 1.8% = 73.0%$_{\text{fully covered curtain}}$.

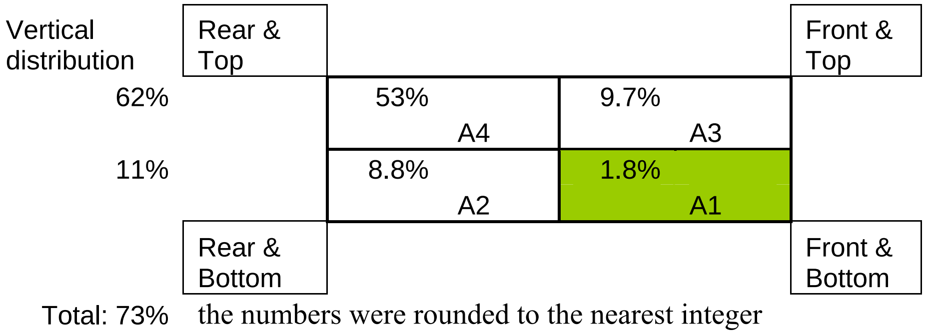

Figure VIII- 4 Baseline with Potential Gaps, Belted Occupants, Risk of Ejection through Each Quadrant, with "Weighted Risk" Method

Although the method previously used in the benefits chapter and this alternative method result in similar containment effectiveness rates, we note that the assumptions used in these methods are slightly different. Unlike the assumption made for the current method, the previous methodology in the benefits chapter assumed that there is a potential gap between the front of the curtain and the A-pillar even if the system is capable of meeting the requirement at the A1. In the benefits chapter, we determined that the curtain may or may not prevent the head form from ejection through the lower portion of the window area below the C.G. of the head form even if

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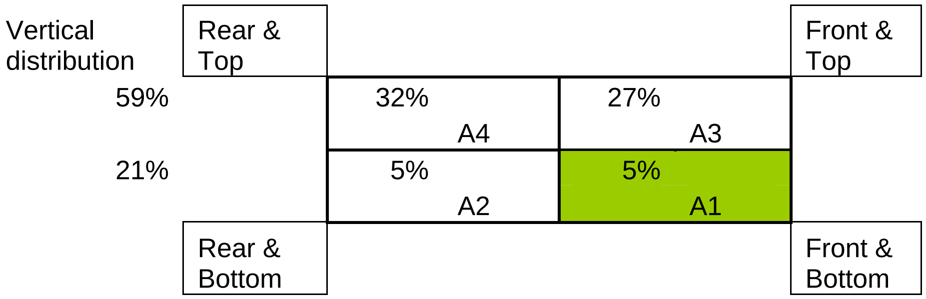
[244] 26% of the ejections would occur through the lower rearward quadrant. If the ejections were evenly distributed, accordingly, 17% of ejection would occur through the 1/3 of the window area, [26%x(1/3)]/(1/2) = 17% (17.3%].

[245] 5% of the ejections would occur through the lower forward quadrant. If the ejections were evenly distributed, 3% of the ejections would occur through the 1/3 of the window area [5%x(1/3)]/(1/2) = 3% (3.3%)].

the opening is completely covered. Accordingly, we assumed that the air bag would not be effective in preventing ejections through the lower 1/3 portion of the window opening area (i.e., potential gap). Similar to the methodology used for the containment effectiveness of a full curtain bag in the benefit chapter, the full but reduced force at A1 curtain would not be effective in preventing occupants from ejection through a potential gap between the curtain and the window sill.

For unbelted occupants, with the weighted distribution method, the partial curtain would be 69% effective in preventing ejection in rollover crashes.[246]



Total: 80% the numbers were rounded to the nearest integer

Figure VIII- 5 Baseline with Potential Gaps, Unbelted Occupants, Risk of Ejection through Each Quadrant, with “Weighted Risk” Method

We note that the derived containment effectiveness for the lower impact force at A1 air bag system was based on several conditions and <u>assumptions</u> including: (a) the air bag has displacements of less than 100 mm in the other impact points and (b) the risk of ejection through a particular area in each quadrant is evenly distributed, and (c) there is a potential gap between the bag and the surrounding structure (such as window sill).

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[246] We estimated that 31.7%, 5.3%, 27.2%, and 5.3% of occupants would ejected through the upper-rear, lower-rear, upper-front, and lower-front quadrants, respectively.

Although we only tested a small number of rollover curtain bags, it appears that the vertical location of the tether anchor at the A-pillar should be lower than (the CG of) the headform impact point to withstand the load. Since the two lower impact points (A1 and A2) in the front window opening area are approximately at the same vertical distance from the window sill (as shown in Figures VIII-1 and VIII-4), the tether line (or lines) would go across the front forward area. We believe that these tether lines would be shortened and the opening could be covered with load baring fabric (i.e. fully covered) to meet the 20 km/h impact force requirement. However, we do not have any laboratory or field data to quantify this limited effectiveness (from tether lines). (Some air bag manufacturers are developing curtain bags that are not utilizing tether lines to attach the bag to the A-pillar. Instead of tether lines, the bag is attached the A-pillar with strong load baring fabric. The fabric would be more effective than the tether lines in preventing occupants from ejection through the front lower opening.)

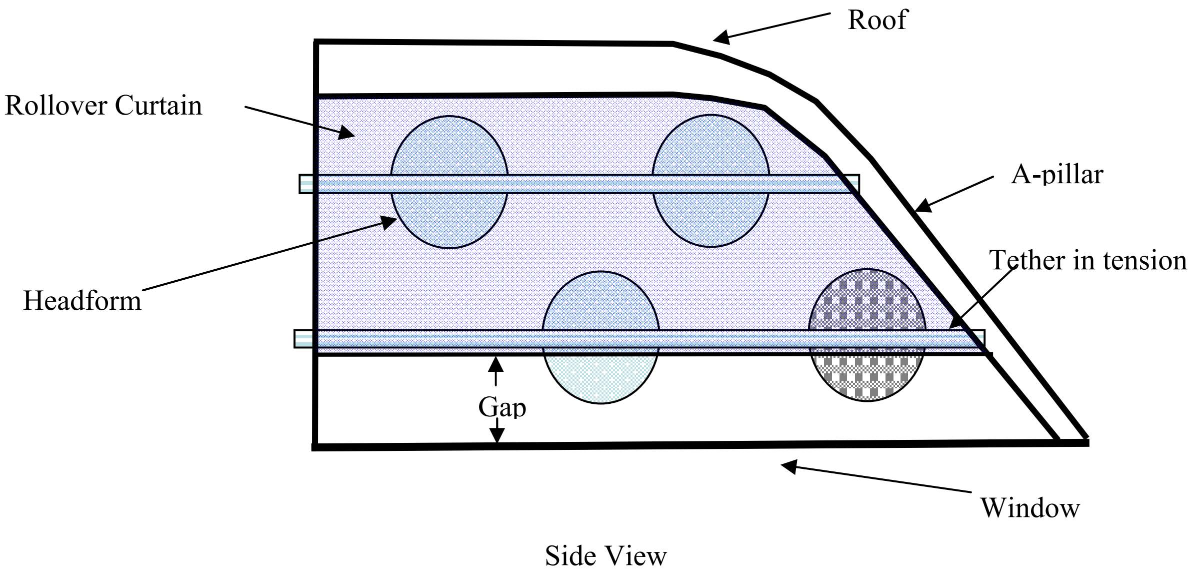

Figure VIII-6A. Illustration of the tether lines

Figure VIII-6B. One-Piece-Woven air bag without tether lines, TRW SHI2

In the previous section above, we estimated the risk of ejection through a particular area in the window opening and derived containment effectiveness values for both belted and unbelted occupants. When a curtain bag meets the proposed 100 mm displacement requirement at a linear impactor speed of 24 km/h, it would capture all potential benefits. However, when the impact speed decreases to, for example, a 20 km/h at a certain area below the proposed 24 km/h, some of occupants would eject through this area.

With a fully covered curtain air bag, all window ejections (whether partial or complete) would initially impact the air bag in rollovers. We believe that when the occupant impact energy increases, the risk of ejection through the curtain covered window opening would increase. However, we do not know the number of occupants impacting the bag at a given occupant-to-window approaching speed.

For the analysis, we considered two different approaches, as discussed below:

For the first approach, we assumed that the number of occupants impacting a curtain air bag would be evenly distributed with respect to occupant-to-window approaching speed when the opening is fully covered. In other words, we assumed that the number of window approaching occupants is the same when the 0-24 km/h speed range is divided equally into different speed segments (i.e., speed "bin"). Under this assumption, the containment effectiveness would decrease by 16.7% when the curtain air bag is designed to meet the 100 mm displacement requirement at an impact speed of 20 km/h (instead of 24 km/h).

Although the first approach would result in a simple estimation of the loss, the agency does not have any field or laboratory data to support the assumption used for the approach. Alternatively, for the second approach, we estimated the loss based on real world crashes and laboratory dummy ejection data. According to the agency's NASS 1999-2007 CDS, there were 2.2 million vehicles in lateral rollover crashes. Among the 2.2 million vehicles, 973,000 were passenger cars and 679,000 were SUVs, 127,000 were Vans and 408,000 were light trucks, as shown below:

Table VIII-1.
Number of Vehicle Crashes, by Vehicle Type, Quarter Turns, 1999-2007 Crash Years

No. of ¼-turns	Passenger car	SUV	Van	Light Truck	Combined	% of
1	125,636	228,570	59,919	95,525	509,650	23.30
2	419,318	162,533	24,472	129,919	736,242	33.66
3	52,375	55,053	6,338	17,015	130,781	5.98
4	217,681	140,325	24,292	98,134	480,432	21.96
5	26,723	19,684	2,461	22,958	71,826	3.28
6	80,754	38,127	2,769	24,078	145,728	6.66
7	2,105	8,147	451	5,214	15,918	0.73
8	40,052	19,355	4,164	9,662	73,233	3.35
9	1,359	987	1,660	1,615	5,620	0.26
10	3,612	3,023	65	1,452	8,151	0.37
11	765	289	33	70	1,157	0.05
12	1,926	2,443	446	514	5,329	0.24
13	369	62	0	124	555	0.03
14	508	145	0	793	1,446	0.07
15	15	0	19	0	33	0.00
16	164	108	27	249	547	0.03
16+	38	375	211	166	789	0.04

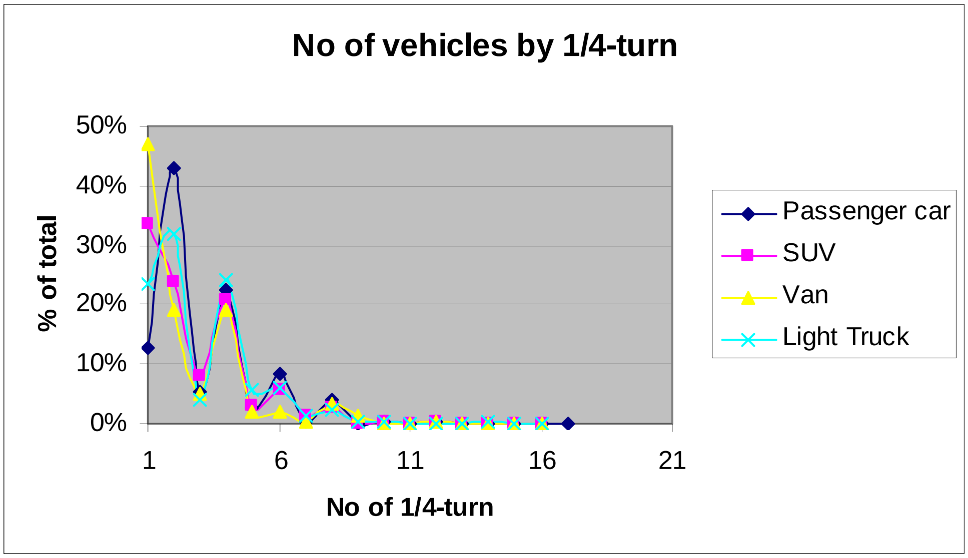

Figure VIII-7 Number of vehicles in rollovers by ¼-turn

The real world rollover crash data showed that the majority of vehicles rolled less than 7 quarter turns and that the number of vehicles decreases drastically as the number of quarter turns increases. In addition, it appears that the geometry of a vehicle affects the tendency of first ¼-turn. SUVs and vans, which have a relatively high C.G. when compared to passenger cars and light trucks, had a greater tendency of (first ¼-turn) rollover. When the rollovers were separated by ½-turn (i.e., one ¼-turn and two ¼ -turns into a ½-turn bin, etc.) it showed that the majority of rollovers were less than three ½-turn rollovers, as shown below:

Table VIII-2. Lateral rollover separated by ½-turn roll

N. of ½-turn	No. of vehicles	% of total
1	1,245,892	57
2	611,213	28
3	217,554	10
4	89,150	4
5	13,771	1
6	6,485	0
7	2,0001	0
8	1,370	0
Total	2,187,437	▨

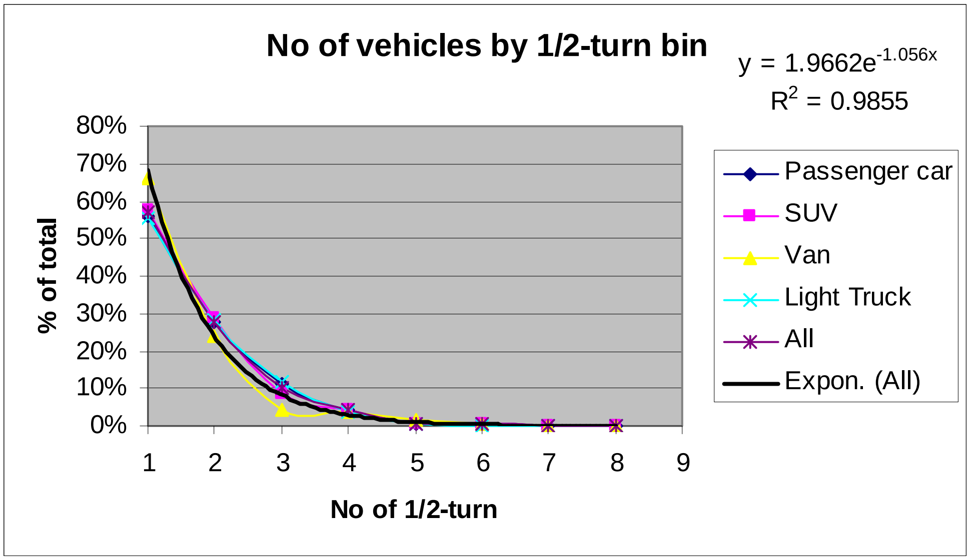

Figure VIII-8 Number of vehicles in rollovers by ½-turn

The figure above showed that the percent of ½-turn could be estimated by a regression curve for all light vehicles, as shown below:

$$y = 1.9662e^{-1.056*x} \quad where\ y: \%\ of\ total;\ x = No.\ of\ 1/2 - turn$$

A series of simulations were performed by the agency to recreate three NASS investigated rollover crashes with ejected occupants.[247] The vehicles are listed in the first column of Table

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[247] "Ejection Mitigation Using Advanced Glazings: A Status Report," November 1995, DOT DMS NHTSA-1996-1782-3. Pg. 6-1.

VIII-3. These simulations were performed to study the injury potential of advanced glazing, but they also gave important insight into the relative velocity of ejected occupants with respect to the window areas through which they were ejected.

The circumstances of the Toyota pickup rollover was that the vehicle was traveling at 96 km/h and went into a sharp turn and yaw, which resulted in a rollover. In the case of the Corrolla, it was also traveling 96 km/h on a gravel road. The vehicle went out of control and left the road, resulting in roll initiation. The Volkswagen was traveling at 88 km/h when the driver fell asleep and the vehicle left the road. It struck a rock embankment and rolled over.

A vehicle handling simulation software was used to reconstruct the vehicle motion up to the point where the vehicle started to roll. The linear and angular velocity at the end of the vehicle handling simulation was then used to drive a MADYMO lumped parameter model of the vehicle to compute its complete rollover motion. Finally, the motion of the vehicle obtained from the MADYMO vehicle model was used to drive a MADYMO occupant simulation.

Table VIII-3 shows the simulation resultant head velocity through the open window when the occupant was ejected. The simulations were also performed with unbroken glazing to determine impact velocities with intact glazing. Table VIII-3 also shows the computed resultant maximum head and torso velocities at contact with the intact glazing for the un-ejected occupant.

It is interesting to note that the slowest head velocity is for the occupant ejected through the open window on the first ¼ turn (Toyota pickup). As might be expected, head velocity was greater than torso velocity. The maximum head velocity was 22 km/h for the Jetta unrestrained occupant into the window opening. The maximum torso velocity was 16 km/h, also for the unrestrained Jetta occupant.

The modeling is also instructive in showing that ejections can occur both early (1st ¼-turn for Toyota PU) and late (last ¼-turn for Corolla and Jetta) in the rollover event.

Table VIII-3a. Head and Torso Velocities of a Hybrid III 50th Percentile Male Dummy in 3 Rollover Simulations

Vehicle	Vehicle ¼ Turns	¼ Turns at Complete Ejection	Restraint Use	Head to Opening (km/h)	Head to Glazing (km/h)	Torso to Glazing (km/h)
Toyota PU	12	▨	Yes	20	20	7
		1	No	5	20	16
Toyota Corolla (86)	6	▨	Yes	15	15	11
		6	No	13	13	10
Volkswagen Jetta (85)	4	▨	Yes	14	14	10
		4	No	22	18	16

Table VIII-3b.
Head Velocities of a Hybrid III 50th Percentile Male Dummy in 3 Rollover Simulations

Belt use	No. of Vehicle ¼ Turns	Head to Glazing speed (km/h)
Belted	12	20
Unbelted	12	20
Belted	6	15
Unbelted	6	13
Belted	4	14
Unbelted	4	18

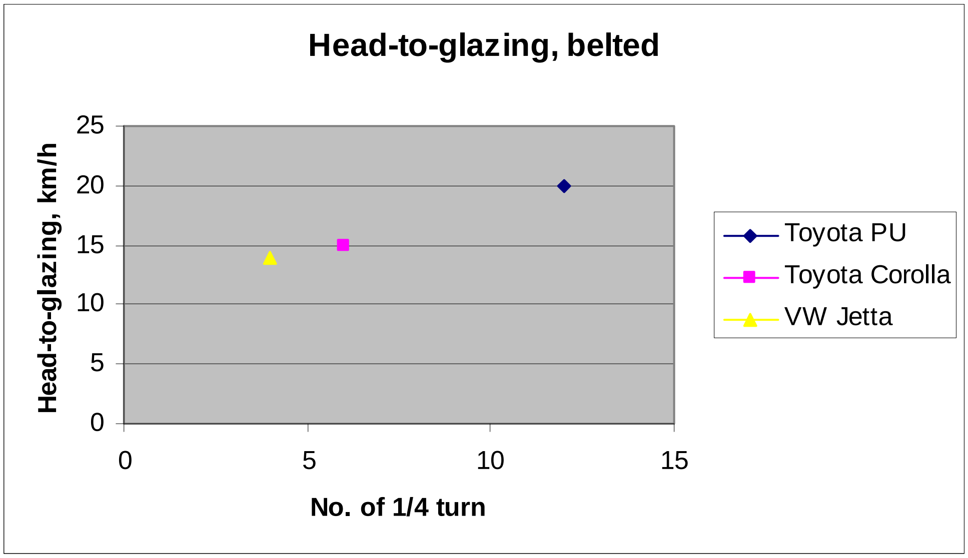


Figure VIII-9 Head Velocities of a Hybrid III 50th Percentile Male Dummy, Belted

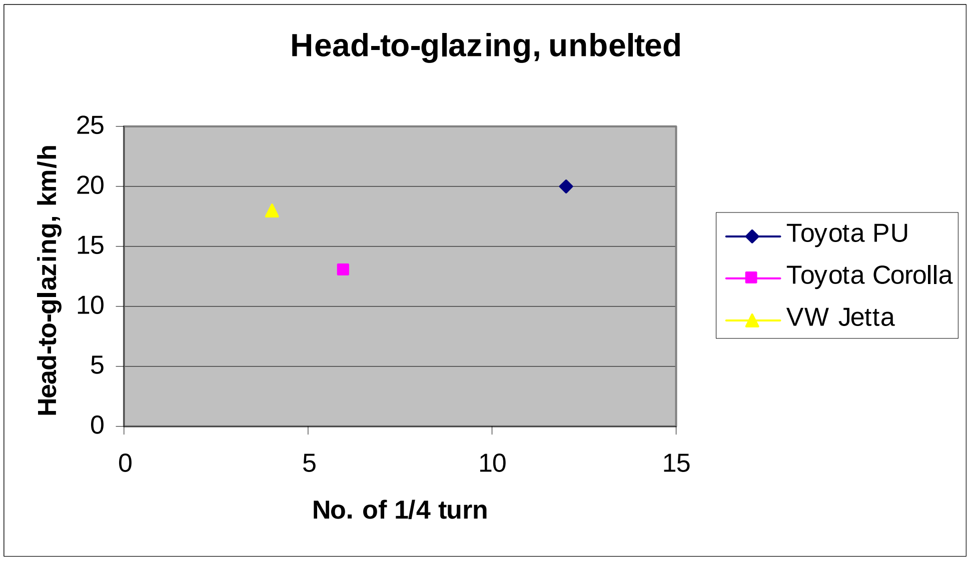


Figure VIII-10 Head Velocities of a Hybrid III 50th Percentile Male Dummy, Unbelted

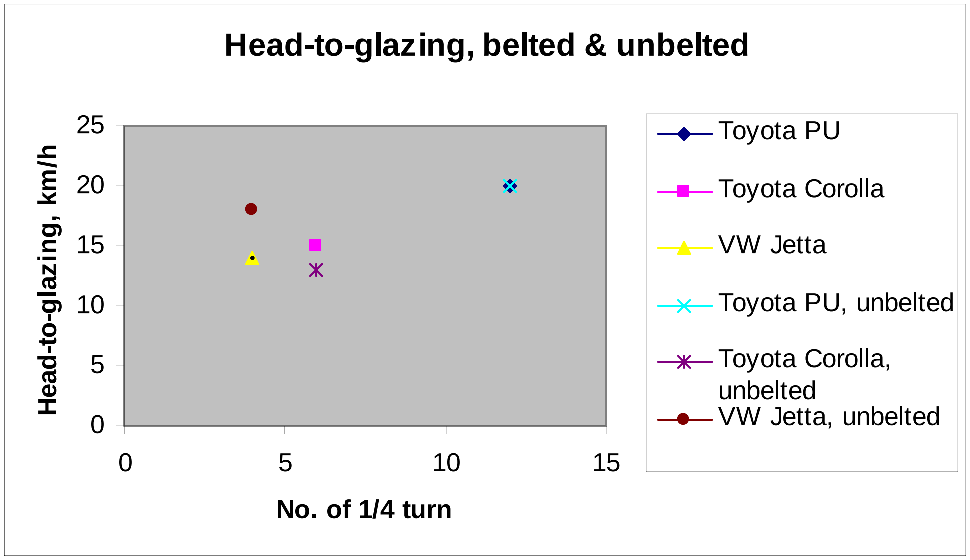


Figure VIII-11 Head Velocities of a Hybrid III 50th Percentile Male Dummy, Belted and Unbelted

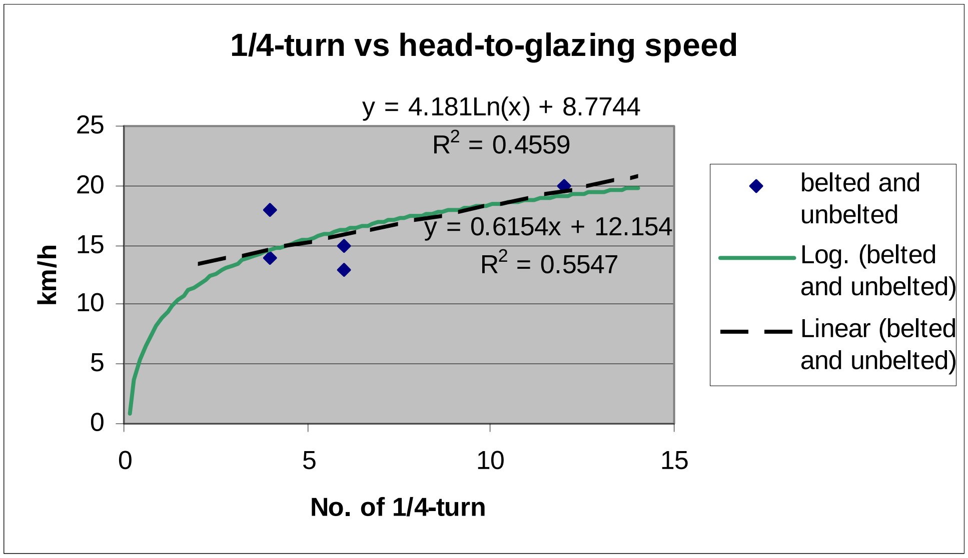


Figure VIII-12 Head Velocities of a Hybrid III 50th Percentile Male Dummy, Belted and Unbelted, with Regression

The head-to-glazing speed measurements showed that in general the occupant approaching speed increases as the number of ¼-turn increases. In addition, although the head-to-glazing speed measurements were made in laboratory test conditions, it showed that the increase in initial kinetic energy would result in a higher number of quarter turns and that the occupant-to-glazing speed increases as the number of quarter-turns increase in rollovers. If the total kinetic energy associated with the subject vehicle just before it rolls, we could express the number of rolls as a function of the initial speed, as shown below:

Kinetic energy associate with vehicle = (1-energy loss)*(Work-done by vehicle in rollover),

$$\frac{1}{2} * vehicle\ mass * (Vehicle's\ initial\ speed)^2 \quad = \quad C_0 * (work - done\ by\ rolling) \quad -(1)$$

We assumed that the work-done by vehicle in rolling is proportional to the number of roll, as shown below:

$$\frac{1}{2} * m * V^2 \quad = \quad C_1 * No.\, of\ \ rolls \quad -(2)$$

$$V = \sqrt{\frac{2 * C_1 * (No.\, of\ \ rolls)}{m}} \quad -(3)$$

$$V = \sqrt{C_2 * (No.\, of\ \ rolls)} \quad -(4)$$

$$V = C_3 \sqrt{No.\, of\ \ rolls} \quad -(5)$$

$$Vehicle's\ initial\ speed = C_3 * \sqrt{No.\, of\ \ rolls} \quad -(6)$$

The equation (6) shows a mathematical relationship between the initial vehicle speed and the number of rolls. In the field data discussed above, the Toyota pickup was traveling at 96 km/h and went into a sharp turn and yaw, which resulted in a rollover. The Corrolla was also traveling 96 km/h on a gravel road. The vehicle went out of control and left the road, resulting in roll initiation. The Volkswagen was traveling at 88 km/h when the driver fell asleep and the vehicle left the road. It struck a rock embankment and rolled over. For these three cases, our modeling showed that on average when the initial speed increased from 88 km/h to 96 km/h (8% increase in speed) the head-to-glazing speed increase from 16 km/h to 17 km/h (6% increase in speed), as shown below:

Table VIII-4. Initial Speed vs. head-to-glazing speed, a Hybrid III 50th Percentile Male Dummy

Vehicle	Initial speed, km/h	Belt use	Head-to-glazing, km/h	Avg. Head-to-glazing speed		Occupant speed by % of vehicle speed
				At 96 km/h	At 88 km/h	
Toyota Pickup	96	Yes	20	17 km/h	NA	18%
	96	No	20			
Toyota Corolla	96	Yes	15			
	96	No	13			
VW Jetta	88	Yes	14	NA	16 km/h	18%
	88	No	18			

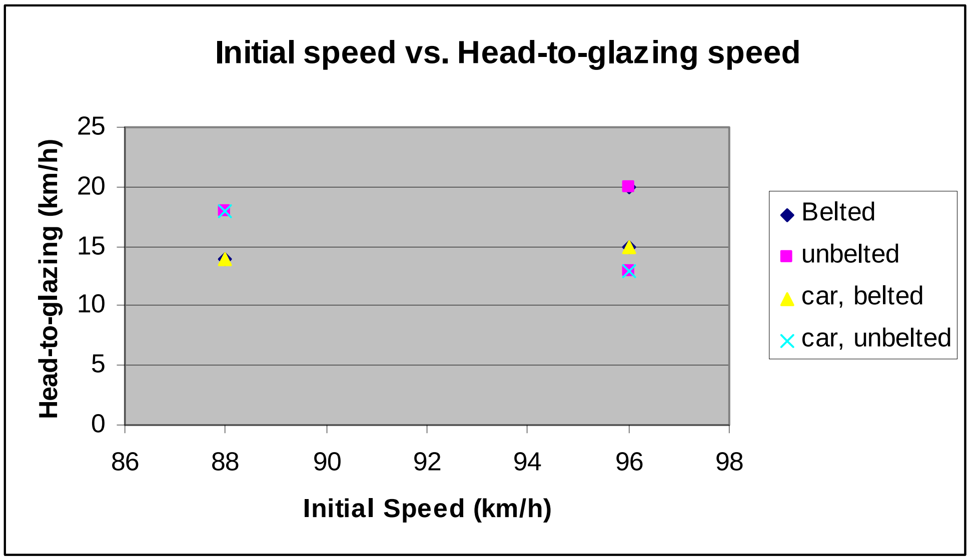


Figure VIII-13. Initial Speed vs. head-to-glazing speed, a Hybrid III 50th Percentile Male Dummy

The results in Table VIII-4 showed that the head-to-glazing speed is about 18% of the initial vehicle speed regardless of the initial speed (i.e., 88 km/h and 96 km/h). Based on the simulation, we assumed that the occupant-to-glazing speed is proportional to the vehicle's initial speed, as shown below:

$$Vehicle's\ initial\ speed = C_4 * (Occupant - to - glazing\ speed) \quad -(7)$$
$$Where\ C_4 = 1/0.18,\ as\ shown\ in\ Table\ VIII-4$$

From the equations (6) and (7) above, the occupant-to-glazing speed could be expressed as a function of number of rolls, as shown below:

$$Occupant - to - glazing\ speed = C_5 * \sqrt{No.\ of\ rolls} \quad -(8)$$

Previously, we examined the number of vehicles in real world rollovers, as shown below:

Table VIII-5. Lateral rollover separated by roll

¼ -turn	No. of vehicles	% of total	½-turn
1-2	1,245,892	57	1
3-4	611,213	28	2
5-6	217,554	10	3
7-8	89,150	4	4
9-10	13,771	1	5
11-12	6,485	0	
13-14	2,0001	0	
15-16	1,370	0	
Total	2,187,437	100%	

The results in Table VIII-5 showed that the majority of rollovers are less than eleven ¼-turns. Therefore, for the analysis, we only considered rollovers with 1-10 ¼-turns. In addition, since the agency believes that the proposed 24 km/h impactor requirement would prevent the majority of ejections (both partial and complete) through the side window opening, for the analysis, we assumed that the occupant head-to-glazing speed is not greater than 24 km/h. Furthermore, we assumed that the number of occupants in a vehicle in rollover is the same regardless of number of rolls. Under the assumptions, we could estimate the number of occupant at a given number of rolls, as shown below:

Table VIII-6. Occupant head-to-glazing speed at given number of rolls

½-turn	Head-to-glazing speed	No. of vehicles	No. of occupants	% of total	Vehicle initial speed
1	$C_5\sqrt{1}$	1,245,892	C_6*(1,245,892)	57%	$C_4C_5\sqrt{1}$
2	$C_5\sqrt{2}$	611,213	C_6*(611,213)	28%	$C_4C_5\sqrt{2}$
3	$C_5\sqrt{3}$	217,554	C_6*(217,554)	10%	$C_4C_5\sqrt{3}$
4	$C_5\sqrt{4}$	89,150	C_6*(89,150)	4%	$C_4C_5\sqrt{4}$
5	$C_5\sqrt{5}$	13,771	C_6*(13,771)	1%	$C_4C_5\sqrt{5}$
Total				100%	NA

The results in Table VIII-6 showed that the maximum occupant-to-glazing speed would be 24 km/h and that the maximum speed would in five ½-turn rollovers. From Equation (8), the following calculation was made:

$$C_5\sqrt{5} = 24\ km/h\ _{head-to-glazing\ speed}$$
$$C_5 = 24/\sqrt{5}\ km/h$$
$$= 10.733\ km/h$$

At an occupant head-to-glazing speed of 24 km/h, the corresponding vehicle initial speed would be expressed by the following equation:

$$Vehicle\ initial\ speed = C_4C_5\sqrt{5} \quad where\ C_4 = 5.56, C_5 = 10.733$$
$$= 133\ km/h \quad (83\ mph),\ ten\ 1/4-turn\ rolls$$

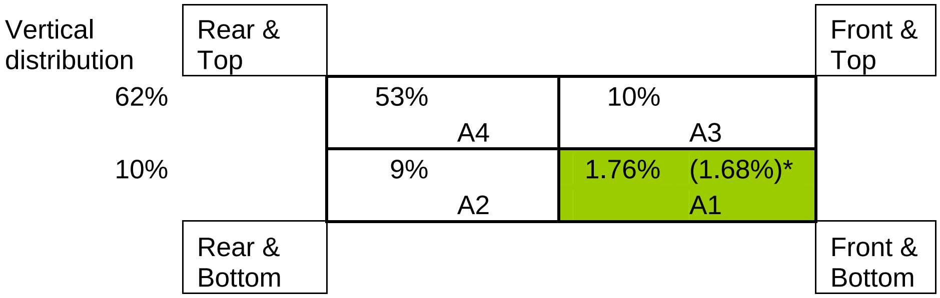
As shown above, the occupant head-to-glazing speed and the corresponding percent of occupants in a given head-to-gazing speed are shown below:

Table VIII-7. Percent of occupants at given head-to-glazing speed

Head-to-glazing speed (km/h)	Vehicle initial speed (km/h)	% of total
11	60	57%
15	84	28%
19	103	10%
21	119	4%
24	133	1%
	total	100%

The results in Table VII-7 showed that when the headform impact speed requirement decreases from 24 km/h to 20 km/h, about 5% of contained occupants at the A1 opening in rollovers would be lost when compared to a curtain bag that is designed to meet the displacement requirement at an impactor impact speed of 24 km/h.

When the 5% percent reduction rate is applied to the A1 quadrant, the containment effectiveness in the front lower corner area decreases slightly, as shown below:



Total: 72% * The reduced percent containment is in parentheses.

Figure VIII- 14. Potential Gaps, Belted Occupants, Containment of Ejection through Each Quadrant, with “Quadrant-Weighted Risk” Method, Rollovers

Total: 67% * The reduced percent containment is in parentheses.

Figure VIII- 15. Potential Gaps, Unbelted Occupants, Containment of Ejection through Each Quadrant, with “Quadrant-Weighted Risk” Method, Rollovers

We note that the methodology assumed that all rollovers would be "trip" rollovers and that the vehicle's roll motion would be retarded as the vehicle rolls on the ground. However, as shown in Table VIII-8, just over 50% of light vehicle rollovers were trip rollovers.

Table VIII-8. Field Relevant Tests and Percentage of LTV Rollovers That Each Represents.

Test Type	Percentage of Field Rollovers of each Test
Soil Trip	47.6
Curb Trip	5.5
Narrow Object Bounce Over	4.3
Corkscrew	5.4
Fall-Over	15.4
Frictional/Gravel Trip	9.7
Pitch-Over	0.1
FMVSS No. 208 Dolly	<1
	88 - 89

In addition, as mentioned in the benefits chapter (B.2.2.1), an occupant in a vehicle subjected to a lower number of rolls could experience a relatively high head-to-glazing speed when the vehicle (initially) impacts a tree or rigid object during the roll. In other words, the number of occupants with a relatively high head-to-glazing speed could be hidden in the low ¼-turn roll categories (i.e., bins). Therefore, the estimated 5% reduction in containment in the A1 area would underestimate the loss resulting from the 20 km/h impact test speed.

For side impacts, we examined real world crashes to determine how the reduction in impactor speed (from 24 km/h to 20 km/h) would affect the containment effectiveness of a curtain air bag. Figure VIII-16 shows the cumulative percentage of near side impact occupants completely ejected, by impact ΔV. This graph was generated from 704 un-weighted occupant ejections representing 15,062 weighted ejections. Table VIII-9 shows the range, average and mode of impact ΔVs for completely ejected occupants. The average side impact ΔV for a completely ejected occupant was 21.4 km/h. Table VIII-10 shows the proposed impact test speeds of 16 and

24 km/h and the percentage of near side impact occupants completely ejected at ΔVs at or below the test speed. More than 1/3 of these occupants are ejected in side impacts with ΔV at or above 24 km/h.

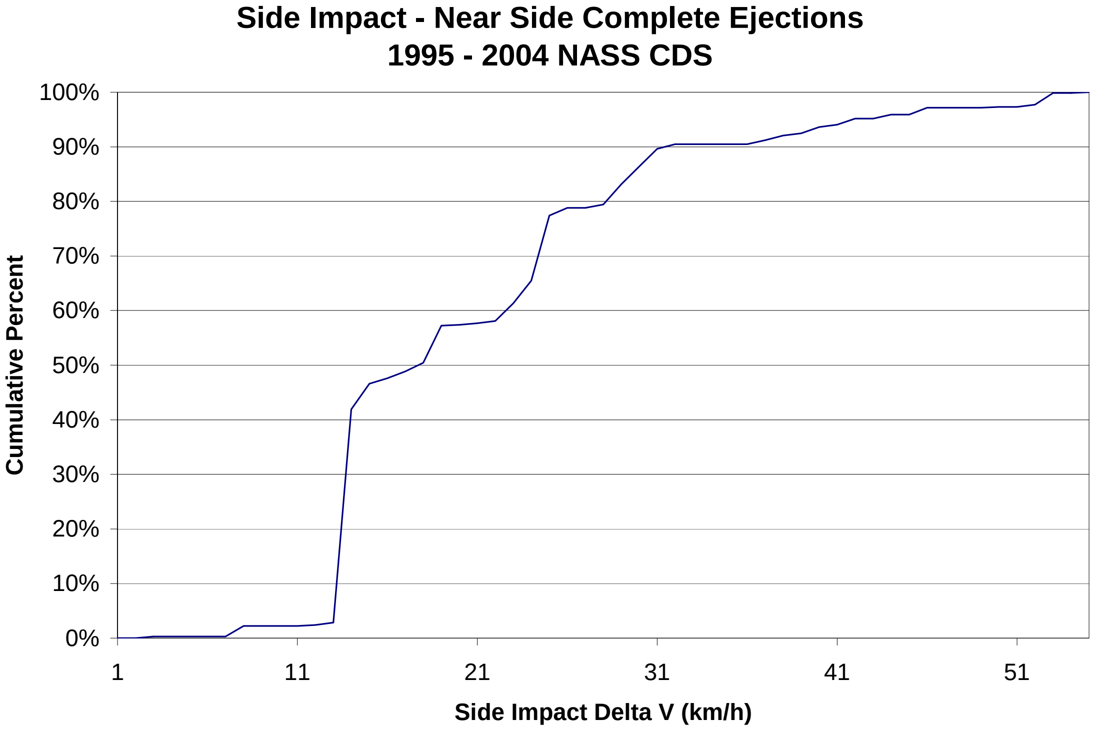


Figure VIII-16. Cumulative Percentage of Completely Ejected Occupants in Side Impacts by Impact Delta V. Generated from 704 Unweighted ejections and 15,062 Weighted Ejections.

Table VIII-9. Side Impact Delta V Statistics for Completely Ejected Occupants (1995 – 2004 NASS CDS).

Statistic	ΔV (km/h)
Range	2 to 55
Average	21.4
Mode	14

Table VIII-10. Percentage of Occupants Completely Ejected in Side Impact at or below the Delta Vs matching the Impact Test Velocities.

Impact Test Velocity (km/h)	Percent of Occupants Ejected in Crashes with ΔVs at or Below the Impact Test Speeds.
16	47.6
24	65.5

Vehicle structure absorbs part of the impact force in side crashes. In order to relate crash speed (i.e., vehicle delta-V) to occupant delta-V, an occupant delta-V conversion factor of 0.769 was used, as shown below:[248]

Table VIII-11. Vehicle Delta-V and Occupant Delta-V at 24 km/h and 20 km/h

Occupant Delta-V	Vehicle Delta-V	Cumulative Percentage
24 km/h	31 km/h	90%
20 km/h	26 km/h	80%

The results in Table VIII-10 showed that when the headform impact speed decreases from 24 km/h to 20 km/h, the percent of contained occupants by a curtain air bag would d decrease from 90% to 80%, resulting 11% reduction in containment effectiveness. When the 11% reduction rate was applied to the containment effectiveness used for the two sub-target populations, "side impact, no rollovers, 12-25 mph" and "side impact, no rollover, children", the containment effectiveness decreased to 89% for these sub-target population groups.

In summary, we divided the window opening area into four quadrants and assumed that ejections through each area are represented by the linear headform impact in that quadrant. Under the assumption, the containment effectiveness would decease slightly when the linear impactor test speed decreases from 24 km/h to 20 km/h in the low forward quadrant (an overall decrease of less than 1% for both belted and unbelted in rollovers and 11% for side impacts). It appears that the reduction in containment at the front-low window opening would have a minor effect on the overall system effectiveness, as shown below:

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[248] FMVSS No. 214, FRIA, NHTSA-2007-29134

Tale VIII-12
Overall System Effectiveness for Fatalities with
20 km/h Headform Test at A1

Occupant	Rollover	Side Impact
Belted Partial	49%	43%
Belted Complete	0%	0%
Unbelted Partial[249]	47%	43%
Unbelted Complete	47%	37%

1.B. Reduction in benefit: According to the 2005 FARS data adjusted with the ESC installation rate, there were a total of 750 fatalities in rollover crashes. Among these fatalities, 112 were belted partial, 12 were belted complete, 107 were unbelted partial, and 519 were unbelted partial. In addition, there were 643 fatalities involving side impacts in the target population. With the quadrant method with the weighted risk, we estimated that a total of 560 lives would be saved under the proposed test requirements (as discussed in the benefit chapter, 418 lives would be saved with the quadrant-weighted risk method when the fatal benefits are adjusted with the compliance and installation rates). When the overall system effectiveness rates in Table VIII-12 were applied to the fatal injury population, assuming no compliance, it would result in 544 lives saved. When the A1 is loaded with an impact speed of 20 km/h, therefore, it would result in a 3% reduction in fatal saving (1-544/560 = 3%).

The agency's linear impactor test results show that none of the tested curtain air bags met the 100 mm displacement at the A1, whereas all bags are capable of meeting the requirement at the other impact points. In the benefit chapter, we estimated that 402 additional lives would be saved when the number of lives saved was adjusted with the belt use rates (15% belted and 85%

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[249] As discussed in the benefit chapter, the Winnicki's reduction rates were based on unbelted occupants. Therefore, the use of unbelted occupant reduction rates would underestimate the overall system effectiveness.

unbelted fatalities in rollovers),and the 55% MY 2011 installation rate,. When we applied the 3% overall percent reduction rate to the 402 additional lives saved, it resulted in 391 additional lives saved, as shown below:

Table VIII-13.
Estimated Reduction Fatality and Serious Injuries with Lowering Load at A1

Potential Benefit	With 24 km/h	With 20 km/h
Additional lives saved	402	391
Additional Injuries prevented	310	301

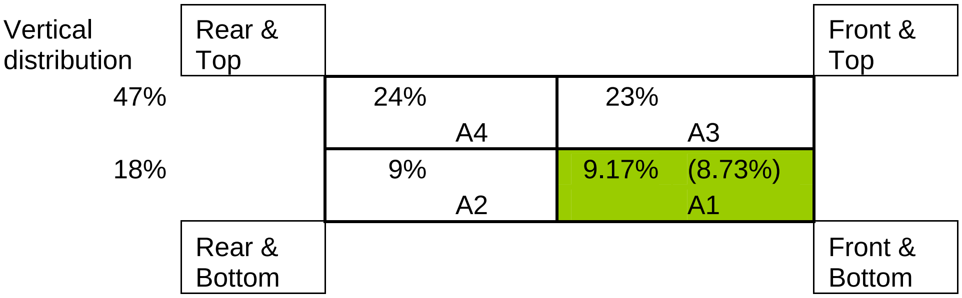
1.C. Reduction in cost: Although the impact speed decreases from 24 km/h to 20 km/h at the front-lower corned, represented by the A1 quadrant, the curtain air bag must be designed to fully cover the window opening. In the cost chapter, we estimated the incremental material costs associated with the full-covered curtain based on the increase in material cost. We believe that the cost difference between a fully complying curtain (tested at 24 km/h) and the lower impact load curtain (tested at 20 km/h at A1) would be from costs associated with the initial design of the countermeasure system, not from additional materials used to fully cover the window opening. Therefore, we assume that lowering the impact at the A1 area would not decrease the overall material costs when compared to a full cover curtain bag meeting the proposed 24 km/h impact speed.

Table VIII-14
Comparing Additional Lives Saved and Material Costs, full Cover Curtain

Additional Lives Saved	Additional Lives Saved	Material Costs (in$M)
Meeting 24 km/h	402	$583
Meeting 20 km/h at A1	391	$583

In the benefit chapter, we estimated the overall benefits using two different assumptions for the containment namely “weighted” and “uniform” risk of ejection through the window opening area. In the previous section above, we estimated that lowering the impact speed from 24 km/h to 20 km/h at the A1 area would reduce the 402 additional lives saved to 391 additional lives saved with the "weighted" risk of ejection method.

As mentioned, we estimated the potential lose of fatal benefits with the "uniform" risk of ejection in the window opening area when the impact load decreases from 24 km/h to 20 km/h at the A1 area. When ejections through the potential gaps were considered, we estimated that the hypothetical full-covered curtain bag would be 65% effective in preventing occupants from ejection, when we assume all ejections through the opening are uniformly distributed, as shown below:



Total: 65% * The reduced percent containment is in parentheses.

Figure VIII- 10 Baseline Belted Occupants, Containment of Ejection through Each Quadrant, with Uniform Risk Method, Rollover

Total: 65% * The reduced percent containment is in parentheses

Figure VIII- 11 Baseline Unbelted Occupants, Containment of Ejection through Each Quadrant, with Uniform Risk Method, Rollovers

For the side impacts, similar to the approaches used for the "quadrant-weighted risk" containment, we used the 11% reduction in containment in effectiveness for the two sub-groups, "Side impact, no rollovers, 12-25 mph" and "Side impact, no rollover, children (0-12 years), 12-25 mph".

1.D. Reduction in benefit with 20 km/h at A1 based on uniform risk distribution : With the quadrant method and the "uniform risk", we previously estimated that a total of 531 lives would be saved under the proposed test requirements (and, as discussed, 397 additional lives would be saved with the quadrant method when the fatal benefits are adjusted with the compliance and installation rates). When the headform impact speed requirement decreases from 24 km/h to 20 km/h, it would result in 513 lives saved (and 384 additional lives saved). When the A1 is loaded with an impact speed of 20 km/h, therefore, it would result in a 3% reduction in fatal saving. When we applied the 3% overall percent reduction to the 390 additional lives saved (that were calculated) in the benefit chapter, it resulted in 377 additional lives saved, as shown below:

Table VIII-15. Estimated Reduction Fatality with Lowering Load at A1, Uniform Risk Distribution

	With 24 km/h	With 20 km/h
Additional lives saved	390	377
Additional Injuries prevented	296	286

1.E. Reduction in cost: As discussed previously, we believe that the fully complying curtain and the lower impact speed curtain would have similar material costs since both curtains are required to fully cover the window opening. As shown in the cost chapter, the estimated increase in cost was based on costs associated with materials used for these fully covered curtains. In other words, costs associated with designing of these full curtains were not considered. Therefore, we assumed that lowering the impact load at the A1 area would not decrease the overall material costs when compared to the fully complying curtain bag, as shown below:

Table VIII-16 Comparing Additional Lives Saved and Material Cost, Full Cover Curtain, with Uniform Risk Method

Additional Lives Saved	Additional Lives Saved	Material Cost ($M)
Meeting 24 km/h	390	$583
Meeting 20 km/h at A1	377	$583

When the impact speed requirement decreases from 24 km/h to 20 km/h at the A1 area (front lower corner of the window opening), it would decrease the potential fatal benefits by 3% with the uniform risk method. Whether the bag is required to meet the proposed 24 km/h impact speed or a lower impact speed of 20 km/h, the window would be completely covered to meet the 100 mm displacement requirement. Therefore, the reduction in impact speed at the A1 area would not result in a reduction in material costs, when compared to the full-cover curtain bag. We speculate that the "lower speed at A1" curtain bag could be redesigned, without adding additional materials, to meet the proposed 24 km/h impact speed requirement, such as reconfigure the air chamber in the air bag.

Alternative 2: Effects of requiring a single impact in each side window opening area.

In the cost chapter, we estimated that the cost burden on manufacturers would be much small when compared to the testing cost to install a curtain air bag that is capable of meeting the proposed displacement requirement. However, when the number of impacts is reduced in the opening area, it would substantially reduce the potential benefits, as shown below.

2.A. Reduction in containment effectiveness: In the benefit chapter we estimated potential benefits when the window opening area is impacted by the headform at four different points. As an alternative, we examined effects of requiring a single headform impact test in the window opening. If a rollover curtain air bag were required to meet a certain displacement requirement at the geometric center of the window opening, covering of the lower portion of the window area would not be necessary to meet the requirement. Thus, there appears to be no reason why a manufacturer would design their air bags to cover the entire opening area if a single impact test were adopted. Similar to the methodology used in the benefit chapter, a rollover curtain air bag that is capable of meeting the headform impact requirement at the geometry center may or may not be effective in preventing occupants from ejection through the lower portion of the window opening. When the window opening is divided into four quadrants, as shown in Figures VIII-2 and VIII-3, the containment effectiveness would be about 63% if the curtain is not effective in preventing occupant ejections through the lower 50% of the window opening area (52.8% $_{\text{upper rear}}$ + 10.6% $_{\text{upper front}}$ = 63.4%).[250] In addition, as we discussed previously, there would be a potential gap between the front of the air bag and the A-pillar, increasing the risk of ejection by 3% for belted and 10% for unbelted occupants.[251] When the risk of ejection through the front potential gap is considered, it resulted in 60% effectiveness for belted and 53% for unbelted occupants in rollovers. When weighted with the belt use rate (15% and 85% for belted and unbelted, respectively), it resulted in 55% (54.6%) containment effectiveness in rollovers. (Several assumptions were used for deriving the containment effectiveness. One of the assumptions was that all ejections through the upper portion of the window opening would be prevented with the curtain air bag that is designed to meet the single impact headform test requirement. However,

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[250] Using the more conservative uniform distribution would give lower effectiveness.

[251] When we excluded the front lower corner of the window opening from meeting the displacement requirement, we estimated that the risk of ejection through a potential gap between the front of a bag and the A-pillar would increase by 3% (3.2% x 0.95 = 3%) and 10% for belted and unbelted occupants, respectively. Similarly, there would be a potential gap between the curtain and the A-pillar when a curtain bag is designed for a single impact at the geometric center of the curtain. For the analysis, therefore, we assumed that the risk of ejection through the gap would increase by the same amount.

the impactor test data showed that meeting the displacement requirement at the geometry center of the window opening may or may not limit the displacement within the required 100 mm at the upper front corner in the window opening, A3 impact point). In the benefit chapter, we estimated that the hypothetical rollover curtain air bag would be about 66% effective in preventing occupant from ejection, when both belted and unbelted occupants were combined (i.e. 15% and 85% fatalities were from belted and unbelted in rollovers).[252] When the 55% containment effectiveness is used, the overall system effectiveness would decrease from 45%$_{\text{weighted}}$ to 37% $_{\text{weighted}}$ (with 77% sensor effectiveness rate and 88% Winnicki's risk reduction rate) in rollover crashes. Although we derived the effectiveness for a curtain air bag that is designed to meet a single impact test requirement in the window opening area, we are far from certain how these air bags would behave in real world crashes. For example, these relatively small curtain air bags may not be effective in preventing occupants from complete ejection in side crashes, particularly small stature occupants and occupants in the far-side seating position.[253] Since the single-impact test requirement may or may not result in a "full" curtain air bag that covers the entire area of the window opening, as discussed previously in the target population section in the benefits chapter, we assumed that the "single-impact" curtain air bag would not prevent occupants from complete ejections in side impacts.

2.B. Reduction in benefit: In the target population, we found that 1,068 fatalities in rollover crashes. Among the 1,068 fatalities, 750 were from in rollover without any side crashes, 251

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[252] In the benefit chapter, we estimated that 15% of fatalities with 71% containment and 85% of fatalities with 65% containment effectiveness in rollovers. .15x.71+.85x.65 = .66, 66%,

[253] In the oblique pole FRIA, completely ejected occupants in side crashes were not included in the target population. The agency determined that side curtain bags with a gap between the curtain and the window sill may not be effective in preventing occupants from complete ejection in side crashes. Accordingly, we assumed that the single-impact bag (that would not cover the lower portion of the window opening) would not be effective in preventing complete ejections in side crashes.

were from side crashes followed by rollovers in all but 12-25 mph, and the remaining 79 were from side crashes followed by rollovers in 12-25 mph. If we assume that the containment effectiveness of a rollover curtain air bag remains unchanged in rollover crashes, whether preceded by side crashes or not, the overall benefits would decrease from 538 lives saved to 349 (about 35% reduction). Previously, we estimated that about 27% of the potential fatal benefits could be achieved with the curtain air bag, with the 55% MY 2011 installation rate. However, we do not have data to show what percentage of currently available ejection mitigation curtain bags would meet the single impact headform requirement. Based on the headform impactor data, we suspect that the majority of current ejection bags would meet the single impact headform test requirement. For the analysis, therefore, we assumed that all currently available ejection mitigation air bags would meet the single impact headform test requirement. Under the assumption, about 52% of the potential benefits could be achieved with currently available curtain air bags, with 55% MY 2011 installation rate. When the 55% potential fatal benefits are subtracted from the 349 lives saved, it result in 168 incremental fatal benefits [349_{lives} x (1-0.55) = $168_{\text{ incremental fatal benefits}}$]. Therefore, the incremental fatal benefits would decrease from 402_{lives} to 168_{lives} when a single headform impact test is required in the window opening.[254] (See Appendix E for the detailed derivation).

We note that, for the benefit estimate, we assumed that most of adult occupants would not bounce off the bag during a roll motion. A dimensional analysis of the curtain and the window opening area indicates that a very large gap (about 10 inches, 249 mm) can be formed between

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[254] The single impactor test could result in a curtain bag that has a large opening (gap) in the lower portion of the bag. Unlike fully covered curtain air bag, the containment effectiveness could decrease substantially as the occupant slides over the bag after the initial impact.

the window sill and the curtain, even if the 100 mm deflection requirement remains unchanged.[255]

2.C. Increase in cost: To meet the single impact test requirement, manufacturers need to replace FMVSS No. 214 combo bags with FMVSS No. 214 curtain air bags. In the cost chapter, we estimated that about 45% of light vehicles will not be equipped with a roll sensor. Although the agency is not proposing any requirements for the sensor, as discussed, we believe that a rollover sensor will be provided as an integral part of the ejection mitigation system. For the total incremental cost associated with the single impact test, when the 45% of light vehicles are equipped with the sensor, the incremental cost would be more than $300 million to cover 1st and 2nd row windows, as shown below:

Table VIII-17
Incremental Costs Associated with Single Impact Headform Test
(With MY 2011 Baseline Head/Side Air Bag, per vehicle in 2006 economics)

Baseline	Est. Sales	Needed	Roll sensor	214-Curtain	Thorax bag	Incre. Per veh	Incremental cost (in $M)
Curtain w/ roll sensor	55%	None	$0	$0	$0	$0	$0
Curtain w/o roll sensor	44%	Roll sensor	$38	$0	$0	$38	$284
Combo	1%	Roll sensor, curtain and thorax bag	$38	$174	$76	$197*	$33
Total veh.	17M						
214-Combo bag cost		($91)	*$38+$174+$76-$91 = $197			Total	$318

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[255] The front side window of a MY 2003 Toyota Camry has a height of 18 inches (457 mm). When the geometry center of the window opening area is moved by 100 mm, hypothetically, it would create a 249 mm gap, $(100)^2 + [(457)/2]^2 = (249)^2$.

Summary of Alternatives:

There were a number of alternative regulatory approaches the agency considered for this rulemaking. These alternatives include:

1. Require the front lower corner of the window area A1 to meet the displacement at a linear headform impact speed of 20 km/h.
2. Require a single impact in each side window opening area.

We compared the incremental costs and benefits associated with these alternatives, as shown in Table VIII-18.

Table VIII-18
Incremental Costs and Additional Lives Saved for Alternatives

Alternatives	Lives Saved (incremental)	Costs (millions)		
		1st & 2nd row	3rd row	total
Proposed Rule (4 impacts)	402	$532	$51	$583
Testing A1 at 20 km/h	391	$532	$51	$583
Single Impact	168	$318	$34*	$352

* We assumed that only top 2/3 of the opening is covered with a curtain ($51M x 2/3 = $34M).

The results in Table VIII-18 show that the proposed linear guided head form test would result in 402 lives saved, annually, when the window opening is tested at four impact points. When the low forward impact point, A1 is required to be tested at 20 km/h, it would result in 391 lives saved. The estimated benefits and costs show that the first alternative (testing at three impact point) would have a moderate impact on the overall system effectiveness. The analysis of the second alternative shows that a rollover curtain air bag that is designed to withstand a load at the geometric center of the window opening would also provide substantial benefits (168 lives saved, incremental benefits). However, we are uncertain how this relatively small bag interacts with an occupant in rollovers. In addition, we note that the head form test data show that most of currently available rollover air bags would meet the 100 mm displacement requirement when the air bag is tested at three impact point (Alternative 1) or at the center of the window opening. Therefore, we expect that the majority, if not all, of manufacturers would be capable of meeting the 100 mm displacement requirement in the single-impact head form test.

IX. REGULATORY FLEXIBILITY ACT AND UNFUNDED MANDATES REFORM ACT ANALYSIS

A. REGULATORY FLEXIBILITY ACT

The Regulatory Flexibility Act of 1980 (5 U.S.C §601 et seq.) requires agencies to evaluate the potential effects of their proposed and final rules on small business, small organizations and small Government jurisdictions.

5 U.S.C §603 requires agencies to prepare and make available for public comments initial and final regulatory flexibility analysis (RFA) describing the impact of proposed and final rules on small entities. An RFA is not required if the head of the agency certifies that the proposed rule will not have a significant impact on a substantial number of small entities. The head of the agency has made such a certification.

The factual basis for the certification (5 U.S.C. 605(b)) is set forth below. Although NHTSA is not required to issue an initial RFA, as a means of venting the issues we discuss below many of the issues that an initial RFA would address (§604).

Section 603(b) of the Act specifies the content of a RFA. Each RFA must contain:

1. A description of the reasons why action by the agency is being considered;
2. A succinct statement of the objectives of, and legal basis for a final rule;
3. A description of and, where feasible, an estimate of the number of small entities to which the final rule will apply;

4. A description of the projected reporting, recording keeping and other compliance requirements of a final rule including an estimate of the classes of small entities which will be subject to the requirement and the type of professional skills necessary for preparation of the report or record;
5. An identification, to the extent practicable, of all relevant Federal rules which may duplicate, overlap or conflict with the final rule;
6. Each final regulatory flexibility analysis shall also contain a description of any significant alternatives to the final rule which accomplish the stated objectives of applicable statutes and which minimize any significant economic impact of the final rule on small entities.

1. <u>Description of the reason why action by the agency is being considered</u>

NHTSA is requiring this action to improve the safety of occupants by mitigating ejection through side windows in vehicle crashes. A test condition has been designed to represent the forces of an unbelted occupant moving toward a side window. The test will assess the ability of a countermeasure to retain an occupant in the vehicle. The availability of air bag related technologies provides an opportunity for consumers to have affordable protection systems in rollover crashes.

2. <u>Objectives of, and legal basis for, the proposed rule</u>

This proposed rule incorporates a linear head form impactor test into a new Federal Motor Vehicle Safety Standard (FMVSS) No. 226, “Ejection mitigation.” The side window openings of light vehicles will be tested with a featureless head form by impacting various areas in the window opening at specific impact speeds. To meet the test requirements, vehicle manufacturers will need to assure head and upper body regions are protected in rollover crashes. It will lead to the installation of new technologies, such as large curtain air bags with rollover sensors, which are capable of preventing occupants from ejection in rollover. The curtain air bag systems installed to meet the head form requirements of this proposed rule will also reduce fatalities and injuries caused by complete ejections through side windows in side crashes.

NHTSA is requiring these changes under the authority of 49 U.S.C. 322, 30111, 30115, 30117, and 30666; delegation of authority at 49 CFR 1.50. The agency is authorized to issue Federal motor vehicle safety standards that meet the need for motor vehicle safety. This proposed rule is also being issued pursuant to the "Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users." Under chapter 301 of title 49, United States Code, Section 10301 of the Act directed the agency to "initiate a rulemaking proceeding to establish performance standards to reduce complete and partial ejections of vehicle occupants from outboard seating positions. In formulating the standards the Secretary shall consider various ejection mitigation systems." In accordance with §10301, the ejection mitigation air bags installed in vehicles will enhance passenger motor vehicle occupant protection in rollover crashes and also certain side impacts.

3. Description and estimate of the number of small entities to which the final rule will apply

The final rule will apply to motor vehicle manufacturers, and to second-stage or final stage manufacturers, and alterers. It will affect air bag manufacturers and rollover sensor manufacturers. Business entities now defined as small business using the North American Industry Classification System (NAICS) code, for the purpose of receiving Small Business

Administration assistance. One of the criteria for determining size, as stated in 13 CFR 121.201, is the number of employees in the firm. For establishments primarily engaged in manufacturing or assembling automobiles, light and heavy duty trucks, buses, motor homes, new tires, or motor vehicle body manufacturing, the firm must have less than 1,000 employees to be classified as a small business. For supplier establishments manufacturing many of the safety systems, the firm must have less than 750 employees to be classified as a small business. For establishments manufacturing motor vehicle seating and interior trim packages, alterers and second-stage manufacturers, the firm must have less than 500 employees to be classified as a small business.

Currently, there are six small light vehicle manufacturers in the United States. Table IX-1 provides information about the six small volume domestic manufacturers in MY 2007. All are small manufacturers, having much less than 1,000 employees.

Table IX-1
Small Volume Vehicle Manufacturers

Manufacturer	Employees	Estimated Sales	Sale Price Range	Est. Revenues*
Fisker Automotive**	N/A	15,000 projected	$80,000	N/A
Mosler Automotive	25	20	$189,000	$2,000,000
Panoz Auto Development Company	50	150	$90,000 to $125,000	$16,125,000
Saleen Inc.	170	1,000[#]	$39,000 to $59,000	$49,000,000
Saleen Inc.	170	16[##]	$585,000	$9,000,000
Standard Taxi***	35	N/A	$25,000	$2,000,000
Tesla Motors, Inc.	250	2,000	$65,000 to 100,000	N/A

* Assuming an average sales price from the sales price range.
** Fisker Automotive is a joint venture of Quantum Fuel Systems Technologies Worldwide, Inc. and Fisker Coachbuild, LLC.
*** Standard Taxi is a subsidiary of the Vehicle Production Group LLC. 35 employees is the total for VPG LLC.
[#] Ford Mustang Conversions
[##] S7 model

The agency has not analyzed the impact of the final rule on these small manufacturers individually. However, the cost is not expected to be substantial.

4. <u>A description of the projected reporting, recording keeping and other compliance requirements of a final rule including an estimate of the classes of small entities which will be subject to the requirement and the type of professional skills necessary for preparation of the report or record</u> .

4.1. Reporting & Recording Impacts:

For the liner head form test, the agency is requiring a phase-in schedule starting the first September 1 three full year after publication of the final rule. For illustration purposes assume the date to be September 1, 2013. Based on that date, the phase-in schedule is set forth below. Credits will be allowed for early compliance, applicable to the 20 percent, 40 percent and 75 percent phase-in requirements.

Table XI-2
Final Rule Phase-In Schedule

Production Period	Percent of each manufacturer's light vehicles that must comply during the production period
September 1, 2013 to August 31, 2014	20 percent of a manufacturer's light vehicles
September 1, 2014 to August 31, 2015	40 percent of a manufacturer's light vehicles
September 1, 2015 to August 31, 2016	75 percent of a manufacturer's light vehicles, and
On or after September 1, 2016	For all light vehicles
On or after September 1, 2017	Manufacturers with limited carlines
On or after September 1, 2018	Alterers, multistage manufacturers

As with previous rules, the agency will allow manufacturers that produce three or fewer car lines the option of achieving full compliance when the phase-in is completed. Furthermore, vehicles manufactured in two or more stages do not have to comply until one year after the phase-in is completed.

For the small domestic automobile manufacturers, the reporting requirements depend upon the phase-in option taken. If they choose a phase-in, then there are reporting requirements to show compliance with the phase-in schedule. If they choose to meet the standard with all models when the phase-in is completed, then there are no reporting requirements. The information to be reported would be developed by management, while an administrative assistant might type up and fill out the report.

4.2. Compliance Impacts:

(a) Small vehicle manufacturers: The rule will directly affect motor vehicle manufacturers. However, we believe that the rule would not have a significant economic impact on small vehicle manufacturers. We believed that the small vehicle manufacturers are not likely to certify compliance with a vehicle test, but will use a combination of component testing by air bag suppliers and engineering judgment. Already much of the air bag work for these small vehicle manufacturers is done by air bag suppliers. Typically, air bag suppliers are supplying larger vehicle manufacturers during the development and phase-in period, and do not have the design capabilities to handle all of the smaller manufacturers. The rulemaking proposal accounted for this limitation by proposing to allow small manufacturers that have limited lines to comply with the upgraded requirements at the end of the phase-in period, to reduce the economic impact of the rule on these small entities.

We also believe that the rulemaking would not have a significant impact on the small vehicle manufacturers because the market for the vehicles produced by these entities is highly inelastic. Purchasers of these vehicles are attracted by the desire to have an unusual vehicle. Further, all light vehicles must comply with the head form impact requirements. Since the price of complying with the rule will likely be passed on to the final consumer, the price of competitor’s models will increase by similar amounts. In addition, we do not believe that raising the price of a vehicle to include the value of a rollover curtain air bag will have much, if any, effect on vehicle sales.

For the reasons explained above, NHTSA concludes that this proposed rule will not have a significant impact on a substantial number of small vehicle manufacturers.

There are six small domestic motor vehicle manufacturers in the United States in MY 2007, as previously shown in Table IX-1. All are small manufacturers, having much less than 1,000 employees.

If a vehicle is equipped with the ejection mitigation curtain air bag, the incremental cost to modify the FMVSS No. 214-curtain system is estimated to cost $49.97 per vehicle. If a vehicle is equipped with a combo air bag system, the cost would be $208.31 per vehicle. Compared to the least expensive vehicle in Table VIII-2, the cost is less than one-half of one percent ($49.97/$25,000 = 0.2% for the curtain system and 0.8% for the combo system). Compared to a weighted average sales price ($58,000), the cost is about one tenth of one percent ($49.97/$58,000 = 0.1% for the curtain system and 0.3% for the combo system).

We believe that the market for the products of these small manufacturers is highly inelastic. Purchasers of these products are enticed by the desire to have an unusual vehicle. Furthermore, the price of competitors' models will also need to be raised by a similar amount, since all light vehicles must pass the standards. Thus, we do not believe that raising the price to include the value of a rollover curtain air bag will have much, if any, affect of vehicle sales. We suspect these price increases will be passed on to the final customer. Based on this analysis, the agency believes that the proposed rule will not have a significant economic impact on these four small domestic manufacturers.

(b) Final stage manufacturers and alterers: There are a significant number (several hundred) of second-stage or final-stage manufacturers and alterers that could be impacted by the proposed rule. These manufacturers buy incomplete vehicles or add seating systems to vehicles without seats, or take out existing seats and add new seats. Many of these vehicles are van conversions, but there are a variety of vehicles affected. We believe that the majority of these incomplete vehicles would be equipped with the ejection mitigation curtain bag to meet the linear head form test requirements. However, some incomplete vehicles were designed to meet the FMVSS No. 214-oblique test requirements with the FMVSS No. 214-combination air bag. In order to meet the proposed linear head form test requirements, these incomplete vehicles would be equipped with the ejection mitigation curtain bag. When rollover curtain air bags are installed in the window header, these manufacturers may need to use the combined engineering judgment of the vehicle designer, curtain air bag supplier and their own judgment to certify compliance. Possibly some exemplar tests could be performed to show compliance. If a higher roof is added, the vehicle is excluded from the head form test. If the side structure is not affected and a higher roof is not added, then the original manufacturer’s certification should apply. Thus, while there are a significant number of second-stage and final stage manufacturers impacted by the proposed rule, we do not believe the impact will be economically significant.

(c) Air bag manufacturers and rollover sensor manufacturers: The agency does not believe that there are any small air bag manufacturers, and only a few small rollover sensor manufacturers. The proposed rule is expected to have a positive impact on their business.

We expect additional business for air bag manufacturers and rollover sensor manufacturers. The proposed rule will require the use of more air bags and rollover sensors. In each case, the proposed rule means positive business for these manufacturers.

5. An identification, to the extent practicable, of all relevant Federal rules which may duplicate, overlap, or conflict with the final rule

We know of no Federal rules which duplicate, overlap, or conflict with the proposed rule.

6. A description of any significant alternatives to the proposed rule which accomplish the stated objectives of applicable statutes and which minimize any significant economic impact of the final rule on small entities.

The only alternatives available for small entities relate to the leadtime phase-in discussed above. There are no other alternatives that can achieve the stated objectives without installing countermeasures into the vehicle.

B. Unfunded Mandates Reform Act

The Unfunded Mandates Reform Act of 1995 (Public Law 104-4) requires agencies to prepare a written assessment of the costs, benefits, and other effects of proposed or final rules that include a Federal mandate likely to result in the expenditures by States, local or tribal governments, in the aggregate, or by the private sector, of more than $100 million annually (adjusted annually for inflation with base year of 1995). Adjusting this amount by the implicit gross domestic product price deflator for the 2007 results in $130 million (119.816/92.106 = 1.30). The assessment may be included in conjunction with other assessments, as it is here.

A proposed rule on rollover curtain air bags is not likely to result in expenditures by State, local or tribal governments of more than $100 million annually. However, it is estimated to result in the expenditure by automobile manufacturers and/or their suppliers of more than $583 million annually. Since the estimated incremental costs depend on a variety of FMVSS No. 214 side air bags that manufacturers plan to install (in vehicles used as "baseline" for the cost estimate), the proposed rule have a variety of costs ranging from an average of at least $34 per vehicle for 17 million vehicles, it will exceed $583 million. The final cost will greatly depend on choices made by the automobile manufacturers to meet the FMVSS No. 214-oblique pole test requirements. These effects have been discussed in this Preliminary Regulatory Impact Analysis. Please see Chapter V on Costs.

The Unfunded Mandates Reform Act requires the agency to select the "least costly, most cost-effective or least burdensome alternative that achieves the objectives of the rule." As an alternative, the agency considered a full-vehicle dynamic test to evaluate a curtain's window coverage and retention capability. Based on our experience on full-vehicle rollover crash tests (such as the vehicle rollover test specified in FMVSS No. 208), we determined that full-vehicle rollover crash tests can have an undesired amount of variability in vehicle and occupant kinematics. Unlike full-vehicle rollover tests, the proposed component test is conducted in a well controlled test environment, which results in an acceptable amount of variability. In addition, the proposed component test not only distinguishes between acceptable and unacceptable performance in side curtain air bags, but has advantages over a full-vehicle dynamic test. The acceptable performance in the laboratory test correlated to the acceptable performance in the dynamic test. In other words, the agency's component test was able to reveal deficiencies in window coverage of ejection mitigation curtains that resulted in partial or full ejections in dynamic conditions. Therefore, we concluded that a full-vehicle test would not achieve the objectives of the rule.

In addition, as discussed in Chapter VIII, the agency considered two alternative component tests. The first alternative is to require the front lower corner of the front side window area (test point A1) from meeting the displacement requirement when impacted at a 20 km/h. The second alternative is to require a single impact at the center of the side window opening area. For the first alternative, the agency undertook several research programs using a dynamic rollover fixture (DRF), which produced full-dummy ejection kinematics in an open window condition, to assess the potential effectiveness of ejection mitigation countermeasures in a rollover. As part of the assessment, a series of tests on the DRF were performed using an unrestrained Hybrid III 6-year- old dummy with two prototype inflatable devices namely "TRW" and "Zodiac" systems. In a series of tests with the dummy lying in a prone position (the dummy was placed on its back at the height of the bottom of the window opening), representing a near worst-case ejection condition, the dummy was completely ejected at the position near the bottom of the inflatable devices (above the sill) with the TRW curtain while the Zodiac system contained the dummy inside the test buck in all testing. The Zodiac prototype system used an inflatable tubular structure tethered near the base of the A- and B-pillars that deployed a woven material over the window opening. The TRW prototype was more akin to a typical air bag curtain and was fixed to the A- and B-pillars at its end points and along the roof rail, but not tethered. The test results showed that the window opening must be fully covered. As for the second alternative, a curtain ejection mitigation system designed to meet the proposed displacement requirement at the center of the side window opening area would most likely have a gap between the curtain and the window sill. Even if the gap is covered with the curtain, there is no assurance that the curtain would prevent ejections through the area without performing the headform test at targets in this area. Therefore, the agency concluded that a curtain mitigation bag designed to meet the single impact would not achieve the objectives of the rule.

Appendix A
Belted Dummy with Selected Interior Impact Objects

		No. of Impacts by Dummy Body Part				
Test No.	Impact Object	Head	Shoulder	Chest	Back	No. Rolls
263	Window header	2				3
Table A-2	Upper door frame	1				
	Window Sill	1				
	A-Pillar					
	B-pillar		2			
	Roof	2				

		No. of Impacts by Dummy Body Part*				
Test No.	Impact Object	Head	Shoulder	Chest	Back	No. Rolls
293	Window header	2				1
Table A-3	Upper door frame					
	Window Sill					
	A-Pillar	1				
	B-pillar	1				
	Roof		1			

		No. of Impacts by Dummy Body Part				
Test No.	Impact Object	Head	Shoulder	Chest	Back	No. Rolls
35412-12	Window header					1
Table A-4	Upper door frame					
	Window Sill					
	A-Pillar					
	B-pillar	1				
	Roof					

		No. of Impacts by Dummy Body Part				
Test No.	Impact Object	Head	Shoulder	Chest	Back	No. Rolls
287	Window header					3
Table A-6	Upper door frame	1				
	Window Sill	1	1			
	A-Pillar					
	B-pillar				1	
	Roof					

		No. of Impacts by Dummy Body Part				
Test No.	Impact Object	Head	Shoulder	Chest	Back	No. Rolls
1336-22C81	Window header	1				2
Table A-9	Upper door frame	1				
	Window Sill					
	A-Pillar					
	B-pillar					
	Roof	1				

* There was a shoulder-to-door contact during the roll. However, the contact was not considered as an impact with areas surrounding the window opening.

Appendix B
Unbelted Dummy with Selected Interior Impact Objects

		No. of Impacts by Dummy Body Part				
Test No.	Impact Object	Head	Shoulder	Chest	Back	No. Rolls
1336-C81	Window header					2
Table A-1	Upper door frame					
	Window Sill					
	A pillar				1	
	B-pillar				1	
	Roof					

		No. of Impacts by Dummy Body Part				
Test No.	Impact Object	Head	Shoulder	Chest	Back	No. Rolls
3541-12	Window header					1
Table A-5	Upper door frame					
	Window Sill					
	A pillar					
	B-pillar					
	Roof	2				

		No. of Impacts by Dummy Body Part				No. Rolls
Test No.	Impact Object	Head	Shoulder	Chest	Back	1.5
45-5	Window header					
Table A-7	Upper door frame					
	Window Sill					
	A pillar					
	B-pillar					
	Roof	1				

		No. of Impacts by Dummy Body Part				
Test No.	Impact Object	Head	Shoulder	Chest	Back	No. Rolls
1336-22C81	Window header					2
Table A-10	Upper door frame	1				
	Window Sill					
	A pillar					
	B-pillar					
	Roof					

Appendix C
201 Headform HIC Results

2003 Model	HIC			
	A-pillar	B-Pillar	Side Rail	Upper Roof
Dodge Durango	699	595	423	482
	387	613		826
	496	510		
Ford Ranger	636	467		
	432	563		
	594	433		
Honda Accord	676	719	260	718
			302	495
			371	590
				630
Honda Pilot	461	598	806	567
	694	563	726	
	630	598		
Hyundai Elantra	848	783	763	621
	753	741	925	835
	602		843	
Jeep Liberty	363	661	753	301
		604	414	952
		682		
Pontiac Vibe	612	623	469	491
	389	551	579	615
	468			
PT Cruiser	562	718	573	559
	679	637		
	458	885		
Saturn Ion	595	569	476	578
	980	607		
	909	802		
Subaru Forester	421	458	429	631
	668	614		522
	646	505		
Suzuki Grand Vitara	692	467	416	490
	744	423		621
	631			537
Toyota Corolla	674	611	552	736
	554	555	374	
		496		
Avg	611	605	550	609
Max	980	885	925	952
Min	363	423	260	301

Appendix D
Winnicki's Effectiveness Rates
Passenger Cars

Complete Ejections
Fatalities

Occupant	Relative Risk of Fatality	Fractional Reduction in Fatalities
Driver	3.25 (0.94)	69.19% (8.92%)
Passenger	3.06 (0.87)	67.29% (9.35%)

Partial Ejections
Fatalities

Occupant	Relative Risk of Fatality	Fractional Reduction in Fatalities
Driver	2.84 (0.68)	64.74% (8.44%)
Passenger	2.54 (0.61)	60.56% (9.44%)

All Ejections
Fatalities

Occupant	Relative Risk of Fatality	Fractional Reduction in Fatalities
Driver	2.94 (0.69)	66.06% (8.00%)
Passenger	2.66 (0.63)	62.46% (8.85%)

Complete Ejections
Incapacitating Injuries

Occupant	Relative Risk of Incapacitating Injuries	Fractional Reduction in Incapacitating Injuries
Driver	1.95 (0.52)	48.71% (13.62%)
Passenger	1.81 (0.48)	44.69% (14.68%)

Partial Ejections
Incapacitating Injuries

Occupant	Relative Risk of Incapacitating Injuries	Fractional Reduction in Incapacitating Injuries
Driver	2.85 (0.69)	64.97% (8.42%)
Passenger	2.54 (0.61)	60.70% (9.45%)

All Ejections
Incapacitating Injuries

Occupant	Relative Risk of Incapacitating Injuries	Fractional Reduction in Incapacitating Injuries
Driver	2.37 (0.55)	57.83% (9.70%)
Passenger	1.88 (0.43)	46.79% (12.26%)

Winnicki's Effectiveness Rates
Light Trucks
Complete Ejections
Fatalities

Occupant	Relative Risk of Fatality	Fractional Reduction in Fatalities
Driver	4.13 (1.48)	75.80% (8.65%)
Passenger	3.94 (1.46)	74.60% (9.42%)

Partial Ejections
Fatalities

Occupant	Relative Risk of Fatality	Fractional Reduction in Fatalities
Driver	6.42 (1.83)	84.43% (4.44%)
Passenger	5.36 (1.53)	81.35% (5.32%)

All Ejections
Fatalities

Occupant	Relative Risk of Fatality	Fractional Reduction in Fatalities
Driver	5.62 (1.49)	82.19% (4.73%)
Passenger	4.66 (1.24)	78.55% (5.70%)

Complete Ejections
Incapacitating Injuries

Occupant	Relative Risk of Incapacitating Injuries	Fractional Reduction in Incapacitating Injuries
Driver	3.14 (1.02)	68.17% (10.36%)
Passenger	1.89 (0.62)	47.04% (17.27%)

Partial Ejections
Incapacitating Injuries

Occupant	Relative Risk of Incapacitating Injuries	Fractional Reduction in Incapacitating Injuries
Driver	2.75 (0.66)	63.58% (8.82%)
Passenger	2.23 (0.54)	55.06% (10.95%)

All Ejections
Incapacitating Injuries

Occupant	Relative Risk of Incapacitating Injuries	Fractional Reduction in Incapacitating Injuries
Driver	2.76 (0.66)	63.76% (8.65%)
Passenger	2.22 (0.53)	54.87% (10.82%)

Appendix E
Estimated Benefits with Different Assumptions

90% sensor without glazing

Crashes		Sensor	Containment	Winnicki's	System	Fatalities	Lives saved	Incremental
rollover, no side impacts:								25.27%
Belted	Partial	90%	71%	88%	56%	112	63	47
Belted	Complete	90%	0%	88%	0%	12	0	0
Unbelted	Partial	90%	65%	88%	51%	107	55	41
Unbelted	Complete	90%	65%	88%	52%	519	268	201
side impacts followed by rollovers:								
Belted	Partial	90%	71%	49%	31%	0	0	0
Belted	Complete	90%	0%	41%	0%	0	0	0
Unbelted	Partial	90%	65%	49%	29%	137	39	29
Unbelted	Complete	90%	65%	41%	24%	114	27	20
side impacts, w/ subsequent rollovers, 12-25 mph:								
Belted	Partial	100%	71%	49%	35%	0	0	0
Belted	Complete	100%	0%	41%	0%	11	0	0
Unbelted	Partial	100%	65%	49%	32%	0	0	0
Unbelted	Complete	100%	65%	41%	27%	68	18	14
side impacts, no rollovers, 12-25 mph:								
Belted	Partial	100%	100%	49%	49%	0	0	0
Belted	Complete	100%	0%	41%	0%	0	0	0
Unbelted	Partial	100%	100%	49%	49%	0	0	0
Unbelted	Complete	100%	100%	41%	41%	259	106	80
side impact, no rollover, children (0-12 YO), include both partial and complete ejections, 12- 25 mph:								
Belted	Partial	100%	100%	49%	49%	29	14	11
Belted	Complete	100%	0%	41%	0%	0	0	0
Unbelted	Partial	100%	100%	49%	49%	0	0	0
Unbelted	Complete	100%	100%	41%	41%	25	10	8
								449

95% sensor without glazing

Crashes			Sensor	Containment	Winnicki's	System	Fatalities w/ ESC	Benefits	incremental Adj. Factor
rollover, no side impacts:								Lives	25.27%
	Belted	Partial	95%	71%	88%	59%	112	66	50
	Belted	Complete	95%	0%	88%	0%	12	0	0
	Unbelted	Partial	95%	65%	88%	54%	107	58	43
	Unbelted	Complete	95%	65%	88%	55%	519	283	212
side impacts followed by rollovers:									
	Belted	Partial	95%	71%	49%	33%	0	0	0
	Belted	Complete	95%	0%	41%	0%	0	0	0
	Unbelted	Partial	95%	65%	49%	30%	137	41	31
	Unbelted	Complete	95%	65%	41%	25%	114	29	22
side impacts, w/ subsequent rollovers, 12-25 mph:									
	Belted	Partial	100%	71%	49%	35%	0	0	0
	Belted	Complete	100%	0%	41%	0%	11	0	0
	Unbelted	Partial	100%	65%	49%	32%	0	0	0
	Unbelted	Complete	100%	65%	41%	27%	68	18	14
side impacts, no rollovers, 12-25 mph:									
	Belted	Partial	100%	100%	49%	49%	0	0	0
	Belted	Complete	100%	0%	41%	0%	0	0	0
	Unbelted	Partial	100%	100%	49%	49%	0	0	0
	Unbelted	Complete	100%	100%	41%	41%	259	106	80
side impacts, no rollovers, children, 12-25 mph:									
	Belted	Partial	100%	100%	49%	49%	29	14	11
	Belted	Complete	100%	0%	41%	0%	0	0	0
	Unbelted	Partial	100%	100%	49%	49%	0	0	0
	Unbelted	Complete	100%	100%	41%	41%	25	10	8
									468

77% sensor with glazing									incremental
Crashes			Sensor	Containment	Winnicki's	System	Fatalities w/ ESC	Benefits Lives	Adj. Factor
rollover, no side impacts:									25.27%
	Belted	Partial	77%	88%	88%	59%	112	66	49
	Belted	Complete	77%	0%	88%	0%	12	0	0
	Unbelted	Partial	77%	86%	88%	58%	107	62	46
	Unbelted	Complete	77%	86%	88%	58%	519	303	226
side impacts followed by rollovers:									
	Belted	Partial	77%	88%	49%	33%	0	0	0
	Belted	Complete	77%	0%	41%	0%	0	0	0
	Unbelted	Partial	77%	86%	49%	32%	137	44	33
	Unbelted	Complete	77%	86%	41%	27%	114	31	23
side impacts, w/ subsequent rollovers, 12-25 mph:									
	Belted	Partial	100%	88%	49%	43%	0	0	0
	Belted	Complete	100%	0%	41%	0%	11	0	0
	Unbelted	Partial	100%	86%	49%	42%	0	0	0
	Unbelted	Complete	100%	86%	41%	35%	68	24	18
side impacts, no rollovers, 12-25 mph:									
	Belted	Partial	100%	100%	49%	49%	0	0	0
	Belted	Complete	100%	0%	41%	0%	0	0	0
	Unbelted	Partial	100%	100%	49%	49%	0	0	0
	Unbelted	Complete	100%	100%	41%	41%	259	106	80
side impacts, no rollovers, children, 12-25 mph:									
	Belted	Partial	100%	100%	49%	49%	29	14	11
	Belted	Complete	100%	0%	41%	0%	0	0	0
	Unbelted	Partial	100%	100%	49%	49%	0	0	0
	Unbelted	Complete	100%	100%	41%	41%	25	10	8
									494

77% sensor uniform distribution without glazing

Crashes			Sensor	Containment	Winnicki's	System	Fatalities w/ ESC	Benefits Lives	incremental Adj. Factor
rollover, no side impacts:									25.27%
	Belted	Partial	77%	63%	88%	43%	112	48	36
	Belted	Complete	77%	0%	88%	0%	12	0	0
	Unbelted	Partial	77%	63%	88%	43%	107	46	34
	Unbelted	Complete	77%	63%	88%	43%	519	224	167
side impacts followed by rollovers:									
	Belted	Partial	77%	63%	49%	24%	0	0	0
	Belted	Complete	77%	0%	41%	0%	0	0	0
	Unbelted	Partial	77%	63%	49%	24%	137	33	24
	Unbelted	Complete	77%	63%	41%	20%	114	23	17
side impacts, w/ subsequent rollovers, 12-25 mph:									
	Belted	Partial	100%	63%	49%	31%	0	0	0
	Belted	Complete	100%	0%	41%	0%	11	0	0
	Unbelted	Partial	100%	63%	49%	31%	0	0	0
	Unbelted	Complete	100%	63%	41%	26%	68	18	13
side impacts, no rollovers, 12-25 mph:									
	Belted	Partial	100%	100%	49%	49%	0	0	0
	Belted	Complete	100%	0%	41%	0%	0	0	0
	Unbelted	Partial	100%	100%	49%	49%	0	0	0
	Unbelted	Complete	100%	100%	41%	41%	259	106	80
side impacts, no rollovers, children, 12-25 mph:									
	Belted	Partial	100%	100%	49%	49%	29	14	11
	Belted	Complete	100%	0%	41%	0%	0	0	0
	Unbelted	Partial	100%	100%	49%	49%	0	0	0
	Unbelted	Complete	100%	100%	41%	41%	25	10	8
									390

Fatal Benefits with Single Impact at Geometry Center of Window Opening

Crashes			Sensor	Containment	Winnicki's	System	Fatalities w/ ESC	Benefits	incremental Adj. Factor
rollover, no side impacts:								Lives	51.86%
	Belted	Partial	77%	60%	88%	41%	112	45	22
	Belted	Complete	77%	0%	88%	0%	12	0	0
	Unbelted	Partial	77%	54%	88%	36%	107	39	19
	Unbelted	Complete	77%	54%	88%	36%	519	188	91
side impacts followed by rollovers:									
	Belted	Partial	77%	60%	49%	23%	0	0	0
	Belted	Complete	77%	0%	41%	0%	0	0	0
	Unbelted	Partial	77%	54%	49%	20%	137	28	13
	Unbelted	Complete	77%	54%	41%	17%	114	19	9
side impacts, w/ subsequent rollovers, 12-25 mph:									
	Belted	Partial	100%	60%	49%	29%	0	0	0
	Belted	Complete	100%	0%	41%	0%	11	0	0
	Unbelted	Partial	100%	54%	49%	26%	0	0	0
	Unbelted	Complete	100%	54%	41%	22%	68	15	7
side impacts, no rollovers, 12-25 mph:									
	Belted	Partial	100%	100%	49%	49%	0	0	0
	Belted	Complete	100%	0%	41%	0%	0	0	0
	Unbelted	Partial	100%	100%	49%	49%	0	0	0
	Unbelted	Complete	100%	0%	41%	0%	259	0	0
Side impacts, no rollover, children 12-25 mph									
	Belted	Partial	100%	100%	49%	49%	29	14	7
	Belted	Complete	100%	0%	41%	0%	0	0	0
	Unbelted	Partial	100%	100%	49%	49%	0	0	0
	Unbelted	Complete	100%	0%	41%	0%	25	0	0
								349	168

77% sensor uniform distribution without glazing, 2nd & 3rd rows

Crashes			Sensor	Containment	Winnicki's	System	fatalities	Fatalities w/ ESC	Benefits Lives	incremental Adj. Factor
rollover, no side impacts:										25.27%
	Belted	Partial	77%	63%	88%	43%	12	2	1	1
	Belted	Complete	77%	0%	88%	0%	0	0	0	0
	Unbelted	Partial	77%	63%	88%	43%	53	11	5	4
	Unbelted	Complete	77%	63%	88%	43%	488	99	43	32
side impacts followed by rollovers:								0		
	Belted	Partial	77%	63%	49%	24%	0	0	0	0
	Belted	Complete	77%	0%	41%	0%	0	0	0	0
	Unbelted	Partial	77%	63%	49%	24%	0	0	0	0
	Unbelted	Complete	77%	63%	41%	20%	70	62	12	9
side impacts, w/ subsequent rollovers, 12-25 mph:								0		
	Belted	Partial	100%	63%	49%	31%	0	0	0	0
	Belted	Complete	100%	0%	41%	0%	0	0	0	0
	Unbelted	Partial	100%	63%	49%	31%	0	0	0	0
	Unbelted	Complete	100%	63%	41%	26%	35	31	8	6
						total	658	205	69	51

ROLLOVER by YEAR

Controlling for BODYTYPE=Passenger Car

ROLLOVER (ROLLOVER)	YEAR(YEAR OF ACCIDENT)									Total
	1,999	2,000	2,001	2,002	2,003	2,004	2,005	2,006	2,007	
NO ROLLOVER	2,819,325	2,614,799	2,787,485	2,508,277	2,648,029	2,355,331	2,465,672	2,369,218	2,411,629	22,980,000
1	27,379	23,292	10,029	5,429	4,553	7,526	7,509	10,795	29,126	125,636
2	54,481	71,290	49,472	28,207	57,599	63,637	23,547	35,555	35,530	419,318
3	2,623	3,423	3,353	4,618	2,712	12,912	15,615	5,341	1,778	52,375
4	15,408	17,715	38,192	13,313	23,055	18,043	22,019	19,925	50,010	217,681
5	283	684	885	1,124	16,613	4,165	943	1,258	767	26,723
6	7,542	3,599	27,644	7,568	4,650	11,955	4,492	5,166	8,136	80,754
7	0	54	344	81	301	40	342	556	386	2,105
8	709	18,311	555	1,221	1,160	1,614	1,340	12,711	2,431	40,052
9	0	0	35	591	0	297	274	162	0	1,359
10	861	35	311	593	783	89	188	468	285	3,612
11	464	0	0	0	42	0	260	0	0	765
12	340	409	70	65	164	579	47	204	45	1,926
13	0	0	0	0	0	0	0	0	369	369
14	139	113	255	0	0	0	0	0	0	508
15	0	0	0	0	0	15	0	0	0	15
16	0	0	0	74	0	90	0	0	0	164
>16	0	0	0	0	28	0	9	0	0	38
END-OVER-END	532	297	800	273	426	567	529	76	134	3,634
ROLL DETAILS UNK	9,240	12,252	8,694	10,160	8,178	6,788	2,609	8,818	10,201	76,940
Total	2,939,325	2,766,274	2,928,124	2,581,594	2,768,294	2,483,648	2,545,394	2,470,254	2,550,827	24,030,000

ROLLOVER by YEAR										
Controlling for BODYTYPE=SUV										
ROLLOVER(ROLLOVER)	YEAR(YEAR OF ACCIDENT)									Total
	1,999	2,000	2,001	2,002	2,003	2,004	2,005	2,006	2,007	
NO ROLLOVER	378,405	405,053	504,717	470,229	513,469	610,222	707,242	776,320	773,887	5,139,544
1	13,102	21,495	23,505	37,385	17,488	17,802	11,344	37,448	49,001	228,570
2	23,580	14,739	25,777	25,462	12,806	20,703	7,361	15,171	16,936	162,533
3	2,011	4,090	2,840	7,534	14,489	6,596	1,698	9,232	6,564	55,053
4	8,569	11,209	7,382	42,964	14,354	20,490	8,516	19,989	6,854	140,325
5	1,143	664	4,859	782	933	3,189	2,605	1,269	4,239	19,684
6	2,926	6,361	1,674	3,036	1,987	7,204	8,863	3,888	2,190	38,127
7	194	226	2,149	114	576	1,043	175	1,886	1,785	8,147
8	3,316	1,158	3,564	3,289	1,020	1,220	2,325	1,113	2,351	19,355
9	0	98	0	108	71	75	111	0	524	987
10	198	167	428	900	125	822	0	222	161	3,023
11	0	0	0	0	59	63	0	167	0	289
12	248	324	304	209	311	130	805	112	0	2,443
13	0	54	0	8	0	0	0	0	0	62
14	0	0	0	0	76	0	0	0	69	145
15	0	0	0	0	0	0	0	0	0	0
16	17	0	0	0	20	71	0	0	0	108
>16	0	375	0	0	0	0	0	0	0	375
END-OVER-END	204	20	0	42	573	42	1,371	125	0	2,377
ROLL DETAILS UNK	7,924	19,398	7,428	7,273	8,355	3,143	7,685	12,133	8,389	81,727
Total	441,837	485,430	584,627	599,332	586,711	692,814	760,099	879,072	872,951	5,902,873

ROLLOVER by YEAR

Controlling for BODYTYPE=Van

ROLLOVER(ROLLOVER)	YEAR(YEAR OF ACCIDENT)									Total
	1,999	2,000	2,001	2,002	2,003	2,004	2,005	2,006	2,007	
NO ROLLOVER	301,548	293,599	300,197	318,448	317,745	356,893	284,751	332,901	239,153	2,745,236
1	10,975	4,483	10,298	5,811	2,965	7,563	4,474	7,932	5,417	59,919
2	529	3,573	472	1,585	5,718	4,825	2,661	1,819	3,289	24,472
3	59	2,856	384	425	224	287	679	403	1,021	6,338
4	828	349	271	6,870	3,965	8,770	394	450	2,395	24,292
5	0	288	148	0	467	41	1,501	17	0	2,461
6	0	1,640	0	208	290	115	73	397	46	2,769
7	0	10	20	31	0	54	232	0	104	451
8	0	86	64	276	1,738	285	0	1,566	149	4,164
9	163	0	79	80	0	0	1,338	0	0	1,660
10	0	0	0	39	0	0	26	0	0	65
11	0	0	0	0	0	0	33	0	0	33
12	0	124	0	0	131	78	74	0	39	446
13	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0
15	0	19	0	0	0	0	0	0	0	19
16	0	0	27	0	0	0	0	0	0	27
>16	53	0	0	0	0	0	158	0	0	211
END-OVER-END	0	0	0	0	0	0	0	366	0	366
ROLL DETAILS UNK	272	5,694	960	973	383	269	3,677	39	836	13,103
Total	314,426	312,721	312,921	334,746	333,626	379,180	300,070	345,891	252,450	2,886,032

ROLLOVER by YEAR

Controlling for BODYTYPE=Light Truck

ROLLOVER(ROLLOVER)	YEAR(YEAR OF ACCIDENT)									Total
	1,999	2,000	2,001	2,002	2,003	2,004	2,005	2,006	2,007	
NO ROLLOVER	695,867	655,369	579,486	696,864	661,264	546,253	457,489	664,969	548,677	5,506,237
1	11,715	18,502	17,856	4,572	9,672	12,860	10,734	3,238	6,376	95,525
2	16,781	17,287	23,374	7,691	15,631	9,256	7,814	16,300	15,783	129,919
3	383	2,025	2,671	3,042	780	3,595	123	3,685	712	17,015
4	10,816	12,767	4,380	5,179	13,464	16,193	19,722	8,112	7,501	98,134
5	2,745	4,396	647	2,703	6,769	1,198	352	2,246	1,903	22,958
6	2,867	4,218	767	1,044	7,075	2,885	1,547	1,959	1,716	24,078
7	293	378	1,112	203	160	1,847	897	36	290	5,214
8	1,953	352	914	809	341	661	780	2,795	1,057	9,662
9	0	171	114	0	0	1,292	0	38	0	1,615
10	0	49	53	120	738	16	170	115	189	1,452
11	0	0	70	0	0	0	0	0	0	70
12	0	131	110	209	63	0	0	0	0	514
13	0	124	0	0	0	0	0	0	0	124
14	0	755	0	0	0	38	0	0	0	793
15	0	0	0	0	0	0	0	0	0	0
16	0	169	0	80	0	0	0	0	0	249
>16	0	166	0	0	0	0	0	0	0	166
END-OVER-END	0	68	21	336	67	21	0	121	39	673
ROLL DETAILS UNK	7,887	6,919	4,990	2,822	6,150	537	5,769	2,333	4,031	41,438
Total	751,308	723,848	636,564	725,671	722,175	596,652	505,397	705,949	588,272	5,955,835

Appendix F
Comprehensive Costs and Relative Value Factors

Comprehensive Costs and Relative Value Factors reflecting $5.8 million Value of a Statistical Life (VSL), in 2007 Economics

CPI	Factor	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatal
1.346066	Medical	$3,204	$21,032	$62,585	$176,747	$447,509	$29,741
1.204077	EMS	$117	$255	$443	$999	$1,026	$1,003
1.277512	Market Prod	$2,234	$31,960	$91,283	$135,977	$560,451	$760,577
1.277512	Household Produce	$731	$9,354	$26,924	$35,782	$190,743	$244,696
1.204077	Ins. Adm.	$892	$8,319	$22,749	$38,934	$82,114	$44,695
1.277512	Workplace	$322	$2,495	$5,450	$6,002	$10,464	$11,117
1.204077	Legal	$181	$5,998	$19,034	$40,559	$96,153	$122,982
1.277512	Travel Delay	$993	$1,081	$1,201	$1,276	$11,697	$11,687
1.204077	Property Damage	$4,628	$4,761	$8,187	$11,840	$11,374	$12,369
1.277512	QALYs	$9,118	$186,525	$262,189	$784,777	$2,674,628	$4,889,799
New Comprehensive Costs		$22,420	$271,780	$500,045	$1,232,893	$4,086,149	$6,128,666
Injury Subtotal		$16,799	$265,938	$490,657	$1,219,777	$4,063,088	$6,104,610
QALY Relatives		0.0019	0.0381	0.0536	0.1605	0.5470	1.0000
Comprehensive relatives (Crash Avoidance)		0.0037	0.0443	0.0816	0.2012	0.6667	1.0000
Comprehensive relatives (Crashworthiness)		0.0028	0.0436	0.0804	0.1998	0.6656	1.0000

QALYs: Quality-Adjusted Life-Years

Note that the $5.8 million value of a statistical life contains elements found in 3 of the factors in the above table (QALY's, household productivity, and the after-tax portion of market productivity). The value of statistical life is thus represented within these 3 factors and is not shown separately.

Appendix G.
Distribution of Target Population by Vehicle Type

	Vehicle	MAIS 1-2	MAIS 3-5	Fatal	MAIS 1-2	MAIS 3-5	Fatal
Complete Ejections	Car	1315	940	1206	10%	22%	27%
	PU	1197	864	822	9%	20%	19%
	SUV	2660	673	861	21%	16%	20%
	Van	390	179	268	3%	4%	6%
	Other	17	2	0	0%	0%	0%
	Subtotal	5579	2658	3157	44%	63%	72%
	Vehicle	MAIS 1-2	MAIS 3-5	Fatal	MAIS 1-2	MAIS 3-5	Fatal
Partial Ejections	Car	1520	889	611	12%	21%	14%
	PU	2986	245	170	23%	6%	4%
	SUV	1385	431	307	11%	10%	7%
	Van	1225	24	132	10%	1%	3%
	Other	18	0	22	0%	0%	1%
	Subtotal	7134	1589	1242	56%	37%	28%
	Vehicle	MAIS 1-2	MAIS 3-5	Fatal	MAIS 1-2	MAIS 3-5	Fatal
Total Ejections	Car	2835	1829	1817	22%	43%	41%
	PU	4183	1109	992	33%	26%	23%
	SUV	4045	1104	1168	32%	26%	27%
	Van	1615	203	400	13%	5%	9%
	Other	35	2	22	0%	0%	1%
	Total	12713	4247	4399	100%	100%	100%

	Cars	Light trucks	total
Fatalities	1,817	2,582	4,399
% of total	41%	59%	100%
	41%	59%	

Appendix H
Number of Lives Saved by Ejection Mitigation System with 100% Observed Safety Belt Use Rate

In order to determine the effect of the increase in belt use rate, first, we calculate the reduction in target population (i.e., the number of fatalities with 100% belt use rate). After adjusting for the potential benefits of ESC and the 214-side curtain system, there are 1,392 observed fatalities in the target population. According to the model developed by the agency, the use rate among potential fatal crashes (UPFC) would be 68% when the average observed usage rate is 82%, as shown below:[256]

Table H-1
Use rate among Potential Fatal Crashes (UPFC) with 82% observed usage rate

Average observed usage rate	82%
Use rate among Potential Fatal Crashes (UPFC)	68%
Safety belt effectiveness	78%
Potential fatality	2,927
Lives saved by belt	1,535

Table H-2
Use rate among Potential Fatal Crashes (UPFC) with 100% observed usage rate

Average observed usage rate	100%
Use rate among Potential Fatal Crashes (UPFC)	91%
Safety belt effectiveness	78%
Potential fatality	2,927
Lives saved by belt	2,065

Tables H-1 and H-2 show that additional 530 lives in the 1,392 observed fatal target population would be saved if the belt use rate increase by 18% from 82% to 100%.[257] When the 530 lives saved are subtracted from the 1,392 fatalities in the target population, it results in 862 fatalities. In the draft PRIA, we estimated that the ejection mitigation system would save 402 lives among 1,392 fatalities. It resulted in an overall effectiveness of 29% (402/1,392 = 29%). When the

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[256] The UPFC equation is from DOT HS 809 639, Table 10, Model 2

[257] 2,065 lives saved by 100% belt use – 1,535 lives saved by 82% belt use = 530 net lives saved.

29% overall effectiveness was applied to the 862 fatalities, it resulted in 249 lives saved, as shown below:

Table H-3
Additional Lives Saved by Increase in Belt Use Rate

Fatalities with 82% belt use rate	1,392
Estimated additional lives saved with 82% belt use rate	402
Overall ejection mitigation system effectiveness	29%
Estimated fatalities with 100% belt use rate	862
Estimated additional lives saved with 100% belt use rate	249

In summary, if the belt use rate increases to 100%, the increase in belt use and the hypothetical ejection mitigation would save 779 lives. Among the 779 lives saved, 530 would result from the increase in belt use rate and the remaining 249 would be from the ejection mitigation system, as shown in Table 6d.

Table 6d shows that the number of lives saved by the ejection mitigation system would decrease from 402 to 249 lives with a 100% belt use rate. In other words, an 18% increase in belt use rate would result in a 38% reduction in ejection mitigation fatal benefits. The percentages show that seat belts are more effective than the ejection mitigation system in rollovers.

Regarding belt use rate, we note that the reduction in fatal benefit was based on 100% observed belt use rate. According to an agency study, belt use rate in actual fatal crashes is lower than the observed belt use for all occupants, as shown in Figure 1.[258]

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[258] L. Blincoe and J. Wang, report DOT HS 809 639.

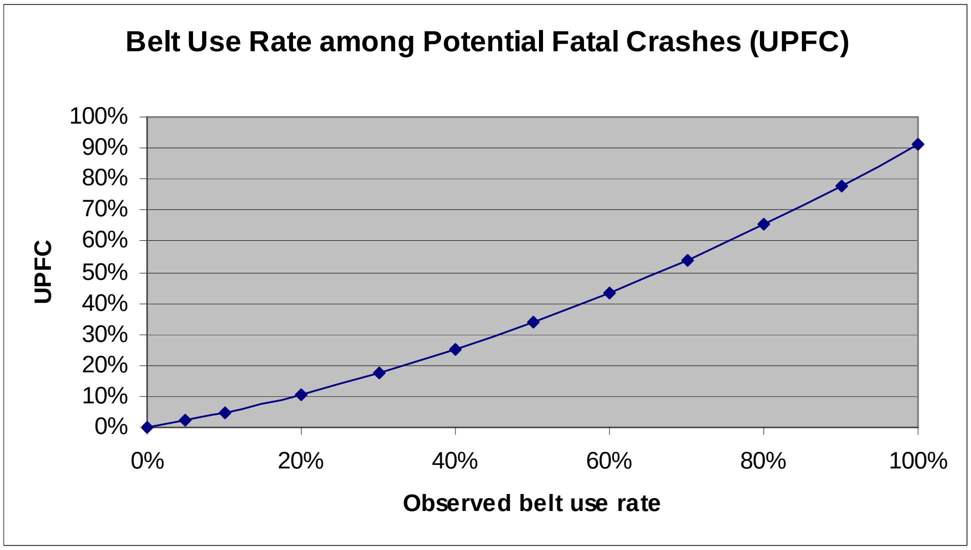

Figure H-1. Observed belt use rate vs. Belt use rate among potential fatal crashes

Figure H-1 shows that UPFC is not linear with respect to the observed belt use rate. As a result, the potential benefits (in terms of lives saved and injuries prevented) would not be linear with respect to the observed belt use rate. For example, Figure 1 shows that if the belt usage rate increases by 10% (from 0% to 10%), UPFC increases by 5% (from 0% to 5%). However, if the use rate increases by the same percentage but from 90% to 100%, UPFC increases by 13%. In other words, the last few percentage increases in seat belt use would be different from the first few percent increases.

There are two important factors related to UPFC. First, observed seat belt use is defined by our survey – which is during the daytime. Nighttime belt use is much lower (about 18% lower based on police reported belt use in fatal crashes) than daytime use. So, even though we say 100% observed seat belt use, it is only 91% in all fatal crashes (daytime and nighttime). Second, the last group of people to buckle up (getting the last 10 percent of people between 90% and 100% belt use) are believed to be the biggest risk takers and are believed to be involved in more fatal crashes than the previous 10 percent, etc. That is what we have found in analyzing crash data as seat belt use has improved. Those that were early adopters of seat belt use were good drivers that were involved in fatal crashes at a lower rate than average. So, you get more benefit from belt use per percentage point increase for the last group. NHTSA seeks comment on this curvelinear assumption, and whether the relationship is linear. NHTSA also seeks comment on the calculation of lives saved from 100% seat belt use.

In addition to the reduction in fatal benefits, the number of injuries prevented would also decrease from 310 to 192 (AIS 3-5) injuries. When the 249 lives saved and 192 serious injuries prevented are converted into Equivalent Life Saved (ELS), it results in 230 and 183 ELS discounted at 3% and 7%, respectively, as shown below.

Table H-4 - Additional Lives Saved by 100% Belt Use Rate with Ejection Mitigation System

Belt use rate	Incremental lives saved by belt	Lives saved by ejection mitigation system	Total lives saved
82% used in PRIA	N/A	402	402
100%	530	249	779

Table H-4 shows that the number of lives saved by the ejection mitigation system is relatively high even with 100% belt use. There are a couple of reasons for the high number of lives saved. First, you still have 9% of unbelted fatalities occurring even with 100% daytime belt use. The ejection mitigation system would prevent some of these fatalities. Second, belt use doesn’t necessarily stop partial ejections. The ejection mitigation system would prevent partial ejections in certain rollovers.

Table H-5 shows that the net benefits would decrease from $1,217M with 82% belt use rate to $532M with 100% belt use rate, when all light vehicles are equipped with the proposed ejection mitigation system.

Table H-5 - Equivalent Life Saved with 100% Belt Use Rate and Full Curtain Ejection Mitigation System

Belt use rate	Lives saved	Equivalent Lives Saved			$ per life (in $M)	Benefits (in $M)		Cost (in $M, 2007$)	Net Benefits ($M)	
		no discount	at 3%	at 7%		at 3%	at 7%		at 3%	at 7%
82%	402	455	371	295	6.1	$2,263	$1,801	$583	$1,680	$1,217
100%	249	282	230	183	6.1	$1,402	$1,115	$583	$818	$532

If all occupants in crashes used safety belts:

Current fatalities: 1,392

UPFC corresponding the average usage rate of 82%

Use rate among Potential Fatal Crashes (UPFC): 68%
Safety Belt Effectiveness: 78%
Potential Fatality: 2,927
Current Saved by Belt: 1,535

Use rate among Potential Fatal Crashes (UPFC): **100%**
Safety Belt Effectiveness: 78%
Potential Fatality: 2,927
Saved by Higher Use Rate: 2,269

Net Fatalities Prevented at Higher Belt Use Rate: 734

Target population, fatal 1,392
Lives saved by the higher belts use rate: 734
Target (fatal) adjusted with the higher belt use rate: 658

Target (fatal) adjusted with the higher belt use rate: 658
Additional fatalities saved with higher belt use rate: 206

Table H-6 - Equivalent Life Saved with 100% Belt Use in All Fatal Crashes

All belt use rate	Lives saved	Equ. Lives Saved			$ per life (in $M)	Benefits (in $M)		Cost (in $M, 2007$)	Net Benefits ($M)	
		no discount	at 3%	at 7%		at 3%	at 7%		at 3%	at 7%
100%	206	233	190	151	6.1	$1,157	$921	$583	$573	$337

Appendix I

Table I -1 Estimated Number of Lives Saved Excluding Alcohol Related Fatalities

Crashes	With ESC & with drunk drivers	No. of Unbelted	% of Unbelted	Re-distributed alcohol, unbelted	No. of Belted	% of Belted	Re-distributed alcohol, belted	With ESC & without alcohol related	Effective.	Lives saved, w/o drunk drivers
rollover, no side impacts:										
Belted Partial	112	0	0%	0	112	22%	41	71	0%	0
Belted Complete	12	0	0%	0	12	2%	4	7	0%	0
Unbelted Partial	107	107	9%	53	0	0%	0	54	33%	18
Unbelted Complete	519	519	42%	257	0	0%	0	262	33%	87
side impacts followed by rollovers:										
Belted Partial	0	0	0%	0	0	0%	0	0	0%	0
Belted Complete	0	0	0%	0	0	0%	0	0	0%	0
Unbelted Partial	137	137	11%	68	0	0%	0	69	18%	13
Unbelted Complete	114	114	9%	56	0	0%	0	58	15%	9
side impacts, w/ subsequent rollovers, 12-25 mph:										
Belted Partial	0	0	0%	0	0	0%	0	0	0%	0
Belted Complete	11	0	0%	0	11	2%	4	7	0%	0
Unbelted Partial	0	0	0%	0	0	0%	0	0	0%	0
Unbelted Complete	68	68	6%	34	68	13%	25	9	20%	2
side impacts, no rollovers, 12-25 mph:										
Belted Partial	0	0	0%	0	0	0%	0	0	0%	0
Belted Complete	0	0	0%	0	0	0%	0	0	0%	0
Unbelted Partial	0	0	0%	0	0	0%	0	0	0%	0
Unbelted Complete	259	259	21%	128	259	50%	95	36	31%	11
side impact, no rollover, children (0-12 YO), include both partial and complete ejections, 12- 25 mph:										
Belted Partial	29	0	0%	0	29	6%	11	18	36%	7
Belted Complete	0	0	0%	0	0	0%	0	0	0%	0
Unbelted Partial	0	0	0%	0	0	0%	0	0	0%	0
Unbelted Complete	25	25	2%	12	25	5%	9	3	31%	1
total	1,392	1,229	100%	609	515	100%	189	595		147

Table I-2 ELS discounted by 3% and 7% for Excluding Alcohol Related Fatalities

Crashes	no discount	at 3%	at 7%
rollover, no side impacts:			
Belted Partial	8	6	5
Belted Complete	0	0	0
Unbelted Partial	19	16	13
Unbelted Complete	98	80	63
side impacts followed by rollovers:			
Belted Partial	1	1	1
Belted Complete	0	0	0
Unbelted Partial	13	10	8
Unbelted Complete	11	9	7
side impacts, w/ subsequent rollovers, 12-25 mph:			
Belted Partial	0	0	0
Belted Complete	0	0	0
Unbelted Partial	2	1	1
Unbelted Complete	6	5	4
side impacts, no rollovers, 12-25 mph:			
Belted Partial	0	0	0
Belted Complete	0	0	0
Unbelted Partial	0	0	0
Unbelted Complete	13	11	9
side impact, no rollover, children (0-12 YO), include both partial and complete ejections, 12- 25 mph:			
Belted Partial	7	5	4
Belted Complete	0	0	0
Unbelted Partial	0	0	0
Unbelted Complete	2	2	1
total	180	147	117

Table I-3 ELS and Net Benefits for Excluding Alcohol Related Fatalities

	Equ. Lives Saved			$ per life (in $M)	Benefits (in $M)		Cost (in $M, 2007$)	Net Benefits ($M)	
Alcohol	no discount	at 3%	at 7%		at 3%	at 7%		at 3%	at 7%
included	455	371	295	6.1	$2,263	$1,801	$583	$1,680	$1,217
excluded	180	147	117	6.1	$896	$713	$583	$312	$129

Appendix J
ELS Broken-Out by Belt Use and Level of Ejection

The proposed ejection mitigation standard would save 402 lives and prevent 310 serious injuries annually. When the lives saved and injuries prevented are converted into ELS and categorized by the level of ejection and belts use, it shows a total of 455, 371 and 295 ELS at no discount, 3% discount and 7% discount, respectively. Among the 455 ELS at no discount, 62 are from partially ejected belted occupants, 67 are from partially ejected unbelted occupants and the remaining 327 are from completely ejected unbelted occupants, as shown below in Table 8a. The net benefits at the various discount levels are given in Tables below.

Table J-1 - ELS by Level of Ejection and Belt Use

Belt use / Level of ejection	Fatal Target Population	Total Effect. - Fatal	Lives Saved	Serious Injury Target Population	Total Effect. AIS 3-5 Serious Injuries	Total Serious Injuries Saved	Total ELS	ELS discounted	
								at 3%	at 7%
Belted partial	141	36.2%	51	290	28.3%	82	61	50	40
Belted complete	22	0.0%	0	40	0.0%	0	0	0	0
Unbelted partial	244	24.8%	60	184	25.5%	47	67	54	43
Unbelted complete	985	29.5%	291	881	20.5%	181	327	267	212
Total	1,392		402	1,396		310	455	371	295

Table J-2 – ELS and Net Benefits by Level of Ejection and Belt Use

Belt use / Level of ejection	Equ. Lives Saved			$ per life (in $M)	Benefits (in $M)		Cost (in $M, 2007$)	Net Benefits ($M)	
	no discount	at 3%	at 7%		at 3%	at 7%		at 3%	at 7%
Belted partial	61	50	40	6.1	$306	$244	$583	$160	$98
Belted complete	0	0	0	6.1	$0	$0		-$146	-$146
Unbelted partial	67	54	43	6.1	$331	$263		$185	$117
Unbelted complete	327	267	212	6.1	$1,626	$1,294		$1,480	$1,148

Note: For the net benefits, the cost ($583M) were evenly divided into the four groups (by belt use & level of ejection)

Appendix K
Excluding A1 from Meeting Head Form Requirements

Injury benefits without A1 in the window opening

Crashes			Sensor	Containment	Winnicki's	System
rollover, no side impacts:						
	Belted	Partial	84%	58%	67%	32%
	Belted	Complete	84%	0%	52%	0%
	Unbelted	Partial	84%	48%	67%	26%
	Unbelted	Complete	84%	48%	52%	21%
side impacts followed by rollovers:				0%		
	Belted	Partial	84%	58%	49%	24%
	Belted	Complete	84%	0%	38%	0%
	Unbelted	Partial	84%	48%	49%	19%
	Unbelted	Complete	84%	48%	38%	15%
side impacts, w/ subsequent rollovers, 12-25 mph:				0%		
	Belted	Partial	100%	58%	49%	28%
	Belted	Complete	100%	0%	38%	0%
	Unbelted	Partial	100%	48%	49%	23%
	Unbelted	Complete	100%	48%	38%	18%
side impacts, no rollovers, 12-25 mph:				0%		
	Belted	Partial	100%	100%	49%	49%
	Belted	Complete	100%	0%	38%	0%
	Unbelted	Partial	100%	100%	49%	49%
	Unbelted	Complete	100%	100%	38%	38%
side impact, no rollover, children (0-12 YO), include both partial and complete ejections, 12- 25 mph:				0%		
	Belted	Partial	100%	100%	49%	49%
	Belted	Complete	100%	0%	38%	0%
	Unbelted	Partial	100%	100%	49%	49%
	Unbelted	Complete	100%	100%	38%	38%

Cost:

Camry window opening:	6,619 cm2
Camry, area covered by bag	5,161 cm2
coverage need:	1,458 cm2
area for the front corner (50% of 1,458 cm^2)	729 cm2
unit cost, cloth	$0.00327
reduction in cost for cloth per window	$2.38
reduction in cost for cloth per vehicle	$4.77
unit cost, inflator per vehicle	$2.36
reduction in cost for inflator	$1.18
total reduction per vehicle	$5.94
number of vehicles	17 million
covering the A1 quadrant, total cost	$101.03 million
Total full curtain estimated incremental cost	$583.46 million
total, excluding A1 incremental costs	$482 million

A1 excluding – upper estimate

	AIS 3	AIS 4	AIS 5	Fatal	total	discounted equ, fatal		cost ($M)	cost per equ. Life saved		stat. Value	Net Saving	
Additional benefits	154	64	24	322		3%	7%		3%	7%	$6.10 in $M	3%	7%
conversion factor	0.0804	0.1998	0.6656	1		0.8155	0.6489						
equivalent fatal	12	13	16	322	363	296	236	$482	1.63	2.05		$1,324	$955

A1 excluding – lower estimate

	AIS 3	AIS 4	AIS 5	Fatal	total	discounted equ, fatal		cost ($M)	cost per equ. Life saved		stat. Value	Net Saving	
Additional benefits	128	53	20	267		3%	7%		3%	7%	$6.10 in $M	3%	7%
conversion factor	0.0804	0.1998	0.6656	1		0.8155	0.6489						
equivalent fatal	10	11	13	267	301	246	195	$482	1.96	2.47		$1,016	$710

Full curtain – benefits estimated in the benefits chapter

	AIS 3	AIS 4	AIS 5	Fatal	total	discounted equ, fatal		cost ($M)	cost per equ. Life saved		stat. Value	Net Saving	
Additional benefits	197	82	31	402		3%	7%		3%	7%	$6.10 in $M	3%	7%
conversion factor	0.0804	0.1998	0.6656	1.0000		0.8155	0.6489						
equivalent fatal	16	16	21	402	455	371	295	$583	1.57	1.98		$1,680	$1,217

Full curtain – if we use the “impact curtain twice” method to the full curtain – lower end range

	AIS 3	AIS 4	AIS 5	Fatal	total	discounted equ, fatal		cost ($M)	cost per equ. Life saved		stat. Value	Net Saving	
Additional benefits	163	68	26	333		3%	7%		3%	7%	$6.10 in $M	3%	7%
conversion factor	0.0804	0.1998	0.6656	1.0000		0.8155	0.6489						
equivalent fatal	13	14	17	333	377	307	245	$583	1.90	2.39		$1,292	$909