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FINAL REGULATORY IMPACT ANALYSIS

FMVSS No. 226
Ejection Mitigation

Office of Regulatory Analysis and Evaluation
National Center for Statistics and Analysis
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Contents

EXECUTIVE SUMMARY i
I. INTRODUCTION 1
II. BACKGROUND 11
III. TEST DATA AND ANALYSIS 17
A. Impactor 17
B. Number and Locations of Impactor Test Targets 22
C. Window Position and Condition 29
D. Vehicle Testing 30
IV. BENEFITS 57
V. TECHNICAL COSTS AND LEADTIME 191
VI. COST-EFFECTIVENESS AND BENEFIT-COST ANALYSES 229
A. Cost –Effectiveness Analysis 229
B. Benefit-Cost Analysis 231
VII. SENSITIVITY ANALYSES 234
A. Introduction 234
B. Sensitivity Factors 234
VIII. ALTERNATIVES 268
IX. REGULATORY FLEXIBILITY ACT 303
X. UNFUNDED MANDATES REFORM ACT 314

Appendix

A. Belted Dummy with Selected Interior Impact Objects A-1
B. Unbelted Dummy with Selected Interior Impact Objects B-1
C. 201 Headform HIC Results C-1
D. Incremental Risk of Injury and Fatality D-1
E. Estimated Benefits with Different Assumptions E-1
F. Comprehensive Costs and Relative Value Factors F-1
G. Distribution of Target Population by Vehicle Type G-1
H. Lives Saved with 100% Observed Safety Belt Use Rate H-1
I. Estimated Number of Lives Saved Excluding Alcohol Related Fatalities I-1
J. ELS Broken-Out by Belt Use and Level of Ejection J-1
K. Excluding A1 from Meeting Headform Requirements K-1

EXECUTIVE SUMMARY

This Final Regulatory Impact Analysis (FRIA) 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 final rule requires that the occupant containment countermeasure be tested by impact from a guided 18 kg featureless headform traveling laterally and horizontally. The performance criterion is a displacement limit for impactor travel 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 20 km/h).[1] The 16 km/h impact will occur 6 seconds after countermeasure deployment and the 20 km/h impact will occur 1.5 seconds after countermeasure 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, "Side impact protection."[2] Side curtain air bags will be made wider or combination (combo) air bags will be replaced with curtain air bags to pass the impactor test. Vehicle manufacturers would install a

[1] In addition, the window opening for cargo areas behind any first and second row vehicle will be impacted.
[2] 72 FR 51908

single-window curtain for each side and these window curtains are assumed to provide protection for both front and rear seat occupants.

The final rule will extend coverage to cargo areas behind the 1st and 2nd rows of vehicles, i.e., 1,400 mm behind the sating reference point (SgRP) for forward facing seats. Field data found that cargo area ejections behind a 2nd row were similar in frequency to 3rd row ejections. The final rule will exempt convertibles. We found compelling the practicability concerns raised by the industry related to the near term technical challenges. We also believe that the final rule change in the 16 km/h-6 second test, to not allow the use of movable advanced glazing, will increase the level of difficulty in devising a compliant countermeasure for convertibles.

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) tested at 20 km/h. For the 20 km/h high impact speed test, manufacturers may install laminated glazing in the window opening (called "curtain plus laminated glazing") to meet the displacement requirement at A1. However, since the final rule requires removal of any glazing in the window opening for the 16 km/h, we expect that the window opening will be completely covered with a curtain air bag whether advanced glazing is used or not.

Benefits

The agency estimated benefits for both partially and completely ejected occupants in rollovers and certain side crashes. The target population estimate for the Final Regulatory Impact Analysis uses annualized injury data from 1997 to 2008 National Automotive Sampling System

(NASS) Crashworthiness Data System (CDS) and fatality counts adjusted to the annual average from Fatal Analysis Reporting System (FARS) for these same years. The crash data show that there are 4,447 fatalities, 4,540 Maximum Abbreviated Injury Scale (MAIS) 3+ non-fatal injuries and 11,292 MAIS 1-2 injuries for occupants ejected through side windows. This target population constitutes 69% of all killed, 80% of MAIS 3-5 injured and 69% of MAIS 1-2 injured side window (rows 1 – 3) ejected occupants in all crashes. The greater number of fatally ejected occupants (3,837) went through the first row window. Similarly, 3,979 MAIS 3-5 and 10,017 MAIS 1-2 injured occupants went through the first row window. The potential benefits estimated in the 214-FRIA for the upgrade to FMVSS No. 214 were excluded from the ejection mitigation benefits. In addition, the benefits resulting from the increase in safety belt use rate 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 final rule, we estimate that the incremental benefits of the final rule being met by the full curtain would save 373 lives and prevent 476 serious injuries, annually.[3] For the estimated benefits, we assumed that the belt use rate observed in 2009 remains unchanged. The majority of the benefits are for unbelted occupants but the analysis shows that 12 percent of the benefits would be from belted occupants: 10 percent from rollovers and about 2 percent from side crashes considered.

Costs

[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 FRIA 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.

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 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 $348.82 in 2009 economics, when compared to a vehicle with no side air bags. This is $49.18 more than a vehicle with two rows of seats with a side air bag system designed to meet the FMVSS No. 214 pole and MDB tests. The estimated MY 2011 sales show that 22% of light vehicles will have a cargo area behind the second row and 14% will have third row seat. When the first through 3rd row and the cargo area behind the second row are covered with a curtain air bag, we estimated the cost per vehicle will increase by $52.31, 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 $39.32 in 2009 economics. Our analysis shows that most vehicles that are equipped with combination air bags would be convertibles (about 1%). Convertibles are excluded from meeting the headform test requirement. Given that 36% of light vehicles have either 3 rows of seats or a cargo area behind the second row, we estimate the average cost per vehicle would increase by $53 if there were no voluntary compliance by

manufacturers for MY 2011.[4] Manufacturers' plans for MY 2011 indicate at least $22 per vehicle of costs toward this proposal. Thus, compared to the manufacturers' plans the final rule will add about $31 per light vehicle at a total cost of $507 million for the full curtain countermeasure.

Total and Average Vehicle Costs
($2009)

Costs	Ejection Mitigation System	Weighted MY 2011 Manufacturers' Plans	Incremental Costs
Per Vehicle Costs	$53	$22	$31
Total Costs	$880 million	$373 million	$507 million

Cost per Equivalent Life Saved and Net Benefits

Estimates were made of the net costs per equivalent life saved. For the full curtain countermeasure, the low end of the range is $1.4 million per equivalent life saved, using a 3 percent discount rate. The high end of the range is $1.7 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

[4] We estimated that a total cost of $880M when all light vehicles are equipped with rollover ejection curtains. The $507M would be a result of the final rule and the remaining $373M would be resulting from voluntarily installed rollover curtain bags.

$1,773 million net benefits using a 3 percent discount rate and $1,307 a 7 percent discount rate. Both of these are based on a $6.1 million cost per life.[5]

Summary Table of Benefits and Costs
(Millions 2009$)*

Benefits	Primary Estimate	High Estimate	Discount Rate
Lifetime Monetized	$1,814	$2,286	7%
Lifetime Monetized	$2,279	$2,872	3%
Costs			
Lifetime Monetized	$507	$1,660	7%
Lifetime Monetized	$507	$1,660	3%
Net Benefits			
Lifetime Monetized	$1,307	$626	7%
Lifetime Monetized	$1,773	$1,213	3%

*The numbers were rounded to the nearest integer

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. In addition to the full curtain with and without advanced glazing, two different occupant ejection risk methods were used for the benefit estimate.

Incremental Benefits

Countermeasure	Weighted risk of ejection method		Uniform risk of ejection method	
	Fatalities	Serious Injuries	Fatalities	Serious Injuries
Full Curtain	373	476	364	461
Curtain with Advanced Glazing	469	604	464	597

[5] 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.

Incremental Costs (in 2009 economics)

Countermeasure	Per Average Vehicle	Total (in millions)
Full Curtain	$31	$507
Curtain with Advanced Glazing	$102	$1,660

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

Countermeasure	Total Cost	with Weighted Distribution (in $M)				with Uniform Distribution (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	$507	$1.36	$1.70	$1,773	$1,307	$1.39	$1.75	$1,717	$1,262
Curtain with Advanced Glazing	$1,660	$3.52	$4.43	$1,213	$626	$3.60	$4.52	$1,155	$580

I. INTRODUCTION

General:

As a crash type, rollovers are second only to frontal crashes in the annual number of fatalities in light vehicles. On December 2, 2009, NHTSA published a notice of proposed rulemaking (NPRM) for an occupant containment performance standard (FMVSS No. 226; "Ejection mitigation") [74 FR 63180]. Our goal was an objective requirement that correlates with real-world field performance. To that end, we proposed that the occupant containment countermeasure be tested by impact from a guided 18 kg featureless headform traveling from inside the vehicle towards the outside, horizontally and in the traverse vertical plane. We proposed 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. We proposed two impact velocities (16 and 24 km/h). The 16 km/h impact would occur 6 seconds after countermeasure deployment and the 24 km/h impact would occur 1.5 seconds after countermeasure deployment.

The proposal stated that every target location must be exposed to the 16 km/h velocity-6 second delay impact. However, the agency made no determination on whether all target locations should be exposed to the 24 km/h-1.5 second delay impact or just the target location that exhibited the greatest displacement in the 16 km/h-6 second impact.

For the FRIA, we update the ejection route vs. annualized injury by adding three years of data. We now use 1997 to 2008 NASS CDS (National Automotive Sampling System Crash Data System, which is a statistical sample of light vehicles in towaway crashes.) and fatality counts adjusted to the annual average from FARS for these same years to analyze ejection routes. All

unknowns have been distributed. All crash types are included. However, the counts are restricted to ejection occupants that were injured or killed.

The analysis of the data set for the final rule (1997 – 2008 NASS CDS) differs somewhat from what was done with the NPRM data set (1997 – 2005 NASS CDS). In NASS CDS, the ejection route for side windows is only explicitly coded for the front (Row 1 Window) and rear rows. In our data analysis for the NPRM we made the assumption that an ejection route coding "rear" meant a second row window and that third and higher row side window ejections were coded as "other" glazing. This assumption was consistent with the coding of seat position in NASS. In the NPRM analysis we attempted, through a hard copy review, to assign an ejection route to the "other" glazing ejected occupants.

Since this previous analysis we have determined that an occupant coded as ejected through a rear window did not necessarily go through the second row window. Similarly, the coding of "other" glazing was determined to not necessarily mean third and higher row. Thus, for the final rule analysis of ejection route, we used the following approach to address those who were coded as ejected through rear or "other" glazing.

Occupants seated in the first 2 rows of a vehicle or if the vehicle was a convertible, two-door sedan, or four-door sedan (that is, without a third row or cargo area) and were coded as ejected through a rear window, were assumed to have gone through a second row window. If an occupant was coded as being seated in other than the first or second rows and was coded as ejected through a rear window, the NASS Case Query System was used to perform a hard copy review to determine the ejection route. We reviewed a total of 41 occupants, for which the ejection route was clear for each of them, and we categorized them accordingly.

Similarly, a hard copy review was performed for any case coded with an ejection through "other" glazing. There were 17 occupants who were reported to have been ejected through "other" glazing. A hard copy review of these cases determined the ejection route (based on comment fields and annotations on the photographs) for each of them.

Finally, there were some cases where the occupant was coded as having been ejected through a window opening that was also coded as being closed or fixed prior to the crash and for whom the window glazing appeared to have been intact (either totally or partially) after the crash. Some of these apparent inconsistencies may reflect ambiguity in identifying the ejection route from the data available in the NASS electronic file, and others may reflect coding errors. A hard copy review was performed on the 31 identified cases. In five cases, the glazing was reported as cracked but still in place, so the glazing may have been partially displaced. In ten cases, the investigator explicitly stated (either in a comment field or by annotating the photographs) that the glazing was disintegrated. There was no explicit explanation in the other 16 cases, and we treated the post-glazing status as "unknown" to avoid over-interpreting the information. However, none of these 16 cases appeared to involve ejection through a closed or fixed window that remained intact after the crash.

This target population estimate for the final rule uses annualized injury data from 1997 to 2008 NASS CDS and fatality counts adjusted to the annual average from FARS for these same years. The estimate adjusts the data for missing side impact ΔV, unknown belt use and unknown ejection route. It adds three years of data to the estimate used in the FRIA.

At its most basic level, the target population is derived from any crash involving a rollover or a side planar crash. However, as explained in the FRIA, it is necessary to make adjustments to this population to account for benefits already attributed to the FMVSS No. 214 upgrade. We will not describe these adjustments here in any great detail. The population is restricted to occupants ejected through rows 1 – 3 of the side windows. However, in this section we sometimes simply refer to these occupants as "side window ejected," rather than specifying the row limitation.

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. Data provided by the Alliance of Automobile Manufacturers (Alliance) indicated that for the 2007 model year, rollover sensors were available on approximately 95 models, with 75 of these models being sport utility vehicles. The systems were standard equipment on 62 vehicles (65%) and optional on 33 vehicles (35%) of these model year (MY) 2007 vehicles.

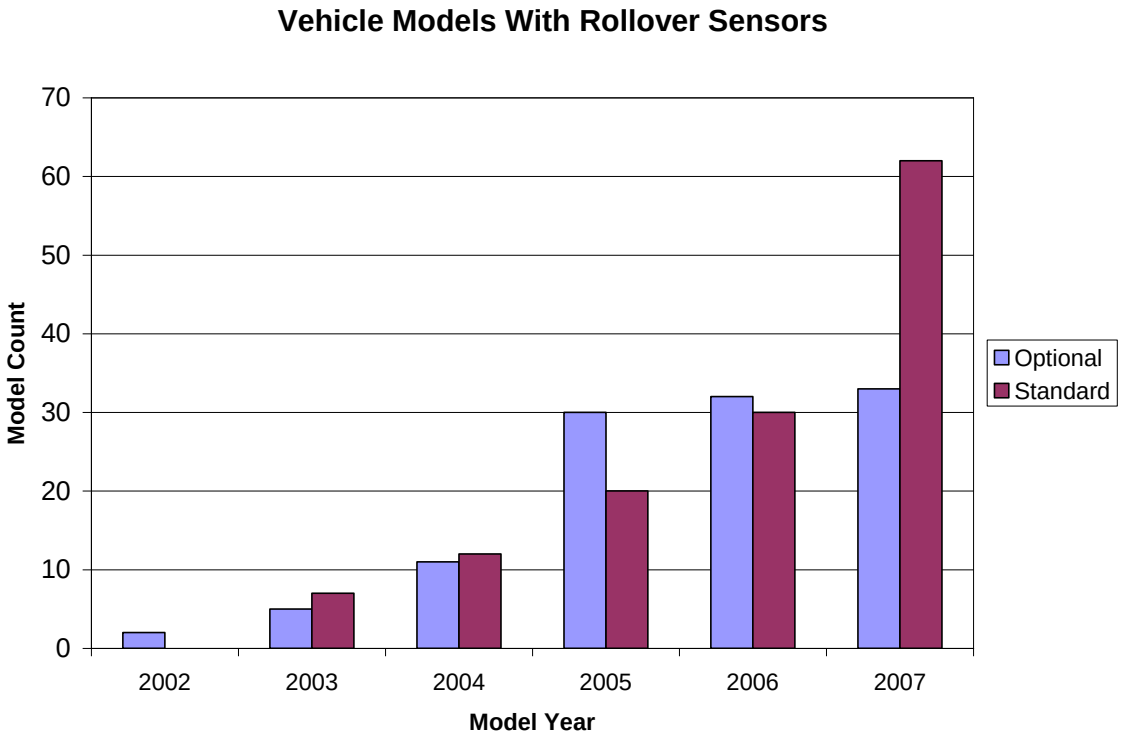

Figure I-1 Vehicles with Rollover Sensors

Annually, NHTSA's New Car Assessment Program (NCAP) office sends a questionnaire to manufacturers requesting information about the availability of certain safety systems on their vehicles. The responses are voluntary.[6] Since 2008, NHTSA has asked manufacturers if their available side impact curtains will deploy in a rollover crash. Figure I-2 shows the percentage of make models for which there was an affirmative response to this question, as a function of the number of make models for which there was any response at all. It seems that the rate of introduction of rollover curtains has slowed since MY2007 given the small change in the NCAP responses for MY2008 – MY2010 (36% to 41%).

[6] The total number of make/models represented in the survey is about 500. The make/model designations in the survey responses are more finely parsed than one might expect in that slight model variations are represented as different models and corporate twins are not combined.

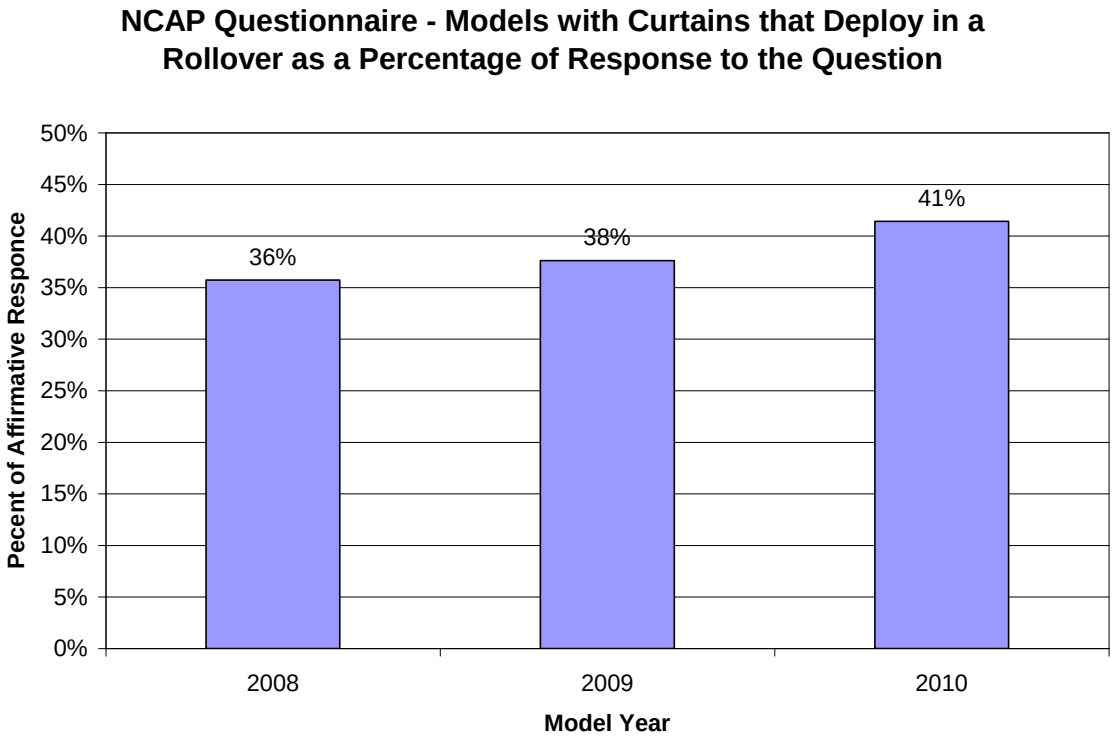

Figure I-2 Percentage of Models with Rollover Curtains in NCAP Questionnaire.

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. 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. 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 claimed 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-3 1999 Volvo S80

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 claimed 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 to the lower part of the air bag to vehicles' A- and C-pillars.

Figure I-4 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, 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-4 2006 Ford Expedition/Navigator

Figure I-5 2007 Ford Expedition/Navigator

Figure I-6 2007 Chevrolet Tahoe

In the minivan vehicle category, the Honda Odyssey has been offering standard rollover protection with full three rows of coverage since the 2005 model year (MY). Figure I-7 shows the second and third occupant seating rows. Note that the lower edge of the curtain extends beyond the sill.

Figure I-7 2005 Honda Odyssey

II. BACKGROUND

Previous Agency Efforts on Rollover Mitigation:

NHTSA has been active in rollover[7] 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;

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

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

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

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

NHTSA followed this with another report in August 1999 titled "Ejection Mitigation Using Advanced Glazings: Status Report II."[9] 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."[10]

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

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

[10] 4 "Ejection Mitigation Using Advanced Glazings: Final Report," August 2001, Docket No. NHTSA-1996-1782-22.

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[11] 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 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 were to have been installed on widespread basis (at least 50%) by 2007 with full implementation by 2009.

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

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

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

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

The agency is requiring that the occupant containment countermeasure be tested by impact from a guided 18 kg featureless headform traveling from inside the vehicle towards the outside, laterally and horizontally. The final test requires that each side window, for up to three vehicle rows and the cargo area behind the second row, be impacted at any of four locations referenced to the edges of the window opening. Two impact velocities (16 and 20 km/h) are used in the test: the 16 km/h impact will occur 6 seconds after air bag deployment and the 20 km/h impact will occur 1.5 seconds after air bag deployment.

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

A. Impactor

Dimensional Characteristics:

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

The headform 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]

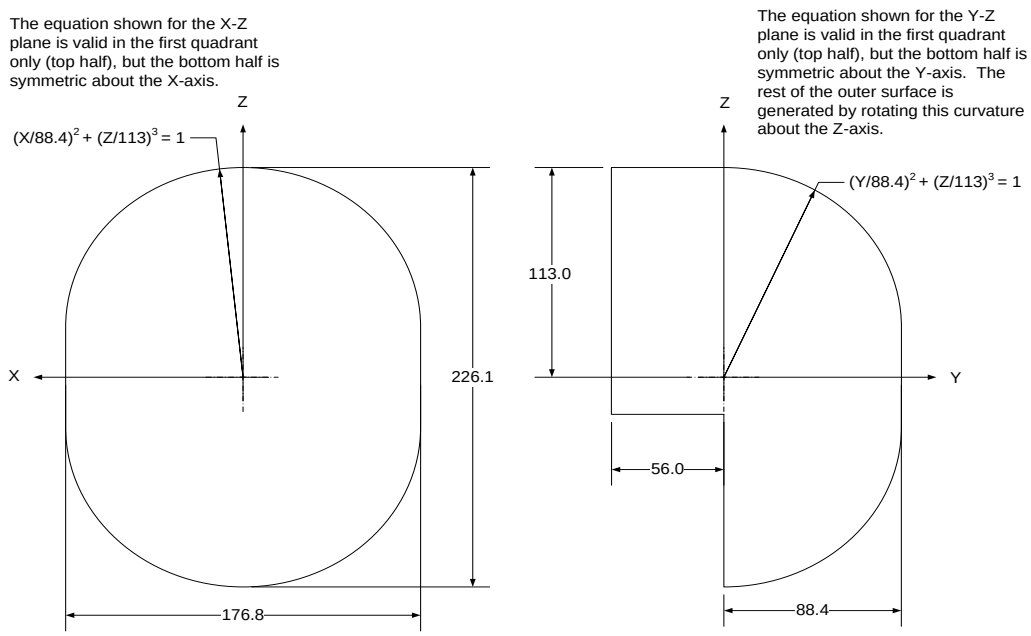
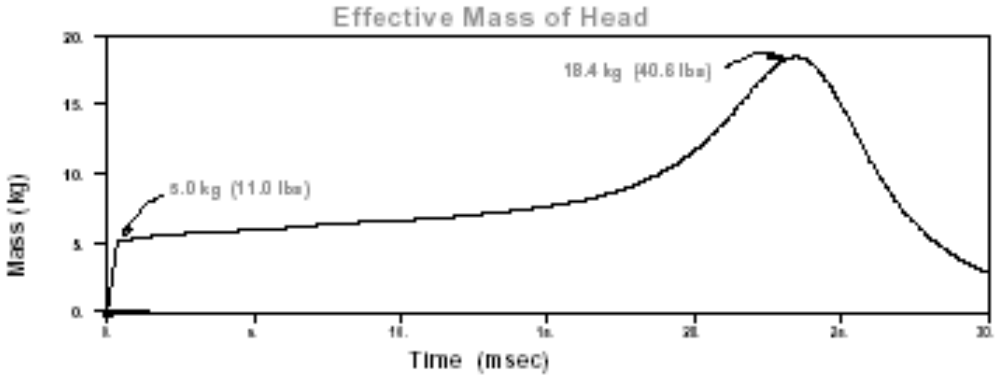


Figure III-1. Front and Side View of Headform Outer Surface (right) with Dimensions given in Millimeters.

<u>Mass Characteristics</u>: The 18 kg mass of the guided impactor was developed through a series of pendulum tests, sled tests and computer modeling. The impactor 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.



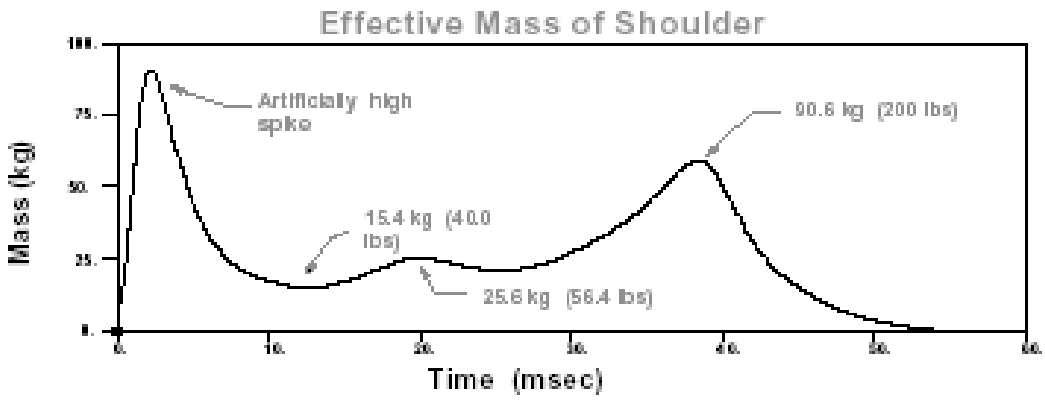


Figure III-2. Example plots of effective mass for 9.7 km/h velocity foam covered pendulum impacts with the dummy head and shoulder.

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. 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.[12] In a meeting held with the Alliance, they also indicated a potential test procedure might utilize an 18 kg impactor.[13]

For this final rule, we have reanalyzed these sled tests primarily for the purpose of determining impact energy, which we address in detail later in this FRIA.[14] However, this analysis also generated estimates of the effective mass of the dummies in these tests. For the side impact configuration, a range of the combined head and shoulder effective mass of 12.9 to 13.1 kg was estimated. The analysis for the rollover configuration is more complex. After making estimates of the impact energy, we back calculated the effective mass assuming the impact energy is equal to the kinetic energy prior to impact. This generated a combined head and shoulder effective mass of 23.7 kg.

New Impactor:

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[12] Ford presentation at SAE Government/Industry Meeting, Washington, D.C., May 9, 2006.
[13] Alliance presentation to NHTSA, Washington, D.C., January 25, 2006. [Docket NHTSA-2006-26467]
[14] The video from these tests and the data from the dummies, load wall and sled can be accessed from the NHTSA Biomechanics Database at http://www-nrd.nhtsa.dot.gov/database/aspx/biodb/querytesttable.aspx. The test numbers are 10282 through 10287.

Many provisions of the impactor test device calibration have been modified to make them consistent with some of the calibration procedures suggested by AORC and others.[15] The static deflection provision has be reduced from 20 mm under a 27 kg load, to 15 mm [Per Lou, we might change this number. Check with Lou before we send it out] under a 981 N force applied in four orthogonal directions, with the device in a test-ready configuration. The final rule requires a limit on the dynamic coefficient of 0.25, measured in four orientations with the shaft loaded with a 100 kg mass. We believe this provision will fulfill the requirement previously specified by the unobstructed velocity test and obstructed push force tests.

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.[16] We will use the definition of "daylight opening" found in FMVSS No.

[15] NHTSA-2009-0183-0019.1

[16] The rationale for the 25 mm offset for the head form edge relates to the potential inaccuracy of the 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.

201.[17] 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.[18]

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 and the cargo area behind the second row. Furthermore, within the first three seating rows, 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. [Don said "It is 1400 mm if the last row is the 1st or 2nd row of seats." I am not sure what he meant.] 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 and the cargo area behind the second row.[19]

If there is a side window opening in a cargo area behind the 1st row of a single row vehicle or behind the 2nd row of a two-row vehicle, this final rule will extend coverage to those cargo areas behind the 1st and 2nd rows of vehicles. The area of side window openings in a cargo area will be

[17] 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.

[18] 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.

[19] 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.

bounded by a transverse plane 1,400 mm behind the seating reference point (SgRP) of the rearmost seat in the 1st row of a single row vehicle or behind the SgRP of the rearmost seat in the 2nd row of a two-row vehicle.

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 headform 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.

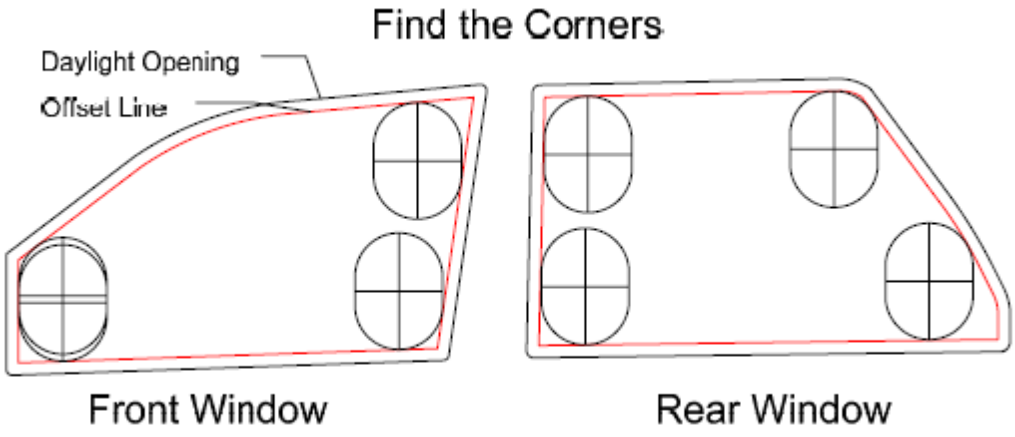

Figure III-3. Target Outlines Placed in Corners of Opening.

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-4.

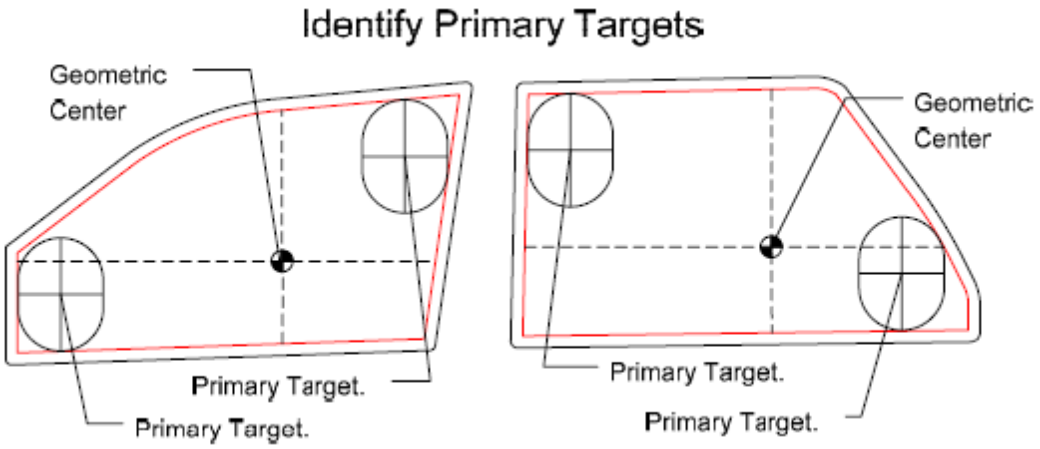

Figure III-4. Target Whose Center Is Closest to Quadrant

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-5, 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.

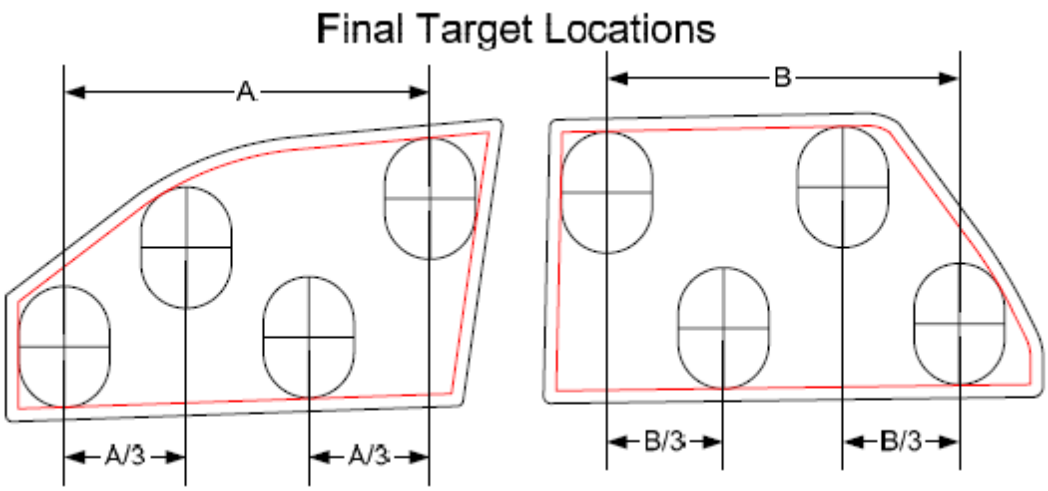

Figure III-5 Locate Corners Identify Primary Targets Final Target Locations[20]

Method for Target Reduction for Small Windows:

[20] The final rule will allow the reorientation of the target outlines and the associated reorientation of the impactor headform, under specific conditions. If a particular daylight opening can accommodate four targets in the vertical orientation (long axis vertical) there is no difference between the NPRM and final rule. However, if three or fewer vertical targets are accommodated, the final rule will dictate that the horizontal orientation will be used if more horizontal targets can fit in the opening. Ultimately, we are guided by our goal of requiring full window coverage. The basis for comments that a window opening that cannot fit a vertical target is not likely to be an ejection portal, is unclear to the agency. Our technical analysis showed that for long narrow windows, popular in many late model vehicles, very limited target coverage of the opening is achieved if the target is kept in the vertical orientation. Similarly, if a window opening would otherwise not accommodate a target unless the target outline is rotated to some oblique angle, the final rule will allow the target to be rotated in 5 degree increments.

Figure III-6 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.

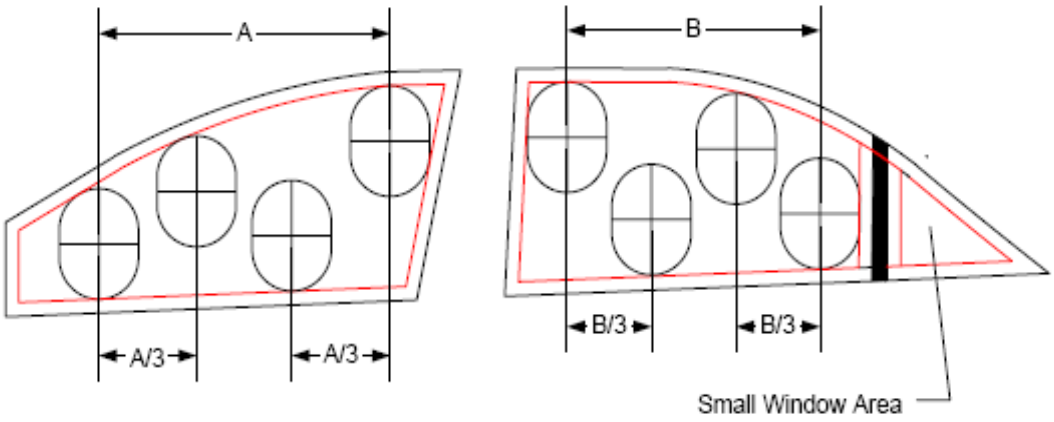

Figure III-6 Small Window Area

Figure III-7 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. The final rule 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.

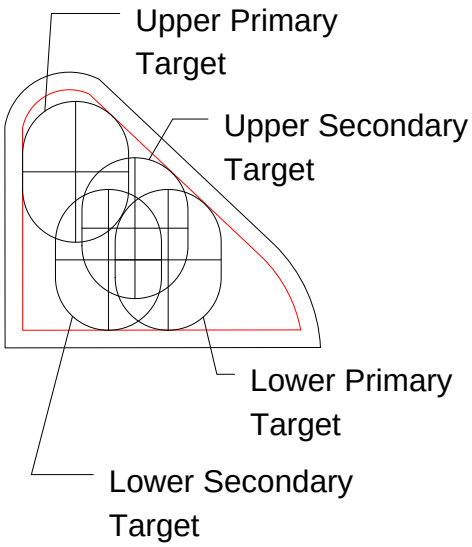

Figure III-7 Small Window Area

Reconstitution of Targets:

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, the final rule requires 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

Window Position:

Under the final test procedure, it is allowed to put windows in position ("up" position), but pre-broken for the 20 km/h impact speed test. 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.[21] Typically this advanced glazing is a three layer construction with a plastic laminate sandwiched between two pieces of tempered glass. Similarly, non-movable glazing can be in position and pre-broken for the 16 km/h impact speed. Movable glazing must be removed or retracted from the opening.

D. Testing Developmental and OEM Systems

Testing Description:

For several years, NHTSA has been testing side window curtain air bags **and** advanced glazing according to the final 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-8

[21]The target population data showed that 69% of occupants were ejected through a front row window that was up prior to the crash.

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.

Figure III-8 Prototype Zodiac (left) and TRW (right) air bag curtains on CK pickup.

D. Vehicle Testing

Since the issuance of the NPRM, we have tested 16 additional vehicle models. Most of the testing was with the test device that dates back to advanced glazing research (old impactor). However, tests from three vehicles were performed with a new test device (new impactor). To date we have performed nearly 700 impacts.

Figure III-9 shows the target location key for the test results. The C1 – C4 targets follow the same positioning as the B1 – B4 targets. In a few instances the A2 and A3 targets were eliminated because they were too close and a target (A5) was placed back in the window because the centers of remaining targets A1 and A4 were more than 360 mm apart.

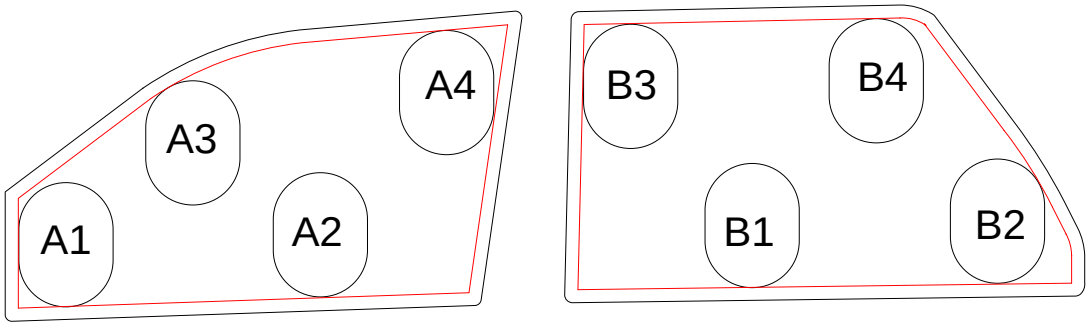

Figure III-9. Target Location Determined by Proposed Method

General Results:

The results of the agency testing are given in Tables III-1 through -9. The results are shade/color coded and given in columns, by target location and are in units of millimeter. Any values exceeding the proposed 100 mm limit on impactor displacement are in red or the darkest shading. Results from 80 to 100 mm are purple or medium shading. Results which are less than 80 mm are in green or the lightest shading. Some cells contain the average from several tests under the same/similar conditions; these results are bolded.

On occasion, target locations were not tested at 24 km/h because the 20 km/h results indicated displacements in excess of 100 mm at that location. These cells are denoted by "(20 km/h)" and are shaded red/dark, since we assume the 24 km/h impact would also have exceeded 100 mm. Similarly, some target locations were not tested at 20 km/h, but the cells are shaded green/light and contain "(24 km/h)" indicating a value below 80 mm of displacement in the 24 km/h test.

We note that some vehicles were tested with pre-broken advanced laminated (designated as "w/lam." next to the vehicle name). Various breaking methods were used. For simplicity in presenting the data, we have averaged the results for various breaking methods, except for the method of breaking the laminated in four places (designated as "4 hole" next to the vehicle

name). Also, a few tests were performed with the headliner in place (designated as "w/liner" next to the vehicle name.

Across all vehicles, target A1 remains the most challenging impact location and A4 the least challenging for the 1st row. This is consistent for all three impactor speeds and time delays. For the 2nd row, B1 and B2 are the most challenging. The available data does not present a clear trend for the 3rd row.

The two best performing vehicles were the MY2007 Mazda CX9 MY 2008 and the Toyota Highlander. We will discuss the performance of these vehicles in more detail in several of the sections below.

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

Vehicle	N/O*	Pos. A1	Pos. A2	Pos. A3	Pos. A4
03 Navigator	O	No Data	(20 km/h)	(20 km/h)	-21
03 Navigator w/lam.	O	No Data	35	No Data	No Data
04 Volvo XC90	O	(20 km/h)	193	130	18
04 Volvo w/lam.	O	(20 km/h)	44	118	15
05 Chevy Trailblazer	O	138	168	159	No Data
05 Chevy Trailblazer w/lam.	O	No Data	No Data	(20 km/h)	No Data
05 Chevy Trail. w/lam. (4 hole)	O	No Data	89	No data	No Data
05 Honda Odyssey	O	No data	**107**	119	No data
05 Infinity FX35	O	128	**101**	**99**	55
05 Nissan Pathfinder	O	(20 km/h)	167	(20 km/h)	**79**
05 Toyota Highlander	O	(20 km/h)	137	142	**116**
06 Dodge Durango	O	174	156	(20 km/h)	54
06 Dodge Durango w/lam.	O	No Data	101	No data	No Data
06 Dodge Dur. w/lam. (4 hole)	O	(20 km/h)	95	(20 km/h)	No Data
06 Mercury Monterey	O	To Stops	208	No data	32
06 Toyota Land Cruiser	O	229	No data	(20 km/h)	62
06 Volvo C70	O	(20 km/h)	No Target	No Target	No Target
07 Chevy Silverado	O	177	(20 km/h)	183	**-1**
07 Chevy Tahoe	O	To Stops	168	125	**-25**
07 Chevy Tahoe w/lam.	O	**113**	**100**	**124**	No data
07 Chevy Tahoe w/lam. (4 hole)	O	No data	99	**109**	No data
07 Ford 500	O	(20 km/h)	160		**38**
07 Ford Edge	O	146	17	**86**	-9
07 Ford Edge	N	175	No data	155	No data
07 Ford Expedition	O	(20 km/h)	(20 km/h)	(20 km/h)	**21**
07 Jeep Commander	O	(20 km/h)	(20 km/h)	(20 km/h)	-62
07 Jeep Commander w/lam.	O	No data	No data	148	No data
07 Mazda CX9	O	**96**	9	**87**	2
07 Mazda CX9	N	**112**	No data	**90**	No data
07 Saturn Vue	O	(20 km/h)	(20 km/h)	(20 km/h)	65
08 Dodge Caravan	O	136	**84**	(20 km/h)	-61
08 Ford Taurus X	O	146	**73**	**99**	-38
08 Subaru Tribeca	O	(20 km/h)	146		**74**
08 Toyota Highlander	O	**64**	41	54	12
08 Toyota Highlander	N	102	No data	77	No data
08 Toyota High. w/liner	N	90	No data	70	No data
09 Chevy Equinox	O	(20 km/h)	**101**	(20 km/h)	30
Average		135	104	114	21
Standard Deviation		42.1	55.8	33.7	45.9

*New or Old Impactor

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	**N/O***	**Pos. A1**	**Pos. A2**	**Pos. A3**	**Pos. A4**
03 Navigator	O	No Data	**191**	To Stops	-37
03 Navigator w/lam.	O	No Data	6	No Data	No Data
04 Volvo XC90	O	163	**96**	**119**	-3
04 Volvo w/lam.	O	**127**	27	97	(24 km/h)
05 Chevy Trailblazer	O	112	**121**	**127**	No Data
05 Chevy Trailblazer w/lam.	O	**86**	80	**109**	No Data
05 Chevy Trail. w/lam. (4 hole)	O	No Data	62	**97**	No Data
05 Honda Odyssey	O	No data	**96**	57	-45
05 Infinity FX35	O	**106**	60	73	30
05 Nissan Pathfinder	O	192	138	248	60
05 Toyota Highlander	O	**168**	**137**	**115**	76
06 Dodge Durango	O	160	140	180	18
06 Dodge Dur. w/lam. (4 hole)	O	106	71	150	No Data
06 Mercury Monterey	O	185	199	No data	-10
06 Toyota Land Cruiser	O	174	No data	256	31
06 Volvo C70	O	200	No Target	No Target	No Target
07 Chevy Silverado	O	142	187	130	(24 km/h)
07 Chevy Tahoe	O	**104**	**110**	87	(24 km/h)
07 Chevy Tahoe w/lam.	O	102	No data	No data	No data
07 Ford 500	O	192	113		(24 km/h)
07 Ford Edge	O	129	(24 km/h)	No data	(24 km/h)
07 Ford Edge	N	**148**	No data	67	No data
07 Ford Expedition	O	**151**	To Stops	**137**	(24 km/h)
07 Jeep Commander	O	To Stops	175	155	(24 km/h)
07 Jeep Commander w/lam.	O	No data	No data	73	No data
07 Mazda CX9	N	76	No data	67	No data
07 Saturn Vue	O	To Stops	**130**	**191**	28
08 Dodge Caravan	O	112	No data	162	(24 km/h)
08 Ford Taurus X	O	110	No data	No data	(24 km/h)
08 Subaru Tribeca	O	180	**106**		(24 km/h)
09 Chevy Equinox	O	149	No data	200	(24 km/h)
Average		140	112	132	15
Standard Deviation		36.5	55.7	56.7	39.0

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

Vehicle	**N/O***	**Pos. A1**	**Pos. A2**	**Pos. A3**	**Pos. A4**
03 Navigator	O	To Stops	74	To Stops	-30
03 Navigator w/lam.	O	157	-36	137	No Data
04 Volvo XC90	O	**161**	**73**	78	-22
04 Volvo w/lam.	O	**96**	26	59	No Data
05 Chevy Trailblazer	O	121	192	124	No Data
05 Chevy Trailblazer w/lam.	O	No Data	102	No Data	No Data
05 Chevy Trail. w/lam. (4 hole)	O	No Data	92	No Data	No Data
05 Honda Odyssey	O	No data	**69**	77	-54
05 Infinity FX35	O	88	22	40	9
05 Nissan Pathfinder	O	**117**	**104**	195	43
05 Toyota Highlander	O	205	210	152	69
06 Dodge Durango	O	138	135	167	13
06 Dodge Durango w/lam.	O	No Data	No Data	142	No Data
06 Dodge Dur. w/lam. (4 hole)	O	97	58	145	No Data
06 Mercury Monterey	O	222	183	No data	**35**
06 Toyota Land Cruiser	O	146	207	229	16
06 Volvo C70	O	135	No Target	No Target	No Target
07 Chevy Silverado	O	145	244	115	-7
07 Chevy Tahoe	O	42	6	10	-136
07 Ford 500	O	151	58		-16
07 Ford 500 w/lam.	O	**96**	No data	No data	No data
07 Ford Edge	O	103	-42	7	-56
07 Ford Edge	N	**123**	No data	33	No data
07 Ford Expedition	O	141	205	**109**	3
07 Jeep Commander	O	255	144	136	-89
07 Jeep Commander w/lam.	O	No data	**56**	62	No data
07 Jeep Commander w/lam. (4 hole)	O	No data	50	60	No data
07 Mazda CX9	O	54	-38	44	-53
07 Mazda CX9	N	**67**	No data	31	No data
07 Saturn Vue	O	**184**	**180**	186	72
08 Dodge Caravan	O	85	-39	121	-141
08 Ford Taurus X	O	**104**	-13	39	-88
08 Subaru Tribeca	O	122	77		-1
08 Toyota Highlander	O	36	0	54	-62
08 Toyota Highlander	N	119	No data	52	No data
09 Chevy Equinox	O	**125**	25	178	-46
Average		125	82	99	-25
Standard Deviation		50.1	87.2	61.1	58.1

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

Vehicle	N/O*	Pos. B1	Pos. B2	Pos. B3	Pos. B4
03 Ford Navigator	O	To Stops	No data	No data	40
04 Volvo XC90	O	(20 km/h)	No data	No data	69
04 Volvo XC90 w/lam.	O	**92**	No data	No data	62
05 Chevy Trailblazer	O	122	No data	No data	35
05 Honda Odyssey	O	152	193	**71**	80
05 Infinity FX35	O	148	No data	No data	47
05 Nissan Pathfinder	O	167	No data	No data	133
05 Toyota Highlander	O	152	No data	No data	154
06 Dodge Durango	O	86	82	76	91
06 Mercury Monterey	O	171	193	**72**	**78**
06 Toyota Land Cruiser	O	159	157	**75**	No Target
07 Chevy Silverado	O	153	(20 km/h)	**78**	117
07 Chevy Tahoe	O	(20 km/h)	**161**	24	74
07 Chevy Tahoe w/lam.	O	No data	48	No data	No data
07 Ford 500	O	184	50	**102**	157
07 Ford 500 w/lam.	O	**91**	No data	No data	**111**
07 Ford 500 w/lam. (4 hole)	O	No data	No data	No data	**99**
07 Ford Edge	O	39	21	-22	27
07 Ford Edge	N	51	33	No data	26
07 Ford Expedition	O	164	55	**66**	75
07 Jeep Commander	O	140	(20 km/h)	64	No data
07 Mazda CX9	O	36	2	51	9
07 Mazda CX9	N	22	No data	44	No data
07 Saturn Vue	O	No Target	144	66	No Target
08 Dodge Caravan	O	59	27	**-16**	-7
08 Ford Taurus X	O	**45**	**34**	22	31
08 Subaru Tribeca	O	133	**85**	**80**	**111**
08 Toyota Highlander	O	106	110	55	109
08 Toyota Highlander	N	125	144	No data	133
08 Toyota High. w/liner	N	133	138	No data	77
09 Chevy Equinox	O	72	22	39	45
Average		112	89	53	76
Standard Deviation		49.2	63.0	32.7	44.0

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

Vehicle	**N/O***	**Pos. B1**	**Pos. B2**	**Pos. B3**	**Pos. B4**
03 Ford Navigator	O	To Stops	No data	No data	-14
04 Volvo XC90	O	183	No data	No data	(24 km/h)
04 Volvo XC90 w/lam.	O	94	No data	No data	(24 km/h)
05 Chevy Trailblazer	O	68	No data	No data	8
05 Honda Odyssey	O	134	**84**	42	34
05 Infinity FX35	O	**90**	No data	No data	21
05 Nissan Pathfinder	O	**143**	No data	No data	**111**
05 Toyota Highlander	O	110	No data	No data	106
06 Mercury Monterey	O	155	**52**	42	51
06 Toyota Land Cruiser	O	127	128	53	No Target
07 Chevy Silverado	O	**114**	232	(24 km/h)	101
07 Chevy Tahoe	O	249	No data	(24 km/h)	(24 km/h)
07 Ford 500	O	152	No data	89	**128**
07 Ford Expedition	O	146	23	(24 km/h)	(24 km/h)
07 Jeep Commander	O	122	**107**	(24 km/h)	No data
07 Saturn Vue	O	No Target	**111**	**40**	No Target
08 Subaru Tribeca	O	**105**	No data	(24 km/h)	No data
08 Toyota Highlander	O	No data	67	(24 km/h)	88
08 Toyota Highlander	N	92	89	No data	110
Average		130	99	53	64
Standard Deviation		43.4	59.3	20.7	49.9

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

Vehicle	**N/O***	**Pos. B1**	**Pos. B2**	**Pos. B3**	**Pos. B4**
03 Ford Navigator	O	126	No data	No data	-27
04 Volvo XC90	O	189	No data	No data	29
04 Volvo XC90 w/lam.	O	63	No data	No data	9
05 Chevy Trailblazer	O	**127**	No data	No data	47
05 Honda Odyssey	O	**121**	28	12	55
05 Infinity FX35	O	64	No data	No data	20
05 Nissan Pathfinder	O	**111**	No data	No data	78
05 Toyota Highlander	O	143	No data	No data	110
06 Dodge Durango	O	36	18	3	71
06 Mercury Monterey	O	223	142	54	**54**
06 Toyota Land Cruiser	O	**107**	**113**	49	No Target
07 Chevy Silverado	O	124	194	53	63
07 Chevy Tahoe	O	120	-83	-21	15
07 Chevy Tahoe w/lam.	O	**67**	No data	No data	No data
07 Chevy Tahoe w/lam. (4 hole)	O	58	No data	No data	No data
07 Ford 500	O	133	-3	56	94
07 Ford 500 w/lam.	O	64	No data	No data	No data
07 Ford Edge	O	-16	-40	-76	-25
07 Ford Expedition	O	89	**159**	22	34
07 Jeep Commander	O	**107**	99	27	57
07 Mazda CX9	O	-15	-58	5	-35
07 Saturn Vue	O	No data	138	26	No data
08 Dodge Caravan	O	-58	-29	-55	-56
08 Ford Taurus X	O	-17	-19	-13	-40
08 Subaru Tribeca	O	76	19	28	20
08 Toyota Highlander	O	49	59	32	57
08 Toyota Highlander	N	87	105	No data	93
09 Chevy Equinox	O	15	-51	1	-14
Average		81	44	12	31
Standard Deviation		63.9	84.5	37.2	46.8

ble III-7 Third Row Window, 24 km/h Impact, 1.5 second Delay

Vehicle	N/O*	Pos. C1	Pos. C2	Pos. C3	Pos. C4
05 Honda Odyssey	O	No data	(20 km/h)	No data	175
06 Mercury Monterey	O	188	(20 km/h)	119	No data
06 Toyota Land Cruiser	O	NC	NC	180	NC
07 Chevrolet Tahoe	O	91	No Target	194	No Target
07 Chevrolet Tahoe w/lam.	O	No Data	106	141	No Data
07 Ford Expedition	O	(20 km/h)	No data	81	186
07 Jeep Commander	O	229	155	120	102
08 Dodge Caravan	O	-42	**112**	35	-41
08 Ford Taurus X	O	No Target	To Stops	48	No Target
08 Toyota Highlander	O	-42	42	92	No data
08 Toyota Highlander	N	No data	No data	110	No data
08 Toyota Highlander w/liner	N	No data	No data	42	No data
Average		85	104	106	106
Standard Deviation		126.1	46.6	53.1	104.5

Table III-8 Third Row Window, 20 km/h Impact, 1.5 second Delay

Vehicle	N/O*	Pos. C1	Pos. C2	Pos. C3	Pos. C4
05 Honda Odyssey	O	No data	To Stops	58	122
06 Dodge Durango	O	No data	To Stops	66	No data
06 Mercury Monterey	O	147	212	75	No data
06 Toyota Land Cruiser	O	NC	NC	128	NC
07 Chevrolet Tahoe	O	58	No Target	No data	No Target
07 Ford Expedition	O	241	No data	No data	**51**
07 Jeep Commander	O	No data	115	102	No data
08 Ford Taurus X	O	No Target	86	(24 km/h)	No Target
08 Toyota Highlander	N	No data	No data	88	No data
Average		149	138	86	86
Standard Deviation		91.5	66.0	25.8	50.6

Table III-9 Third Row Window, 16 km/h Impact, 6 second Delay

Vehicle	**N/O***	**Pos. C1**	**Pos. C2**	**Pos. C3**	**Pos. C4**
05 Honda Odyssey	O	To Stops	To Stops	44	80
06 Dodge Durango	O	No data	No data	52	No data
06 Mercury Monterey	O	**186**	204	142	225
06 Toyota Land Cruiser	O	NC	NC	98	NC
07 Chevrolet Tahoe	O	30	No Target	64	No Target
07 Chevrolet Tahoe w/lam.	O	No Data	57	66	No Data
07 Ford Expedition	O	233	No data	**49**	34
07 Jeep Commander	O	170	104	92	56
08 Dodge Caravan	O	-91	34	-42	-113
08 Ford Taurus X	O	No Target	60	7	No Target
08 Toyota Highlander	O	No data	-23	37	No data
Average		106	73	55	56
Standard Deviation		133.4	76.5	48.2	120.6

Effect of Impactor Test Device on Displacement Values:

As indicated above, some vehicles were tested using both the old and new impactor. These vehicles were the MY2007 CX9, MY 2007 Edge and MY 2008 Highlander. Table III-10 shows the difference in displacements measured at target locations where both impactors were used.[22] For most targets, the displacement measurements for the new impactor exceeded the old (positive difference). The largest difference was 83 mm for the 16 km/h-6 second test at A1 on the Highlander. The old impactor displacement exceeded the new impactor (negative difference) at several targets as well. The largest negative value was -14 mm for the 24 km/h-1.5 second test at B1 on the CX9.

The CX9 was the only vehicle that was impacted multiple times at the same targets by both the old and new impactor. As such, a student's t-test could be done to determine if the difference in

[22] In some cases average values were used to calculate the differences.

the results were significant.[23] Table III-11 shows the displacement values and statistics for targets A1 and A3. The difference in displacement was statistically significant ($p \leq 0.05$) for the A1 target, but not the A3 target.

As would be expected, these data generally indicate that the new impactor tends to have greater displacement. This is likely the result of lower dynamic friction. However, the old impactor shaft flexibility may have contributed to increased displacement in some tests. Nonetheless, in the remainder of the analysis of the vehicle test data in this section of the FRIA we will not compare results across the two impactors. However, we do believe that the test results from the old impactor provide useful data to assess the relative performance of ejection mitigation countermeasures.

Table III-10 – Change in Displacement between Old and New Impact Test Device

Vehicle	**Test Vel. (km/h)**	**A1**	**A3**	**B1**	**B2**	**B3**	**B4**	**C3**
07 Ford Edge	24	29.0	69.0	12.0	12.0		-1.0	
07 Mazda CX9	24	15.5	3.0	-14.0	0.0	-7.0	0.0	
08 Toyota Highlander	24	38.5	23.0	19.0	34.0		24.0	18.0
07 Ford Edge	20	18.5						
08 Toyota Highlander	20				22.0		22.0	
07 Ford Edge	16	19.5	26.0					
07 Mazda CX9	16	13.0	-13.0					
08 Toyota Highlander	16	83.0	-2.0	38.0	46.0		36.0	
	Average	31.0	17.7	13.8	28.5	-7.0	20.3	18.0
Average All		21.6						

[23] The t-test was performed assuming equal variance.

Table III-11 – Impactor Comparison for Mazda CX9

	A1		**A3**	
Test Vel. (km/h)	**Old**	**New**	**Old**	**New**
24	94	110	84	90
	98	113	89	89
Average	96.0	111.5	86.5	89.5
Std.	2.8	2.1	3.5	0.7
P-Value	0.013		0.224	

Trends in Performance of Ejection Mitigation Systems by Model Year Using Old Impactor:

Based on the vehicles the agency has tested, there appears to be a trend toward improved performance as each model year passes. This is exemplified by increased and more robust coverage of the window opening. It is difficult to quantify this trend. Below we attempt to show this trend graphically by plotting the displacement values by model year for the 1st row (Figure III-9) and 2nd Row (Figure III-10). These graphs are restricted to the 24 km/h-1.5 second test using the old impactor and exclude any testing with advanced glazing. An important factor to consider in examining these graphs is that in older vehicles there was often no curtain coverage at a particular target. If this occurred the agency did not test the target. One could think of such targets are having infinite displacement. They cannot be shown on the graph, but are also indicative of improved performance over time.

Since the graphs span multiple vehicles, there is a great deal of scatter. Nonetheless, when a trend line is plotted through the data for each impact location it almost always shows decreasing displacement for newer models.

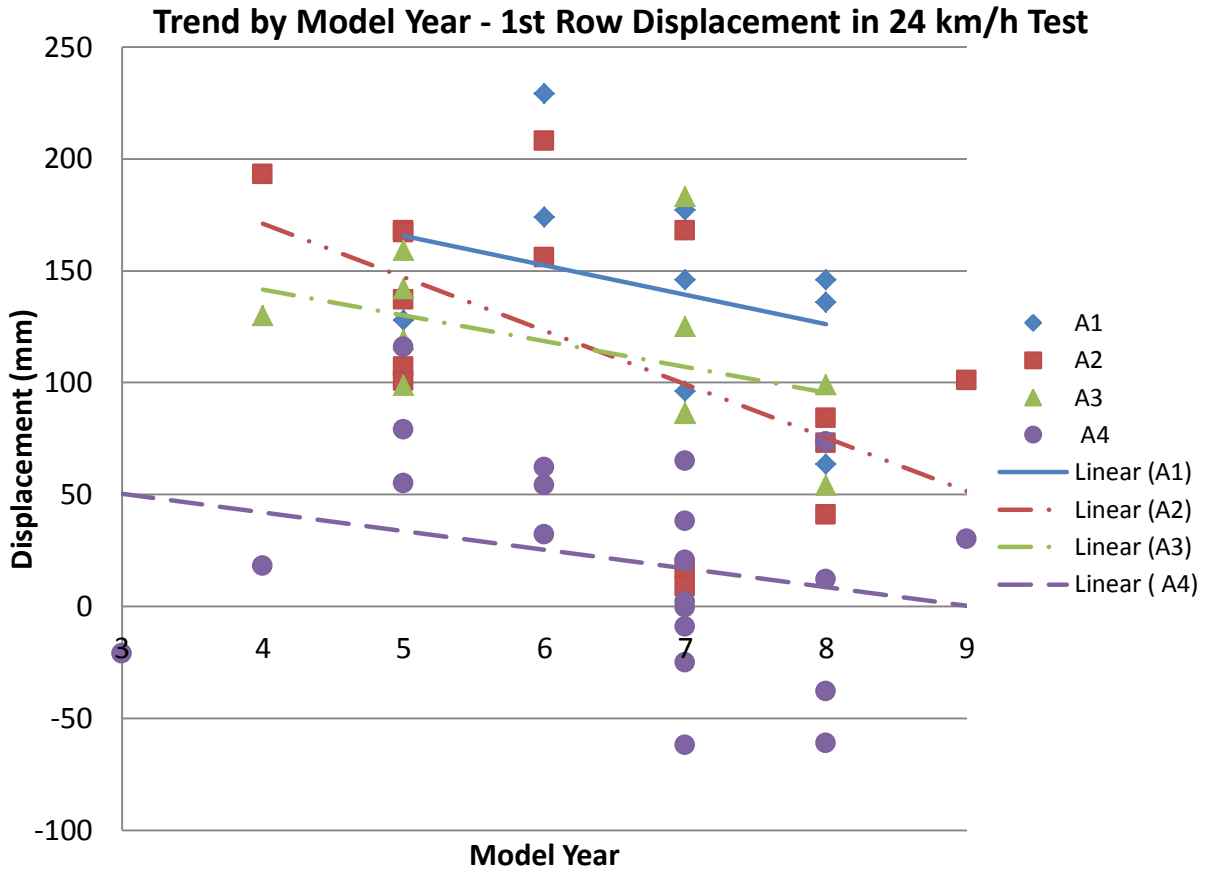
Trend by Model Year - 1st Row Displacement in 24 km/h Test
250
200
150
100
50
0
-50
-100
Displacement (mm)
3
4
5
6
7
8
9
Model Year
A1
A2
A3
A4
Linear (A1)
Linear (A2)
Linear (A3)
Linear (A4)

Figure III-9

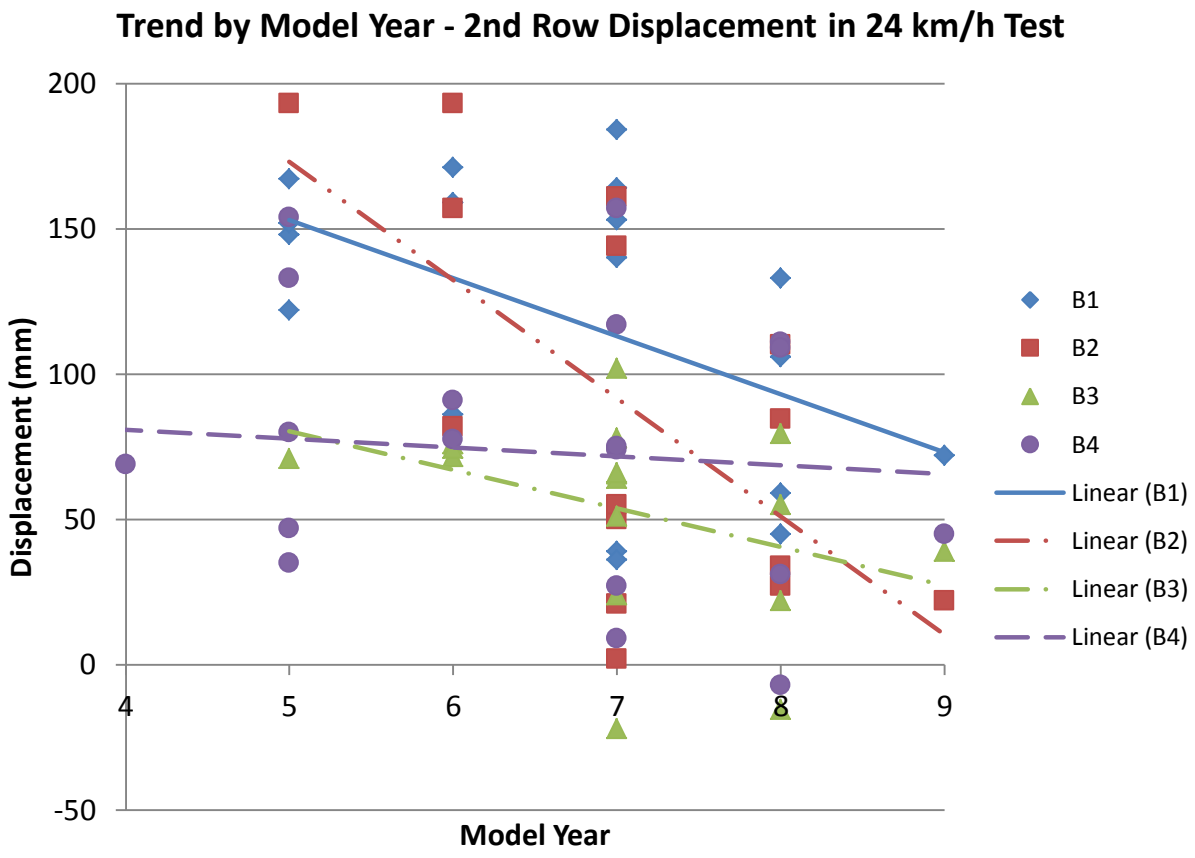

Figure III-10

One comparison we will draw attention to below is the improved performance of the MY2008 Highlander in comparison to the MY2005 Highlander. Table III-12 shows the change in displacement values for the two model years of the Highlander at each target location and across impact speeds. The largest change in displacement value was for the 16 km/h tests at targets A1 and A2 (169 mm and 210 mm, respectively). On an average basis, the MY2008 Highlander had 87 mm less displacement, for a 76% overall reduction.

Table III-12 – Absolute and Percentage Change in Displacement (mm) between MY2005 and MY2008 Toyota Highlander

Test Vel.	A1	A2	A3	A4	B1	B4
24		-96	-88	-104	-46	-45
16	-169	-210	-98	-131	-94	-53
Average (mm)	-103					
24		-70%	-62%	-90%	-30%	-29%
16	-82%	-100%	-64%	-190%	-66%	-48%
Average (%)	-76%					

Figure III-10 shows a 16 km/h-6 second test for target A1. The left and right side images are the MY2005 and MY2008 Highlander, respectively. The images of the MY2008 Highlander have been reversed to allow for a better visual comparison. The upper two images are pre-impact and the lower two are at maximum displacement. Note the increased coverage of the MY2008 Highlander and the increased size of the inflated chambers. The impactor does not contact the inflated part of the MY2005 curtain. However, for the MY2008 curtain, the impactor makes early contact with a large inflated chamber.

Figure III-10 MY2005 (left) and MY2008 Highlander (right) before impact (top) and at maximum displacement (bottom), in 16 km/h-1.5 second test of target A1.

Finally, we wish to highlight the performance of the MY2007 CX9 and MY 2008 Highlander. Figure III-11 shows the displacement values for the new impactor for these two vehicles by target location and test speed. We did not test each target point because previous testing using the old impactor indicated which targets were or were not challenging. The largest value for the Highlander is the 24 km/h-1.5 second test at B2 (144 mm). The largest value for the CX9 was the 24 km/h-1.5 second test at A1 (112 mm average).

Restricting the analysis to the 20 km/h-1.5 second and 16 km/h-6 second test, the Highlander exceed the 100 mm limit at B4 (110 mm) for the 20 km test and A1 (119 mm) and B2 (105 mm) in the 16 km/h test. We would expect that an improved ability to maintain air bag pressure at 6 seconds would help the 16 km/h results.

All tested targets for the CX9 passed at the lower speeds. Although the number of targets was limited, previous data from the old impactor would suggest that these untested locations would have performed well. It is reasonable to assume that the current CX9 system would be capable of compliance with final rule tests (20 km/h-1.5 second and 16 km/h-6 second).

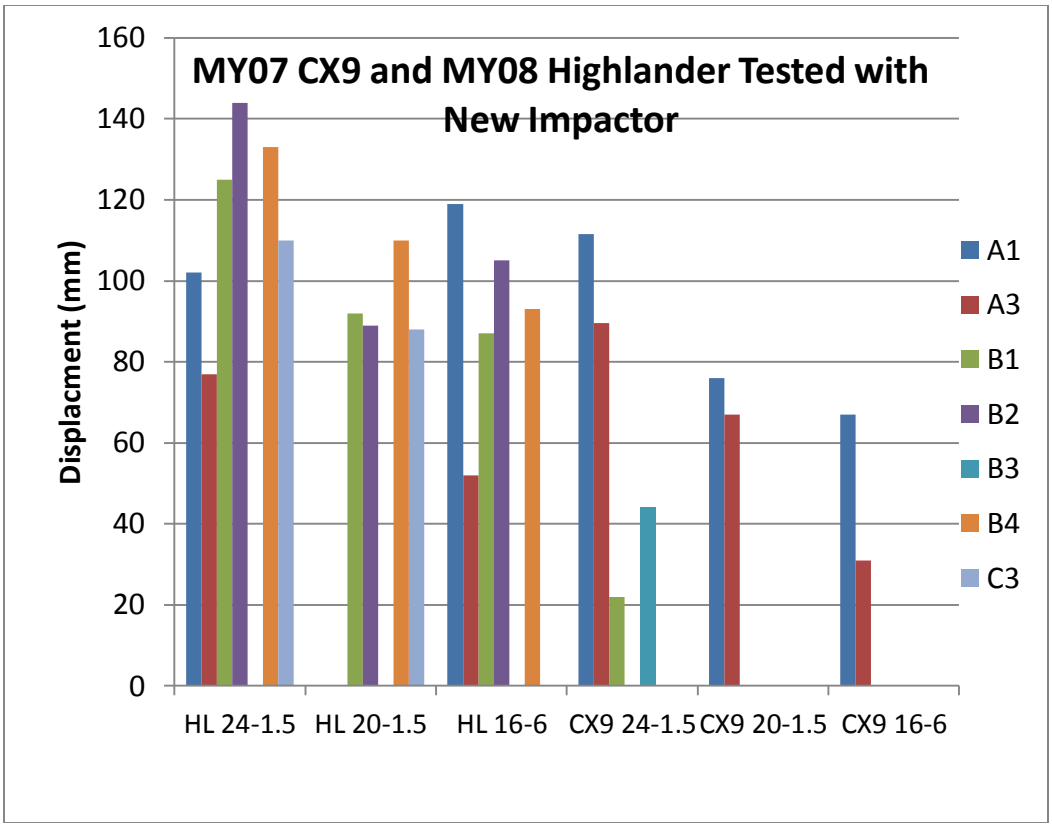

Figure III-11

<u>Relationship between Displacement by Target and Vehicle Row for the Three Impact Velocities Utilized in Research Testing with New Impactor:</u>

The following analysis uses only data from the new impactor. Although these data only consist of limited testing of three vehicles, the results are not confounded by impactor differences. Table III-13 shows the change in displacement between the 24 km/h-1.5 second, 20 km/h-1.5 second and 16 km/h-6 second tests at various target locations for the MY2007 Edge, MY2007 CX9 and MY 2008 Highlander. As would be expected, the 24 km/h-1.5 second test always had greater displacement than the 20 km/h-1.5 second test. On average this difference was 38.9 mm when averaged over all vehicles and target locations. This is an expected result because the only difference is the impact speed.

Comparisons with the 16 km/h-6 second impact to the other higher speed impacts with 1.5 second delay are not necessarily as simple because of the change in time delay. For two target locations, the 16 km/h-6 second test had a greater displacement than the higher speed tests. These were the CX9 24 km/h to 16 km/h comparison at A1 and the Highlander 20 km/h to 16 km/h comparison at B2. On an average basis, the 24 km/h-1.5 second test had 44.7 mm more displacement than the 16 km/h-6 second test. There was only a 15.7 mm difference between the 20 km/h-1.5 second and 16 km/h-6 second tests.

Table III-13 New Impactor, Change in Displacement (mm) between 24 km/h 1.5 second, 20 km/h 1.5 second and 16 km/h 6 second Tests

Vehicle	**Test Comparison**	**A1**	**A3**	**B1**	**B2**	**B4**	**C3**
07 Ford Edge	24-20	28	88				
07 Mazda CX9	24-20	36	23				
08 Toyota Highlander	24-20			33	55	23	22
07 Ford Edge	24-16	53	122				
07 Mazda CX9	24-16	45	59				
08 Toyota Highlander	24-16	-17	25	38	39	40	
07 Ford Edge	20-16	25	34				
07 Mazda CX9	20-16	9	36				
08 Toyota Highlander	20-16			5	-16	17	
Average All – 24-20		38.3					
Average All – 24-16		44.7					
Average All – 20-16		15.7					

There were only two vehicles/target locations that had more than one impact at multiple test speeds. Although this is extremely limited data, they allow a t-test to be performed. The results are given in Table III-14. The results indicate that the 16 km/h-1.5 second impact had statistically significant less displacement than both the higher speed tests at target A1.

Table III-14 New Impactor Comparison of Target A1 Displacement as a Function of Impact Velocity

Vehicle	**CX9**		**Edge**	
Test Type	**16 km/h-6 sec.**	**24 km/h-1.5 sec.**	**16 km/h-6 sec.**	**20 km/h-1.5 sec.**
	75	110	126	152
	59	113	119	143
Average	67.0	111.5	122.5	147.5
Std.	11.3	2.1	4.9	6.4
P-Value	0.016		0.024	

Finally, we are interested in the displacement rank of each impact location in a vehicle row. For our very limited data with the new impactor, the only data upon which to base a comparison is the 2nd row of the MY2008 Highlander. We have ranked the target locations from most to least displacement for each test speed and time delay. We note that target B3 was not tested because, previous testing with the old impact showed this to be the target with the least displacement for this vehicle. The results are given in Table III-15. The rank is identical for the 24 km/h-1.5 second test and the 16 km/h-6 second test, i.e., B2 had the most and B1 had the least displacement. However, for the 20 km/h-1.5 second test, the rank has B4 with the most and B2 with the least displacement.

This result showed that there tended to be less difference between the 20 km/h-1.5 second and 16 km/h-6 second tests. One can envision that if there are small differences for these two test speeds and time delays and if there are small differences between the displacements across multiple targets, the displacement rank of the target locations might tend to change for each test speed.

Table III-15 New Impactor Displacement Rank for MY2008 Toyota Highlander

Impact Vel. And Time Delay	Left to Right, Most to Least Displacement
24 km/h – 1.5 sec. Delay	B2, B4, B1
20 km/h – 1.5 sec. Delay	B4, B1, B2
16 km/h – 6 sec. Delay	B2, B4, B1

Effect of Advanced Glazing and the Breaking Method:

As is apparent from the results provided in the previous section, more than 100 tests were performed with advanced laminated glazing in combination with side curtain air bags. The testing clearly shows that pre-broken advanced glazing can contribute to the reduction of the impactor displacement. The extent of this reduction varies by vehicle, impact location, impact speed/time delay, and glazing breaking method. The focus of this section of the FRIA is to represent information about the effect of the various methods used to break the advanced glazing prior to the impact test.

Since the publication of the NPRM, we have a more extensive data set of tests with additional hole punch patterns. To perform the current analysis we isolated the tests where all conditions were identical, except the breakage procedure, and multiple replicates at each breakage condition were performed. We used a variant of the 50 mm matrix that we call the "50 mm offset." It is similar to the 50 mm matrix proposed by the agency in that on the outside surface of the glazing a 50 mm x 50 mm pattern is used. The pattern is aligned with the geometric center of the daylight opening. The deviation from the NPRM method occurs on the inside glazing surface. Rather than following the same hole pattern, the pattern is offset by 25 mm horizontally (see Figure III-14). The "75 mm offset" pattern has a 75 mm x 75 mm pattern on the outside surface of the glazing and the same pattern, offset by 37.5 mm horizontally, on the inside surface (see Figure III-15). In the figures below, the 75 mm offset pattern has 53% fewer punch holes.

Figure III-16 includes photographs of actual vehicle glazing broken by the 4-hole and pummeled with a hammer. Note that the difference in the breakage pattern associated with these two methods. Finally, Figure III-17 shows the breakage achieved with the 50 mm offset pattern.

Figure III-12 Starrett 18B Automatic Center Punch with Adjustable Stroke.

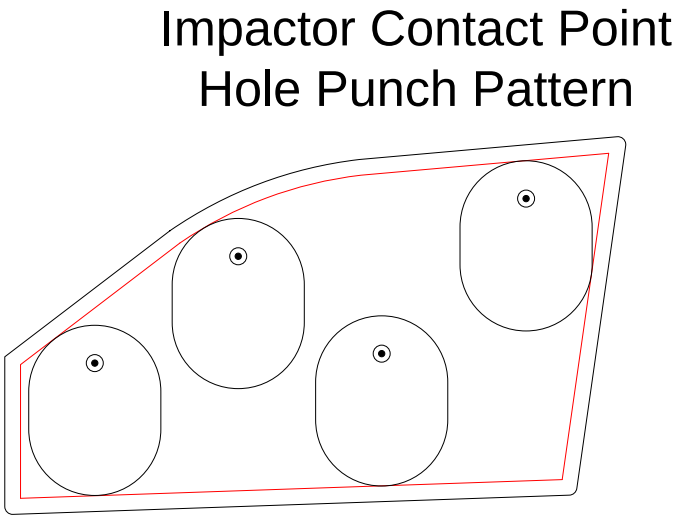

Figure III-13 Contact points of headform determine location of 4-hole punch pattern.

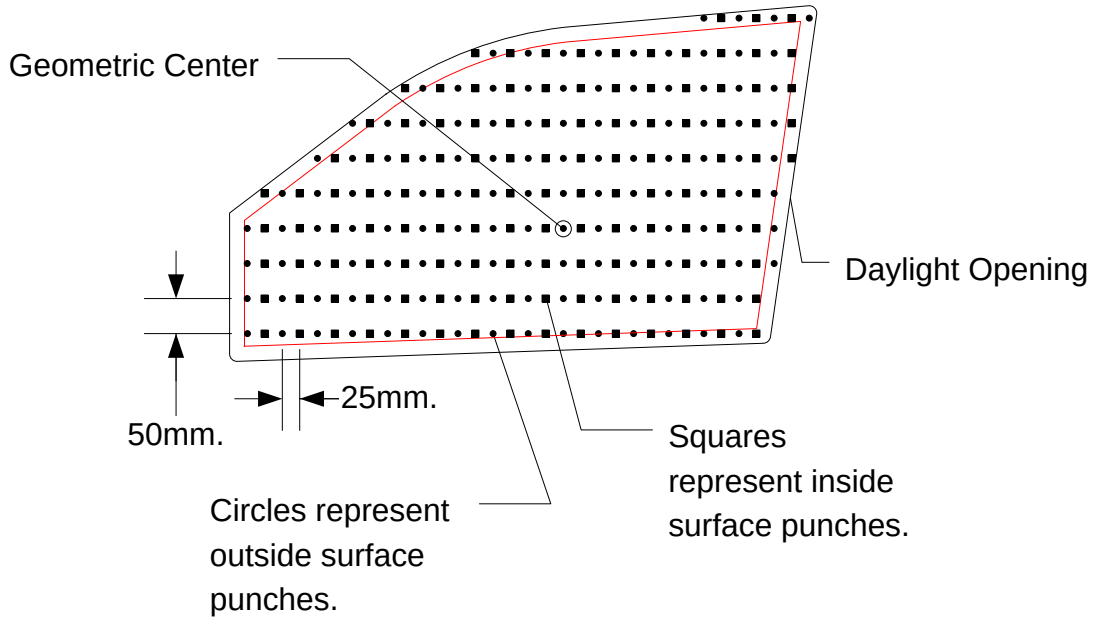

Figure III-14 Glazing is punched in a 50 mm matrix, horizontally offset by 25 mm on the inside surface.

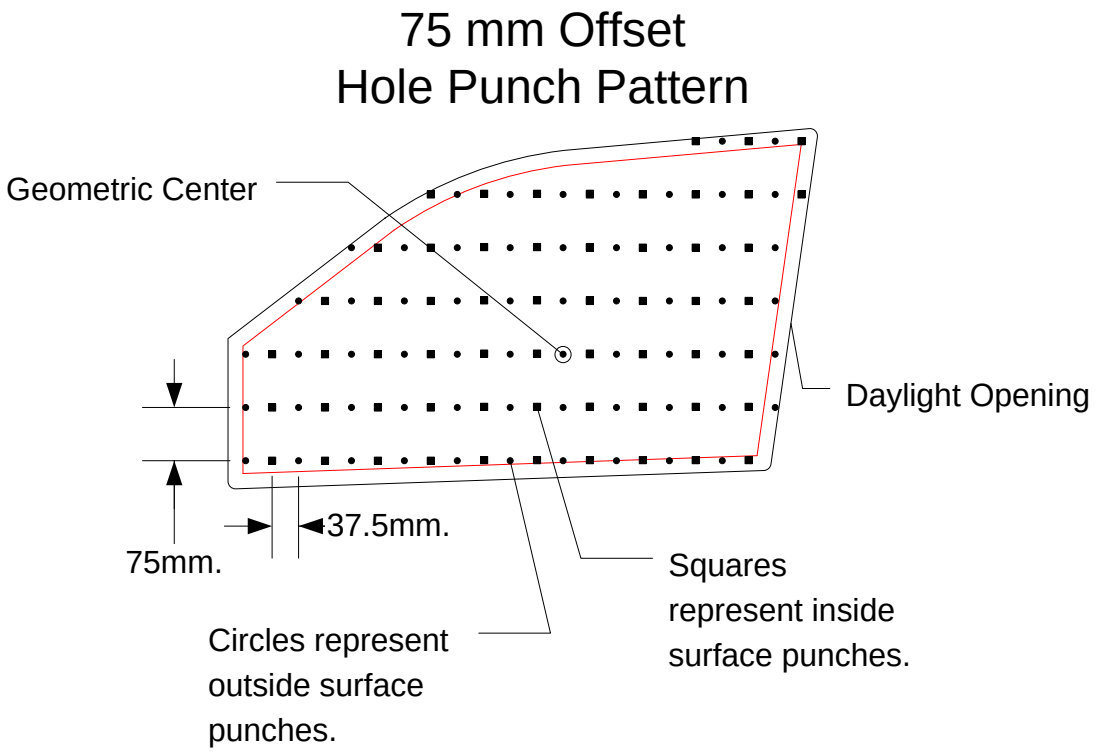

Figure III-15 Glazing is punched in a 75 mm matrix, horizontally offset by 37.5 mm on the inside surface.

Figure III-16 4-hole pattern (left) and pummeled window from MY2007 Jeep Commander

Figure III-17 50 mm offset pattern in the 3rd row of a MY2007 Tahoe.

The target locations where multiple repeat tests were performed with more than one glazing breakage condition were A1, A3, B1 and B4. Three different vehicles were tested at three impact speeds (16, 20 and 24 km/h). For all these comparative tests the old impactor was used. A total of 43 tests are used in this analysis. The impactor displacement results as a function of glazing condition are given in Table III-13. The last column in this table also provides the results for the same tests performed without glazing.

All test conditions involved the Pummeled glazing treatment. One might theorize that the Pummeled condition would allow the most displacement, and then, in order of decreasing

displacement, would be the 50 mm offset, 75 mm offset and 4-hole treatments. In fact, the Pummeled condition on average did allow the largest displacement in 4 of 5 vehicles; the lone exception being the Ford 500-24 km/h-B4 test. At that test condition, the 75 mm offset provided the most displacement. Also, as expected, under the four test conditions where the 4-hole condition was used, it allowed the least average displacement. Under the Tahoe-16 km/h-B1 test, only one 4-hole test was performed. [24] In the three test conditions in which both the 50 and 75 mm offset methods were used, the 75 mm offset pattern had a higher average displacement than the 50 mm offset. [25]

We attempted some basic statistical analyses of these data. We note that the paucity of the data limits the value of such analyses. The results of the statistical analyses are given in Table III-14. First, a one-way ANOVA was performed for each test condition. This will tell us if the variance of any one of the glazing treatments is significantly different than any of the others as it relates to allowed displacement.[26] At a $p < 0.05$, none of the glazing treatments is significantly different. At a lower threshold for significance of $p < 0.1$ (***bolded and italicized*** text in the table), the Ford 500-16 km/h-A1 test and the Tahoe-24 km/h-A3 test show that the differences in at least one of the treatments is different.

In addition, we performed a student's t-test assuming equivalent variance to determine if mean values from individual pairs of glazing treatments were significantly different. At a $p \leq 0.05$ (**bolded and non-italicized**), the Pummeled glazing was significantly different from the 4-hole

[24] In general, testing was limited by the availability of replacement glazing. The impactor displacement for the 4-hole test of the Tahoe had the smallest value of any laminate test for that target and vehicle, so priority for testing was given to the other breakage conditions.
[25] This would appear to be counterintuitive. However, it is consistent with the statistical analysis that follows, which indicates there is not statically significant difference between these treatments for the vehicles and targets tested.
[26] The ANOVA was not performed on the Trailblazer data because there was only a pair of glazing conditions tested.

pattern for both the Trailblazer-20 km/h-A3, Tahoe-24 km/h-A3 and Ford 500-24 km/h-B4 tests. The 4-hole pattern was also significantly different from the 50 and 75 mm offset for the Tahoe-24 km/h-A3 and Ford 500-24 km/h-B4 tests, respectively. Also significantly different was the Pummeled to 75 mm offset for the Ford 500-16 km/h-A1 and 24 km/h B4.

It is clear from these results that the 4-hole pattern allows the glazing to retain the most resistance to impactor displacement. On the other end of the spectrum, glazing pummeled with the hammer usually provided the least resistance. These data do not clearly indicate a difference between the 50 and 75 mm offset hole punch pattern as it relates to impactor displacement. When these treatments were able to be compared statistically, there was no significant difference between the resulting displacements.

Table III-13 Old Impactor Displacement Data for Advanced Glazing Pre-Broken by Different Methods.

Test Conditions			Displacement (mm) vs. Glazing Condition				
Vehicle	Speed (km/h)	Target	Pummeled	50 mm Offset	75 mm Offset	4 Hole	None
07 Ford 500	16*	A1	103	87	93		151
07 Ford 500	16	A1	96	100	85		
07 Ford 500	16	A1	120	95	88		
Average			106.3	94.0	88.7		151
Std			12.3	6.6	4.0		
05 Trailblazer	20	A3	107			96	118
05 Trailblazer	20	A3	110			98	136
Average			108.5			97.0	127.0
Std			2.1			1.4	12.7
07 Tahoe	24	A3	124	122		98	125
07 Tahoe	24	A3	128	126		112	
07 Tahoe	24	A3	142	129		121	
Average			131.3	125.7		110.3	125
Std			9.5	3.5		11.6	
07 Tahoe	16	B1	79	67	64	58	120
07 Tahoe	16	B1	62	55	71		
07 Tahoe	16	B1	69	63	69		
Average			70.0	61.7	68.0	58	120
Std			8.5	6.1	3.6		
07 Ford 500	24	B4	106	93	117	95	157
07 Ford 500	24	B4	112	116	115	102	
07 Ford 500	24	B4	109	120	114		
Average			109.0	109.7	115.3	98.5	157
Std			3.0	14.6	1.5	4.9	

*****The 16 km/h tests are at 6 seconds. All other tests are at 1.5 seconds.

Table III-14 – Statistical Comparison of Breakage Methods

Test Conditions			P-Value						
				Student's t-test					
Vehicle	Speed (km/h)	Target	ANOVA	Pum.-50 mm	Pum. - 75 mm	Pum. - 4 Hole	75 mm-50 mm	75 mm-4 Hole	50 mm-4 Hole
07 Ford 500	16	A1	***0.099***	0.101	**0.039**		0.148		
05 Trail.	20	A3				**0.012**			
07 Tahoe	24	A3	***0.064***	0.193		**0.036**			**0.047**
07 Tahoe	16	B1	0.321	0.121	0.364		0.098		
07 Ford 500	24	B4	0.255	0.471	**0.016**	**0.028**	0.270	**0.005**	0.196

IV. BENEFITS

This chapter estimates the potential benefits of the occupant retention requirements. These benefits would be achieved from providing window curtains 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.[27] 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.

Overview of fatal and non-fatal injuries in real world crashes:

The agency's annualized injury data from 1997 to 2008 NASS CDS and fatality counts adjusted to the annual average from FARS for these same years show that ejection through side windows makes up the greatest part of the ejection problem.[28] There are 6,412 fatalities, 5,209 MAIS 3-5

[27] 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 ΔV (which would be observed in the 20 mph vehicle ΔV 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

[28] In the benefit analysis, we used annualized injury data from 1997 to 2008 NASS CDS and fatality counts adjusted to the annual average from FARS for these same years 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.

injuries, and 16,272 MAIS 1-2 injuries for occupants ejected through the first three rows of side windows. These make up 62%, 51% and 68% of all ejected fatalities, MAIS 3-5 injuries and MAIS 1-2 injuries, respectively, as shown in Tables IV-1 and IV-2. We note that the side glazing for the 4th row, 5th row and cargo area behind the second row were the ejection routes for about 1% of the fatalities.[29]

Table IV-1
Occupant Injury and Fatality Count by Ejection Route in All Crash Types
(Annualized 1997-2008 NASS and FARS)

Ejection Route	MAIS 1-2	MAIS 3-5	Fatal
Windshield	1,517	1,400	1,078
First Row Windows	14,293	4,980	5,589
Second-Row Windows	1,700	641	796
Third-Row Windows	279	88	27
Fourth-Row Windows	0	0	39
Fifth-Row Window	0	0	7
Cargo Area Rear of Row 2	342	17	52
Backlight	1,621	1,364	495
Roof Panel or Glazing	1,000	367	324
Roof Other	420	105	81
Multiple Windows	0	19	0
Not Glazing	2,848	2,207	1,814
Subtotals			
Rows 1-3	16,272	5,709	6,412
4th, 5th Row and Cargo	342	17	98
Total	24,020	11,188	10,302

[29] The crash data didn't contain ejections from cargo area behind any other seating rows. We considered the cargo area any area of glazing behind seating rows. Although there are some light vehicles with 5 rows, no 5th row occupant was part of the data

Table IV-2
Occupant Injury and Fatality Percentages by Ejection Route in All Crash Types
(Annualized 1997-2008 NASS and FARS)

Ejection Route	MAIS 1-2	MAIS 3-5	Fatal
Windshield	6.3%	12.5%	10.5%
First Row Windows	59.5%	44.5%	54.2%
Second-Row Windows	7.1%	5.7%	7.7%
Third-Row Windows	1.2%	0.8%	0.3%
Fourth-Row Windows	0.0%	0.0%	0.4%
Fifth-Row Window	0.0%	0.0%	0.1%
Cargo Area Rear of Row 2	1.4%	0.2%	0.5%
Backlight	6.8%	12.2%	4.8%
Roof Panel or Glazing	4.2%	3.3%	3.1%
Roof Other	1.7%	0.9%	0.8%
Multiple Windows	0.0%	0.2%	0.0%
Not Glazing	11.9%	19.7%	17.6%
Subtotals			
Rows 1-3	67.7%	51.0%	62.2%
4th, 5th Row and Cargo	1.4%	0.2%	1.0%
Total	100.0%	100.0%	100.0%

Tables IV-1 and IV-2 show that side windows are the most common ejection routes. In particular, real world crash data show that ejection is the largest safety problem for occupant protection in rollover crashes.[30] Among the 6,412 occupants who were killed when they were ejected from vehicles through side windows,[31] 6,385 were from occupants in the 1st and 2nd rows and 73 fatalities were from the 3rd – 5th rows. In addition, 52 fatalities were from the cargo area behind the second row.

[30] S. Partyka, "Incremental Risk of Injury and Fatality Associated with Complete Ejection," November 2009, Docket Number NHTSA-TBD. J. Winnicki, "Estimating the Injury-Reducing Benefits of Ejection Mitigation Glazing," February 1996, Docket Number NHTSA-1996-1782-18, DOT HS 808 369.
[31] Among these fatalities, 6,385 were from occupants in the 1st and 2nd rows and 73 fatalities were from the 3rd – 5th rows. In addition, 52 were from the cargo area behind the second row.

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.[32] 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. Partyka analyzed the incremental injury associated with complete ejection from the front seat of a light vehicle. The study found that avoiding complete ejection would reduce the risk of fatality by75 percent and serious injuries by 84 in rollovers.

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[33] from ejection in some rollover and side crashes,[34] as most curtain air bags are designed to deploy from vehicle's roof rail. Similar to the approaches used in the FMVSS Nos. 208 and 214[35], 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.

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[32] DOT HS 808 369.

[33] 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.

[34] 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. For vehicles with three rows and a cargo area behind the second row, as shown in the costs chapter, we assumed that the three rows can be covered with a single curtain air bag.

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

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 impactor 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.

Target population: The target population is based on annualized injury data from 1997 to 2008 NASS CDS and fatality counts adjusted to the annual average from FARS for these same years. However, the counts are restricted to ejected occupants that were injured. 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 mitigation systems.[36] The NHTSA linear headform test[37] results show that these vehicles would not consistently meet the 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 lateral rollovers and non-rollover side crashes. The population is restricted to occupants ejected through rows 1 – 3 of the side windows and the cargo area behind the 2nd row. However, in this chapter we sometimes simply refer to these occupants as "side window ejected," rather than specifying the row limitation.

[36] 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-2009 target population.
[37] 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.

Table IV-3 – Occupant Injury and Fatality Counts by Ejection Route in Target Population Crash Types (Annualized 1997 – 2008 NASS and FARS)

Ejection Route	MAIS 1-2	MAIS 3-5	Fatal
Windshield	735	961	837
First Row Windows	10,017	3,979	3,837
Second-Row Windows	1,067	499	587
Third-Row Windows	207	62	23
Fourth-Row Windows	0	0	39
Fifth-Row Window	0	0	7
Cargo Area Rear of Row 2	342	17	36
Backlight	953	800	453
Roof Panel or Glazing	999	288	296
Roof Other	420	52	81
Multiple Windows	0	19	0
Not Glazing	2,279	1,874	1,425
Subtotals			
Subtotal-Rows 1-3	11,292	4,540	4,447
Subtotal-4th Row and Cargo	342	17	83
Total	17,019	8,550	7,622

Table IV-4 – Occupant Injury and Fatality Percentages by Ejection Route in Target Population Crash Types (Annualized 1997 – 2008 NASS and FARS)

Ejection Route	MAIS 1-2	MAIS 3-5	Fatal
Windshield	4.3%	11.2%	11.0%
First Row Windows	58.9%	46.5%	50.3%
Second-Row Windows	6.3%	5.8%	7.7%
Third-Row Windows	1.2%	0.7%	0.3%
Fourth-Row Windows	0.0%	0.0%	0.5%
Fifth-Row Window	0.0%	0.0%	0.1%
Cargo Area Rear of Row 2	2.0%	0.2%	0.5%
Backlight	5.6%	9.4%	5.9%
Roof Panel or Glazing	5.9%	3.4%	3.9%
Roof Other	2.5%	0.6%	1.1%
Multiple Windows	0.0%	0.2%	0.0%
Not Glazing	13.4%	21.9%	18.7%
Subtotals			
Subtotal-Rows 1-3	66.3%	53.1%	58.3%
Subtotal-4th Row and Cargo	2.0%	0.2%	1.1%
Total	100.0%	100.0%	100.0%

While the total count of injured and killed occupants decreases by about 30%, when compared to the overall crashes, there is not much change in the distribution between the ejection routes. For rollover crashes, complete and partial ejections were considered, whereas only complete ejections were considered in non-rollover 12-25 mph ΔV (ΔV) side crashes.[38] We note that vehicles that are required to meet the linear headform displacement requirement would also meet FMVSS No. 214 oblique pole test requirements. In 12-25 mph ΔV side crashes, vehicle's side impact sensor would deploy the curtain. Although the majority of vehicles in the target population (pre-2009) were not equipped with an ejection mitigation system, several recent vehicle models (MY 2009, 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 final rule begins in September 1, 2014.[39] For the benefit analysis, we used the projected MY 2011 vehicle sales as a baseline. Potential benefits from these countermeasure systems were excluded from the incremental benefit estimate.[40]

Subcategories of target population:

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[38] 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).

[39] The agency is requiring phase-in of the 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, 2011, the effective date of the phase-in would start September 1, 2014. Although the agency prefers to use MY 2015 projected vehicle sales data of ejection mitigation systems as a baseline, the sales data were not available for this analysis. As a result, we used the available MY 2011 projected data.

[40] 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%).

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.

Table IV-5 – Breakdown of Crash Categories and Occupant Characteristics/Outcomes for Side Window Ejected Occupants
(Rows 1 – 3) Necessary for Ejection Mitigation Standard Target Population Identification

Major Crash Categories	**Crash Subcategory**	**Impact ΔV (km/h)**	**Occupant Age**	**Ejection Degree**	**Injury Outcome**	**Num. Key**
Planar-Only	Side	19 to 40	0 to 12 Yr.	All	All	A
			13+ Yr.	Complete	All	A
				Partial		B
		All Other	All	All	All	C
	Front	All	All	All	All	C
	Rear	All	All	All	All	C
Rollover about Longitudinal Axis	Rollover Preceded by Side Impact	19 to 40	All	Partial	Fatal	B
					Non-Fatal	A
				Complete	All	A
		All Other ΔV	All	All	All	A
	All Other Rollovers	All ΔV for planar component	All	All	All	A
End-Over-End	NA	NA	All	All	All	C
Other (non-rollover)	NA	All	All	All	All	C

Key:

A: Ejection Mitigation Target Population	B: FMVSS 214 Upgrade Ejection Population	C: Remainder of Side Window Ejected

Table IV-6 gives the counts of the injured and killed side window (rows 1 – 3) ejected occupants by the window row they were ejected through, ejection degree and restraint condition. Note that there is no double counting of occupants between the MAIS 3-5 and Fatal categories. Table IV-7 shows the same data as a percentage of total side window ejected fatalities, MAIS 3-5 and MAIS 1-2 injuries. The shaded cells have the maximum counts in each injury level. As would be expected based on occupancy rates, the first row windows provide the ejection route for the most injured and killed occupants. The greatest number of fatally ejected occupants (3,837) went through the first row window. This represents 88% of all side window ejected fatalities. Similarly, 3,979 (89%) MAIS 3-5 and 10,017 (87%) MAIS 1-2 injured occupants went through the row 1 windows. Within each row, the greatest number of fatal and MAIS 3-5 occupants were completely ejected and unbelted. In fact, there were 2,623 (59% = 2,623/(3,837 + 587 + 23)) fatalities and 2,269 (50% = 2,269/(3,979 + 499 + 62)) MAIS 3-5 injuries that were unbelted and completely ejected through the row 1 windows.

Table IV-6 – Distribution of Target Population by Ejection Row and Injury Level by Ejection Degree and Belt Use (Annualized 1997 – 2008 NASS and 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	95	29	54	139	78	5	0	8	0
Complete	No	3,501	2,269	2,623	782	309	421	95	54	23
Partial	Yes	4,345	1,097	484	43	32	38	109	0	0
Partial	No	2,076	584	675	103	80	123	4	0	0
Total		10,017	3,979	3,837	1,067	499	587	207	62	23

Table IV-7 - Distribution of Target Population by Ejection Row and Injury Level by Ejection Degree and Belt Use, as a Percentage of Totals at each Injury Level

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	1%	1%	1%	1%	2%	0%	0%	0%	0%
Complete	No	31%	50%	59%	7%	7%	9%	1%	1%	1%
Partial	Yes	38%	24%	11%	0%	1%	1%	1%	0%	0%
Partial	No	18%	13%	15%	1%	2%	3%	0%	0%	0%
Total		89%	88%	86%	9%	11%	13%	2%	1%	1%

Table IV-8 presents the distribution of the target population for this standard across five vehicle type categories. These categories are passenger car (Car), pickup truck (PU), sports utility vehicle (SUV), Van and Other. The data is separated into complete and partial ejections and the percentages of the total for each injury level are given.

The greatest numbers of fatalities come from occupants completely ejected from passenger cars. These account for 28% of the total fatalities. The greatest numbers of MAIS 3-5 injuries come from occupants partially ejected from passenger cars. These account for 21% of the total at these injury levels. Combining partial and complete ejections, cars account for 43% and 42% of fatalities and MAIS 3-5 injuries, respectively. SUVs and pickups, in that order, account for the next highest levels. Vans makeup the smallest percentage (7% and 4%, respectively) of fatal and MAIS 3-5 ejections in the target population, other than the catchall “other” category.

Table IV-8 – 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	1,158	928	1,239	10%	20%	28%
	PU	1,236	812	793	11%	18%	18%
	SUV	1,881	858	907	17%	19%	20%
	Van	324	147	188	3%	3%	4%
	Other	12	2	0	0%	0%	0%
	Subtotal	4,612	2,747	3,127	41%	61%	70%
	Vehicle	MAIS 1-2	MAIS 3-5	Fatal	MAIS 1-2	MAIS 3-5	Fatal
Partial Ejections	Car	1,429	971	660	13%	21%	15%
	PU	2,515	375	190	22%	8%	4%
	SUV	1,590	402	350	14%	9%	8%
	Van	1,133	44	103	10%	1%	2%
	Other	13	0	17	0%	0%	0%
	Subtotal	6,680	1,793	1,320	59%	39%	30%
	Vehicle	MAIS 1-2	MAIS 3-5	Fatal	MAIS 1-2	MAIS 3-5	Fatal
Total Ejections	Car	2,588	1,899	1,899	23%	42%	43%
	PU	3,750	1,187	983	33%	26%	22%
	SUV	3,471	1,260	1,257	31%	28%	28%
	Van	1,457	192	291	13%	4%	7%
	Other	25	2	17	0%	0%	0%
	Total	11,292	4,540	4,447	100%	100%	100%

In Table IV-9 the target population data from Table IV-8 has been modified in several ways in order to show the relative risk of injury and death by vehicle type. First, all vehicle categories other than Car have been combined to create a Light Truck and Van (LTV) category. Next, the data was normalized by the number of registered Cars or LTVs in millions.[41] This data normalization shows the much higher risk of injury and death associated with LTVs.

The greatest numbers of normalized fatalities and MAIS 3-5 injuries come from occupants completely ejected from LTVs. These account for 51% and 48% of the totals at these injury

[41] The source of the registered vehicle data was R.L. Polk. The data from 1997 through 2007 was averaged. It was necessary to combine all non-car vehicles into a single category because the Polk data did not separated the LTV category into PU, SUV and Van types.

levels, respectively. Combining partial and complete ejections, LTVs account for 69% and 69% of fatalities and MAIS 3-5 injuries, respectively.

Table IV-9
Distribution of Target Population by Vehicle Type per 1 Million Registered Cars and LTVs.

	Vehicle	MAIS 1-2	MAIS 3-5	Fatal	MAIS 1-2	MAIS 3-5	Fatal
Complete Ejections	Car	9	7	10	7%	15%	21%
	LTVs	43	23	24	34%	48%	51%
	Subtotal	52	30	33	40%	63%	71%
	Vehicle	MAIS 1-2	MAIS 3-5	Fatal	MAIS 1-2	MAIS 3-5	Fatal
Partial Ejections	Car	11	8	5	9%	16%	11%
	LTVs	66	10	8	51%	22%	18%
	Subtotal	77	18	13	60%	37%	29%
	Vehicle	MAIS 1-2	MAIS 3-5	Fatal	MAIS 1-2	MAIS 3-5	Fatal
Total Ejections	Car	20	15	15	15%	31%	31%
	LTVs	109	33	32	85%	69%	69%
	Total	129	48	47	100%	100%	100%

For pre and post crash window condition, we estimated in the PRIA that 69% of occupants ejected from the front row window were ejected through a window which was closed prior to the crash. The percentage increased slightly for the 1997 – 2008 crash data used in the FRIA. For the entire target population, the 1997 – 2008 crash data showed that 72% were ejected through a side window that was closed or fixed in position, prior to the crash.

We expect ejection mitigation systems to deploy an ejection countermeasure in a rollover crash.[42] 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

[42] 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.

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.

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 ΔV ranges where appropriate. Both the subcategories of side impact and rollover proceeded by side impact are separated into side impacts with ΔV 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 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 ΔV 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 ΔVs that precede a rollover are also part of the Ejection Mitigation population. Finally, any other crash with a rollover[43] is counted in the Ejection Mitigation population. The breakdown of the target population is shown in Tables IV-10 and -11.

Table IV-10
Breakdown of Crash Categories and Occupant Characteristics/Outcomes for Side Window Ejection Occupants for Ejection Mitigation Target Population Identification for First Three Rows

Major Category	Subcategory	Impact ΔV (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	37	55
			13 & older	Complete[44]	All	91	254
Rollover about Longitudinal Axis	Rollover preceded by side impact	12-25	All	All	Non-fatal	305	0
				Complete	Fatal	0	81
		All other ΔV	All	All	All	204	322
	All other rollovers	All ΔV for planar component	All	All	All	3,903	3,735
					total	4,540	4,447

[43] 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.
[44] 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.

Table IV-11
Breakdown of Crash Categories and Occupant Characteristics/Outcomes for Side Window Ejection Occupants for Ejection Mitigation Target Population Identification for Cargo Area behind Second Row

Major Category	Subcategory	Impact ΔV (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	0	0
			13 & older	Complete[45]	All	0	0
Rollover about Longitudinal Axis	Rollover preceded by side impact	12-25	All	All	Non-fatal	0	0
				Complete	Fatal	0	0
		All other ΔV	All	All	All	0	0
	All other rollovers	All ΔV for planar component	All	All	All	17	43
					total	17	43

The results in Table IV-10 show that the target population for the ejection mitigation standard is 4,490 fatalities and 4,557 MAIS 3-5 injuries for occupants who were partially or completely ejected through the first three rows and the cargo area behind the second row.

For occupants who were ejected in rollover crashes not preceded by a side impact, there were a total of 3,736 fatalities and 3,903 MAIS 3+ non-fatal serious injuries in the target population, when the first three rows were considered. The crash data show that the majority of fatal and non-fatal serious injuries were from unbelted occupants who were completely ejected (4,810 out of 7,639) in rollover crashes not preceded by a side impact, as shown below:

[45] 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.

Table IV-12
Target Population Fatalities and MAIS 3-5 Serious Injuries in
Rollover not Preceded by Side Impacts (Annualized 1997 – 2008 NASS & FARS), First Three Rows

	Fatality			Serious Injury		
Occupant	Partial	Complete	Total	Partial	Complete	Total
Belted	486	50	536	1,074	91	1,165
Unbelted	603	2,597	3,200	525	2,213	2,738
total	1,089	2,647	3,736	1,599	2,304	3,903

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 ΔV's, excluding 19 – 40 km/h ΔV's (12 – 25 mph); (b) side impacts followed by rollover for ΔV's between 19 km/h and 40 km/h;[46] and (c) side impacts without subsequent rollover for ΔV's between 19 km/h and 40 km/h. Each sub-target population is further discussed in the following section.

(a) Side impacts followed by rollover for all but 19 - 40 km/h ΔV's: The crash data show that there were 202 partially ejected and 120 completely ejected occupant fatalities when all ΔV's are considered (a total of 322).[47] Among the 322 fatalities, 7 were belted and 315 were unbelted occupants. Among the 315 unbelted occupants, 195 were from unbelted occupants who were partially ejected and the remaining 120 fatalities were from unbelted occupants who were completely ejected from vehicles.[48] For MAIS 3-5 serious non-fatal injuries, there were 64 partially ejected and 140 completely ejected occupant injuries, a total of 204 serious injuries.

[46] For side impacts followed by rollovers at ΔV's lower than 19 km/h, vehicle's side impact sensors may not deploy the bag. In this ΔV 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 ΔV's higher than 40 km/h, 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 ΔV's higher than 40 km/h.
[47] As discussed above, we excluded belted occupant fatalities from the target population.
[48] 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.

Among the 204 serious injuries, 65% were from unbelted occupants (132). The fatal and non-fatal serious injuries are shown below:

Table IV-13
Target Population Fatalities and MAIS 3-5 Serious Injuries in Side Impacts Followed by Rollovers for
All ΔV's except 19 – 40 km/h mph ΔV's[49]

	Fatal			Serious Injury		
Occupant	Partial	Complete	Total	Partial	Complete	Total
Belted	7	0	7	48	24	72
Unbelted	195	120	315	16	116	132
total	202	120	322	64	140	204

(b) Side impacts followed by rollover for ΔV's between 19 and 40 km/h: We estimated a total of 81 complete fatal ejections: 9 from belted occupants and 72 from unbelted occupants.[50] For serious injuries, a total of 305 MAIS 3-5 injuries occurred: 124 partially ejected and 181 completely ejected occupants, as shown below:

Table IV-14
Fatalities and Serious Injuries in Side Impacts Followed by Rollovers for
ΔV's between 19 km/h and 40 km/h

	Fatal			Serious Injury		
Occupant	Partial	Complete	total	Partial[51]	Complete	total
Belted	0	9	9	6	0	6
Unbelted	0	72	72	118	181	299
total	0	81	81	124	181	305

(c) Side impacts without subsequent rollover for ΔV's between 19 km/h and 40 km/h: This subgroup was further divided by occupant age. For adults (13+ years), there were 254 fatalities and 91 serious injuries in the subgroup, as shown in Tables IV-15 and -16.

[49] The injury numbers were rounded to the nearest integer.
[50] There were 123 partial and 81 complete fatal ejections in a ΔV range of 19 – 40 km/h in side impacts followed by rollovers. The 123 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 81 fatal complete ejections are considered in the analysis.
[51] The FMVSS No. 214-benefit analysis did not include seriously injured occupants who were partially ejected in side crashes (19 – 40 km/h ΔV's) followed by rollovers. These injuries were included in this analysis.

Table IV-15
Fatalities and Serious Injuries in Side Impacts without Subsequent Rollovers for ΔV's between 19 km/h and 40 km/h for 13+ Year Occupants

	Fatal			Serious Injury		
Occupant	Partial	Complete	total	Partial[52]	Complete	total
Belted	0	0	0	0	0	0
Unbelted	0	254	254	0	91	91
total	0	254	254	0	91	91

We note that there were 573 fatalities from partially ejected occupants in the side crashes.[53] 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 in the target population.

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 impactor 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 ΔV range of 19 – 40 km/p.

[52] The FMVSS No. 214-benefit analysis did not include seriously injured occupants who were partially ejected in side crashes (19 – 40 km/p ΔV's) followed by rollovers. These injuries were included in this analysis.
[53] There were 234 fatalities from belted and 339 fatalities from unbelted adult occupants who were partially ejected through side windows in side impacts without any subsequent rollover in a lateral ΔV range of 19 to 40 km/h. These fatalities were included in the 214-target population and, as a result, were not considered in the ejection mitigation benefits.

There were a total of 55 fatalities and 37 serious injuries for children under 13 years old (0-12 years old), as shown in Table IV-16 and Figure IV-1.

Table IV-16
Fatalities and MAIS 3-5 Serious Injuries in Side Impacts without Subsequent Rollovers for ΔV's between 19 km/p and 40 km/p, Children (0-12 years old)*

	Fatal			Serious Injury		
Occupant	Partial	Complete	Total[54]	Partial	Complete	total
Belted	29	0	29	0	0	0
Unbelted	0	26	26	6	31	37
total	29	26	55	6	31	37

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

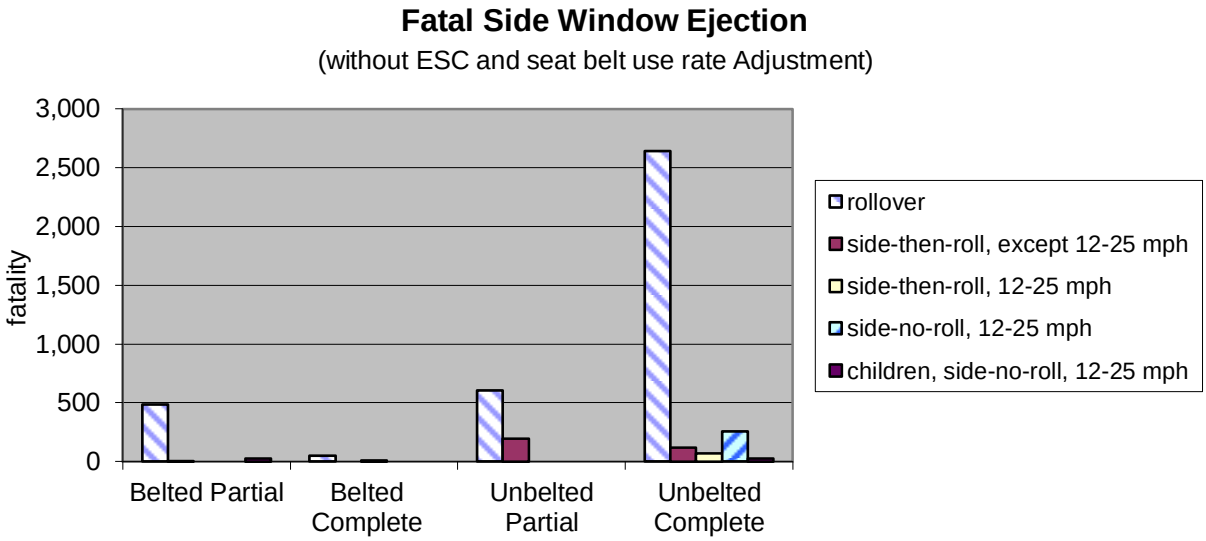

Figure IV-1 Target Population Fatalities and Serious Injuries through First Three Rows and Cargo Area behind Second Row

<u>Additional adjustments made to target population</u>:

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

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

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. We believe that occupants who 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. For the benefit analysis, therefore, we assumed that the system is not effective in protecting completely ejected belted occupants in rollover crashes. Accordingly, completely ejected belted occupants in rollover crashes were not considered for the benefit analysis.[55] There were 50 fatally injured completely ejected belted occupants in rollover crashes.[56] 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, there were 536 belted occupant fatalities. Among the 536 belted occupant fatalities, 486 were partial and the remaining 50 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 50 fatal belted occupants. The assumption implies that all partially ejected belted occupants in fatal crashes 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 10 times higher than the risk of catastrophic fatal crashes

[55] 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.

[56] Among the 50 fatalities, 45 were from the first row window opening and the other 5 were from the second row window opening. For unbelted occupants, similar to the belted occupants, we excluded fatalities resulting from catastrophic rollover crashes.

(486/50 = 9.72 times, or 9.33% of all belted fatalities would be from catastrophic crashes, 50/536 = 9.33%). In other words, the number of fatalities in catastrophic crashes would be 10 times smaller than the number of fatalities resulting from partial ejections. For unbelted occupants, there were 3,243 fatalities in rollovers. Among the 3,243 unbelted fatalities, 603 were from partial ejections and the remaining 2,640 were from unbelted complete ejections. Note that for 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 unbelted occupants would be from non-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 10 (9.72) times smaller than the number of fatalities resulting from partial ejections. Therefore, 62 fatalities out of the 2,640 complete-unbelted ejections ($603_{\text{partial ejection}}/9.72$) = 62) 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 62 unbelted complete fatalities in catastrophic rollovers (i.e., 62 fatalities out of the 2,640 unbelted complete ejections were from catastrophic rollover crashes, i.e., 2.35% of the 2,640 complete unbelted fatalities). Accordingly, these unbelted partial ejection fatalities were not considered in the target population.[57]

[57] 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.

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,[58] as shown below:

Table IV-17
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%	

Based on the ESC rulemaking, for the analysis, we assumed that all applicable new vehicles will be equipped with ESC before this rule is effective.[59] When the target population 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 excluding completely ejected belted occupants in rollovers without any side impacts. Among the 761 fatalities, 226 would be from partial ejections and the remaining 535 would be from complete ejections, as shown below:

[58] 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.

[59] 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.

Table IV-18
After ESC Adjustment, Fatalities for
Occupants Ejected through Side Windows
In Rollover without Side Impacts When Fatalities from Catastrophic Rollovers are Excluded

Occupant	Partial	Complete[60]	Total
Belted	101	0	101
Unbelted	125	535	660
total	226	535	761

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 41% and 6% effective for single vehicle crashes (SVCs) and multiple vehicle crashes (MVCs), respectively, when both passenger cars and light trucks/SUVs are combined in fatal side crashes. Since the target population is 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 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.[61] The ESC adjusted side impact sub-target populations are shown below:

[60] When the unbelted complete ejection fatalities from catastrophic rollover crashes were excluded from the 547 unbelted complete ejection fatalities, it resulted in 535 fatalities. The methodology used for the adjustment is discussed in the method section in this chapter.

[61] 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. In the 214 FRIA, we estimated a total of 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 ΔV range of 12 -25 mph (12% weighted ESC: 41%x16% + 6%x84% = 12%)

Table IV-19
After ESC Adjustment, Fatal Side Impacts Followed by Rollovers for
All ΔV's except 19 – 40 km/h

Occupant	Partial	Complete	Total
Belted	6	0	6
Unbelted	173	106	278
total	173	106	284

Table IV-20
After ESC Adjustment, Fatal Side Impacts Followed by Rollovers, 19 – 40 km/h ΔV

Occupant	Partial	Complete	total
Belted	0	8	8
Unbelted	0	63	63
total	0	71	71

Table IV-21
After ESC Adjustment, Fatal Side Impacts without
Subsequent Rollovers, 19 – 40 km/h ΔV (13+ old)

Occupant	Partial	Complete	total
Belted	0	0	0
Unbelted	0	225	225
total	0	225	225

Table IV-22
After ESC Adjustment, ESC Adjusted Fatal Side Impacts without
Subsequent Rollovers, 19 - 40 mph ΔV, Children

Occupant	Partial	Complete	total
Belted	24	0	24
Unbelted	0	23	23
total	24	23	47

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

Table IV-23. Keys to Table IV-24

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

Table IV-24. ESC adjusted fatal target population, including Ejections through Caro Area, Excluding Catastrophic Crashes

Crash	Occupant	W/o ESC	With ESC	% reduction
A. rollover, no side impacts	Belted Partial	486	101	
	Belted Complete	50	0	
	Unbelted Partial	603	125	
	Unbelted Complete	2,640	535	80%
B. side impacts followed by rollovers, excludes ΔV 12-25 mph	Belted Partial	7	6	
	Belted Complete	0	0	
	Unbelted Partial	195	173	
	Unbelted Complete	120	106	12%
C. side impacts, w/ subsequent rollovers, 12-25 mph:	Belted Partial	0	0	
	Belted Complete	9	8	
	Unbelted Partial	0	0	
	Unbelted Complete	72	63	12%
D. side impacts, no rollovers, 12-25 mph, no children	Belted Partial	0	0	
	Belted Complete	0	0	
	Unbelted Partial	0	0	
	Unbelted Complete	254	225	12%
E. side impact, no rollover, children (0-12 YO), include both partial and complete ejections, 12- 25 mph	Belted Partial	29	26	
	Belted Complete	0	0	
	Unbelted Partial	0	0	
	Unbelted Complete	26	23	12%
	Total	4,490	1,390	69%

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:

The greatest numbers of fatalities come from occupants completely ejected from passenger cars. These account for 28% of the total fatalities. The greatest numbers of MAIS 3-5 injuries come from occupants partially ejected from passenger cars. These account for 21% of the total at these injury levels. Combining partial and complete ejections, cars account for 43% and 42% of fatalities and MAIS 3-5 injuries, respectively. PUs and SUVs combined (light trucks) account for 50% and 54% of all fatalities and MAIS 3-5 injuries, respectively. Vans makeup the smallest percentage (7% and 4%, respectively) of the target population fatal and MAIS 3-5 ejections, other than the catchall *Other* category. 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 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.[62] 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. According to NOPUS, the safety belt use rate has steadily increased for a period of 1994 – 2009, as shown below:

Table IV-25
Safety Belt Use Rate Reported by NOPUS for 1994 - 2009

Year	Estimate
1994	58%
n/a	n/a
1996	61%
n/a	n/a
1998	65%
1999	67%
2000	71%
2001	73%
2002	75%
2003	79%
2004	80%
2005	82%
2006	81%
2007	82%
2008	83%
2009	84%

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

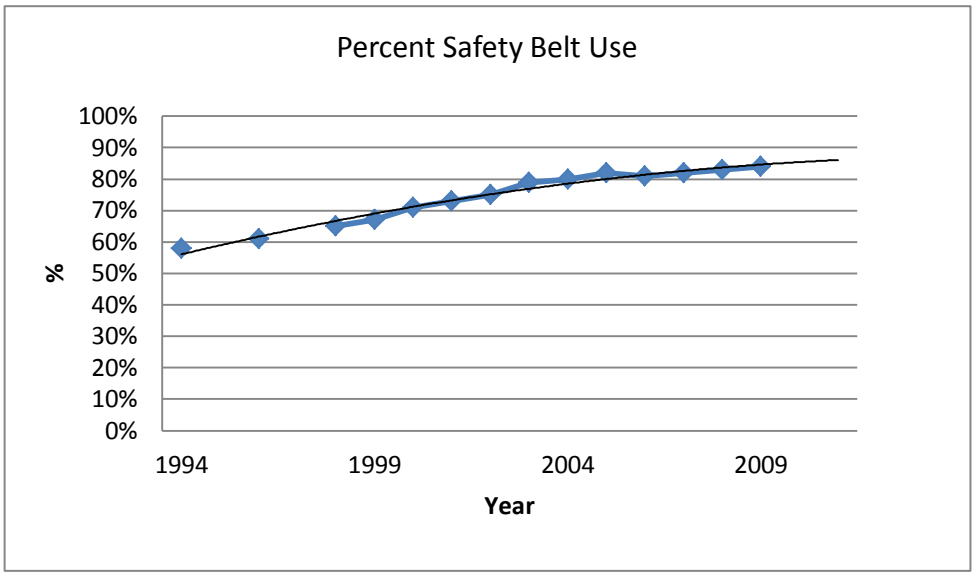

Figure IV-2 Safety Belt Use Rate Reported by NOPUS for 1994 - 2009

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 43% of the side window ejection fatalities were from occupants in passenger cars and the remaining 57% were from light trucks. Therefore, safety belts are 77% and 36% effective in preventing side window ejection fatalities in rollovers and side impacts, respectively

Table IV-27. Weighted Safety Belt Effectiveness in Rollovers and Side Impacts

Fatality & Crash	Cars	Light trucks	weighted
Fatality	43%	57%	
Eff. In Rollovers (primary)	74%	80%	77%
Eff. In Side impacts	21%	48%	36%

For the analysis, due to limited data, we assumed that the most recent 2009 safety belt use rate remains unchanged in 2011. Our analysis showed 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 (on average 76% in a period of 1997 - 2008) and the number of belted fatalities was relatively small.[63] So, the belt use adjustment is from the average 76% belt use rate in the 1997-2008 data base to an 84% belt use rate. Even if the belt use rate increases two or three percentage points in the future (MY 2011), the number of additional lives saved by the increase in belt use would be a small percentage of the overall benefits. ESC and belt use rate adjusted target population is shown below:

[63] If we assume that the belt use rate increases from 76% to 84% in rollovers, 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 = 61% with the 76% use rate and 70% with the 84% use rate. For 100 observed fatalities, the potential fatalities would be 188 with 61% UPFC and 77% safety belt effectiveness in rollovers. Thus, 88 lives would be saved with 76% safety belt use rate. With the 84% safety belt use rate and 70% UPFC, safety belts would save 102 lives. Therefore, lives saved by the higher belt use rate would be 14 (lives) or 14%. Accordingly, the fatal target population would be reduced by 14%. Similar to the method used for rollover fatality, we estimated that the side impact fatal target population would be reduced by 4%. 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.

Table IV- 27. After Adjustment for ESC and Belt Use Rate, Fatal Target Population, including Ejections through Caro Area, Excluding Catastrophic Crashes

Crash	Occupant	W/o ESC	With ESC	Adj. belt use rate	% reduction
A. rollover, no side impacts	Belted Partial	486	101	87	
	Belted Complete	50	0	0	
	Unbelted Partial	603	125	125	
	Unbelted Complete	2,640	535	535	80%
B. side impacts followed by rollovers, excludes ΔV 12-25 mph	Belted Partial	7	6	6	
	Belted Complete	0	0	0	
	Unbelted Partial	195	173	173	
	Unbelted Complete	120	106	106	12%
C. side impacts, w/ subsequent rollovers, 12-25 mph:	Belted Partial	0	0	0	
	Belted Complete	9	8	8	
	Unbelted Partial	0	0	0	
	Unbelted Complete	72	63	63	12%
D. side impacts, no rollovers, 12-25 mph, no children	Belted Partial	0	0	0	
	Belted Complete	0	0	0	
	Unbelted Partial	0	0	0	
	Unbelted Complete	254	225	225	12%
E. side impact, no rollover, children (0-12 YO), include both partial and complete ejections, 12- 25 mph	Belted Partial	29	26	24	
	Belted Complete	0	0	0	
	Unbelted Partial	0	0	0	
	Unbelted Complete	26	23	23	14%
	Total	4,490	1,390	1,374	69%

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

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 that were 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 19 – 40 km/h, (b) followed by rollovers in a ΔV range of 19 – 40 km/h, (c) adults in side impacts without any subsequent rollover in a 19 – 40 km/h vehicle ΔV range, and (d) children in side impacts without any subsequent rollovers in a vehicle ΔV range of 19 – 40 km/h.

For the complete and partial ejections in rollovers not preceded by side impacts, the adjusted target population show that 213 partial and 535 complete fatal ejections would occur, annually.[64] Among these fatalities, 87 would be from belted occupants and the remaining 660 would be from unbelted occupants. When these fatalities are separated by vehicle's seating row, it showed that 659 would be from the first row, 75 would be from the second row, 5 would be from third row and the remaining 9 would be from the cargo area behind the second row. For MAIS 3-5 injuries, we estimated that 320 and 496 serious injuries would occur from partial and complete ejections, respectively, in rollover crashes. Among these injuries, 224 would be from belted and the other 592 would be from unbelted occupants. When the serious injuries are separated by vehicle's seating row, it showed that 729 would be from the first row, 77 would be from the

[64] 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.

second row, 6 would be from third row and the remaining 4 would be from the cargo area behind the second row.

Table IV-28
Adjusted 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	169	72	6	91	3	0	2	8	252	99
Unbelted	158	48	8	217	411	183	105	783	913	1,000
Total	327	120	14	309	414	183	107	790	1,165	1,099

* The injury numbers were rounded to the nearest integer

Table IV-29
Adjusted 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	4	2	0	26	19	2	11	0	37	26
Unbelted	22	7	1	80	77	34	19	155	160	236
Total	26	9	1	106	96	36	30	155	198	262

* The injury numbers were rounded to the nearest integer

Table IV-30
Adjusted 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	0	0	0	1	0	1	0	2	0
Unbelted	0	0	0	0	21	9	5	5	35	5
Total	0	0	0	0	22	9	6	5	37	5

* The injury numbers were rounded to the nearest integer

Table IV-31
Adjusted Fatal and MAIS 3-5 Injuries
Ejection through Cargo Area behind Second Row

Occupant	Partial Ejection				Complete Ejection				Total*	
	MAIS			Fatal	MAIS			Fatal		
	3	4	5		3	4	5		Injury	Fatal
Belted	1	0	0	0	1	0	1	0	3	0
Unbelted	0	0	0	0	0	0	0	9	1	9
Total	1	0	0	0	1	0	1	9	4	9

Benefits Derivation:

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 ΔV range of 19 km/h 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.[65]
- 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.[66]

[65] 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 could underestimate the potential benefits.

[66] 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.

- Side head air bags (that are designed to meet the FMVSS No. 214-oblique pole requirements) are not effective in preventing occupants from complete ejection in side impacts.
- 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.
- 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.
- Two separate assumptions were used for the 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: group fatal and serious injuries (MAIS 3-5) by crash type (rollover or side impacts), ejection type (partial or

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

complete) and belt use in Section B.1; calculate performance of the ejection mitigation air bag system in Section B.2; calculate overall percentage reduction rates in Section B.3; and derive benefits in Section B.4. The following is a detailed description of these steps.

B.1 Group Fatal and Serious Injuries: The fatal and serious injuries in the target population were categorized by crash mode, ejection type and belt use. We considered four different crash types in the analysis namely rollovers without side impacts, side impacts followed by rollovers excluding 19 – 40 km/h ΔV's, side impacts with subsequent rollovers in a vehicle ΔV range of 19 – 40 km/h, and finally, side impacts without subsequent rollovers in a vehicle ΔV range of 19 – 40 km/h. 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. As discussed in the target population section, when adjusted with the potential benefits of ESC, 214-pole requirements, and increase in seat belt use rate, we estimated a total of 1,374 fatalities and 1,403 serious injuries in the target population. The adjusted target population showed that 87% of fatalities and 72% of serious injuries were unbelted occupants.

B.2 Calculate Performance of Ejection Mitigation System: 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]

[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.

B.2.1. Sensor Effectiveness:

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. The agency has not done any comprehensive 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. For the benefits analysis, we assumed that 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.[70]

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.[71] For the analysis, therefore, we assumed that rollover sensors are

[70] 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.

[71] The agency is aware of non-deploying rollover bags in real world crashes. However, these non-deployment cases would not be indicative of the performance of rollover sensors. As part of the final rulemaking, the agency examined SCI rollover crashes, NASS CDS cases from the target population of the final rule and data from the Rollover Data Special Study (RODSS) project and found five case vehicles where the vehicle was apparently equipped with a side curtain air bag that was supposed to be deployed by a rollover sensor. These curtains did not deploy in the rollover event. On a crash basis, the average number of ¼ turns was 3.6.

There were two completely ejected occupants and one partial ejected occupant in these crashes. The results of these ejections were 3 fatalities. All of these ejections were through side windows that would have been covered to some extent by the curtain, except one. The one exception was a MY2006 Ford Explorer where the front passenger door was dislodged from the vehicle and provided the ejection route for the unbelted driver. What seems to be consistent

not effective in low-energy (slow) lateral rolls, which result in a single quarter turn. 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 Investigation 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

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among several of these non-deployment cases is that the rollover was preceded by a significant front impact. The MY2006 Ford Explorer in RODSS case 6121 had a right front corner impact with a large tree prior to the rollover. The MY2003 Lincoln Aviator in RODSS case 7242 had an offset frontal impact with an oncoming vehicle prior to the rollover. The MY2006 Cadillac SRX in SCI case DS07009 impacted a large tree prior to the rollover. The EDR data from this case indicated that the tree impact had a longitudinal and lateral ΔV of -38.9 mph and -10.2 mph, respectively. The EDR also indicated that the rollover sensor status was "invalid" and the curtain deployment was not commanded. The MY2009 Dodge Journey had a narrow offset frontal impact with another vehicle, which the crash investigator stated disrupted the power supply from the battery. The frontal air bags deployed in the above four crashes.

RODSS and SCI rollover cases where the rollover curtain did not deploy

CASE ID	Year/Make/Model	1/4 Turns	Curt. Depl.	Seat Pos.	Belt Use	Age	Eject.	Route	Injury/ MAIS
RODSS									
5032	04 Lincoln Aviator‡	3	No	11	No	68y	Comp.	Row 2 R	Fatal
6121	06 Ford Explorer	4	No	11	No	23y	Comp	Door (13)	Fatal
7242	03 Lincoln Aviator‡	3	No	11	Yes	28y	No	NA	Serious
7242	03 Lincoln Aviator‡	3	No	13	Yes	26y	No	NA	Serious
7242	03 Lincoln Aviator	3	No	21	CRS	3y	No	NA	Serious
7242	03 Lincoln Aviator	3	No	23	Yes	7y	No	NA	Serious
SCI									
DS07009	06 Cadillac SRX	4	No	11	No	81y	Part.	Row 1 L	Fatal
DS09071	09 Dodge Journey	4	No	11	Yes	63y	No	NA	2
DS09071	09 Dodge Journey	4	No	13	Yes	60y	No	NA	1

‡These seating positions had laminated glazing adjacent to them.

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

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. The 2000 to 2009 NASS CDS crash data showed that 11% of partially ejected occupants who were killed in rollovers were from one-1/4 turn rollovers. For AIS 3+ injuries, excluding fatality, the CDS data showed that 6% were from one-1/4 turn rollovers.[73] Accordingly, we assumed that the sensor is 89% (1-0.11 = .81, 89%) effective in fatal rollovers and 94% (1-0.06 = .94, 94%) in MAIS 3+ injuries rollovers.

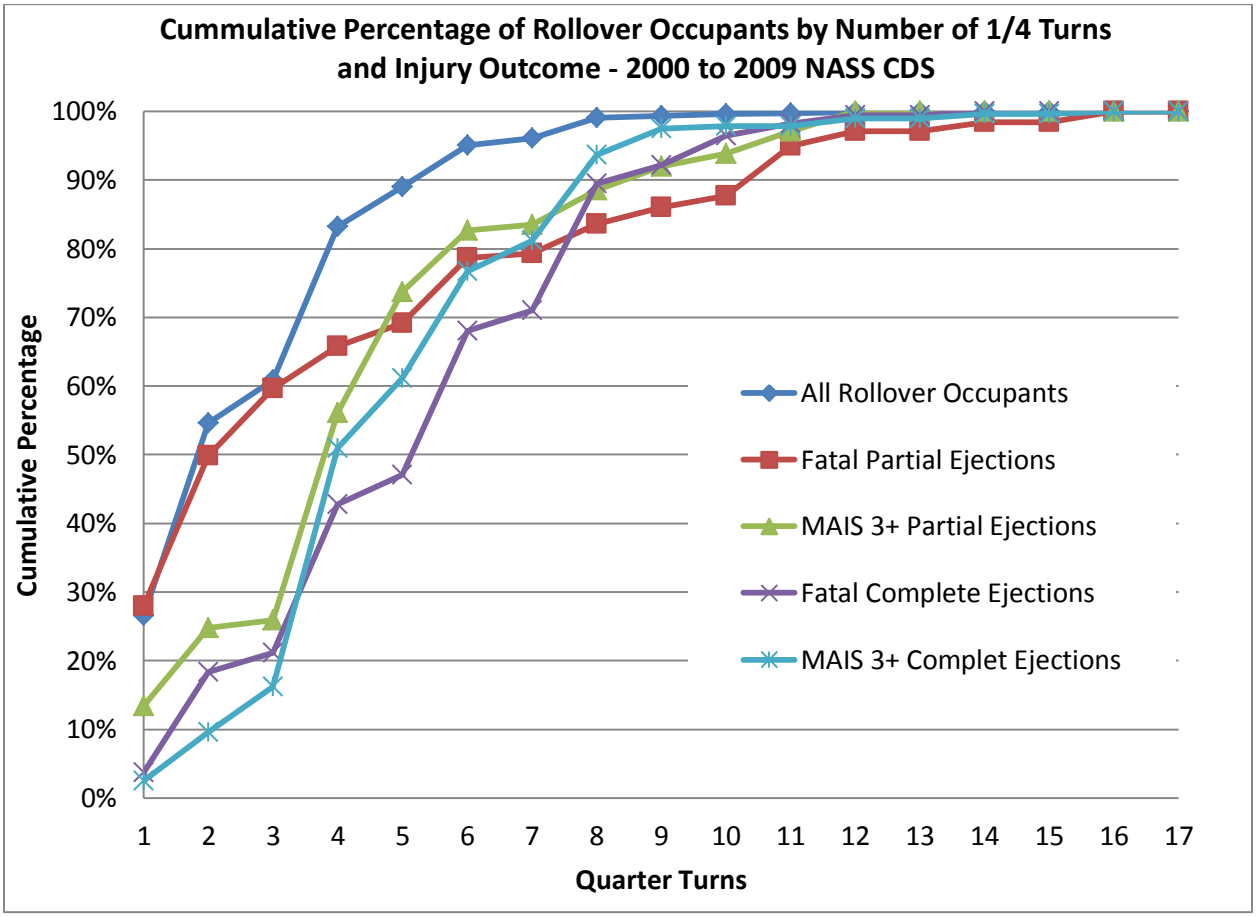

Figure IV-3 Cumulative Percentage of Rollover Occupants by Number of ¼-turn

[73] We note that suppliers estimate their rollover sensors will work between 90% and 95% of rollovers.

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 ΔV's equal to or higher than 19 km/h.[74] 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 ΔV's, (2) side impacts followed by rollover with 19 - 40 km/h, and (3) side impacts without any rollover in a lateral ΔV range of 19 - 40 km/h.

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 ΔV's lower than 19 km/h. In other words, when a vehicle rolls more than one-quarter turn after a side impact, which occurs at a vehicle lateral ΔV of 19 km/h or lower, its rollover sensor would deploy the air bags.[75] As for side impacts followed by rollover at ΔV's higher than 40 km/h, 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. For ΔV's higher than 40 km/h 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.[76] For the second and third side impact cases mentioned above, we assumed

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[74] Although side sensors would be effective in this ΔV's (19+ km/h), we estimated that the countermeasures and/or vehicle structure would not be effective in ΔV's higher than 40 km/h in side crashes.

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

[76] 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 ΔV 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

that side impact sensors detect impacts and trigger the deployment in a vehicle ΔV range of 19 - 40 km/h, 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 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, at least early in the rollover event. If we assume that the peak ejection velocity increases as the number of rolls 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). (We note that, in addition to withstanding the peak occupant ejection velocity, a rollover curtain air

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is not capable of detecting these single quarter turn rolls. Consequently, by assuming its rollover sensor triggers the bag at these ΔV's, we would underestimate the potential ejection mitigation benefits.

bag must have a sufficient deployment time to prevent late ejections in a sever rollover.) To validate the conjecture that the energy level is proportional to the number of rolls, we examined how test dummies behave during a 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-32
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). Thus, this very limited 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: 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 leading-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.[77] In the report, D. Knapton states that a total of 10 impacts are 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

[77] 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.

(below the opening, such as window sill) for belted occupants in rollovers.[78] The real world rollover crash and laboratory test data indicate 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.[79] For the analysis, therefore, we assumed that 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 the lower portion of the opening, when such ejections occur.[80]

While the majority of vehicle occupants would be contained by rollover air bags, the current design indicate that some occupants could be ejected through potential gaps around the bottom

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[78] 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.

[79] 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 15% and 9%, respectively. We note that in this study 46% of the tests were less than a ¼-turn, 27% were one ¼-turn and 27% were two ¼-turns. (O'Brian-Mitchell, Bridget M., Lange, Robert C., "Ejection Mitigation in Rollover Events – Component Test Development," SAE 2007-01-0374.)

[80] The real world crash data and limited laboratory test data 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 minimum containment 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.

and front lower portion of the air bag.[81] To determine the effectiveness, we derived the 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.[82, 83]

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 the 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]

Table IV-33
Belted and Unbelted Test Dummies Combined

	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

[81] The potential gap is further discussed in the latter part of the containment section.
[82] For light vehicles with three seating rows or a cargo area behind the second row, we assumed that the curtain air bag is attached at A- and D-pillars.
[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.
[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-34
Unbelted Test Dummy with Interior Impact Objects around Window Opening

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

Table IV-35
Belted Test Dummy with Interior Impact Objects around Window Opening:

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

Table IV-36
Belted dummy impacts above and below window opening area

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

[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.

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

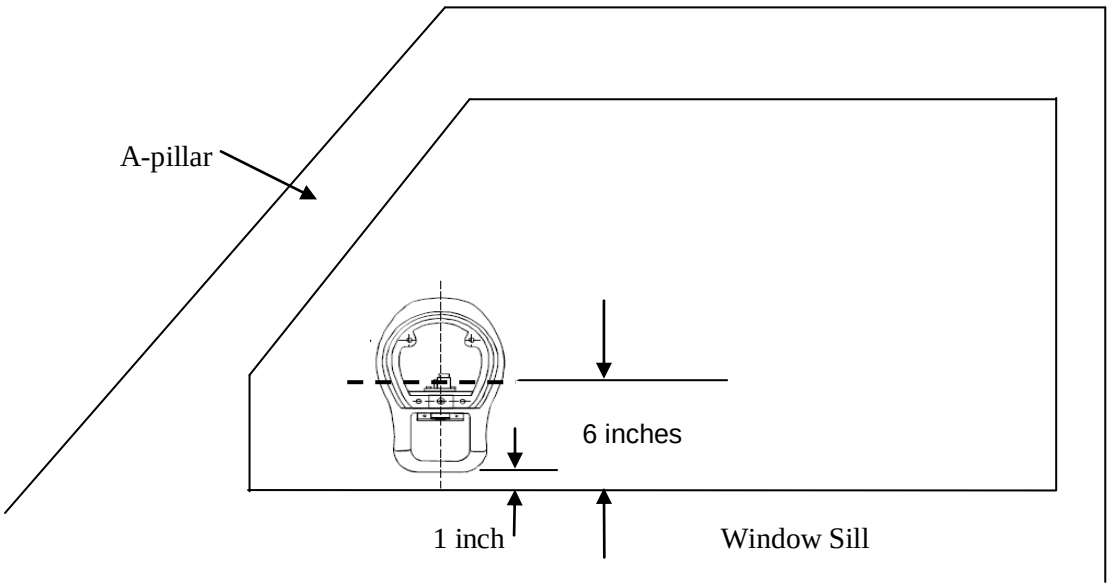

Figure IV-4. Position of Impactor (headform) with respect to Window Sill

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 through the front window opening 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]

[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

For example, the window opening of a 2003 model year Toyota Camry has a height of 46 cm (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-4). If the 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). Therefore, 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

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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”.

[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 headform 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-5), 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 of an occupant 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.

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). The derivation 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, the dolly test in FMVSS No.208 (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 rollovers. However, we note that almost all of the 208 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

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[91] In other words, if the ejections are 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, more than 67% of ejections would occur through the upper 67% of the window opening area. Therefore, the containment effectiveness would be greater than 67%.

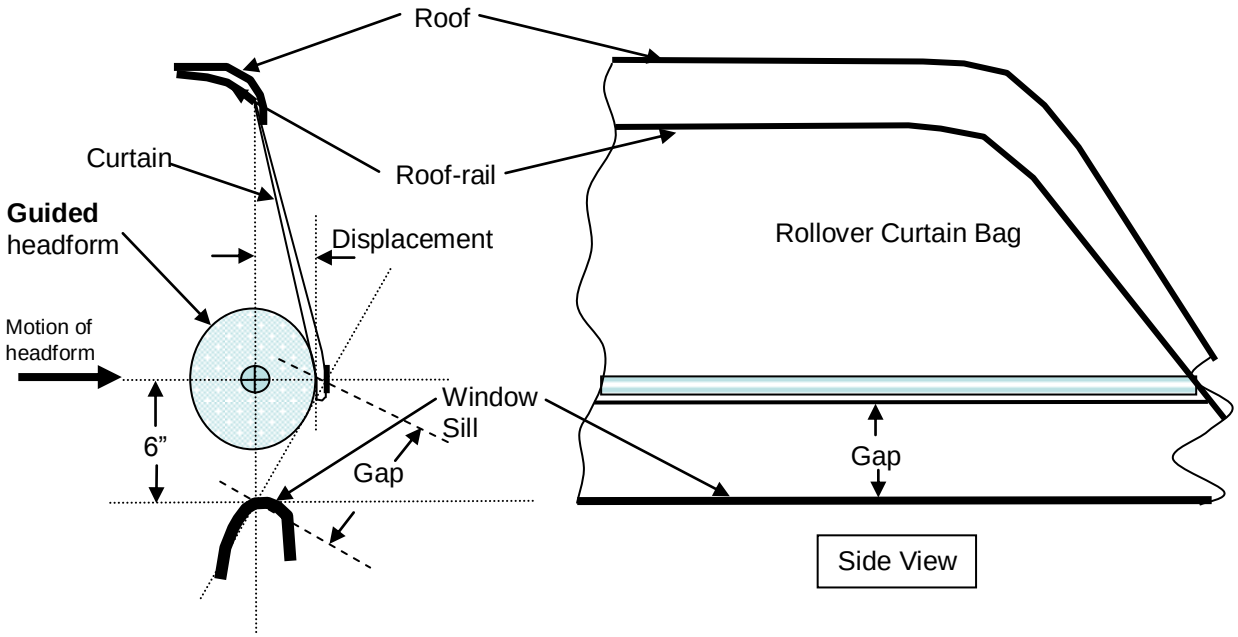
[92] The 6 inch potential gap would be large enough to allow upper extremities (hands, arms and shoulders) to contact exterior objects in rolls. For belted occupants, we speculate that the majority of upper extremity injuries would occur when these body parts are ejected through areas near the window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

[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 leading 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.

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] We note that, as discussed in the target population section, 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 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 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.

[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. 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 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-5. 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. In addition, the risk of ejection through the window opening area in vertical and lateral directions was estimated separately.

Risk of ejection with respect to the upper and lower portions of the window (i.e., vertical direction):

(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-37
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-38
Likelihood of Impact Above and Below Window Opening, Belted Occupants

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, 33% would occur through the lower 50% of the window opening. Accordingly, 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 impactor requirements would be 78% for belted occupants in rollover crashes, if there were no other potential gaps 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 rollovers and side impact crashes involving different occupant kinematics. The impactor 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 impactor 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 head and 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

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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 belted occupant ejections would occur through the potential gap in the lower portion of the window opening. As discussed, the rollover test results showed that 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 belted 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 belted occupants, 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 belted occupants in rollovers. When both 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 belted occupants 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 impactor requirements.

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 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-leading 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 Vertical 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. We determined that the number of dummy impacts were too small to derive an impact distribution

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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.

with respect to the window opening area. Therefore, for unbelted occupants who 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 vertical 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-39a
Percent Distribution of injury Sources in Rollovers, 1988-1990 NASS/GES

Restrained			Unrestrained		
Injury Source	Sample Count	Injured %	Injury Source	Sample Count	Injured %
Lower Side Intr	11	2.1%	Exterior	117	14.0%
Seatbelt	22	4.3%	All Other	516	61.6%
Exterior	12	2.3%	Roof	45	5.4%
All Other	331	63.5%	A & B Pillars	13	1.5%
Rail/Headers	10	1.9%	Rail/Headers	21	2.5%
Roof	32	6.1%	Windshield Edges	6	0.7%
Upper Side Intr	7	1.3%	Windshield	28	3.3%
A & B Pillars	2	0.4%	Lower Side Intr	16	1.9%
Noncontact	29	5.6%	Steering Assemble	21	2.5%
Loose Objects	5	1.0%	Dash	34	4.1%
Steering Assemble	18	3.5%	Seatback	2	0.2%
Dash	32	6.2%	Flying Glass	19	2.3%
Windshield Edges	2	0.4%			
Armrests	6	1.2%			
Seatback	2	0.4%			
Total	521	100.0%	Total	838	100.0%

Table IV-39b
Occupant Impacts on Upper Portion of Window Opening Area
1988-1990 NASS/GES

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

[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

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

Table IV-41
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 interior impacts	5.76%	5.97%

The results in Table IV-41 show that 5.76% of interior impacts occurred with side interior components for restrained occupants and 5.97% for unrestrained occupants.[102] The field data show that it would be reasonable to assume that both 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. Previously we estimated that the probability of impacting the upper portion of the window opening would be 67% for belted occupants in rollovers. With the 1.3 adjustment factor, we estimated that the probability of impacting the upper portion would be 73% for unbelted occupants, when such impacts occur, as shown below:

Table IV-42
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%[103]
Lower portion (below window)	33%	27%
Total	100%	100%

[102] Although the NASS sample count shows that belted and unbelted occupants would have a similar risk of striking interior side components, 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.
[103] [(67/33)x1.3]/[(67/33)x(1.3) + 1] = 0.725, 73%

Table IV-42 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.[104] 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% vertical containment effectiveness rate that was derived for belted occupants as a proxy.[105] In summary, the real world crash data suggest that unbelted occupants would have a higher risk of ejection through the upper portion of the window opening, when compared to belted occupants. The assumption that unbelted occupants would have the same risk of ejection through the window opening as belted occupants in rollovers would not over estimate the potential benefits.

Risk of ejection through area between curtain air bag and A-pillar (i.e., lateral direction): Previously, we estimated the risk of ejection with respect to the upper and lower areas of the window opening (i.e., vertical direction). Since the impact points spread across the window

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[104] 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. As a result, they would 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.

[105] Consequently, the use of the containment effectiveness rate derived for belted occupants, as a proxy, for unbelted occupants would underestimate the potential benefits.

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).

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

Table IV-43
Belted Dummy Impacts with A- and B-Pillars, Front Window Opening

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

The results in Table IV-43 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. Similar to the methodology used for the vertical direction, 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-44
Belted Dummy Impact Points, with respect to
Front and Rear of Front 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-45
Likelihood of Impacting Rear and Front of Window Opening
Belted Occupants, Ejection through Front Window Opening

Segment of Front Window Opening	% of
Rear half of window opening	83%
Front half 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.[106] For a typical two row passenger car, 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 the air bag is attached to the lower 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 air bag 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), 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 impactor at this area. To meet the impactor

[106] 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 8.5% (17%/2 = 8.5%).

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). The new front anchor position would provide a sufficient tension without excessive gas pressure in the air chambers. [107] The configuration of the front window of a typical passenger car shows that the CG of the headform positioned at A1 would be near the midpoint of the front window opening.[108] 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 assumed that only the bottom ½ of the area (that is, the area between the bag and A-pillar) would allow (partial) ejection,[109] as shown in Figure IV-6.

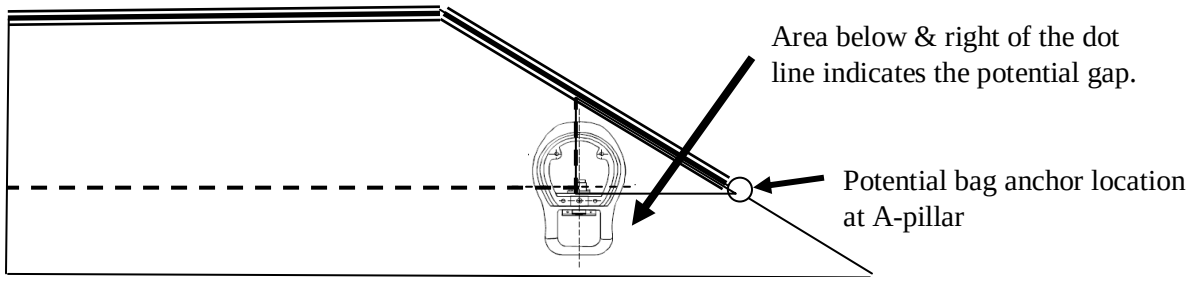

Figure IV-6. Illustration of Front Window Opening & Potential Ejection Area in Front Window Opening

[107] 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).
[108] 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.
[109] As shown in Figure IV-6, 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, 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.

The majority of current single-piece curtain air bags installed in two row passenger cars 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 that meets the impactor displacement requirement would prevent them from ejection in rollover crashes.[110] Under the assumptions, approximately 5% of belted occupants would be ejected through the potential opening in the front lower corner of the window opening (between A-pillar and the window sill).[111] 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 the window sill and the lower portion of the A-pillar, as illustrated in Figure IV-6. Therefore, we suspect that the head of an adult occupant in a passenger car is too large to go through this narrow opening area. However, upper extremities (such 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 above, we assumed that window openings are rectangular in shape with a height of 46 cm (18 inches) and an opening area of

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[110] 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.

[111] 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, we estimate that 5% of ejection would occur through the potential opening. 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%].

6,619 cm^2 (1,026 in^2) of the Camry. One of the consequences of assuming "rectangle" shape 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 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 FRIA.

Unbelted Occupants (lateral distribution):

As discussed previously, we have very limited data for unbelted dummies. 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. The dummy test results 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. For the containment estimate, therefore, we have decided to use the unbelted dummy impact data for the lateral distribution for unbelted occupants.

Table IV-45
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-46
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-47
Likelihood of Ejecting through Potential Gap between A-pillar and Bag, Unbelted Occupants

Segment	% of
Rear half of gap	50%
Front half of gap	50%

The results in Table VI-47 show that 50% of unbelted occupants would be ejected through the front ½ portion of the front window opening area. 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 front window opening area.

<u>Overall risk of ejection through front window opening</u>:

(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-48
Risk of Ejection through Front Window Opening
Belted Occupants without Considering Ejection through Sun/Moonroof
Weighted Risk Containment Method

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-49 show the risk of ejection through the front side window opening, which was based on the relative position of the impactor and also rollover tests performed with selected vehicles. Due to limited data, we assumed that AIS 3+ injuries, including fatalities, were head-lead ejections in the analysis. With the potential gaps in the front low corner and bottom of the curtain air bag, we estimated that the hypothetical ejection mitigation curtain air bag would be 75% effective in preventing belted occupants from ejection through the front side window opening in rollover crashes.[112]

(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

[112] The numbers were rounded to the nearest integer. We note that 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-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. Under the assumption, the containment effectiveness would be 75% (65% + 6% +6%x (1/2) = 75%, rounded to the nearest integer).

distributed than belted occupants: assuming 25% risk of ejection through the opening, as shown below:

Table IV-49
Risk of Ejection through Front Window Opening
Unbelted Occupants without Considering Ejection through Sun/Moonroof
Weighted Risk Containment Method

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

Similar to the method used for belted occupants, with the potential gaps in the front and bottom of the curtain, we estimated that the hypothetical ejection mitigation curtain air bag would be about 68% effective in preventing unbelted occupants from ejection through the front window opening in rollover crashes.[113]

Table IV-50
Containment Effectiveness without
Considering Ejection through Sun/Moonroof

Belt Use	Containment Effectiveness
Belted	75%
Unbelted	68%

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 impactor test 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

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

(that is capable of meeting the requirements) would not allow complete ejections even with the potential gaps in most rollovers.

Ejection through a Moonroof or Sunroof for Belted Occupants:

According to the 1997 – 2008 crash data, there were 10,302 fatalities and 11,188 serious injuries when occupants were ejected from vehicles. Among these fatalities and serious injuries, 324 fatally and 367 seriously injured occupants were from ejections through the roof panel or glazing. For the lateral roll target population, the crash data showed a total of 7,622 fatalities and 8,550 serious injuries. Among these fatalities and serious injuries in the target population, 296 fatally and 288 seriously injured occupants were from ejections through the roof panel (sunroof) or glazing (moonroof). We note that most of fatal roof panel or roof glazing (sun/moonroof) ejections occurred during lateral rollover crashes. When the crashes were limited to lateral rollovers, as considered in the target population, the number of fatalities decreased from 324 to 296 (i.e., decreased by 8.6%). In other words, 91.4% of all fatal sun/moonroof ejections occurred in lateral rollovers that were considered for the target population. For serious injuries, the number of serious injuries decreased from 367 to 288 (i.e., decreased by 21.5%).

Table IV-51
Occupant Injury and Fatality Counts by Ejection Route in **All Crash Types**
Annualized 1997 – 2008 NASS and FARS)

Ejection Route	MAIS 1-2	MAIS 3-5	Fatal
Windshield	1,517	1,400	1,078
First Row Windows	14,293	4,980	5,589
Second-Row Windows	1,700	641	796
Third-Row Windows	279	88	27
Fourth-Row Windows	0	0	39
Fifth-Row Window	0	0	7
Cargo Area Rear of Row 2	342	17	52
Backlight	1,621	1,364	495
Roof Panel or Glazing	1,000	367	324
Roof Other	420	105	81
Multiple Windows	0	19	0
Not Glazing	2,848	2,207	1,814
Subtotals			
Rows 1-3	16,272	5,709	6,412
4th, 5th Row and Cargo	342	17	98
Total	24,020	11,188	10,302

Table IV-52
Occupant Injury and Fatality Counts by Ejection Route in Target Population Crash Types
(Annualized 1997 – 2008 NASS and FARS)

Ejection Route	MAIS 1-2	MAIS 3-5	Fatal
Windshield	735	961	837
First Row Windows	10,017	3,979	3,837
Second-Row Windows	1,067	499	587
Third-Row Windows	207	62	23
Fourth-Row Windows	0	0	39
Fifth-Row Window	0	0	7
Cargo Area Rear of Row 2	342	17	36
Backlight	953	800	453
Roof Panel or Glazing	999	288	296
Roof Other	420	52	81
Multiple Windows	0	19	0
Not Glazing	2,279	1,874	1,425
Subtotals			
Subtotal-Rows 1-3	11,292	4,540	4,447
Subtotal-4th Row and Cargo	342	17	83
Total	17,019	8,550	7,622

Table IV-53
Occupant Injury and Fatality Percentages by Ejection Route in Target Population Crash Types
(Annualized 1997 – 2008 NASS and FARS)

Ejection Route	MAIS 1-2	MAIS 3-5	Fatal
Windshield	4.3%	11.2%	11.0%
First Row Windows	58.9%	46.5%	50.3%
Second-Row Windows	6.3%	5.8%	7.7%
Third-Row Windows	1.2%	0.7%	0.3%
Fourth-Row Windows	0.0%	0.0%	0.5%
Fifth-Row Window	0.0%	0.0%	0.1%
Cargo Area Rear of Row 2	2.0%	0.2%	0.5%
Backlight	5.6%	9.4%	5.9%
Roof Panel or Glazing	5.9%	3.4%	3.9%
Roof Other	2.5%	0.6%	1.1%
Multiple Windows	0.0%	0.2%	0.0%
Not Glazing	13.4%	21.9%	18.7%
Subtotals			
Subtotal-Rows 1-3	66.3%	53.1%	58.3%
Subtotal-4th Row and Cargo	2.0%	0.2%	1.1%
Total	100.0%	100.0%	100.0%

When the ejection route is limited to side window opening, including the cargo area behind the second row, it resulted in 4,825 fatalities and 4,845 serious injuries.

Table IV-54
Occupant Injury and Fatality Counts by Ejection Route in Target Population Crash Types
Limited to Windshield, Side Window Opening, Back Light and Roof Glazing &
Panel(Annualized 1997 – 2008 NASS and FARS)

Ejection Route	MAIS 1-2	MAIS 3-5	Fatal
Windshield	735	961	837
Row 1 window	10,017	3,979	3,837
Row 2 window	1,067	499	587
Row 3 window	207	62	23
Row 4 window	0	0	39
Row 5 window	0	0	7
Cargo area rear of 2nd	342	17	36
Backlight	953	800	453
Roof panel or glazing	999	288	296
Roof Other	420	52	81
Multiple Glazing	0	19	0
Not glazing	2,279	1,874	1,425
Side window & roof total	12,632	4,845	4,825

During lateral rollover events, our analysis shows that side windows and the sun/moonroof would be most likely ejections routes. For the target population, as shown in Table IV-55, the agency's real world crash data show that 5.9% of seriously and 6.1% of fatally injured occupants were resulting from ejections through the sun/moonroof, when the ejection route is limited to side window opening, including the cargo area behind the second row. In addition, the crash data showed that 49.9% of MAIS 3+ injuries were fatalities and the remaining 50.1% were serious but non-fatal injuries. On average, therefore, 6% of MAIS 3+ injuries were from occupants who were ejected through the roof panel or roof glazing. In other words, when ejections through side windows and the sun/moonroof are considered, the crash data show that 6% of the ejections occurred through the sun/moonroof.[114] (Note that the 6% sun/moonroof ejection rate is based on 1997-2008 NASS and FARS.

The rollover crash data show that some occupants would bounce off the interior components before ejecting through an opening (including sun/moonroof) in certain multiple rollovers. Therefore, we suspect that the actual percentage would be higher than the 6% estimated ejection rate, when vehicles have a curtain ejection mitigation system.[115] Although a small number of adult occupants would rebound if the sun/moonroof were closed and intact, we do not have data to quantify the number of these occupants. Due to limited data, therefore, we assumed that 6%

[114] There were 4,845 serious (50.1%) and 4,825 fatal (49.9%) ejection injuries in the target population, a total of 9,670. Among these injuries, 288 serious (5.9%) and 296 fatal (6.1%) injuries were from sunroof ejections. Thus, (50.1%*5.9%) + (49.9%*6.1%) = 6.0%.

[115] The 6% 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 sun/moonroof would be higher than 6% when all vehicles are equipped with (rollover curtain bags). However, we were unable to quantify the percentage of ejections through the sun/moonroof with a curtain air bag meeting the proposed requirements.

of all AIS 3+ (induced) ejections occur through the sun/moonroof as some occupants bounce off side window curtain air bags.

Below, in Tables IV-55.and -56, we explore the roof ejection route in more detail in all crashes. To that end, we separated the "Roof Panel or Glazing" category into its constituents and also indicated whether these structures were closed, open or unknown if open before the crash. The largest number of ejections from this group comes from the closed roof glazing (221 fatalities and 219 MAIS 3+ injuries), representing 55% and 46% of all roof ejection fatalities and serious injuries, respectively. However, ejections through closed roof glazing represents only 2.1% [221/10,302] of all ejection fatalities. The largest constituent from of the "Roof Other" category is open convertibles (31 fatalities and 84 MAIS 3+ injuries), representing 8% and 18% of all roof ejection fatalities and serious injuries, respectively.

Table IV-55 – Occupant Injury and Fatality Counts by Roof Ejection Route in All Crash Types (Annualized 1997 – 2008 NASS and FARS)

Ejection Route	MAIS 1-2	MAIS 3+	Fatal
Roof glazing, closed	855	219	221
Roof glazing, open	61	39	56
Roof glazing, unknown	74	97	28
Roof panel, closed	0	1	0
Roof panel, open	10	11	18
Roof, convertible top, closed	212	18	16
Roof, convertible top, open	105	84	31
Roof, convertible top, unknown	23	3	3
Roof, removable, closed	26	0	0
Roof, modified, open	13	0	18
Roof, modified, unknown	0	0	13
Roof, camper shell, closed	42	0	0
Subtotals			
Roof glazing	990	356	306
Roof panel	10	12	18
Roof panel+ glazing closed	855	220	221
Roof panel+ glazing open	71	50	74
Total Roof	1,419	472	405

Table IV-56 – Occupant Injury and Fatality Percentages by Roof Ejection Route in All Crash Types (Annualized 1997 – 2008 NASS and FARS)

Injury Level	MAIS 1-2	MAIS 3+	Fatal
Roof glazing, closed	60.2%	46.4%	54.6%
Roof glazing, open	4.3%	8.3%	13.9%
Roof glazing, unknown	5.2%	20.6%	6.9%
Roof panel, closed	0.0%	0.2%	0.0%
Roof panel, open	0.7%	2.3%	4.4%
Roof, convertible top, closed	14.9%	3.8%	4.0%
Roof, convertible top, open	7.4%	17.8%	7.8%
Roof, convertible top, unknown	1.6%	0.6%	0.8%
Roof, removable, closed	1.8%	0.0%	0.0%
Roof, modified, open	0.9%	0.0%	4.4%
Roof, modified, unknown	0.0%	0.0%	3.2%
Roof, camper shell, closed	3.0%	0.0%	0.0%
Subtotals			
Roof glazing	69.8%	75.3%	75.5%
Roof panel	0.7%	2.5%	4.4%
Roof panel+ glazing closed	60.2%	46.6%	54.6%
Roof panel+ glazing open	5.0%	10.6%	18.3%
Total Roof	100.0%	100.0%	100.0%

Table xx shows that there were no ejections through a closed roof panel (sunroof) and only 4.4% of all roof ejections and 5.5% [18/323] of sun/moonroof ejections were through an open sunroof. By contrast, 54.6% of roof ejections were through roof glazing (moonroof) that was closed before the crash. Also, where it was known if the roof glazing was opened or closed prior to the crash, 80% [221/277] of ejections were through closed moonroofs. Thus, we believe that the moonroof designs represented in these data are not likely to be effective in preventing an occupant from ejection in rollovers.[116]

[116] We are not aware of any strength or impact requirements for roof glazing. Although some advanced 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

We believe that a small number of the vehicles in this NASS/FARS data set would be equipped with a sun/moonroof since the majority of these vehicles are older model vehicles. However, the number of vehicles equipped with the sun/moonroof has increased steadily since MY 1997. For example, the percentage of U.S. domestic passenger cars with a sun/moonroof increased from 20.3% in MY 1999 to 25.3% in MY 2005.[117] We expect that the sun/moonroof ejection rate (estimated 6%) would also increase as the number of vehicles with a sun/moonroof increases. With the 6% ejection through the sun/moonroof, the containment effectiveness would decrease from 75% to 70% for belted occupants and from 68% to 64% for unbelted occupants.[118]

From anecdotal observations, we also believe that there is a trend toward glazing roof panels (moonroofs) and away from roof panel without glazing (sunroofs). As indicated above, 94.5% of the roof panel ejections were through a moonroof. Thus, discussions in Chapter IV later in this FRIA on the effects of roof openings on occupant safety will be restricted to moonroofs.

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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lateral rollovers (i.e., when ejection through side windows and the sunroof are considered). Consequently, the assumption would underestimate the containment effectiveness.

[117] 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 sun/moonroof.

[118] Previously we estimated that bags are 75% effective in preventing belted occupants from ejection through the window opening area. With 6% ejection through the sunroof, the effectiveness would decrease from 75% to 70% ($75\%_{effectiveness} x 94\%_{window} + 0\%_{effectiveness} x 6\%_{sunroof} = 70\%$, for unbelted: 68%x94% + 0%x6% = 64%).

Table IV-57
Overall Air Bag Containment Effectiveness Rates*
Occupant Ejections through Front Window Opening

Belt Use	Fatality (% of total)	Containment Effectiveness, (Vertical)	Loss of Containment Effectiveness, (Lateral)	Combined	Loss of Containment Effectiveness, (Sun/moonroof)	Overall
Belted	13%	78%	3%	75%	5%	70%
Unbelted	87%	78%	10%	68%	4%	64%

* The percentages were rounded to the nearest integer.

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 impactor displacement requirement) the air bag would prevent 78% of both belted and unbelted occupants from ejection in the front window opening.[119] 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 window 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[120] when the air bag meets the impactor displacement requirement.[121] The 75% and 68% containment effective rates were then adjusted with the sun/moonroof ejection rate for both belted and unbelted occupants, respectively, to derive the 70% and 64% overall containment effectiveness rates for belted and unbelted occupants ejected through the front window opening, respectively.[122]

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[119] As discussed previously, due to limited data, we used the belted ejection rate for unbelted occupants, as a proxy.
[120] The term "lateral roll" is used to describe rollovers that occur about vehicle's longitudinal axis.
[121] As discussed previously, we assumed that some occupants who are initially contained by the bag would be ejected through the sunroof.
[122] The derived containment 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 Harm was from head related injuries. Based on this observation, we believe that a bag that is capable of preventing the head of

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 previously, 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 direct knowledge of occupant ejection paths in the window opening, laboratory and real world crash data indicate that the ejections may not be uniformly distributed in the opening and that 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 severe rollovers that make up the majority of the benefits of the rule is not well understood. 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. We note that the uniform risk of ejection method is simpler and easier to understand than the weighted risk of ejection method. In addition, the "uniform" method does not require any laboratory or real world data and, as we have implemented it, does not distinguish belted and unbelted occupant ejections for the containment effectiveness.

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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).

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 impactor displacement requirement. If we assume that all ejections are uniformly distributed in the window opening, the bag could allow 1/3 of ejections through the potential gap in rollover crashes (resulting in a 67% containment effectiveness rate) since the bag may or may not prevent ejections through this area. When the 67% containment rate is adjusted with the 6% ejection rate through the sun/moonroof, it would result in a 63% overall containment rate ($67\%_{\text{containment, uniform risk}}$ - $67\%x(1-.6_{\text{ejection through sunroof}})= 63\%$).

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 21% of the lives saved were from occupants who were ejected in side crashes without any rollovers. The air bag containment effectiveness in these side crashes would remain the same whether the weighted or uniform distribution methods are used.

<u>3. Injury risks associated with remaining inside the vehicle</u>:

As part of the Advanced Glazing Project of NHTSA,[123] 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 NHTSA's National Center for Statistics and Analysis (NCSA).[124] 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 for partially ejected occupants in the analysis.[125]

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 during a rollover). 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 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:

[123] 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.

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

[125] The risk of injury inside vehicles for completely ejected occupants is discussed later in this chapter.

Table IV-58
Percent Distribution of Brain/Head Injuries by Injuring Source in Rollovers, Digges

Restrained				Unrestrained			
Injury Source	Injured Body Region	NASS Sample Count	Injured %	Injury Source	Injured Body Region	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 sample counts		521	100.0%			838	100.0%
Total Head/Brain w/Interior Components			4%				13%

Table IV-56 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,[126] 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 around and the head of an unbelted occupant impacts interior objects much more than belted

[126] 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.

occupants in rollover.[127] If occupants are contained inside a vehicle, belted occupants would have a higher percent injury reduction rate when compared to unbelted occupants.[128] Therefore, the use of the reduction rates (i.e., Winnicki's) based on the unrestrained occupants for both belted and unbelted occupants would somewhat underestimate the overall effectiveness.

Since the publication of the Preliminary Regulatory Impact Analysis, the agency performed an analysis to determine the incremental injury risk associated with complete ejection from the front seat of a light vehicle. Avoiding complete ejection is associated with a decrease in the risk of death and injury estimated as:

- 64 percent for fatalities, based on double-pair comparisons from the Fatality Analysis Reporting System (FARS);
- 70 percent for serious injuries, based on patterns of injury contacts identified by the National Automotive Sampling System's Crashworthiness Data System (NASS CDS);
- 65 percent for moderately-severe injuries, based on patterns of injury contacts in the NASS CDS; and
- 39 percent for incapacitating injuries, based on double-pair comparisons from the State Data System (SDS).

[127] 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").

[128] 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.

The report concluded that avoiding complete ejection appears beneficial in all types of crashes, and it appears most effective in rollover and far-side impacts.[129] In particular, the report analyzed the most-recent 10 years of FARS data which include 30,462 light vehicles that meet the following criteria.

- Exactly two occupants in the front row,
- One person in the driver's seat and one right-front passenger,
- Both front-seat occupants reported as unbelted,
- Both front-seat occupants at least 13 years old, and
- At least one front-seat occupant fatality between 1999 and 2008.

The analysis of the FARS data showed that avoiding complete ejection is beneficial in all types of crashes. The reduction in fatality risk estimated from these data is: 75 percent in rollovers, 32 percent in front-end crashes, 21 percent in near-side impacts, 50 percent in far-side impacts, and 48 percent in back-end crashes.

For serious injuries, we analyzed the NASS CDS. The NASS CDS file includes detailed injury data for occupants of these vehicles. The data include injury contact points and the Abbreviated Injury Scale (AIS)[130] rating for each injury. We used the Maximum AIS (MAIS) for each occupant in a double-pair analysis of the benefits of being retained in the vehicle. For this purpose, we defined "seriously injured" to include all fatalities (regardless of MAIS) and all those with MAIS 3+ injury. The NASS CDS data were limited to 1995 and later data. The

[129] The report titled “Incremental Risk of Injury and Fatality Associated with Complete Ejection” is in the Docket, Docket xxxxxx

[130] *National Accident Sampling System, 1993 Crashworthiness Data System, Injury Coding Manual*, January 1993, DOT HS 807 969. Washington, DC: National Highway Traffic Safety Administration.

most-recent 14 years of NASS CDS data include 1,449 towed light vehicles that meet the following criteria. They had:

- Exactly two occupants in the front row,
- One person in the driver's seat and one right-front passenger,
- Both front-seat occupants reported as unbelted,
- Both front-seat occupants at least 13 years old,
- Both front-seat occupants identified as either retained in the vehicle or completely ejected, and
- At least one front-seat occupant seriously injured between 1995 and 2008.

Complete ejection is associated with a higher risk of serious injury. When compared to the experiences of those completely ejected, the risk of serious injury for those retained in the vehicle is estimated to be reduced by:

84 percent lower in rollovers,

87 percent lower in front-end crashes,

86 percent lower in near-side impacts,

79 percent lower in far-side impacts, and

94 percent lower in back-end crashes.

We note that the study only analyzed the incremental injury risk associated with completely ejected occupants from the front seat of a light vehicle. The study did not address the incremental injury risk associated with partially ejected occupants. We suspect that the reduction rates for partially ejected occupants would be higher than the reduction rates estimated by Winnick. For the partial ejection analysis, therefore, we used the reduction rates determined by Winnick.

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

Ejections Occurred in Rollovers:

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). It reports that the relative risk of fatality is reduced by 85.6% for partially ejected drivers when ejection is eliminated in rollover crashes. For partially ejected passengers, the relative risk of fatality is reduced by 90.1%.

For partially ejected occupants, 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-59
Average Fatal Injury Risk Reduction Rates for Partial Ejection in Rollovers

Occupant	Reduction in Risk
Driver:	86%
Passenger:	90%
Avg. (rounded):	88%

The results in Table IV-58 show that partially ejected occupants in rollover crashes would have an average reduction rate of 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 fatally and incapacitating injured occupants who were partially ejected in side impacts when ejection is eliminated, as shown below.

Table IV-60
Average Fatal Injury Risk Reduction Rates in Near Side Crashes

Occupant	Reduction in Risk
Driver:	57%
Passenger:	40%
Avg.	49%

Table IV-61
Average Incapacitating Injuries Risk Reduction Rates in Near Side Crashes

Occupant	Reduction in Risk
Driver:	53%
Passenger:	45%
Avg.	49%

B.3 Overall Injury 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 44%[131] as presented in Table IV-61). For side impacts, the overall effectiveness ranges from 18% to as high as 49%, when the weighted risk of ejection method was used. The complete list of overall system effectiveness rates for fatally injured occupants is shown below:

[131] The target population shows that 13% of the fatalities were belted and the remaining 87% were unbelted occupants. In the following section, we estimated that the ejection mitigation system has an overall effectiveness of 50% for partially ejected belted occupants and 43% ((46%+39%)/2 = 43%) for unbelted occupants: (13% x 50%) + (87% x 43%) = 44%.

Table IV-62
Overall System Effectiveness for Fatalities, Weighted Risk of Ejection Method

Crashes			Sensor	Containment	Risk Reduc.	System
Rollover, no side impacts:						
	Belted	Partial	81%	70%	88%(1)	55%
	Belted	Complete	81%	0%(2)	75%	0%
	Unbelted	Partial	81%	64%	88%	50%
	Unbelted	Complete(3)	81%	64%	75%	43%
Side impacts followed by rollovers, excluding 12-25 mph:						
	Belted	Partial	81%	70%	49%	30%
	Belted	Complete	81%	0%	36%	0%
	Unbelted	Partial	81%	64%	49%	28%
	Unbelted	Complete	81%	64%	36%	20%
Side impacts, w/ subsequent rollovers, 12-25 mph:						
	Belted	Partial	100%	70%	49%	34%
	Belted	Complete	100%	0%	36%	0%
	Unbelted	Partial	100%	64%	49%	31%
	Unbelted	Complete	100%	64%	36%	23%
Side impacts, no rollovers, 12-25 mph:						
	Belted	Partial	100%	100%	49%	49%
	Belted	Complete	100%	0%	36%	0%
	Unbelted	Partial	100%	100%	49%	49%
	Unbelted	Complete	100%	100%	36%	36%
Side impacts, no rollovers, children (0-12 yrs), partial & complete, 12-25 mph:						
	Belted	Partial	100%	100%	49%	49%
	Belted	Complete	100%	0%	36%	0%
	Unbelted	Partial	100%	100%	49%	49%
	Unbelted	Complete	100%	100%	36%	36%

(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 completely ejected unbelted occupants in catastrophic rollover crashes.

When the uniform risk of ejection method was used for the containment, the overall system effectiveness decreased slightly. For example, according to the FARS data, 70% of all fatalities in rollovers were completely ejected unbelted occupants. The overall system effectiveness for these completely ejected unbelted occupants decreases from 39% to 38% when the uniform distribution method was used instead of the weighted risk of ejection method, as shown below.

Table IV-63
Overall System Effectiveness for Fatalities, Uniform Risk of Ejection Method

Crashes			Sensor	Containment	Risk Reduc.	System
Rollover, no side impacts:						
	Belted	Partial	89%	63%	88%	49%
	Belted	Complete	89%	0%	75%	0%
	Unbelted	Partial	89%	63%	88%	49%
	Unbelted	Complete	89%	63%	75%	42%
Side impacts followed by rollovers, excluding 12-25 mph:						
	Belted	Partial	89%	63%	49%	27%
	Belted	Complete	89%	0%	36%	0%
	Unbelted	Partial	89%	63%	49%	27%
	Unbelted	Complete	89%	63%	36%	20%
Side impacts, w/ subsequent rollovers, 12-25 mph:						
	Belted	Partial	100%	63%	49%	31%
	Belted	Complete	100%	0%	36%	0%
	Unbelted	Partial	100%	63%	49%	31%
	Unbelted	Complete	100%	63%	36%	22%
Side impacts, no rollovers, 12-25 mph:						
	Belted	Partial	100%	100%	49%	49%
	Belted	Complete	100%	0%	36%	0%
	Unbelted	Partial	100%	100%	49%	49%
	Unbelted	Complete	100%	100%	36%	36%
Side impacts, no rollovers, children (0-12 yrs), partial & complete, 12-25 mph:						
	Belted	Partial	100%	100%	49%	49%
	Belted	Complete	100%	0%	36%	0%
	Unbelted	Partial	100%	100%	49%	49%
	Unbelted	Complete	100%	100%	36%	36%

In summary, 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. For the weighted risk of ejection method, the impact distribution was derived from a film analysis of laboratory tests, whereas the uniform risk method was based on an assumption that ejections are evenly distributed in the opening area. 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 any 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 ΔV range. In the FMVSS No. 214 FRIA for the oblique pole, we estimated that a compliant curtain air bag system (FMVSS No. 214 curtain air bag system) would be effective in a lateral ΔV range of 19 – 40 km/h. 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 ΔV range. In the 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 FMVSS No. 214 curtain air bag system would be effective in preventing occupant ejection through the window opening in a lateral ΔV range of 19 – 40 km/h.

For serious occupant injuries, the derivation shows that the ejection mitigation system would be less effective when compared to fatal injuries. The effectiveness ranges from 25% for unbelted partially ejected occupants in side-then-roll crashes to 49% for belted ejections in side crashes.[132] The complete list of overall system effectiveness rates for serious injuries is shown below:

[132] 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-64
Overall System Effectiveness for Serious Injuries Weighted Risk of Ejection Method

Crashes			Sensor	Containment	Risk Reduc.	System
Rollover, no side impacts:						
	Belted	Partial	94%	70%	67%	44%
	Belted	Complete	94%	0%	84%	0%
	Unbelted	Partial	94%	64%	67%	40%
	Unbelted	Complete	94%	64%	84%	50%
Side impacts followed by rollovers, excluding 12-25 mph:						
	Belted	Partial	94%	70%	49%	32%
	Belted	Complete	94%	0%	83%	0%
	Unbelted	Partial	94%	64%	49%	29%
	Unbelted	Complete	94%	64%	83%	50%
Side impacts, w/ subsequent rollovers, 12-25 mph:						
	Belted	Partial	100%	70%	49%	34%
	Belted	Complete	100%	0%	83%	0%
	Unbelted	Partial	100%	64%	49%	31%
	Unbelted	Complete	100%	64%	83%	53%
Side impacts, no rollovers, 12-25 mph:						
	Belted	Partial	100%	100%	49%	49%
	Belted	Complete	100%	0%	83%	0%
	Unbelted	Partial	100%	100%	49%	49%
	Unbelted	Complete	100%	100%	83%	83%
Side impacts, no rollovers, children (0-12 yrs), partial & complete, 12-25 mph:						
	Belted	Partial	100%	100%	49%	49%
	Belted	Complete	100%	0%	83%	0%
	Unbelted	Partial	100%	100%	49%	49%
	Unbelted	Complete	100%	100%	83%	83%

Table IV-65
Overall System Effectiveness for Serious Injuries, Uniform Risk of Ejection Method

Crashes			Sensor	Containment	Risk Reduc.	System
Rollover, no side impacts:						
	Belted	Partial	94%	63%	67%	39%
	Belted	Complete	94%	0%	84%	0%
	Unbelted	Partial	94%	63%	67%	39%
	Unbelted	Complete	94%	63%	84%	49%
Side impacts followed by rollovers, excluding 12-25 mph:						
	Belted	Partial	94%	63%	49%	29%
	Belted	Complete	94%	0%	83%	0%
	Unbelted	Partial	94%	63%	49%	29%
	Unbelted	Complete	94%	63%	83%	49%
Side impacts, w/ subsequent rollovers, 12-25 mph:						
	Belted	Partial	100%	63%	49%	31%
	Belted	Complete	100%	0%	83%	0%
	Unbelted	Partial	100%	63%	49%	31%
	Unbelted	Complete	100%	63%	83%	52%
Side impacts, no rollovers, 12-25 mph:						
	Belted	Partial	100%	100%	49%	49%
	Belted	Complete	100%	0%	83%	0%
	Unbelted	Partial	100%	100%	49%	49%
	Unbelted	Complete	100%	100%	83%	83%
Side impacts, no rollovers, children (0-12 yrs), partial & complete, 12-25 mph:						
	Belted	Partial	100%	100%	49%	49%
	Belted	Complete	100%	0%	83%	0%
	Unbelted	Partial	100%	100%	49%	49%
	Unbelted	Complete	100%	100%	83%	83%

B.4 Derive Benefit:

B.4.1 Lives saved and injuries prevented by ejection mitigation system:

To comply with the 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.[133] For 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 19 – 40 km/h vehicle ΔV's; (C) side impacts followed by rollovers in a vehicle ΔV range of 19 – 40 km/h; (D) side impacts without rollover crashes in a vehicle ΔV range of 19 – 40 km/h; (E) Children in side impacts without rollover crashes in a vehicle ΔV range of 19 – 40 km/h. The estimated benefits derived with the weighted risk of injury are shown below.

B.4.1.1 Rollover Crashes without Side Impacts

Lives Saved:

For the rollover sub-target population, the fatalities were adjusted with the projected 84% belt use rate in 2011. In addition, we assumed that all light vehicles would be equipped with ESC and that the ejection mitigation system is not effective in catastrophic rollovers. Previously we estimated that all belted fatal complete ejections and 2% of the unbelted complete fatal ejections would be from catastrophic crashes where the structure would not withstand the crash loads. Accordingly, these fatalities were excluded from the target population. When all light vehicles are equipped with the ESC system, for the target population, we estimated a total of 747 fatalities would occur in rollover crashes, annually. Among the 747 fatalities, 212 would be from partial ejections and the remaining 535 would be from complete ejections. The overall system effectiveness for these crashes ranges from zero percent for completely ejected belted occupants

[133]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 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.

to 50% for partially ejected belted occupants. When the system is fully implemented, we expect a total of 338 lives would be saved, annually, in rollover crashes, as shown below.

Table IV-66
Adult Lives Saved in Rollover Crashes without Side Impacts with Weighted Risk of Ejection Method

Occupant	Fatality	Adj. fatality	System effectiveness	Benefits (lives)
Belted partial	486	87	55%	48
Belted complete	50	0	0%	0
Unbelted partial	603	125	50%	63
Unbelted complete	2,640	535	43%	228
total	3,779	747	n/a	338

In the following section, the estimated 338 lives saved were further adjusted with the performance of currently available rollover bags and their projected voluntary installation rate in MY 2011.

Injuries prevented:

With the adjustment, we estimated a total of 816 serious injuries (MAIS 3-5) would occur in rollover crashes, annually. Among the 816 serious injuries, 320 would be from partial ejections and the remaining 496 would be from complete ejections. The system effectiveness rate ranges from zero percent for completely ejected belted occupants to 44% for completely ejected unbelted occupants. When the system is fully implemented, we expect a total of 377 serious injuries would be prevented, annually, in rollover crashes, as shown below:

Table IV-67
Adult Serious Injuries Prevented in Rollover Crashes without Side Impacts

Occupant	Injuries	Adj. injuries	System effectiveness	Benefits (MAIS 3-5)*
Belted partial	1,079	205	44%	90
Belted complete	99	19	0%	0
Unbelted partial	525	115	40%	46
Unbelted complete	2,217	477	50%	241
Total	3,920	816	n/a	377

* The numbers were rounded to the nearest integer.

Similar to the estimated fatal benefit, the estimated 377 serious injuries prevented were further adjusted with the performance of currently available rollover bags and their projected voluntary installation rate in MY 2011.

B.4.1.2 Side Impacts Followed by Rollovers, Excluding 19 – 40 km/h Vehicle ΔV

Lives saved:

We estimated a total of 284 fatalities would be in the target population of ejections for side impacts followed by rollovers at all but 19 – 40 km/h vehicle ΔV's, annually. Among the 284 fatalities, 179 would be from partially ejected occupants and the remaining 106 would be from completely ejected unbelted occupants. (We note that the fatality numbers were rounded to the nearest integer.) When the system is fully implemented, we expect a total of 71 lives would be saved, annually, as shown below:

Table IV-68
Adult Lives Saved in Side Impacts Followed by Rollovers
Excluding 19 - 40 km/h Vehicle ΔV's

Occupant	Fatality	Adj. fatality	System effectiveness	Benefits (Fatalities)*
Belted partial	7	6	30%	2
Belted complete	0	0	0%	0
Unbelted partial	195	173	28%	48
Unbelted complete	120	106	20%	21
Total	322	284	n/a	71

* The numbers were rounded to the nearest integer.

Injuries prevented:

For the target population, we estimated a total of 186 serious injuries would occur in the crashes, annually. Among the 186 seriously injured occupants, 58 would be from partial ejections and

the remaining 129 would be from complete ejections.[134] When the system is fully implemented, we expect a total of 72 serious injuries would be prevented, annually, as shown below:

Table IV-69
Adult Injuries Prevented in Side Impacts Followed by Rollovers
Excluding 19 – 40 km/h Vehicle ΔV's

Occupant	Injuries	Adj. injuries	System effectiveness	Benefits (MAIS 3-5)*
Belted partial	48	43	32%	14
Belted complete	24	21	0%	0
Unbelted partial	16	15	29%	4
Unbelted complete	116	108	50%	53
Total	204	186	n/a	72

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.

B.4.1.3 Side Impacts Followed by Rollovers in Vehicle ΔV Range of 19 – 40 km/h

Lives saved:

We estimated a total of 71 fatalities would occur in the target population of ejections for side impacts followed by rollover crashes, annually. Among the 71 fatalities, 8 would be from completely ejected belted occupants and the remaining 63 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 ΔV range of 19 – 40 km/h. Accordingly, the FMVSS No. 214-fatal benefits were excluded from the ejection mitigation benefit estimate. We estimated that the system would save 14 lives, annually, as summarized below:

[134] The injury numbers were rounded to the nearest interger.

Table IV-70
Adult Lives Saved in Side Impacts Followed by Rollovers in Vehicle ΔV Range of 19 – 40 km/h

Occupant	Fatality	Adj. fatality	System effectiveness	Benefits (Fatalities)
Belted partial	0	0	34%	0
Belted complete	9	8	0%	0
Unbelted partial	0	0	31%	0
Unbelted complete	72	63	23%	14
Total	81	71	n/a	14

Injuries prevented:

We estimated a total of 282 serious injuries would occur in side impacts followed by rollover crashes, annually: 114 from partial and 168 from complete ejections. As discussed, we included potential benefits for both partially and completely ejected occupants who were seriously injured in a ΔV range of 19 – 40 km/h. When fully implemented, we expect a total of 125 serious injuries would be prevented by the ejection mitigation system, annually. The estimated benefits are shown below:

Table IV-71
Adult Injuries Prevented in Side Impacts Followed by Rollovers in Vehicle ΔV Range of 19 – 40 km/h

Occupant	Injuries	Adj. injuries	System effectiveness	Benefits (MAIS 3-5)*
Belted partial	6	5	34%	2
Belted complete	0	0	0%	0
Unbelted partial	118	109	31%	34
Unbelted complete	181	168	53%	89
Total	305	282	n/a	125

B.4.1.4 Side Impacts without Rollover Crashes in Vehicle ΔV Range of 19 – 40 km/h:

Lives saved:

Similar to the side impacts with subsequent rollovers in a ΔV range of 19 – 40 km/h, only unbelted occupants who were completely ejected in fatal side impacts in the ΔV range were

considered. For the target population, we estimated a total of 225 fatalities would occur in side impacts without rollover crashes, annually. When the system is fully implemented, we expect a total of 80 lives would be saved, annually, in non-rollover side impacts, as shown below:

Table IV-72
Adult Lives Saved in Side Impacts without Rollover Crashes in
Vehicle ΔV Range of 19 – 40 km/h

Occupant	Fatality	Adj. fatality	System effectiveness	Benefits (Fatalities)
Belted partial	0	0	49%	0
Belted complete	0	0	0%	0
Unbelted partial	0	0	49%	0
Unbelted complete	254	225	36%	80
Total			n/a	80

Injuries prevented:

For the benefit analysis, only occupants who were completely ejected in side impacts in the ΔV range (19 – 40 km/h) were considered. We estimated a total of 84 serious injuries would occur in side impacts without rollover crashes, annually. These 84 seriously injures would be from completely ejected unbelted occupants. When the system is fully implemented, we expect a total of 69 serious injuries would be prevented in non-rollover 19 – 40 km/h side impacts, annually, as shown below:

Table IV-73
Adult Injuries Prevented in Side Impacts without Rollover Crashes in
Vehicle ΔV Range of 19 – 40 km/h

Occupant	Injuries	Adj. injuries	System effectiveness	Benefits (MAIS 3-5)*
Belted partial	0	0	49%	0
Belted complete	0	0	0%	0
Unbelted partial	0	0	49%	0
Unbelted complete	91	84	83%	69
Total	91	84	n/a	69

We note that the benefit estimates are based on assumptions that side impacts sensors are effective in detecting crashes in the ΔV 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 19 – 40 km/h side crashes.

B.4.1.5 Children (0-12 years) in Side Impact with No Rollover in ΔV of 19 – 40 km/h:

Lives saved:

For children in side impacts without subsequent rollovers in a ΔV range of 19 – 40 km/h, both partially and completely ejected children were considered in the ΔV range. We estimated that a total of 47 child fatalities would occur in 19 – 40 km/h side impacts without rollover crashes, annually. Among the 47 fatalities, 23 were from completely ejected unbelted children and the remaining 24 were from partially ejected belted children. When the system is fully implemented, we expect a total of 20 lives would be saved for 0-12 years old children, annually, in non-rollover side impacts, as shown below:

Table IV-74
Child Lives Saved in Side Impacts without Rollover Crashes in Vehicle ΔV Range of 19 – 40 km/h

Occupant	Fatality	Adj. fatality	System effectiveness	Benefits (Fatalities)
Belted partial	29	24	49%	12
Belted complete	0	0	0%	0
Unbelted partial	0	0	49%	0
Unbelted complete	26	23	36%	8
Total	55	47	n/a	20

Injuries prevented:

We estimated a total of 34 serious injuries would occur in side impacts without rollover crashes, annually. These 34 seriously injures would be from both partially and completely ejected unbelted children. When the system is fully implemented, we expect a total of 26 serious injuries would be prevented, annually, in non-rollover 19 – 40 km/h side impacts, as shown below:

Table IV-75
Child Injuries Prevented in Side Impacts without Rollover Crashes in Vehicle ΔV Range of 19 – 40 km/h

Occupant	Injuries	Adj. injuries	System effectiveness	Benefits (MAIS 3-5)*
Belted partial	0	0	49%	0
Belted complete	0	0	0%	0
Unbelted partial	6	5	49%	3
Unbelted complete	31	29	83%	24
Total	37	34	n/a	26

* The numbers were rounded to the nearest integer.

In summary, as shown in Figure IV-7, the hypothetical ejection mitigation system would save 487 lives and prevent 606 serious injuries, annually, when the system is fully implemented. The majority of the potential benefits would be from protecting occupants in rollover crashes. About 63% of the fatal and 54% of the serious injury benefits would be from the rollover protection. As discussed in the following section, the estimated 487 lives saved and 606 serious injuries prevented were further adjusted with the performance of voluntarily installed rollover air bags in MY 2011.

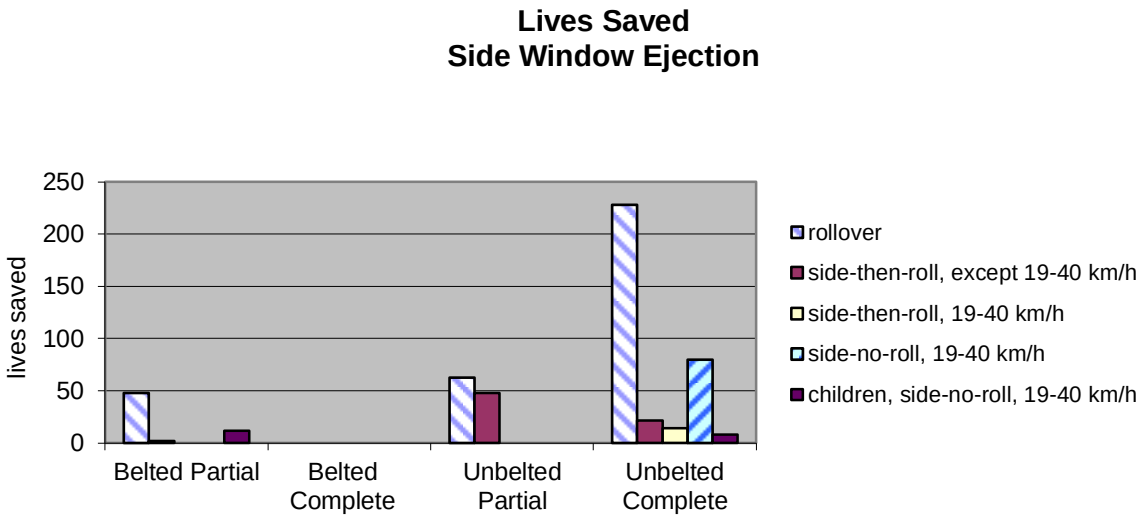

Figure IV-7. Number of Lives Saved with Ejection Mitigation Air Bag

B.4.2 Incremental benefits over MY 2011 voluntary installations: The benefit estimate derived above was based on an assumption that the vehicles (involved in the rollover and side crashes) were not equipped with ejection mitigation air bags, as summarized in Table IV-76.

Table IV-76
Benefits of Ejection Mitigation Air Bag, AIS 3-5 and Fatal
Assuming None of Vehicles are Equipped with Ejection Mitigation Air Bag
Weighted Risk of Ejection Method

Crash	AIS 3	AIS 4	AIS 5	Fatalities
Rollover, no side impact:	237	99	40	338
Side impacts followed by rollover, not 12-25 mph:	44	19	8	71
Side impact with subsequent rollover, 12-25 mph:	79	31	15	14
Side impacts, no rollover, 12-25 mph:	41	18	10	80
Side impacts, no rollover, Children, 12-25 mph:	16	7	4	20
Total:	417	174	77	668

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 consisting of two curtain air bags and a rollover sensor per vehicle). Based on the impactor test results, we believe that some of the voluntarily installed 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 currently available rollover air bags and also the compliance rate.[135] For the adjustment, individual air bag type was not considered. Rather, it was assumed that vehicles are equipped with production rollover curtain air bags regardless of vehicle model or type. For the compliance rate (i.e., passing rate for the impactor test requirements), each impact point was considered separately and the impactor tests performed at an impact speed of 20 km/h at 1.5 second delay were used[136], as shown in Table IV-77

[135] By applying the current vehicle compliance rate, we are assuming that the performance of the current ejection mitigation curtain air bags remains unchanged.

[136] The use of the 20km/h (with 1.5 second delay) headform data does not imply that air bags that meet the displacement 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 20 km/h impact requirement will be in compliance with the proposed requirements at 6 second delay. Accordingly, the use of the 20 km/h performance data, as a proxy, would underestimate the (overall) additional benefits by overestimating their passing rates.

Table IV-77
Impactor Test Compliance Rate
20 km/h at 1.5 second delay Front Window Opening

Vehicle	N/O*	Pos. A1	Pos. A2	Pos. A3	Pos. A4
03 Navigator	O	No Data	**191**	To Stops	-37
03 Navigator w/lam.	O	No Data	6	No Data	No Data
04 Volvo XC90	O	163	**96**	**119**	-3
04 Volvo w/lam.	O	**127**	27	97	(24 km/h)
05 Chevy Trailblazer	O	112	**121**	**127**	No Data
05 Chevy Trailblazer w/lam.	O	**86**	80	**109**	No Data
05 Chevy Trail. w/lam. (4 hole)	O	No Data	62	**97**	No Data
05 Honda Odyssey	O	No data	**96**	57	-45
05 Infinity FX35	O	**106**	60	73	30
05 Nissan Pathfinder	O	192	138	248	60
05 Toyota Highlander	O	**168**	**137**	**115**	76
06 Dodge Durango	O	160	140	180	18
06 Dodge Dur. w/lam. (4 hole)	O	106	71	150	No Data
06 Mercury Monterey	O	185	199	No data	-10
06 Toyota Land Cruiser	O	174	No data	256	31
06 Volvo C70	O	200	No Target	No Target	No Target
07 Chevy Silverado	O	142	187	130	(24 km/h)
07 Chevy Tahoe	O	**104**	**110**	87	(24 km/h)
07 Chevy Tahoe w/lam.	O	102	No data	No data	No data
07 Ford 500	O	192	113		(24 km/h)
07 Ford Edge	O	129	(24 km/h)	No data	(24 km/h)
07 Ford Edge	N	**148**	No data	67	No data
07 Ford Expedition	O	**151**	To Stops	**137**	(24 km/h)
07 Jeep Commander	O	To Stops	175	155	(24 km/h)
07 Jeep Commander w/lam.	O	No data	No data	73	No data
07 Mazda CX9	N	76	No data	67	No data
07 Saturn Vue	O	To Stops	**130**	**191**	28
08 Dodge Caravan	O	112	No data	162	(24 km/h)
08 Ford Taurus X	O	110	No data	No data	(24 km/h)
08 Subaru Tribeca	O	180	**106**		(24 km/h)
09 Chevy Equinox	O	149	No data	200	(24 km/h)
Average		140	112	132	15
Standard Deviation		36.5	55.7	56.7	39.0

* "O" Old headform; "N" new headform.

The 20 km/h headform test results showed an average displacement of 140 mm at A1, 112 mm at A2, 132 mm at A3 and 15 mm at A4. When the test results from the new headform were considered separately, it showed an average displacement of 112 mm at A1 and 67 mm at A3. As discussed in the test data & analysis chapter, the new impactor tends to have greater displacement. Ideally, the displacement results from the old headform should not be used with the displacement results from the new imapctor when comparing to the compliance value of 100mm. However, due to limited new headform displacement test data, the displacement test measurements from the new and old headforms were combined to derive the compliance rate of current rollover air bags. Since, the old headform would provide lower displacement values when compared to the old headform, the use of the old headform test results would (slightly) overestimate the compliance rate of current rollover air bags. In other words, the use of the old headform test result would underestimate the incremental benefits.

Table IV-78
Linear Headform Test Compliance/Passing Rate
Front Window opening, Combining both Old and New Headform Test Results

Opening	Impact Point			
Impact Point	A1	A2	A3	A4
Passing Rate	8%	45%	35%	100%

The impactor test results show that only the curtain air bags installed in the 2005 Chevy Trailblazer with laminated glazing (86 mm) and the 2008 Mazda CX9 (76 mm) met the displacement requirement at A1 in the front window opening, as highlighted in the table. Although the test data were very limited, the impactor test data showed that the displacement requirement at A1 could be met without using lamented glazing. In contrast to the small number

of current air bags meeting the displacement requirement at A1, none of the vehicles failed the requirement at A4.[137]

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 impactor displacement requirement at a particular impact point, we assumed that the air bag would be effective in preventing occupants from ejection through that quadrant.[138] The risk of ejection through each quadrant for both belted and unbelted occupants are shown below:

Table IV-79
Risk of Ejection With Respect To Window Opening Area[139]
Ejection through Front Window Opening
(Quadrant Weighted Risk of Ejection Method)

Occupant Restraint	Headform Impact Point			
	A1	A2	A3	A4
Belted	5%	26%	10%	52%
Unbelted	16%	16%	31%	31%

The results in Table VI -79 show that the majority of belted occupants would be ejected through the rear upper portion of the window opening (52%), whereas most unbelted occupants would be

[137] For additional discussion, see Chapter III, "Test Data."
[138] 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 impactor 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 air bags.
[139] We note that the percentages do not add up to 100% since we assumed that about 6% of occupants would be ejected through the sunroof even after they are initially contained by the ejection mitigation air bag.

ejected through the upper portion of the opening (62% through A3 and A4) . For both belted and unbelted occupants, with the weighted risk of ejection methodology, the quadrant method showed that 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 quadrant 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.[140]

For the risk of ejection through each quadrant, we considered belted and unbelted occupants together. The agency's real world crash data show that 13% of all fatal window ejections were from belted occupant and the remaining 87% were from unbelted occupants.[141] These belt use rates for fatally ejected occupants (13% and 87%) were used to derive a weighted risk of ejection at a given quadrant in the window opening, as shown below:

Table IV-80
Weighted Risk of Ejection through Front Window Opening Area
Combined both Belted and Unbelted Occupants
Weighted Risk of Ejection Method

Impactor test point	A1	A2	A3	A4
Risk of ejection	14%	17%	29%	34%

[140] We note that, 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 (i.e., risk of ejection is assumed to be uniform in the window opening).

[141] As shown previously in the target population section, there were 581 belted and 3,910 unbelted fatalities (a total of 4,490) when occupants were ejected through side window openings including the 3rd row and the cargo area behind the 2nd row.. Among the 581 belted fatalities, 538 were from the 1st row window opening, 43 were from the 2nd row, and none of the fatal ejections were from the 3rd and cargo area openings. For unbelted occupants, 3,299 were from the 1st row window opening, 544 were from 2nd row, 23 were from 3rd row and the remaining 43 were from the cargo area opening behind the 2nd row. The numbers were rounded to the nearest integer.

Table IV-80 shows that the risk of ejection through each quadrant ranges from 14% at the lower forward section to 34% at the upper rear portion of the front window (near the B-pillar) in the front window opening when both belted and unbelted are considered. The results show that the majority of ejections would be through the upper portion of the opening (63%[142]). To derive the percent of ejections that could be prevented (if all applicable vehicles are equipped with currently available rollover 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-81
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	8%	45%	35%	100%	
Weighted risk of ejection	14%	17%	29%	34%	
% of ejection prevented	1%	8%	10%	34%	53%

The results in Table IV-81 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) and that the majority of ejections would occur through the upper portion of the opening area. When the risk of ejection and the passing rate are combined, the results show that the currently available rollover curtain air bags would prevent about 51% of front window ejections when both belted and unbelted occupants are considered.[143]

[142] 29% at the A3 and 34% at the A4 = 63%, when both belted and unbelted fatalities were considered. As discussed previously, the percentages would not be added up to 100% since we assumed that 6% of the occupants who were initially contained by ejection mitigation curtain air bags would be ejected through the sunroof in rollovers.

[143] The ejection prevention rates showed that currently available rollover curtain air bags would be relatively effective in preventing occupants from ejection. On the other hand, as mentioned, the potential gap under between the curtain and the window sill was not considered for the ejection prevention rate. Therefore, we suspect that the actual containment effectiveness of currently available ejection curtain air bags would be lower than what we estimated.

Potential benefits result from voluntarily installed rollover air bags: The percent of ejection prevented was applied to the number of vehicles that will be equipped with currently available rollover air bags. For the baseline air bags sales, we utilized MY 2011 vehicles that will be equipped with rollover air bags, as shown below: [144]

Table IV-82
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	16.6M	15M	9M	55%

When the weighted risk of ejection is adjusted with the MY 2011 rollover air bag installation rate, it resulted in a 29% adjustment factor (53% $_{\text{effectiveness, currently available air bag systems}}$ x 55%$_{\text{installation rate}}$ = 29% (28.8%)). In other words, if we assume that all vehicles are equipped with ESC, the performance of current rollover bags remains unchanged, and future rollover bag sales are same as the projected sales in MY 2011 vehicles, 29% of the total potential benefits would be realized by these bag systems. When the 29% adjustment factor was applied to the previously derived potential benefits[145], it resulted in 373 additional lives saved and 476 serious injuries prevented,[146] as shown below:

[144] Although the phase-in begins in MY 2014, the MY 2011 vehicle data is most current data we have.
[145] Additional benefit = potential benefit x (1-29%).
[146] 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. Although we suspect that certain bags would provide some benefits even if they failed to meet the displacement, we do not have data to substantiate the speculation. Accordingly, these potential benefits were not considered in the analysis.

Table IV-83
Incremental Benefits of Ejection Mitigation Air Bag*, Weighted Risk of Ejection Method

Crash	AIS 3	AIS 4	AIS 5	Fatality
Rollover, no side impact:	169	71	28	241
Side impacts followed by rollover, not 19 – 40 km/h:	31	13	6	51
Side impact with subsequent rollover, 19 – 40 km/h:	56	22	10	10
Side impacts, no rollover, 19 – 40 km/h:	29	13	7	57
Side impacts, no rollover, Children, 19 – 40 km/h:	11	5	3	14
Total:	297	124	55	373

* The numbers were rounded to the nearest integer.

Summary of Benefits:

According to the annualized 1997 – 2008 FARS, there were 7,622 fatalities in lateral rollovers. Among the 7,622 fatalities, 4,490 were ejected through the first three rows of window openings and the cargo area window opening behind the second row. When the target population was adjusted with the potential benefits of ESC, FMVSS No. 214, and the increase in seat belt use rate expected in 2011, it showed 1,374 fatalities excluding occupants who were killed in catastrophic crashes in the target population.[147] 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. Two different methods were used for the containment effectiveness, namely weighted risk of ejection and uniform risk of ejection. 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[148], a total of 524 lives would be saved and 668 AIS 3+ serious injuries would be prevented, annually. The majority of the benefits would result from preventing occupants from ejection in rollovers crashes (65% of fatalities and 56% of serious injuries). It shows that a relatively small percentage of the benefits would be from protecting belted occupants (about 12% of fatalities

[147] 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.
[148] In other words, these bags are capable of meeting the impactor displacement requirement.

and 16% of serious injuries), when compared to unbelted occupants whether they are completely or partially ejected. 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 373 additional lives and prevent 476 additional serious injuries (MAIS 3-5), annually. The estimated potential and additional benefits are summarized below:

Table IV- 84 Incremental Benefits with Weighted Risk of Injury Method

Crash Type, Belt Use, Ejection Type		Target population (adj.)		Benefits		Incremental Benefits		Total Incremental Benefits	
		Fatality	Injuries	Fatality	Injuries	Fatality	Injuries	Fatality	Injuries
Rollover, no side impacts:									
Belted	Partial	87	205	48	90	34	64		
Belted	Complete	0	19	0	0	0	0		
Unbelted	Partial	125	115	63	46	45	33		
Unbelted	Complete	535	477	228	241	163	171	241	268
Side impacts followed by rollovers, exclude 12-25 mph:									
Belted	Partial	6	43	2	14	1	10		
Belted	Complete	0	21	0	0	0	0		
Unbelted	Partial	173	15	48	4	34	3		
Unbelted	Complete	106	108	21	53	15	38	51	51
Side impacts, w/ subsequent rollovers, 12-25 mph:									
Belted	Partial	0	5	0	2	0	1		
Belted	Complete	8	0	0	0	0	0		
Unbelted	Partial	0	109	0	34	0	24		
Unbelted	Complete	63	168	14	89	10	63	10	89
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	225	84	80	69	57	49	57	49
Side impact, no rollover, Children, 12-25 mph									
Belted	Partial	24	0	12	0	8	0		
Belted	Complete	0	0	0	0	0	0		
Unbelted	Partial	0	5	0	3	0	2		
Unbelted	Complete	23	29	8	24	6	17	14	19
	Total[149]	1,374	1,403	524	668	373	476	373	476

[149] The fatal and non-fatal benefit nu125mbers were rounded to the nearest integer. 40

When the risk of ejection through the window opening is assumed to be uniform, we estimated that 364 additional lives would be saved and 461 additional serious injuries would be prevented, annually, as shown below:

Table IV-85
Incremental Benefits with Uniform Risk of Injury Method

Crash Type, Belt Use, Ejection Type		Target population (adj.)		Benefits		Incremental Benefits		Total Incremental Benefits	
		Fatality	Injuries	Fatality	Injuries	Fatality	Injuries	Fatality	Injuries
Rollover, no side impacts:									
Belted	Partial	87	205	43	80	30	57		
Belted	Complete	0	19	0	0	0	0		
Unbelted	Partial	125	115	61	45	44	32		
Unbelted	Complete	535	477	224	236	159	168	233	257
Belted	Partial	6	43	2	12	1	9		
Belted	Complete	0	21	0	0	0	0		
Unbelted	Partial	173	15	47	4	33	3		
Unbelted	Complete	106	108	21	52	15	37	49	49
Belted	Partial	0	5	0	2	0	1		
Belted	Complete	8	0	0	0	0	0		
Unbelted	Partial	0	109	0	33	0	24		
Unbelted	Complete	63	168	14	87	10	63	10	87
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	225	84	80	69	57	49	57	49
Belted	Partial	24	0	12	0	8	0		
Belted	Complete	0	0	0	0	0	0		
Unbelted	Partial	0	5	0	3	0	2		
Unbelted	Complete	23	29	8	24	6	17	14	19
	Total[150]	1,374	1,403	511	648	364	461	364	461

Discussion:

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

1. Advanced glazing:

The agency received several comments regarding advanced glazing discussed in the PRIA, as shown below.

Solutia stated that the cost/benefit analysis unduly favors air bags over advanced glazing. Air bag costs are underestimated while glazing costs are overestimated. The agency assumes air bags will deploy prior to a crash but no data is presented to support this; IIHS suggests air bags may not always deploy when expected. On the other hand, glazing remains deployed as long as the window is in the up position.[151]

PGW stated that the agency should rework its cost/benefit analysis to reflect benefits from advanced glazing: enhanced security, UV shading, weight reduction, improved energy efficiency. "Synergistic cost reductions."[152]

EPGAA stated that the cost analysis is incomplete because it does not consider the potential absence of air bag systems (non-deployment) or the potential benefits of passive nature of advanced glazing. Also, a complete air bag system has yet to be developed so true costs are unknown. Costs of advanced glazing will decrease because of economies of scale. The PRIA had an unbalanced cost/benefit analysis that favors air bag systems.[153]

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[151] Docket: NHTSA-2009-0183-0033.
[152] Docket: NHTSA-2009-0183-0041
[153] Docket: NHTSA-2009-0183-0008

Public Citizen[154] and laminated glazing manufacturers assert that NHTSA should consider whether laminated glazing would reduce ejections through the sun and moon roof.

In the NPRM, the agency requested comments on the use of advanced glazing as a supplement to the door mounted curtain or as a standalone countermeasure for convertibles. Honda and others stated that the advanced glazing on a convertible door is likely to fall out due to lack of roof structure and structure around the glazing. We have no reason to dispute these comments. The commenter correctly pointed out that the use of advanced glazing for moveable windows would not be effective in preventing occupants in multiple rollovers even if it is in the up position. In fact, based on similar reasoning and field data, the final rule will not allow movable advanced glazing to be present during the 16 km/h-6 second test. With this change in the test procedure, the glazing-only countermeasure is no longer viable for a movable window opening. However, we believe that advanced glazing could be effective in preventing occupant ejections through the sun/moonroof, backlight and other openings. Regarding occupant ejections through the sun/moonroof and backlight, Glazing Suppliers and Safety Advocates requested that the final rule extend the testable area to the roof opening and backlight; some even requested coverage of the windshield and doors. For the reasons expressed below, we are declining to cover these potential ejection portals.

There are no provisions in the FMVSSs that are related to ejection mitigation through backlight and movable or fixed roof panels. As a reminder, we refer to movable and fixed roof panels made of glazing as “moon roofs” and movable panels having a sheet metal exterior as “sun roofs.” The updated ejection route data indicate that the backlight and roof ejections rank just

[154] Docket: NHTSA-2009-0183-0045

behind 2nd row window ejections.[155] For all crash types the backlight and roof represent 4.8% and 3.1% of fatalities, respectively. When crashes are limited to target population crash types, i.e., crashes involving lateral rollovers and side impact crashes, the backlight and roof represent 5.9% and 3.9%, respectively. However, backlights are on nearly every vehicle and sun/moon roofs are not, so if a roof opening is present it represents a greater risk for ejection than the backlight. The agency has very limited data on the effectiveness of advanced glazing when used for the backlight and sun/moonroof. The following discussion attempted to compare the potential benefits and costs for using advanced glazing for the backlight and sunroof based on two hypothetical containment effectiveness values.

Backlight: According to the agency's 1997 – 2008 NASS and FARS, there were 495 fatally and 1,364 seriously injured occupants who were ejected through the backlight of a light vehicle, as shown below:

Table IV-86
Occupant Injury and Fatality Counts by Ejection Route in All Crash Types
(Annualized 1997 – 2008 NASS and FARS)

Ejection Route	MAIS 1-2	MAIS 3-5	Fatal	MAIS 3+	% of MAIS 3+
Windshield	1,517	1,400	1,078	2,478	12%
First row windows	14,293	4,980	5,589	10,569	49%
Second row windows	1,700	641	796	1,437	7%
Third row windows	279	88	27	115	1%
Fourth row windows	0	0	39	39	0%
Cargo area windows	342	17	59	76	0%
Backlight	1,621	1,364	495	1,859	9%
Roof windows*	886	313	243	556	3%
Multiple windows	0	19	0	19	0%
Not window	3,381	2,367	1,976	4,343	20%

* Ejections through closed and open roof glazing.

[155] These rankings exclude ejections through non-glazing areas.

If crashes are severe enough to result in belted occupant ejections through the backlight, advanced glazing installed in the backlight would be damaged in the crashes. In other words, most belted occupants would not be ejected through the backlight unless the crashes are so catastrophic that it results in severe structural damages to the supporting structure of the backlight. For the benefit analysis, therefore, we excluded the belted occupants who were ejected through the backlight from the target population since advanced glazing would not be effective. According to the 1997-2008 annualized NASS data, there were 475 MAIS 3, 796 MAIS 4, 83 MAIS 5 and 477 fatal injuries for unbelted occupants who were ejected through the backlight, as shown below:

Table IV-87
Unbelted Occupant Injury and Fatality Counts for Backlight Ejections by Crash Types
(Annualized 1997 – 2008 NASS)

Crash Type	MAIS 3	MAIS 4	MAIS 5	Fatal
Lateral rollover	372	170	68	295
End-over-end rollover	3	23	0	2
Side impact before lateral roll	11	0	0	46
Side impact, no lateral roll	67	89	14	98
Others, no roll	22	514	1	36
Total	475	796	83	477

As discussed in the FMVSS No. 226 PRIA, we expect that all light vehicles would be equipped with ESC when these vehicles are required to have the ejection mitigation system. ESC is highly effective in rollover crashes. The effectiveness ranges from 26% for occupants in cars in non-fatal subsequent rollovers to as high as 88% for first-event light truck rollovers, as shown below. We estimated on average ESC is 79% effective in fatal first event rollovers.

Table IV-88
ESC Effectiveness for Light Vehicles by Injury Severity and Vehicle Type in Rollovers

Vehicle Type	First-event rollovers		Subsequent rollovers	
	Fatal	Non-fatal	Fatal	Non-fatal
Cars	70%	64%	36%	26%
LTVs	88%	85%	63%	48%
Avg.	79%	75%	50%	37%

For side impacts, the effectiveness of ESC is about 12% for light vehicles when all single and multiple vehicle crashes are combined. We expect a similar ESC effectiveness rate for the end-over-end crashes.

The crash type in Table 2 includes side impacts without lateral rollover and also side impacts with a subsequent lateral roll (i.e., "side impacts before lateral roll"). The "other" crash type includes impacts to the front and the rear of a vehicle without rollover. For the "side impacts before lateral roll" crashes, the ESC rollover effectiveness was applied to exclude the potential ESC benefits. For the "side impacts without lateral rollover" and "other-no-roll" crashes, the ESC side impact effectiveness was applied. When the target population was adjusted with the potential ESC benefits, it resulted in 757 serious injuries and 190 fatalities, as shown below:

Table IV-89
After Adjusting for ESC, Unbelted Occupant Injury and Fatality Counts for Backlight Ejections by Crash Types (Annualized 1997 – 2008 NASS and FARS, First Event)

Crash Type	MAIS 3	MAIS 4	MAIS 5	Fatal
Lateral rollover	78	36	14	62
End-over-end rollover	1	5	0	0
Side impact before lateral roll	2	0	0	10
Subtotal	81	41	14	72
Side impact, no lateral roll	59	79	12	86
Others, no roll	18	452	1	32
Subtotal	78	532	12	118
Total	159	571	27	190

With a relatively high ESC effectiveness rate in rollovers, the results in the table above show that the number of fatal and serious backlight ejection injuries would decreases substantially when all light vehicles are equipped with ESC.

If the backlight was made of advanced glazing that was especially designed to stay in place in rollovers, it could prevent occupants from ejection in certain crashes. However, the agency has a

very limited knowledge on the performance of the backlight advanced glazing in real world crashes. We suspect that the majority of advanced glazing installed in the backlight would be broken or separated from the frame as the vehicle impacts the ground during a severe rollover event. Our evaluation of laminated glass in the windshield showed no effectiveness against fatalities and extremely good effectiveness against facial lacerations.[156]

Nevertheless, hypothetically, we could assume that advanced glazing installed in the backlight is 100 percent effective in preventing occupants from ejection in all types of crashes. Under the assumption, the advanced glazing could save a total of 335 (96+239 = 335) equivalent lives (EQL), as shown below:

Table IV-90
Equivalent Lives Saved with 100 Percent Glazing Effectiveness Installed in Backlight
Lateral Rollovers and Side Impacts with Lateral Roll

Injury level	No. of injury	Conversion factor	Equivalent life
MAIS 3	81	0.0804	7
MAIS 4	41	0.1998	8
MAIS 5	14	0.6656	10
Fatal	72	1.0000	72
Total			96

Table IV-91
Equivalent Lives Saved with 100 Percent Glazing Effectiveness Installed in Backlight
Side Impacts without Lateral Roll and Others Crashes

Injury level	No. of injury	Conversion factor	Equivalent life
MAIS 3	78	0.0804	6
MAIS 4	531	0.1998	106
MAIS 5	13	0.6656	9
Fatal	118	1.0000	118
Total			239

[156] Lives Saved by the Federal Motor Vehicle Safety Standards and Other Vehicle Safety Technologies, 1960-2002 (NHTSA Report No. DOT HS 809 833, Author: Charles J. Kahane) http://www-nrd.nhtsa.dot.gov/Pubs/809833.PDF

Although the risk of fatality would decrease substantially when an occupant remains inside a vehicle, not all contained occupants would be saved in crashes. According to Partyka, the relative risk of fatality would be reduced by 75% for completely ejected occupants in rollovers when ejection is eliminated. For side impacts, the fatal risk would be reduced on average by 36% with the reduction rate ranges from 21% to 50% for completely ejected occupants.[157] The percent reduction rates show that ESC is most effective in rollover crashes.

If advanced glazing were 100 percent effective in preventing occupants from ejection through the backlight in rollovers and side impacts with lateral roll, we could estimate the potential benefits for the hypothetical glazing system, assuming the 75% reduction rate is applicable to rollovers, as shown below:

Number of equivalent fatalities adjusted with ESC: 96
Partyka's adjustment factor: 75%
Assumed glazing system effectiveness: 100%
Potential Equivalent lives saved: 96*.75*1 = 72 equivalent lives

The above calculation shows that if we assume that the glazing system is 100% effective in preventing occupants from ejection in rollovers and side impacts with lateral roll, the glazing system would save 72 equivalent lives, annually. Similarly, the hypothetical glazing system would save 86 equivalent lives in side impact (without roll) and other non-rollover crashes if it prevents all ejections through the backlight, as shown below:

Number of equivalent fatalities adjusted with ESC: 239
Average Partyka's adjustment factor: 36%
Assumed glazing system effectiveness: 100%
Potential Equivalent lives saved: 239*.36*1 = 86 equivalent lives

[157] Left impact driver = 52.48%; left impact passenger = 71.06%; right impact driver = 71.73%; right impact passenger = 44.29%

When the 158 total ELS (72+86 = 158 $_{rounded}$) were discounted at 3% and 7%, it resulted in 129 and 103 equivalent lives saved, respectively, as shown below.

Table IV-92
Present Discounted Value of Lives Saved for Backlight Advanced Glazing

Fatal Equivalent	Discount Rate	Discounted Fatal Equivalent
158	0.8155 at 3%	129
158	0.6489 at 7%	103

Regarding the incremental costs, a field survey performed by the agency showed that on average the front side window opening was 1,022 in^2. However, since the dimensions of the backlight were not measured during the survey, we used a MY 2003 Toyota Camry as a proxy for the backlight. The measurement showed that the Camry has a 1,537in^2 backlight opening. In the PRIA, the agency estimated the incremental difference in costs for going from a tempered glass to a laminated glass (advanced glazing) for standard size front or rear seat window would be $24 (in 2007 dollars). Based on the side window size (1,022 in^2 from the survey) and the estimated cost in the PRIA ($24), the unit cost was estimated to be $0.0235/$in^2$. When the $0.0235/$in^2$ unit cost was applied to the backlight, it resulted in $36 per vehicle. With 16.6 million light vehicles produced annually, the total incremental cost was estimated to be $600 million.

Since the issuance of the PRIA, a glass manufacturer provided additional information on advanced glazing cost. According to the glass manufacturer, the incremental costs are $16 for sunroof, $15 for front side window, $8 to $11 for rear side window, $25 for rear (backlight) window.[158] With 16.6 million light vehicles, the incremental costs were estimated to be $415M for the backlight and $67M for the sunroof.

[158] A meeting with glass manufacturers, the incremental costs are $18 for sunroof, $15 for front side window, $8 to $11 for rear side window, $25 for rear (backlight) window.

With the overall incremental costs of $415M for the backlight, the cost per equivalent life saved (ELS) would be $4.0M discounted at 7% if advanced glazing is 100% effective in preventing occupants from ejection in all crashes ($415/103 = $4.0M).

However, as mentioned, we do not know how effective advanced glazing is. The results in Table IV-89 show that 12% of all seriously and fatally injured occupant ejections occurred through the windshield. Since the construction and materials of advanced glazing used for the backlight and the windshield would be similar, contrary to what we assumed, the windshield ejection data show that the backlight glazing would not be 100% effective.

Alternative to the assumed 100% effectiveness, we could assume that advanced glazing is 20% effective in preventing occupants from ejection through the backlight in rollovers and 100% effective in other non-rollover crashes, the cost per equivalent life saved (ELS) would be $6.4M discounted at 7% with the overall incremental costs of $415M. However, if we assume that the glazing is 20% effective in preventing occupants from ejection in both rollovers and non-rollover crashes, the cost per ELS would be $20.2M discounted at 7%.

Although more rigorous analyses are needed to estimate the cost effectiveness of using advanced glazing for the backlight, it appears that, as shown above, advanced glazing must be extremely effective to be cost effectiveness when used for the backlight.

Table IV-93
Cost per Equivalent Life Saved (ELS) through Backlight with Advanced Glazing

Assumed containment	Cost per ELS	
	3%	7%
100%	$3.2M	$4.0M
20%	$16.1M	$20.2M

Roof glazing ejection:

During a rollover event, vehicle occupants are ejected through openings including the sun/moonroof. As indicated earlier, based on 1997 – 2008 NASS and FARS data, for all crash types, more than 94% of ejections through sun/moonroofs are through moonroofs. Thus our analysis here is limited to roof glazing (moonroofs). According to the annualized NASS and FARS data, 280 serious injuries 208 fatalities occurred annually when unbelted occupants were ejected through the moonroof in all crash types. When adjusted with the ESC potential benefits, it resulted in 122 serious injuries and 44 fatalities in the target population.

Table IV-94
Unbelted Occupant Injury and Fatality Counts for Roof Glazing Ejections by Crash Types (Annualized 1997 – 2008 NASS)

crash type	MAIS 3	MAIS 4	MAIS 5	fatal
lateral rollover	123	54	23	201
end-to-end rollover	0	0	0	7
side impact, lat. Roll	0	0	0	0
side impact, no lat. Roll	0	0	0	0
Others	80	0	0	0
	203	54	23	208

Table IV-95
ESC Adjusted Unbelted Occupant Injury and Fatality Counts for Roof Glazing Ejections by Crash Types (Annualized 1997 – 2008 NASS)

crash type	MAIS 3	MAIS 4	MAIS 5	fatal
lateral rollover	26	11	5	42
end-to-end rollover	0	0	0	2
side impact, lat. Roll	0	0	0	0
side impact, no lat. Roll	0	0	0	0
Others	80	0	0	0
Total	106	11	5	44

Similar to the method used for the backlight, we assumed that advanced glazing is 100 percent effective in preventing unbelted occupants from ejection through the moonroof, as shown below:

Table IV-96
Equivalent Lives Saved with 100% Glazing Effectiveness for Moonroof, Unbelted Occupants, Lateral Rollovers

Injury level	No. of injury	Conversion factor	EQL
MAIS 3	26	0.0804	2
MAIS 4	11	0.1998	2
MAIS 5	5	0.6656	3
Fatal	44	1.0000	44
Total			51

Table IV-97
Equivalent Lives Saved with 100% Glazing Effectiveness for Moonroof, Unbelted Occupants, Side Impacts and Others

Injury level	No. of injury	Conversion factor	EQL
MAIS 3	80	0.0804	6
MAIS 4	0	0.1998	0
MAIS 5	0	0.6656	0
Fatal	0	1.0000	0
Total			6

For the moonroof ejection target population, we used the same baseline that was used for the rollover curtain air bag benefit analysis. In other words, we were not trying to estimate the number of occupants ejected through the moonroof when all light vehicles are equipped with rollover curtains. Rather, the target population is based on occupants who were ejected from pre-FMVSS No. 226 vehicles.

We do not have any laboratory or real world crash data on the effective of a glazing system when tempered glazing currently used in the moonroof is replaced by advanced glazing. Although we do not have any laboratory or field data to show the containment effectiveness of moonroof glazing, we have anecdotal data on the effectiveness. As discussed in a report titled “Ejection Mitigation Using Advanced Glazing, A Status Report 1995”, the agency performed a series of impact tests on side window glazing made with various glazing materials.

The advanced glazing materials used in the research incorporate three material constructions. The first construction involves a glass-plastic formulation (hereafter referred to as bilaminate) in which a thin plastic film is bonded to the glass. In these formulations, the plastic film actually consists of two or more polymers bonded together resulting in desired performance properties. The second construction is similar to conventional windshields in which a plastic film is laminated in between two glass layers (hereafter referred to as trilaminate). The third construction is a monolithic rigid plastic that has been covered with an abrasion resistant coating and thermoformed to match the curvature of the tempered glass part. The edges of the glass-plastic windows were encapsulated with a polyurethane mold. The "T" shaped mold restrained the glazing edges within the window frame resulting in increased penetration resistance.

Initial testing was conducted using the FMH test on the advanced glazing module system. The headform was aligned with the test fixture to impact the window at its geometric center. For all impact tests, the headform was angled 5 degrees downward. This was done to ensure that initial contact occurred in the FMH forehead impact zone, as prescribed in the upgrade to FMVSS 201. The results from the testing are summarized in the table below.

Table IV-98
FMH/Advanced Glazing Test Results

TEST #	IMPACT SPEED	IMPACTING SURFACE	HIC	COMMENTS
0252FM01	25 km/h	Saint-Gobain Bilaminate	106	Top and right diagonal corner pulled out of window frame
0252FM02	25 km/h	Monsanto Trilaminate	570	Glass did not break and remained in window frame
0252FM03	29 km/h	Monsanto Trilaminate	858	Glass broke and remained in window frame
0252FM04	25 km/h	Dupont's Bilaminate	137	Top and right diagonal corner pulled out of window frame
0252FM05	24 km/h	Makrolon Polycarbonate	256	Glazing remained in window frame
0252FM06	29 km/h	Makrolon Polycarbonate	426	Glazing remained in window frame
0252FM07	30 km/h	Lexan Polycarbonate	180	Lexan cracked completely thru in lower corner of A-pillar verticle edge
0252FM08	24 km/h	Tempered Glass	27	Glass shattered upon impact
0252FM09	20 km/h	Tempered Glass	37	Glass shattered upon impact

The results in the table above show that advanced glazing with the "T" shaped mold could prevent occupants from ejection through the moonroof in certain rollovers. However, even if the glazing withstands the forces generated from occupant impact, the structure surrounding the moonroof might fail during a violent and catastrophic rollover. Therefore, we could assume that the advanced glazing would not be effective in catastrophic rollover crashes. In the PRIA, we estimated that 2% of unbelted completely ejected fatalities would be from catastrophic rollovers. Accordingly, we could assume that the glazing used in the moonroof is 98% effective in containing occupants from ejection. The 98% containment resulted in a cost/ELS value similar to that with 100% containment effectiveness.

The free-motion headform (FMH) specified in FMVSS 201 was used to evaluate the structural integrity of advanced glazing. The FMH is a Hybrid III head, modified for use as a free-motion impactor. It is unattached from the neck and body of the dummy and has a weight of 4.5 kg (10 lb). Tri-axial accelerations of the headform center of gravity are measured, from which a HIC value can be calculated. The 4.5 kg headform mass is lighter than the guided 18 kg featureless headform specified in the FMVSS No. 226 NPRM. The total kinetic energy associated with the FMH (107 Joules) was lower than that of the linear headform used in the displacement test specified in the proposed rule (278 J) when tested at 5.56 m/s (20 km/h).[159] When the FMH test was conducted at 8.1 m/s (29 km/h) impact speed, the Monsanto Trilaminate was broken but remained in the window frame. We do not have an established correlation between the energy absorbed by laminated glazing in the 4.5 kg FMH test and the 18 kg linear impactor test in the final rule. In addition, energy level alone may not be the only factor in such a correlation.

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[159] KE = ½ * mass of head-form*velocity of head-form^2; At 20 km/h impact speed, KE = ½ * 4.5 kg * (5.56 m/s)^2; KE = 71J. With 18 kg head form mass, KE = 278J at 5.56 m/s

Nonetheless it may be inferred from this testing of the Monsanto Trilaminate glazing that it would be feasible to design a moonroof that meets the 18 kg headform 20 km/h test requirement.

As of today, we do not have a test procedure to evaluate the structural integrity of the moonroof. However, depending on the impact angles and headform contact location, a test fixture similar to the current 201 FMH fixtures could be developed to test the moonroof if the measurement is limited to displacement when impacting glazing. (However, it would require a substantial effort to develop the fixture since the current 201 FMH is not a suitable device for measuring displacement.) Since the glazing would be most likely broken in rollovers, the glazing would need to be pre-broken to simulate real world conditions during a rollover. (In the FMVSS no. 226 final rule, we are requiring a 75 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.)

Subsequent to the moonroof glazing analysis in the PRIA, the agency performed a more detailed assessment of roof ejections. The annualized 1997 – 2008 NASS and FARS data show that 80% of the fatally injured occupants were ejected through closed moonroof glazing in fatal crashes, when such ejections occur. Therefore, we assumed that 80% of moonroofs are closed when occupants who had fatal or serious injuries in rollovers were ejected through the moonroof.

The number of equivalent lives saved with advanced glazing system was further adjusted with Partyka's adjustment factor and sunroof closing rate, as shown below:

Number of equivalent fatalities in lateral rolls, adjusted with ESC: 51
Partyka's adjustment factor: 75%
Assumed glazing containment effectiveness: 100%
Assumed percent of moonroof closing: 80%

Potential Equivalent lives saved: 51*.75*1.00*.80 = 30.6 ELS

Number of equivalent fatalities in side impacts and others, adjusted with ESC: 6
Partyka's adjustment factor: 36%
Assumed glazing containment effectiveness: 100%
Assumed percent of sunroof closing: 80%
Potential Equivalent lives saved: 6*.36*1.00*.80 = 1.7 ELS

Total Equivalent Lives saved: 32 ELS (21 ELS discounted at 7%)

In the previous backlight section, we estimated that the incremental material cost would be $16 for moonroof per vehicle. The glazing test results show that the edges of the glass-plastic windows need be encapsulated with a polyurethane "T" mold to increase penetration resistance for a window that needs to be movable. However, due to limited cost data, the costs associated with the "T" mold were not considered in the analysis. Alternatively, moonroofs can be fixed (glued) to a frame and then the entire frame move. With 16.6M annual light vehicle production, the total incremental cost was estimated to be $67 for the moonroof. The calculation above shows that the hypothetical moonroof system with advanced glazing with hypothetical 100% containment effectiveness would save 32 ELS. With the $67M total incremental cost, the cost effectiveness was estimated to be $3.2M ($67M/21 ELS $_{\text{discounted at 7\%}}$ = 3.2M) discounted at 7%.

As mentioned, we do not know how effective advanced glazing is when used in the moonroof. If glazing used in the moonroof is 20% effective in containing occupants from ejection as shown in the previous backlight discussion, the cost per equivalent life saved would be $13.2M discounted at 7%, as shown below.

Number of equivalent fatalities in lateral rolls, adjusted with ESC: 51
Partyka's adjustment factor: 75%
Assumed glazing containment effectiveness: 20%
Assumed percent of moonroof closing: 80%
Potential Equivalent lives saved: 51*.75*.20*.80 = 6.1 ELS

Number of equivalent fatalities in side impacts and others, adjusted with ESC: 6
Partyka's adjustment factor: 36%
Assumed glazing containment effectiveness: 20%
Assumed percent of moonroof closing: 80%
Potential Equivalent lives saved: 6*.36*.20*.80 = .3 ELS

Total ELS = 6.4
Total equivalent life saved was discounted at 7% = 4.2 ELS at 7%
$67M/(4.2) = $16.1M/ELS, discounted at 7%

With the $67M total incremental cost, the cost effectiveness was estimated to be $16M ($67M/4.2 ELS $_{\text{discounted at 7\%}}$ = 16M) discounted at 7%.

We note that the assumed 20% effectiveness (of moonroof advanced glazing) appears significantly lower than the containment effectiveness resulting from the agency's advanced glazing research. Therefore, the assumed 20% effectiveness could be considered as the low end of the effectiveness.

As we stated in the PRIA, some of occupants retained by the air bag could be ejected through the sunroof. The occupant injury and fatality counts by ejection route in all crash types and lateral rollovers showed that 97% of the fatally and 66% of seriously injured moonroof occupant ejections occurred during lateral rollovers (1- 0.03 = 0.97), as shown below.

Table IV-99
Fatal Ejection Occupant Counts by Crash Type,
Annualized NASS 1997 - 2008 NASS and FARS

Ejection Route	All crashes	Lateral rolls	Difference	% difference
Windshield	1,078	837	214	29%
First Row Windows	5,589	3,837	1,751	46%
Second-Row Windows	796	587	209	36%
Third-Row Windows	27	23	4	17%
Fourth-Row Windows	39	39	0	0%
Cargo Area Windows	59	43	16	37%
Backlight	495	453	42	9%
Roof Window	243	236	7	3%
Multiple Windows	0	0	0	N/A
Not Window	1,976	1,566	410	26%

For simplicity, we could assume that all MAIS 3+ moonroof ejections occur in lateral rollovers. The 1997 – 2008 NASS & FARS data showed that 4,540 serious injuries and 4,447 fatalities occurred when occupants were ejected through the first three row side windows in lateral rollovers. For the moonroof ejection, 233 serious injured and 236 fatalities were occurred in lateral rollovers. Under the assumption that all MAIS 3+ moonroof ejections occur during lateral rollovers, the ejection through the moonroof is relatively small when compared to the window ejections, slightly higher than 5%, in lateral rollovers ($236_{\text{roof window}}/(236+4{,}447_{\text{three side row windows and roof window}}) = 5.3\%$).

Table IV-100
Occupant injury and fatality counts by ejection route in lateral rollovers,
Annualized NASS 1997 - 2008 NASS and FARS

Ejection Route	MAIS 1-2	MAIS 3-5	Fatal	Fatal % of
Windshield	735	961	837	11%
First Row Windows	10,017	3,979	3,837	50%
Second-Row Windows	1,067	499	587	8%
Third-Row Windows	207	62	23	0%
Fourth-Row Windows	0	0	39	1%
Cargo Area Windows	342	17	43	1%
Backlight	953	800	453	6%
Roof Window	886	233	236	3%
Multiple Windows	0	19	0	0%
Not Window	2,812	1,980	1,566	21%
Subtotals				100%
Subtotal-Rows 1-3	11,292	4,540	4,447	
Subtotal-4th Row and Cargo	342	17	83	
Total	17,019	8,550	7,622	
Through window openings		4,540	4,447	

Although occupants are ejected through openings other than side window openings in lateral rollovers, we do not have data on the motion of an occupant after the occupant impact with a deployed rollover curtain air bag in lateral rollovers. We suspect that only a small number of adult occupants would rebound when they impact with a curtain bag in lateral rollovers. In addition, we believe that most of these rebounded occupants would bounce off the side, floor or roof of the vehicle in lateral rollovers. In other words, a rebounded occupant with a deployed curtain air bag in lateral rollovers would bounce around on a plane perpendicular to vehicle's longitudinal axis. If we assume that all occupants bounce off a deployed curtain air bag and that the rebounded occupants bounce around the perpendicular plane, as discussed previously, the rate of ejections through moonroof would be doubled. For example, the annualized NASS 1997 - 2008 NASS and FARS data showed 4,529 fatal ejections through the first three rows and the cargo area behind the 2nd row. If we assume rollover curtain air bags are 64% effective in

preventing occupants from ejection through these portals, the total ejection through moonroof would be (236 + 154 = 389, where 4,529*64%*5.3% = 154). In this illustration, the curtain air bags prevent 2,899 occupants from ejection through the side portals in lateral rollovers. Under the assumption, 154 out of the 2,899 initially contained occupants (2,899*5% = 154) would be ejected through the sunroof in a subsequent lateral rollover.[160])

In the FRIA, we estimated 660 fatally injured, 366 MAIS-3, 151 MAIS-4 and 76 MAIS-5 unbelted occupants in the adjusted target population. With the 64% overall air bag containment effectiveness as estimated in the FRIA and the estimated 5% ejection rate through the moonroof, 26 additional equivalent occupants would be ejected through the moonroof with deployed air bags, as shown below.

Table IV-101
Number of Occupants Ejected through Moonroof after Bounced off Curtain Air Bag, if All Occupants Bounce off Air Bag

Injury level	No. of injury	No. of contained	Sunroof eject	Conver. factor	EQL
MAIS 3	366	234	12	0.0804	1
MAIS 4	151	97	5	0.1998	1
MAIS 5	76	49	3	0.6656	2
Fatal	660	422	22	1.0000	22
Total					26

With the assumed 20% moonroof glazing containment effective, 75% Partyka's adjustment factor and 80% closing rate, additional 3 out of the 26 equivalent lives could be saved for occupants who were initially bounced off deployed air bags. With the additional 3 equivalent lives saved, the total equivalent lives saved would be 6.1 discounted at 7% ((6.4+3)*0.6489 = 6.1) and the cost per equivalent would be $11M discounted at 7%, as shown below.

[160] Under assumption, one could conclude that the risk of ejection through moonroof is proportional to the number of rolls in lateral rollovers and that the number of occupants ejected through moonroof increases by 5% in each roll.

Table IV-102
Cost per Equivalent Life Saved (ELS) through Moonroof with Advanced Glazing

Assumed containment	Cost per ELS	
	3%	7%
Theoretical high: 100%	$2.6M	$3.2M
Estimated low: 20%	$13M	$16M
20% containment effectiveness, considering subsequent sunroof ejection	$12M	$11M

If advanced glazing used in the backlight and moonroof is assumed to be 100 percent effective in preventing occupants from ejection, the cost per equivalent life saved would be $4.0M and $3.2M discounted at 7%, respectively. However, real world crashes data showed that some occupants would be ejected through these portals even if they are covered with advanced glazing. Although we do not know how effective advanced glazing is in real world crashes, an analysis of real world crash data suggested that the containment effectiveness of advanced glazing used in the backlight could be about 20% effective in preventing occupants from ejection in MAIS 3+ rollovers. If we assume that the glazing is 20% effective in preventing occupants from ejection through the backlight, the cost per equivalent life saved would be $20.2M for the backlight discounted at 7%. For the moonroof, the analysis showed a range of $16M to $11M cost per ELS discounted at 7%, depending on if we assume 5% of the occupants prevented from side window ejections are redirected to the roof.

Table IV-103
Comparison of Cost per Equivalent Life Saved (ELS) of Ejections through Backlight and Roof Glazing with Advanced Glazing

	Cost per ELS			
Assumed Containment Effectiveness	Backlight		Roof Glazing	
	3%	7%	3%	7%
20%	$16M	$20M	$13M	$16M

The above analysis assessed the cost effectiveness of using advanced glazing for the backlight and closed roof glazing. This analysis included all crash types (not limited to side impacts and rollovers) since the advanced glazing countermeasure does not need to deploy. The results are given in the table above at the 3% and 7% discount rates and at assumed ejection effectiveness levels of 20%.

2. Minor (AIS 1-2) injuries prevented by rollover curtain bags in side crashes: Based on the 2000-2009 NASS CDS, we determined that on average 50,229 injuries occurred from flying glass involving 32,095 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 32,095 injured occupants, 19,915 had face/head injuries from flying glass. Among the 19,915 occupants with head/facial injuries, 7% (1,398) were children under 13 years. These data show 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-104
Injuries from flying glass by body region and AIS, 2000-2009 NASS CDS

Body region	AIS 1	AIS 2	Adjusted annual*
Torso	568	0	568
Face/head	30.739	2	30,740
Neck	706	0	706
Arm & hand	16,007	0	16,007
Leg & foot	1,635	0	1,625
Unknown	583	0	583
Total	50,227	2	50,229

* The numbers were rounded to the nearest integer.

As discussed in the FMVSS No. 214 FRIA, we believe that side air bags would be effective in a ΔV range of 19 to 40 km/h. When head/face, arm/hand injuries from flying glass were

considered, the crash data showed that 57% of the injuries occurred in a lateral ΔV range of 19 – 40 km/h.

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 substantially 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. However, the agency believes that laminated glass in the side windows could reduce flying glass injuries.

3. Effect of FMVSS No. 216 Roof Crush Resistance:

In their response to the NPRM, IIHS stated that NHTSA's 1.0 unit increase in the strength-to-weight ratio (SWR) reduces ejection risk by 41 percent. It said that NHTSA underestimated benefits of FMVSS No. 216 and overestimated target population for FMVSS No. 226.

> "NHTSA's analysis of 5,562 rollovers from the National Automotive Sampling System-Crashworthiness Data System found only an inconsistent relationship between roof intrusion and ejection risk (Strashny, 2009). However, the absence of any roof strength measure for the vehicles in these crashes prevents analysis of the link between FMVSS

> 216 test performance and ejection risk. By assuming that stronger roofs will have no influence on ejection, NHTSA has both underestimated the benefits of the upgraded FMVSS 216 and overestimated the target population for the proposed FMVSS 226."[161]

The target population for FMVSS No. 216 "Roof Crush Resistance" is limited to belted non-ejected fatalities or injuries in rollovers with vertical intrusion over the injured occupant's seat, where the injury was caused by roof contact and the injury is the single maximum level injury experienced by the occupant. In other words, the Roof Crush Resistance target population is limited to belted occupants who were not-completely ejected or partially ejected. For these ejections, we estimated that the FMVSS No. 216 upgrade would save 135 lives. We note that the crashes considered in the Roof Crush Resistance target population were very severe crashes where the roof collapsed in rollovers. Unlike the "roof crush" target population, belted not-completely-ejected occupants were not considered in the ejection mitigation target population. Therefore, there is no overlap of target populations for belted not-completely-ejected occupants. For belted partially ejection occupants, we examined the target population used for the roof crush resistance rulemaking. In the FMVSS No. 216 target population, there were 10,150 fatalities in non-convertible light vehicle rollovers, as shown below.

[161] NHTSA-2009-0183-0032, p. 1.

Table IV-105
FMVSS No. 216 Target Population

All vehicles	AIS 1	AIS 2	AIS 3-5	Fatalities
Non-Convertible Light Vehicles in Rollovers	199,822	37,305	21,673	10,150
Roof-Involved Rollover	164,213	32,959	19,262	8,645
Some Fixed Object Collision on Top	153,520	29,419	17,766	7,559
Not Totally Ejected	149,850	26,033	12,355	3,654
Using Safety Restraints	116,670	14,327	8,970	2,096
Outboard seats	115,018	14,241	8,781	2,096
Roof Component Intrusion	68,730	10,922	6,842	1,444
Head, Neck, or Face Injury from Intruding Roof Component	24,035	6,580	2,993	957
Injury - Not MAIS	0	-1,900	-1,252	-237
Injury at MAIS - Not Sole Injury	-17,818	-292	-253	-53
Sole MAIS Injury	6,216	4,388	1,487	667

Among the 10,150 non-convertible light vehicles in rollovers, 2,096 were belted occupants who were either partially ejected or remained in the vehicle in rollovers. The table above shows 667 fatalities and 1,487 serious injuries in the FMVSS No. 216-target population. Among the 667 fatalities, 113 were belted partially ejected occupants. It showed that the target population used for the FMVSS No. 216 FRIA showed that 17% of the fatalities were from partially ejected belted occupants.

Table IV-106
FMVSS No. 216 Target Population

216 FRIA Target Population	AIS 1	AIS 2	AIS 3-5	Fatal
Not ejected	6216	3845	933	552
Partially ejected	0	433	554	113
Sole MAIS injury	6216	4278	1487	665
Percent Partially Ejected	0%	10%	37%	17%

If we assume that the strengthening the roof would save 17% of the partially ejected belted occupants in the ejection mitigation target population (FMVSS No. 226), it showed that a relatively small percentage of the belted partially ejected occupants in the ejection mitigation target population would be saved by the Roof Crush Resistance requirements. According to the ejection mitigation target population, there were 486 partially ejected belted occupants in

rollovers. With the 17% reduction rate, the number of fatalities in the target population decreases from 486 to 403 [486*(1-0.17) = 403]. With the 403 belted partially ejected occupants, the overall fatal benefits would decrease from 487 to 478 and the incremental lives saved would be decreased by less than one percent (from 352 to 345, 2% reduction in benefits). As illustrated above, the impact of FMVSS No. 216 would be insignificant to the ejection mitigation benefits estimate.

4. Air bag fails to deploy:

Guardian commented that NHTSA should analyze "what protections exist under conditions when an airbag does not deploy" or an air bag doesn't deploy quickly enough and an occupant is trapped. We examined SCI rollover crashes, NASS CDS cases from the target population of the final rule and data from the RODSS project to find if the rollover sensors deployed the rollover side air curtains in a rollover. RODSS is a new source of rollover crash data that began in April 2007. NHTSA initiated RODSS as a pilot project to obtain additional field data for rollover crashes not covered by other agency databases. Cases were identified through the FARS database. NASS CDS and SCI cases were excluded from consideration because detailed information from those crashes would be available from those databases. In general, field data indicate that rollover sensors have been recognizing a rollover and deploying rollover curtains in rollover crashes.

We found five case vehicles where the vehicle was apparently equipped with a side curtain air bag that was supposed to be deployed by a rollover sensor and the curtains did not deploy in the rollover event (see Table 29). There were two completely ejected occupants and one partial ejected occupant in these crashes. The results of these ejections were 3 fatalities. All of these

ejections were through side windows except one where the front passenger door was dislodged from the vehicle and provided the ejection route for the unbelted driver.

Consistent among these non-deployment cases is that the rollover was preceded by a significant frontal impact. Four of the five non-deployment cases had a significant frontal impact that preceded the rollover. The MY 2006 Ford Explorer in RODSS case 6121 had a right front corner impact with a large tree prior to the rollover. The MY 2003 Lincoln Aviator in RODSS case 7242 had an offset frontal impact with an oncoming vehicle prior to the rollover. The MY 2006 Cadillac SRX in SCI case DS07009 impacted a large tree prior to the rollover. The EDR data from this case indicated that the tree impact had a longitudinal and lateral ΔV of -38.9 mph and -10.2 mph, respectively. The EDR also indicated that the rollover sensor status was "invalid" and the curtain deployment was not commanded. The MY 2009 Dodge Journey had a narrow offset frontal impact with another vehicle, which the crash investigator stated disrupted the power supply from the battery. The frontal air bags deployed in the above four crashes. (There is some doubt as to whether RODSS case 6121 (SCI CA9062) was definitely equipped with a rollover sensor, since the system was an option on this vehicle. Ultimately, no definitive determination was made.) For the cases involving initial frontal impacts, these impacts may have destroyed the vehicle battery and thus eliminated the primary power source for deploying the rollover curtain.

In RODSS case 5032 (SCI CA9061), it appears the sensor may not have been able to make a determination that a rollover occurred. However, in studying the details of this case, the

vehicle's kinematics were very complex and may have included some motion not typical of a lateral rollover.

Table IV-106– RODSS and SCI rollover Cases Where The Rollover Curtain Did Not Deploy

CASE ID	Year/Make/Model	Quarter Turns	Curt. Depl.	Seat Pos.	Belt Use	Age	Eject.	Route	Injury/ MAIS
RODSS									
5032*	04 Lincoln Aviator‡	3	No	11	No	68y	Comp.	Row 2 R	Fatal
6121*	06 Ford Explorer	4	No	11	No	23y	Comp	Door (13)	Fatal
7242*	03 Lincoln Aviator‡	3	No	11	Yes	28y	No	NA	Serious
7242*	03 Lincoln Aviator‡	3	No	13	Yes	26y	No	NA	Serious
7242*	03 Lincoln Aviator	3	No	21	CRS	3y	No	NA	Serious
7242*	03 Lincoln Aviator	3	No	23	Yes	7y	No	NA	Serious
SCI									
DS07009	06 Cadillac SRX	4	No	11	No	81y	Part.	Row 1 L	Fatal
DS09071	09 Dodge Journey	4	No	11	Yes	63y	No	NA	2
DS09071	09 Dodge Journey	4	No	13	Yes	60y	No	NA	1

* These are also SCI cases.[162] ‡These seating positions had laminated glazing adjacent to them.

The agency is monitoring the performance of rollover air bags in real world rollover crashes. For air bag deployment, we would point out that no safety devices installed in a vehicle is 100% effective. We believe that curtain air bags are the most practical device to protect occupants in both side impacts and rollovers.

5. <u>ESC benefit estimate</u>:

Public citizen commented that the estimated ESC benefits might not be achieved. They claimed that the estimate was not based on sufficient evidence, but rather on extrapolation. ESC is most

[162] These three RODSS cases were made into SCI remote investigations to facilitate documentation of photographs and other crash details. The SCI case numbers are RODSS 5032 (CA09061), RODSS 6121 (CA9062) and RODSS 7242 (CA9063).

effective in single vehicle rollover crashes which account for only 54 percent of fatal rollover crashes. Public Citizen stated their belief that the agency under estimated benefits of FMVSS No. 226 because we overestimated the effectiveness of ESC.

> "NHTSA underestimates benefits of ejection mitigation because it assumes, without sufficient evidence, that electronic stability control will reduce fatalities and serious injuries from ejections by roughly one-half. Of a projected 6,174 fatalities and 5,271 serious injuries, NHTSA assumes that electronic stability control will eliminate 3,003 and 2,854, respectively. This estimate is not based on real-world crash data on electronic stability control, but rather on extrapolations from a relatively small real-world sample of vehicles. The final electronic stability control rule went into effect in April 2007. It is unlikely that the agency has enough data to conduct a rigorous analysis of the effectiveness of these systems at this time. Moreover, electronic stability control systems are most effective in single vehicle rollover crashes, which account for only 54 percent of fatal rollover crashes. These casts even further doubt on the agency's estimates of lives and injuries prevented."[163]

The commenter did not provide any data to support the claim that the actual real world ESC effectiveness values are lower than ones used in the analysis. We believe that the ESC effectiveness estimate, which was based on analyses of real world crashes, is rigorous enough to be used in the ejection mitigation analysis. Further, the commenter suggested that the ESC effectiveness used in the ejection mitigation analysis is too high. It stated "Moreover, electronic stability control systems are most effective in single vehicle rollover crashes, which account for

[163] NHTSA-2009-0183-0045, p. 4.

only 54 percent of fatal rollover crashes" (emphasis added). We agree with the commenter that the potential benefits resulting from the ejection mitigation rule making would be higher if lower effectiveness values were used. However, as stated, the commenter did not provide any data to support the claim that the actual real world ESC effectiveness values are lower than ones used in the analysis. The agency is currently updating the ESC effectiveness previously estimated and used in the analysis. The evaluation methods are similar to the 2007 NHTSA evaluation of ESC effectiveness. The additional years of data in this evaluation allow for greater vehicle variety and for more precise estimates. For the first time, the General Estimates System (GES) is bring used to compute nationally representative estimates of ESC effectiveness. The preliminary findings of the study indicate that the updated ESC effectiveness is very close to the previously estimated overall ESC effectiveness.

V. TECHNICAL COSTS AND LEADTIME

In this chapter, we discuss the cost of different technologies that could be used to comply with the impactor test and estimate the compliance test costs. 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 advanced glazing for fixed windows. Among the potential design approaches, we believe the one-piece curtain design would be most cost effective in meeting the requirement for vehicles with up to three seating rows or two seating rows with a cargo area behind the second row. The agency believes that one-piece curtain air bags designed for head protection in side impacts will have to be larger to meet the headform requirements. In addition to the increase in size, we believe that manufacturers would need to modify other air bag characteristics, such as duration of inflation and location of bag tether attachments. Manufacturers may also choose to increase air bag volume and/or pressure. For the analysis, we assumed that vehicle manufacturers utilize the one-piece design to comply with the displacement requirement.[164]

The curtain air bag modifications discussed above 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. Alliance stated in their comments to

[164] 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. However, the agency does not have data to quantify these secondary benefits and, as a result, these benefits were not considered in the benefit estimate. Notwithstanding the complementary benefits, the 20 km/h impactor test results indicated that the displacement requirement could be met with the ejection mitigation curtain air bag without advanced glazing.

the NPRM that the rule will require larger air bags that will require further changes to adjacent interior trim components.

> "In addition to the above observation, it is also noted that the packaging space required for larger airbags will necessitate further changes to adjacent interior trim components (e.g., headliner). This is in contrast to NHTSA's assertion that 'any modifications to the structure would not be significant.' In fact, the necessary modifications are significant and are not reflected in the cost analysis presented in the NPRM." [165]

However, Alliance did not provide any data to show the potential increase in cost. As stated in the FRIA above, we believe that the costs to design a model to install a larger 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 2009 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 major 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

[165] Docket: NHTSA-2009-0183-0029.1

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.

Air Bag: 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.[166] The estimated $134.02 is based on the minimum coverage of the window opening to meet the FMVSS No. 214-oblique pole requirement. However, it is unlikely that vehicle manufacturers design head/side air bags to just cover 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 analyzed actual costs associated with current side curtain

[166] 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 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).

air bags that are capable of meeting the FMVSS No. 214-oblique pole requirements. These costs were used as a baseline to estimate incremental costs associated with (wider) rollover curtain air bags.

An 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.[167] 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.[168] The Accord 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 16 inches and a width of 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

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[167] 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

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

have curtain air bags that are similar in construction and size[169]. 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[170]) to derive the incremental material costs associated with a rollover curtain air bag.

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 window 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 ($6{,}619_{\text{window opening}} - 5{,}161_{\text{size of 214-curtain}} = 1{,}458\ cm^2$), as shown in Figure V-1.

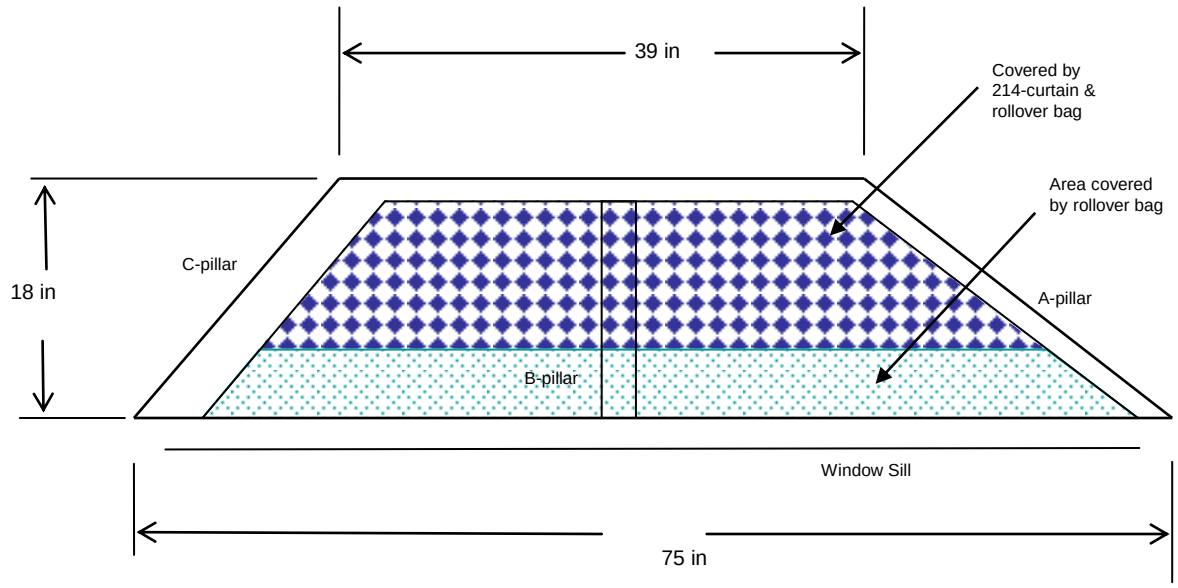

Figure V-1 Air Bag Coverage Area with respect to MY 2003 Toyota Camry Front and Second Side Window Opening (not to scale)

[169] Although the curtain air bag installed in the Accord has a longer bottom, the curtain in the Camry was about 3% larger than the curtain in the Accord.
[170] 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.

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:

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 $34.90 per vehicle ($17.45 per air bag) end user cost in 2009 economics.[171] The unit material cost was estimated to be $0.00338 per cm^2 based on the 5,161 cm^2 air bag coverage area and the $17.45 estimated material cost per air bag [($17.45 per bag)/5,161 cm^2 = $0.00327/$cm^2$] in 2009 economics. 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 $0.00338 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 $ 9.86 per vehicle (1,458 cm^2 x $0.00338/$cm^2$ = $4.93/curtain, 4.93_{\text{per curtain}}$ x 2_{sides} = $9.86 per vehicle in 2009 economics).[172]

[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, 2009 = 109.615, 2003 = 94.100, the multiplier = 109.615/94.100 = 1.1649, $34.90, ($29.96 x 1.1649 = $34.90) for two bags per vehicle. Thus, for each bag, $17.45

[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.

In summary, for the incremental costs associated with the hypothetical rollover air bag, we assumed that vehicle manufacturers need to spend $9.86 per vehicle to widen the FMVSS No. 214-curtain bag to meet the impactor displacement requirement (in 2009 economics) at the front and second row window openings with a single-unit curtain air bag. The $9.86 incremental air bag cloth cost showed that 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 $94.25 for the wider FMVSS No. 214-combo air bag[173] and $189.72 for the hypothetical rollover curtain air bag per vehicle (excluding the incremental costs associated with a larger inflator and adding a rollover sensor, in 2009 economics). Therefore, material costs for replacing the FMVSS No. 214-comb bag would be about $95.47 ($189.72 - $94.25 = $95.47), excluding rollover sensor[174], as summarized in Table V-2.

<u>Inflator</u>: 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 vehicle.

(1,458 cm^2/5,161 cm^2 = 0.2825. The added cloth would increase the vehicle weight by 0.73 lbs., 2.59 lbs x 0.2825 = 0.73 lbs., per vehicle.

[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 $94.25 in 2009 economics.

[174] When the rollover sensor is included in the incremental cost, the incremental cost was estimated to be $134.79 ($189.72$_{\text{rollover curtain}}$ +39.32_{\text{rollover sensor}}$ - 94.25_{\text{wider combo}}$ = 134.75_{\text{incremental cost.}}$ Note that we assumed that the inflators used in the wide combo air bag system would be large enough for the rollover curtain air bags. In addition, for the overall incremental costs, we assumed that manufacturers would install thorax bags when combo bags are replaced by rollover curtain bags. We estimated $78.25 for two thorax bags installed in a vehicle in 2009 economics.

(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 100 mm impactor displacement requirement, the majority of air bag manufacturers would not have to incorporate additional gas chambers to prevent occupants from ejection in the extended air bag area in rollovers. 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 inflator cost by $2.50 ($7.61 x $0.2825_{\text{28\% increase}}$ x $(109.615/94.100)_{\text{Ratio of implicit GDP price inflator}}$ = $2.50 incremental cost in 2009 economics).

<u>Tether</u>: In the benefit chapter, we determined that some of the tether anchors (to the A- and C-pillars) need to be strengthened 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 $39.32 (in 2009 dollars) per vehicle.[175]

[175] The cost of the sensor is $39.32 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.

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). 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 Impactor 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.

Table V-2
MY 2011 Estimated Bag Sales[176]

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%

[176] These are based on manufacturer sales projections/plans prior to FMVSS 214 requirements
[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 and the system would not be capable of meeting the headform displacement requirement. The numbers were rounded to the nearest integer.

* 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 95 percent of MY 2011 passenger cars, SUVs and light trucks will voluntarily be equipped with head air bags. The majority of these head air bags will be curtain air bags and, in addition, 55% of these curtain bags will be equipped with rollover sensors. It is assumed that 100% of vehicles will need head air bags to meet the FMVSS 214 requirements. Among the MY 2011 vehicles, we assumed that 55% would have curtain air bags with rollover sensors, 44% would have curtain air bags without rollover sensor and the remaining 1% of the vehicles would have combination air bags.

Compliance Rate of Current Rollover Curtain Bags

The impactor test results showed that some of currently available curtain bags are capable of meeting the displacement requirement at each impact point. However, the impactor test results indicate that most of current curtain air bags (whether they are designed for side impacts or both side impacts and rollovers) would not meet the 100 mm deflection requirement at all four (4) impact points in the front window opening. 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 impactor displacement requirement in the front window opening area, we believe that manufacturers will design the air bags such that they meet the displacement requirement at both front and rear window opening areas including the 3rd row and the cargo area behind the 2nd row. On the other hand, even if current one-piece curtain air bags meet the displacement requirement in the rear opening area, they must be redesigned since they would be redesigned to meet the displacement requirement at all impact points in the front window opening area. Thus, we did

not consider impactor tests performed in the rear opening area in the cost analysis 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 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 impactor 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 TablesV-4.[180]

[178] These rollover bags would be wider than the hypothetical 214-curtain bag.
[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. It is possible that the projected percentage of MY 2011 vehicles with ejection mitigation systems would increase when the final rule is issued.

Table V-4
Estimated Technology Cost Summary for Covering Window Openings
(in 2009 economics)

Systems	Costs ($ in 2009)	Estimated percentage of MY 2011 baseline
Combination Air Bag (w/ 2 sensors)	$94.25	1.34%
Window Curtain System (w/ 2 sensors):		44.08%
214-curtain bags	$179.86	
thorax bags[181]	$78.25	
Total	$258.11	
Window Curtain System (w/ 2 side and one roll sensors):		54.59%
214-curtain bags	$179.86	
thorax bags	$78.25	
roll sensor	$39.32	
Total	$297.43	
Weighted average cost[182]:	$277.41	(per MY 2011 manufacturers' plans)

Table V-5. Ejection Mitigation System
(Two side and one roll sensors, in 2009 economics)

Components	Cost
curtain bags (w/ 2 side sensors)	$189.72
thorax bags	$78.25
roll sensor	$39.32
Increase in inflator cost	$2.50
Total	$309.79

The weighted cost in Table V-4 and the rollover air bag cost in Table V-5 do not include other costs associated with the system, such as wires, connecting hardware and side impact sensor. The costs associated with these components would be very similar for both FMVSS No. 214 head air bag and rollover curtain air bag. Therefore, the actual costs would be higher when these components were included. The overall costs for FMVSS No. 214-curtain and FMVSS No. 214

[181] The wide 214-throax bag: $69.08 per vehicle in 2004 economics. Adjusted with the implicit GDP price inflator, $69.08x(109.615/96.770) = $78.25 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 combination air bag covers the 1st row window opening whereas the one-piece curtain air bag covers 1st and 2nd row window openings.

combination air bags are discussed extensively in the FMVSS No. 214 FRIA. The costs estimated in the tables above were used to show the difference in cost between the FMVSS No. 214 head air bag and the rollover curtain air bag. The results in Tables V-4 and -5 showed that the incremental cost per vehicle would be $32.38, based on MY 2011 sales.

Costs Associated with 3rd Row Window Curtain

Previously, we estimated that vehicle manufacturers need to spend $12.36 ($9.86 for curtain and $2.50 for inflator) per vehicle to enlarge the FMVSS No. 214-curtain air bag to completely cover the 1st and 2nd row windows. Accordingly, these costs do not include costs associated with covering 3rd row windows. According to MY 2009 sales data, 22% of light vehicles have first and second seating rows with a cargo area behind the second row. In addition, 14% of the MY 2009 vehicles have three rows but no cargo area behind the second row. Therefore, we estimated that 36% of all MY 2011 vehicles would have either a cargo area behind the second row or third row seating. When curtain air bags are installed in SUVs with a cargo area behind the second row and vans with three rows to meet the FMVSS No. 214-oblique pole requirements, 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. If a SUV has a cargo area behind the second row, it would be also covered with the FMVSS No. 214-curtain air bag. Accordingly, for incremental costs over manufacturers' plans, we assumed that SUVs and vans would have a similar cost for both front and rear windows. 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, as shown in the PRIA, 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). Previously, we estimated that the incremental cost to enlarge the FMVSS No. 214-curtain air bag installed in the first and second windows of the MY 2003 Toyota Camry would be $12.36 per vehicle. The first and second window opening of the Camry has a width of 75 inches. Therefore, we estimated that

the unit incremental cost would be $3.13 per vehicle [$12.36 *(19-inch/75-inch) = $3.13. The total incremental costs associated with 3rd row bags would be about $18.3 million based on 16.3 million vehicle sales excluding convertibles (16.3 million vehicles x 36% $_{\text{w/ 3rd row seat \& cargo}}$ x $3.13 = $18.3 million).

Total Incremental Costs

Table V-6 shows estimated incremental costs to meet the impactor displacement requirement for the baseline 214-curtain and 214-combination air bags.

Table V-6
Average Incremental Vehicle Costs for 1st and 2nd Rows (in 2009 economics)

Existing System	Assumed 214 Weighted Sales (%)	Need		Roll rate sensor	Curtain minus combo bag(1)	Increased $ in inflator	Widen curtain	Per vehicle
		Bag	sensor	$39.32	$173.72	$2.50	$9.86	
Curtain w/ roll sensor	55%	Wider curtain	None	$0	$0	$2.50	$9.86	$12.36
Curtain w/o roll sensor	44%	Wider curtain	Roll sensor	$39.32	$0	$2.50	$9.86	$51.68
Combo [183]	1%	Rollover curtain	Roll sensor	$39.32	$173.72	$0	$0	$213.04
total	100%							

(1) 189.72_{\text{Rollover curtain}}$ - 94.25_{\text{combo}}$ + 78.25_{\text{thorax bag}}$ = $173.72

[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 and separate thorax bags. Accordingly, the costs associated with the 214-combination system were subtracted from the costs of the rollover curtain system.

Table V-7
Total Incremental Costs
MY 2011 as baseline, in 2009 economics,
Based on 16.3 million sales of passenger vehicles under 10,000 GVWR
Excluding Convertibles

Baseline 214-bag System	Weighted Sales	Per Vehicle	Weighted Incremental Cost	Total Cost (in $M)
Curtain w/ roll sensor	55.31%	$12.36	$6.75	$111.35
Curtain w/o roll sensor	44.66%	$51.68	$22.78	$375.87
Combination air bag[184]	0.04%	$213.04	$2.85	$1.27
Weighted incremental cost per vehicle[185]			$30.00	
Total incremental cost for 1st and 2nd rows for 16.3 million vehicles				$488.5
Total 3rd row and Cargo behind 2nd row for SUVs and Vans				$18.3
Total incremental cost 1st, 2nd, 3rd rows and Cargo for 16.3 million vehicles				$507 million

For the estimated costs, 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 showed that the incremental cost would be $32.38 per vehicle if 1st and 2nd row windows are covered with a curtain air bag.[186] When convertibles were excluded, the unit incremental cost decreased to $30.00 per vehicle if 1st and 2nd row windows are covered with a curtain air bag. When the 3rd row window and the cargo area window behind the second row are covered with a curtain bag to meet the displacement requirement, the total incremental cost would be $507 million ($488.5M + $18.3M = $507 million, as shown in Table V-7) and unit incremental cost would be $31.12.

[184] For the analysis, we used the FMVSS No. 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% combo $_{weighted}$ and 98.6% curtain $_{weighted}$ (1.4% + 98.6% = 100%).
[185] If convertibles are not exclude, the unit incremental cost would be $32.38.
[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.

In summary, with estimated 16.3 million light vehicles excluding convertibles and assuming no compliance, the total incremental cost for the 1st and 2nd row windows would be $489 ($488.5) million in 2009 economics. When the 3rd row window and the cargo area behind the 2nd row are covered with a rollover curtain air bag, the total incremental cost would be $507 million. For the $507 million total and $31.12 unit incremental costs, we estimated that vehicle manufacturers need to spend $12.36 for FMVSS No. 214-curtain bags with rollover sensor and $51.68 for 214-curtain bags without rollover sensor for each vehicle.

Convertibles:

All comments from OEMS and Air Bag Suppliers requested that the agency reconsider the inclusion of convertibles in FMVSS No. 226. Many stated that there were unaware of any technology that would allow a convertible to meet the proposed requirements. TRW stated that "[t]he retention of occupants within such vehicles in a rollover, especially for unbelted cases, appears to be particularly problematic with today's known, and foreseen, technologies."[187] GM stated that since there was no current solution, it would require a significant period of time to develop a solution. For the same reasoning, VSCI believed that if the agency still wished to include convertibles, the final rule should provide for three more years of lead time for convertibles.

The AIAM extensive comments, provided below, explain the limitations of door mounted air bags and systems combined with advanced glazing.

[187] NHTSA-2009-0183-0013, p. 8.

"Door or seat mounted airbags are the only form of inflatable side restraint that can be used on convertible vehicles. There are a number of challenges with these systems for both convertibles and sports cars with frameless doors. The first is the lateral stiffness of the inflated bag. Current technology would not meet these requirements and we believe that improved airbag designs would require stronger tethers and additional inflation rows. Providing stronger tethers is an issue especially for frameless doors and convertible vehicles as there are not sufficient locations to attach the tether.

Secondly, with a door mounted airbag system, it is essential to have good engagement of the side window glass to help retain the airbag within the occupant compartment. The precise effect that the proposed glazing pre-breaking procedure will have on this engagement is currently unknown, but it is assumed that it will make it worse.

For FMVSS 214 pole test compliance, convertibles and frameless door designs could use a door mounted airbag. However, these airbags will not necessarily meet the ejection tests due to the issues discussed above. NHTSA recognizes the unique challenges manufacturers face with implementing door mounted/curtain airbags on convertibles (see 73FR 32478) and granted a 1 year delay over the 100% effective date of the pole test.

For convertible vehicles, the curtains need to be deployed upwards from the door and need to be retained by the convertible top, which may not have the same retention capability as the door trim of conventional vehicles. Technology does not exist for these vehicles currently (potentially frameless doors on coupes). For these reasons, AIAM

recommends that convertibles be excluded from the requirements until further technological development renders compliance practicable."[188]

The Alliance takes issue with the agency's reference to the Porsche research, presented in the docket that suggested the feasibility of a door mounted air bag system for ejection mitigation. They stated that the Porsche system was "not intended to serve as an ejection mitigation countermeasure."[189] Similarly Volvo stated that "[t]he door-mounted side airbag curtain in Volvo's C70 is primarily designed and developed to reduce head injuries for front-seated occupants in side impacts."[190]

The Alliance commented that it was Porsche's intent in their discussions with NHTSA to "describe a technologically neutral solution for a coupe without a side curtain airbag. The Porsche submission focused on advanced laminated glazing for application in a coupe, which unlike a convertible, can be fitted with framed windows." The Alliance went on to state that it is their position "that advanced glazing, with or without a door-mounted airbag, does not constitute a practicable compliance solution for convertibles."[191]

The Alliance also wished to remind the agency of the exclusion in FMVSS No. 216 for convertibles. They believe this is an acknowledgement of "the special situation of convertibles regarding protection in rollover crashes... [I]n the same way that compliance with the enhanced roof strength requirements is not practicable for vehicles where the A and B pillars are not joined

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[188] NHTSA-2009-0183-0028, p. 7.
[189] NHTSA-2009-0183-0029, p. 8.
[190] NHTSA-2009-0183-0030, p. 3.
[191] NHTSA-2009-0183-0029, p. 8.

(i.e., convertibles), it is similarly not practicable to install curtain airbag systems in vehicles that lack a roof structure in between the A and B pillars."[192]

The Alliance also explained how in their opinion the Safety Act precludes the agency from applying FMVSS No. 226 to convertibles and to vehicles with partitions because of the impracticability of doing so. The implication of the legal argument is that the Safety Act requires the agency to consider different classes of vehicles and that standards "shall not be used as a device to bring about their extinction."[193]

Honda opined that "ensuring the safety of convertible occupants in a rollover crash should be based on the premise that the occupants are properly restrained by seatbelts."[194] They stated that door mounted air bags improvements in ejection mitigation may be possible by increasing the thickness and controlling the pressure of the air bags, but this might lead to adversely affecting side impact protection and problems for out-of-position occupants. Honda also stated that advanced glazing may be even more likely to fall out in convertible rollovers than in vehicles with roof structures that meet FMVSS No. 216. Thus its use as an ejection countermeasure may not be effective.

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[192] NHTSA-2009-0183-0029, p. 9.
[193] NHTSA-2009-0183-0029, p. 10.
[194] NHTSA-2009-0183-0034, p. 7.

Takata opined that even if convertibles were able to comply with the proposed ejection mitigation criteria they may have limited effectiveness in the field because "occupants may be ejected through the top of the vehicle."[195]

The AORC struck a somewhat more optimistic chord in stating that their "members have been working on this technology but have not yet verified performance relative to this specification, nor evaluated how such a technology could be applied over a wide range of vehicles."[196]

We have decided that the final rule will not apply to convertibles. There are several factors which influenced this decision. First, we found compelling the practicability concerns raised by industry comments related to the near term technical challenges involved with producing a compliant convertible. Second, the final rule change in the 16 km/h-6 second test, that will not allow movable advanced glazing, will increase the level of difficulty in devising a compliant countermeasure for the near term.

In NPRM preamble, we mentioned Porsche's development of door-mounted curtains that would deploy upward toward the vehicle roof in a rollover. Comments from Porsche to the NPRM indicated that they were not developing this curtain for ejection mitigation of convertibles, but rather for a coupe. In so doing they could have a single design for both vehicles. Notwithstanding Porsche's comments, the fact remains that the agency wanted comments on the feasibility of such a system for ejection mitigation of convertibles. Commenters to the Notice

[195] NHTSA-2009-0183-0015, p. 2.
[196] NHTSA-2009-0183-0019, p. 4.

indicated that such a system would not be effective alone, since it cannot be tethered. We have no basis to dispute these comments.

The agency also wanted comments on the use of advanced glazing as a supplement to the door mounted curtain or as a standalone countermeasure. Honda and others stated that the advanced glazing on a convertible door is likely to fall out due to lack of roof structure and structure around the glazing. Again, we have no reason to dispute these comments. In fact, based on similar reasoning and field data, the final rule will not allow movable advanced glazing to be present during the 16 km/h-6 second test. With this change in the test procedure, the glazing-only countermeasure is no longer viable for a movable window opening. In addition, a convertible would have to pass the 16 km/h-6 second test with just the door mounted air bag. We are uncertain of the practicability of meeting this requirement at the present time, given the industry comments.

Finally, for the most part, ejection mitigation countermeasure would be expected to only be effective for unbelted occupants when the convertible roof is closed. Takata questioned the wisdom of applying the standard to convertibles since occupants may still get ejected through the closed roof. The 1997 – 2008 NASS and FARS data show that there were 16 fatalities and 18 MAIS 3+ injuries due to ejections through a convertible roof closed prior to the crash. For convertibles where the roof was open, the fatalities and MAIS 3+ injuries were 31 and 84, respectively. So, about half of the ejection fatalities through the roof area occurred even when the roof was closed before the crash. We acknowledge that these estimates are based on an

extremely small sample size. However, it does reflect the problematic nature of convertible ejection protection.

Below we explore the effect on incremental costs of exempting convertibles from the requirement. We believe that most convertibles will be equipped with combo air bags when the final rule is issued. The MY 2011 vehicle sales show that 54.59% of light vehicles would have curtain air bags with a roll sensor, 38.98% curtain air bags without roll sensor, 1.34% combination (combo) air bags 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). We believe that the 5.1% vehicles with "other" countermeasures would be equipped with curtain air bags to meet the FMVSS No. 214-pole test requirement. Accordingly, we expect that 44.08% of MY 2011 vehicles would be equipped with curtain air bags without a roll sensor (38.98% + 5.1% = 44.08%). The sales data showed that 1.30% of vehicles are convertibles which would be equipped with combination air bags to meet the FMVSS No. 214-pole test requirement. If convertibles are exempted, the 16.3 million vehicles need to meet the impactor displacement [16.5 million x (1- 0.013) = 16.3 million]. Among the 16.3 million MY 2011 vehicles, 0.04% of these vehicles would be equipped with combo air bags (1.34% - 1.30% = 0.04%).[197] Therefore, the weighted incremental cost would be $30.00 for 16.3 million vehicles ($55.31\%x\$12.36_{\text{curtain w/ roll sensor}} + 44.66\%x\$51.68_{\text{curtain w/o roll sensor}} + 0.04\%x\$213.04_{\text{combo}}$= $30.00. The total incremental cost excluding convertibles would be $489M ($488.5M)[198]. Previously, we estimated that the total incremental costs associated with covering the 3rd row

[197] We assumed that all convertibles would be equipped with combo air bags.
[198] $29.99 * [16.5* (1-0.013)] = $488.5M. When the 0.04% combination air bags were excluded from the vehicle sales, it resulted in 99.96%. 54.59% of 99.96% is 55.31% and 44.08% of 99.96% is 44.66%. 55.31% + 44.66 + 0.04% = 100%.

window opening and the cargo area would be $18.3 million. Therefore, as convertibles are excluded from the final rule, the total incremental cost would be $507 million to cover first three row windows and the cargo area behind the second row.[199]

Fourth Row:

The final rule does not require vehicle manufacturers to test the 4th row window opening. However, although it would be technically very challenging to extend coverage to the 4th row with a one-piece curtain air bag, manufacturers could cover the 4th row window opening with a one-piece curtain air bag. If we assume that a curtain air bag that covers the first three row windows is extended to cover the 4th row window opening and that the size of the 4th window opening is the same as the 3rd row window opening, the costs associated with the coverage would be $3.13. According to MY 2009 sales, 39,618 light vehicles would have four seating rows. Therefore, the total incremental cost to cover the 4th row window opening was estimated to be $0.12M. The target population showed 39 fatal ejections through the 4th row window opening (but no serious injuries in the target population). If we assumed that the curtain air bag covering the 4th row is as effective as the curtain covering the front rows, it would save 3 lives, annually, as shown below:

Table V-8
Estimated Lives Saved by Preventing 4th Row Ejection

Overall Fatalities in rollover	3,779
ESC and Catastrophic crash adjusted fatalities in rollover	761
Lives saved in rollover	315
Percentage of lives saved	8.3%
4th row fatalities	39
Lives saved for 4th row (with 8.3% adjustment factor)	3 (3.25)

[199] When convertibles are excluded from meeting the impactor displacement requirements, the total incremental cost would decrease from $534 million to $489 million dollars. We note that we are assuming that all non-convertibles are equipped with curtain bags (no combo bags).

When the 4th row window is covered with a one-piece curtain air bag which covers all four rows of window openings, it resulted in $0.05M and $0.06M per equivalent life discounted at 3% and 7%. Although it would be cost effective if the first four rows are covered with a single curtain air bag, as mentioned, it would be technically very challenging to extending coverage to the 4th row.

Table V-9
Cost per Equivalent Live Saved by Preventing 4th Row Ejection

Discount Equ. Fatal		Cost (in $M)	Cost per Equivalent Life Saved (in $M)	
at 3%	at 7%			
0.8155	0.6489		at 3%	at 7%
2.65	2.11	$0.12	$0.05	$0.06

Although it would be possible to cover the first four window openings with a single curtain air bag, it would be challenging. If vehicle manufacturers used two separate curtain air bags to cover the first four rows, a total of four curtain air bags per vehicle, the associate costs would be relatively high when compared to the one-piece curtain air bag. If two curtain air bags are used to cover the first 4 rows, we expect that the first curtain covers the first two rows and the second curtain covers the 3rd and 4th row window openings. In this chapter, we previously estimated $189.72 for the rollover curtain covering two seating rows and $78.25 for thorax bags. In addition, our cost analysis of air bag systems shows that the end user cost of the inflator would be 44.65% of the air bag (loomed cloth) cost.[200] Therefore, the cost of the second curtain air bag was estimated to be $352.68 without considering other components such as wiring, etc. With the estimated 39,618 light with four seating rows and 2 million light vehicles with three seating row, the total cost would be $747M, as shown below.

[200] DOT HS 809 842, Table 2-1, End User Cost.

Table V-10
Cost for Second Curtain Air Bag, in 2009 economics

Components	Cost per vehicle
Curtain bag	$189.72
Thorax bag	$78.25
inflator	$84.71
total	$352.68

The target population showed 23 fatal and 62 serious injured ejections through the 3rd row and 39 fatal ejections through the 4th row window openings. If we assume that the second curtain air bag is as effective as the one-piece curtain air bag, the second curtain air bag installed in a vehicle with four seating rows would save 5 lives (23+39 = 62, 62*8.3% = 5.1) and 5 serious injuries. The estimated $747 cost and the 5 lives saved clearly showed the cost would be far greater than the potential benefits. In summary, we found that it is only cost effective if a three row curtain is simply extended to four rows.

As shown in the target population, 3rd row ejections are a very limited part of the ejection population. Nonetheless, we proposed to extend coverage to 3 rows since it appeared practicable because many vehicles with 3 row of seating were equipped with rollover deployable side curtain air bags that covered daylight openings adjacent to all 3 rows. What concerned the agency at the time of the NPRM was requiring side daylight opening coverage into 4th and higher rows.[201] Glazing Suppliers' comments have indicated that some manufacturers have chosen to place advanced glazing in fixed window positions in the most rear rows of large vans. We have not tested these glazing applications to the NPRM requirements, nor has any data been submitted to the agency. Thus, the practicability of such a glazing-only application is not known to us. The use of advanced glazing in combination with a curtain would also be possible. The agency

[201] 74 FR 63201

met with glass representatives to discuss current applications of advanced glazing. Based on the discussion with the representatives, the agency has anecdotal incremental cost date for covering side windows with advanced glazing. The incremental cost ranges from $8 to $11 per side. If the 4th row is covered with advanced glazing for 39,618 light vehicles with four seating rows, the total incremental cost would be in a range of $640M to $880M. As shown previously, there were 39 fatalities through the 4th window opening. Even if advanced glazing is used with the rollover air bag, we suspect that the benefits would be relatively small. If we assume that advanced glazing is 20% effective in preventing occupants from ejections through the 4th row fixed window, the overall system effectiveness would be 12% for completely ejected unbelted occupants. If all 39 fatalities were from completely ejected unbelted occupants, it would save 5 lives annually. With the $640M - $880M estimated costs, the cost per live saved would range from 128M to 176M.

Third row and cargo area behind second row:

The estimated incremental cost for covering the 3rd row and the cargo area behind the second row window opening is based on a typical minivan and SUVs. When the first three row openings are covered with a single curtain air bag, the incremental cost of covering the third window opening would be $7.14 million. In the target population, we determined that 62 serious injuries and 23 fatalities when occupants were ejected thorough the 3rd row window opening. We estimated that a total 7 serious injuries and 2 fatalities would be prevented when the third row window opening is covered with a curtain air bag. The equivalent cost per fatality would be $2.64 and $2.10 million discounted at 3% and 7%, respectively, for covering the third row window opening. (The cost effectiveness is further discussed in the cost-effectiveness and

benefit-cost analyses chapter.) In addition, the net benefits would be $8.96 and $5.67 million discounted at 3% and 7%, respectively, as shown below.

Table V-11
Cost Effectiveness of Covering Third Row Window Opening

Target population								
Injuries & fatalities					Serious Injuries			Fatality
Ejections thru all side openings					4,557			4,490
Incremental injuries prevented & lives saved					476			373
Overall effectiveness					10.44%			8.31%
Third row only								
Injuries & fatalities					Serious Injuries			Fatality
					MAIS 3	MAIS 4	MAIS 5	
Ejections thru 3rd row opening					37	16	9	23
Overall effectiveness					10.44%	10.44%	10.44%	8.31%
Injuries prevented & lives saved					4	2	1	2
Conversion for Equivalent Life Saved (ELS)					0.0804	0.1998	0.6656	1.0000
Equivalent Life Saved (ELS)					0.31	0.34	0.64	2
Cost Effectiveness for Third Row only								
Total* ELS	Discount Equ. Fatal		Cost in millions	Cost per Equivalent Life Saved (in $M per ELS)		Comprehensive cost in $M	Net benefit, in $M	
	at 3%	at 7%						
	0.8155	0.6489		at 3%	at 7%	$6.1	at 3%	at 7%
3.24	2.64	2.10	$7.14	$2.70	$3.40		$8.96	$5.67

* The numbers were rounded to the nearest integer.

Although most of light vehicles with three rows or two rows with a cargo area behind the second row are either minivans or SUVs, a small number of vehicles with three rows are not minivans or SUVs. For these large light vehicles (under 10,000 lbs. GVWR), the incremental cost would be higher. In their comments to the NPRM, Mercedes commented that the agency has not addressed the level of burden imposed on large vehicles such as the Mercedes-Benz Sprinter. This increased burden stated by Mercedes is summarized by the following bullets.

- This vehicle integrates large window openings, which Mercedes anticipates a completely new generation of large air bags curtains – possibly in combination with

advanced glazing – may be required to meet the standard. (Note: standard passenger car side windows have a height of about 400 mm or less.)

• This vehicle is exempt from the MDB requirements of FMVSS No. 214 and therefore does not have to include side air bags for the rear seating rows. Thus, Mercedes concludes that the proposed ejection mitigation requirements will force substantive change to the vehicle. In addition, they believe this will necessitate various solutions for a range of seating rows, side window layouts, roof heights, and wheelbases offered.

• This vehicle has a large payload capacity and allows extensive flexibility in the placement and securing of cargo. Mercedes claims that because of the resulting variability in the vehicle's center of gravity, the rollover detection technology used in typical passenger vehicles cannot be directly adapted to it. Mercedes believes that this special condition will result in much higher sensor development and production costs than the passenger-car estimates provided by the agency in the NPRM.

As part of their response, Mercedes confidentially provided the estimated incremental costs associated with the Sprinter with the supplementary side impact sensors, modification of the air bag control unit and modification of curtain bag. Although the cost would be higher than the estimate made in the FRIA, which based on a fleet wide average, the Sprinter incremental cost would not be overly burdensome. Mercedes commented that the burden to bring vehicles such as their Sprinter into compliance will be greater than for other vehicles and provided a confidential cost comparison. In general, we do not dispute the premise that there will be differences in bringing vehicles into compliance with the standard as a function of many

different factors. These may include daylight opening area, vehicle structural configuration, interior design, current level of curtain air bag integration, and current level of ejection mitigation countermeasure integration. The agency's cost estimates are a fleet wide average. Some vehicles will cost more and some will cost less. However, this is not the same as not having practicable solutions for particular vehicles.

Volkswagen (VW) provided extensive comments and tabular data comparing the agency cost estimates to their own.[202] Volkswagen estimated an incremental cost of meeting the standard would be much higher than as compared to the agency's estimate of $32.38.[203] A close examination of the confidentially submitted VW cost data showed that the incremental cost associated with the VW air bag (loomed cloth) is higher than what the agency estimate 28%. The 28% incremental cost is based on the teardown cost study done by our contractor and a dimensional analysis of the FMVSS No. 214-curtain air bag. The cost analysis showed that the FMVSS No. 214-curtain air bag would be large enough to completely cover the front window opening if the bag size is increased by 28%. Since Volkswagen did not provide information on the air bag size or window opening, we could not determine the root cause of the difference in incremental cost. However, since the incremental cost would be proportional to the area cover by the bag, it appears that the VW rollover air bag comes down below the window sill. In additional, the cost of the VW roll sensor is higher than the agency's sensor cost estimates that were based on a fleet wide average. Some vehicles will cost more and some will cost less.

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[202] NHTSA-2009-0183

[203] As shown in the benefit chapter, we estimated that the incremental cost would be $30.00 when convertibles are excluded.

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 modification on a per-vehicle cost would be insignificant especially when the modifications are made during the redesign cycle. Costs associated with vehicle compliance tests are discussed below in section C.

B. Other Potential Technology Costs

Costs associated with advanced glazing:

In the impactor test, side window glazing is removed prior to the impact test. Therefore, advanced glazing cannot be used as a standalone device for movable windows to meet the displacement requirement. However, 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 in rollovers. These laminated side window glazing would provide a reaction surface for the curtain air bag in certain less severe rollovers. The agency is proposing that windows with advanced laminated glazing are fully raised and pre-broken prior to the 20 km/h impactor test. The test results showed that the pre-broken glazing in combination with side curtain have been found to be effective and complementary.[204]

[204] The laminated glazing installed in the vehicles was primarily designed for theft protection, not ejection mitigation.

In a November 1995 report,[205] 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 supplier representatives, it was found that the difference in cost between tempered glass and laminate glass is lower today when compared to the cost in 1995. The glass supplier representatives provide that the incremental cost to replace the side window tempered glass with a laminated glass would be $15 in 2010 economics. The $15 incremental cost is much lower than the $24 (in 2007 dollars) incremental cost estimated in 1995 for going from a tempered glass to a laminate glass for standard size front or rear seat window.

However, Ford commented that laminated glazing is 3.2 – 7.5 times the cost of tempered glazing.[206] Since removable side window glazing is removed from the window frame during the 16 km/h-6 second impactor test, we do not expect manufacturers use advanced glazing in the side window if the cost is excessive when compared to tempered glazing unless they cannot meet the 20 km/h-1.5 second test without it.

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[205] "Ejection Mitigation Using Advanced Glazing, A Status Report, November 1995", NHTSA Advanced Glazing Research Team.
[206] NHTSA-2006-26467-002

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 not moveable.

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 to determine how they behave in rollovers. We note that the agency received comments to the NPRM requesting clarification on how the hole-punch pre-breaking procedure would be used for polycarbonate advanced glazing. The final rule will apply the same test procedure to all glazing as we have no firm basis at this time to treat one type of advanced glazing any differently than another. However, it is conceivable that the punches might not break polycarbonate, but could produce stress concentrations that weaken it.

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 2009 economics.

The linear guided headform impact test is similar to the headform test specified in FMVSS No. 201 “Occupant Protection in Interior Impact.” The FMVSS No. 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 FMVSS No. 201-headform test is not guided test. Since the FMVSS No. 201-headform test is already run by vehicle manufacturers, tests like the FMVSS No. 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 headform 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.[207] 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 $.11per vehicle.[208]

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[207] Assumptions used for the weighted test cost are shown below:
[217] make/models, 16.5 million annual vehicle production, 78,000 average annual make/model production (16.5M/217 = 76,000), 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. 40,800/76,000 = $0.54/veh/ design cycle, $0.54/5 = $.11 per/vehicle.
[208] 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.

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 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 headform test.

D. Leadtime and Phase-in

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 year 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 adequate leadtime followed by a phase-in of the requirements. This accomplishes two objectives. 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 phase-in of the new ejection mitigation requirements starts the first September 1 two years from the date of publication of a final rule. Assuming that a final rule would be issued January 31, 2011, the phase-in would be implemented in accordance with the following schedule:

September 1, 2013 for 25 percent of a manufacturer's light vehicles,

September 1, 2014 for 50 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 (with advanced credits), and

September 1, 2017 for all light vehicles (no credits may be used).

Advanced credits earned prior to the phase-in would be allowed during the phase-in period prior to September 1, 2017, as would carry-forward credits.

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 FMVSS No. 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 FMVSS No. 214 and impactor test requirements. We expect that cost savings resulting from the "one time" design would not be substantial with respect to the total cost. The estimated incremental costs in 2009 economics are shown below:

Table V-12
Total Cost and Weighted Average Cost per Vehicle,
Excluding Convertibles in 2009 economics
(Assuming all 214-head bags are either curtain or comb bags)

Baseline 214-Head Bags, MY 2011			Assuming No Compliance[209]		
Bag Type	Sales (%)[210]	Estimated Weighted Sales (%)	Total Sales: 16.3M	Avg. Incremental Cost per Vehicle	Total Cost (in Millions)
214-Curtain w/ roll sensor	55%	55.31%	9.01M	$12.36	$111
214-Curtain w/o roll sensor[211]	39%	44.66%	7.28M	$51.78	$376
214-Combo	1%	0.04%	0.01M	$213.04	$1
Total	95%	100%	16.5M	N/A	$489
3rd row and Cargo area behind 2nd row					$18
Total Weighted Incremental Cost					$507

[209] Agency's impactor 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.

[210] Convertibles were not included in the estimated weighted sales, whereas all light vehicle types were included in the sales.

[211] When all light vehicles are equipped with head air bags to meet the FMVSS No. 214-oblique pole requirements, we assumed that vehicles without any head air bags would be equipped with FMVSS No. 214-curtain bags (without rollover sensors) to comply with the FMVSS No. 214-oblique pole requirements.

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 rollovers and some side impacts. 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 impactor 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.[212] 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.

[212] 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	Incremental Benefits	Conversion Factor	Equivalent Fatalities (Undiscounted)
Fatalities	373	1.0000	373
AIS-5	55	0.6656	37
AIS-4	124	0.1998	25
AIS-3	297	0.0804	24
Total			458

The results in Table VI-1 show that the curtain ejection mitigation air bag would save 458 equivalent fatalities.[213]

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
458	0.8155 at 3%	374
458	0.6489 at 7%	297

The discounted fatal equivalents in Table VI-2 show that curtain ejection mitigation curtain air bags would save 374 and 297 equivalent lives when discounted at 3% and 7%, respectively.

[213] The estimated 458 equivalent fatalities saved were based on the weight risk of ejections method.

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

Table VI-3
Range of Costs[214] per Equivalent Life Saved
(Weight Risk of Ejection Method)

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	$507	374	297	$1.4	$1.7

The results in Table VI-3 show that the cost per equivalent life saved for the curtain ejection mitigation air bag system ranges from $1.4 million ($1.36M) to $1.7 million ($1.70M) at 3% and 7% discount rates, respectively. With the uniform risk of ejection method, the air bag system would result in $1.4 million ($1.39M) and $1.8 million ($1.75M), 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

[214] In the benefit analysis, we used an array of FMVSS No. 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 FMVSS No. 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.

that this value be compared to the monetary value of costs to derive a net benefit. In valuing reductions in premature fatalities, we used a value of $5.8 million per statistical life.[215]

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. 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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[215] "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
(Weighted Risk of Ejection Method)

Ejection Mitigation System	Benefits ($M)		Net Benefit ($M)	
	3%	7%	3%	7%
Rollover Curtain Air Bag	$2,279	$1,814	$1,773	$1,307

The results in Table VI-4 show that ejection mitigation air bags would result in net benefits of $1,773 million and $1,307 million at 3% and 7% discount rates, respectively. With the uniform risk of ejection method, the air bag system would results in $1,717 million and $1,262 million, respectively.

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 advanced glazing including advanced glazing in the roof, (4) excluding A1 from the test requirements, (5) 100% belt use rate, (6) cost benefit for belted versus unbelted occupants, (7) crashes involving alcohol, and (8) replacement costs for air bag deployments.

B. Sensitivity Factors

(1) <u>Cost of rollover sensor:</u>

In the cost chapter, we estimated that each vehicle needs one rollover sensor at an average cost of $39.32 (in 2009 economics). The average cost is based on NHTSA contractor teardown studies of five vehicle makes/models. The rollover sensor cost ranged from $24.18 to $55.32 per vehicle (in 2009 economics). The unit costs of these sensors are significantly different among different models and manufacturers. If the $55.32 sensor cost is used, the cost for each ejection mitigation system would increase greatly, as shown below:

Table VII-1
Upper Range
Costs for Air Bag System with $55.32 Rollover Sensor (in 2009 economics)

Baseline 214-Air Bag System	Estimated Sales	Average Incremental Cost Per Vehicle
Curtain with Roll Sensor	55%	$12.36
Curtain without Roll Sensor	44%	$67.69
Combo	1%	$229.04

With the $55.32 sensor cost (in 2009 economics), the weighted total incremental cost would be $623 million ($605 $_{\text{1st and 2nd rows w/ \$55.32 sensor}}$ + $18.3 $_{\text{3rd row \& cargo}}$ = $623) and the cost per equivalent life saved would increase to $2.1 million with 7% and $1.7 million at 3% discount. When the $24.18 (lower end) was used, it would result in a weighted total incremental cost of $397 million ($378.3$_{\text{1st and 2nd rows w/ \$24.18 sensor}}$ + $18.3 $_{\text{3rd row \& cargo}}$ = $377million, $1.3 million per equivalent life saved at 7% and $1.1 million at 3% discount.

(2) <u>Effectiveness of rollover sensor:</u>

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 89% effectiveness rate used for fatal injuries in our analysis.

With the use of the 90% effectiveness rate, the number of overall additional lives saved would increase from 373 to 376 lives, annually. For the 95% sensor effectiveness rate, the number of overall additional lives saved increases from 373 to 393 lives, annually, as shown in Table VII-2.

Table VII-2
Summary of Expected Incremental Lives Saved[216]
With Different Rollover Sensor Effectiveness Rates, Weighted Risk of Ejection Method

Estimate	Effectiveness (in fatal)	Overall Additional Lives Saved
Agency estimate	89%	373
Supplier estimate – lower range	90%	376
Supplier estimate – upper range	95%	393

(3) Use of advanced glazing:

In the benefit analysis, we assumed that the impactor displacement requirement would be met with rollover curtain air bags without advanced glazing. For the 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 laboratory data suggest that even pre-broken advanced glazing could be effective in preventing occupant ejection through the potential gaps between the bottom of the bag and the window sill in certain crashes when rollover curtain bags are used.[217]

(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 70% to 87% for belted and 64% to 85% for

[216] For the fatal benefits in the table, we assumed that all side windows would be made out of tempered glass.
[217] 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.

unbelted (weighted with the 69% window-up percentage)[218], if we assume that all ejections through the potential gaps would be prevented by the glazing.[219] However, as reflected in the 16 km/h impactor test performed at 6 second time delay, we believe that removable side window glazing would be separated from the window frame in severe multiple rollovers. In the impactor test occurring at 1.5 second, the agency allows the use of pre-broken glazing. In the 6-second impactor test, window glazing is completed removed from the window frame. We believe that window glazing would be separated from the window frame sometime after 1.5 second but not after 6 seconds. However, we do not know when window glazing is separated from the window frame during the 1.5 – 6.0 second period. In addition, we note that glazing has no effect in preventing occupants from ejection when it is down. Although it would overestimate the effectiveness of advanced glazing, due to limited data, we assumed that advanced glazing when it is in rolled-up position would be effective in rollovers lasting less than 6 seconds. Based on the ¼-turn data presented in the preamble of the FMVSS No. 226 final rule (Table 31 in the preamble), the agency derived the equation y = 0.48x, where y = rollover time in seconds and x = number of ¼-turns. The equation showed that the number of ¼-turns would be 13 ¼-turns when the rollover time is 6 second. The 2000-2009 NASS CDS data (presented in the benefits chapter of this FRIA) showed that almost all rollover crashes would be less than 13 ¼-turns. Therefore,

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[218] The agency's 1997-2008 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 94% of ejections through the window opening (with the 6% 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.

[219] With the 6% sunroof ejection rate, we estimated that the curtain+glazing system would be 94% effective in preventing occupant ejection. Previously, we estimated that the curtain system would be 70% and 64% effective for belted and unbelted occupant, respectively, with the weighted risk of ejection method in rollovers. These containment rates were adjusted with the 69% window-up rate to derive the combined effectiveness (94% x $69\%_{\text{window up}}$ + 70% x $(100\%-69\%)_{\text{window down}}$ = 87% for belted, 94% x 69% + 64% x (100%-69%) = 85% for unbelted. The weighted combined containment effectiveness would be 86%: 13% were belted and 87% were unbelted in fatal rollovers. 13% x .87 + 87% x .85 = 85%.

the 87% and 85% derived for belted and unbelted occupants adjusted with the glazing rolled-up rate, respectively, were not further adjusted. 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 55% effective in reducing belted partial fatal injuries in rollover crashes, with the weighted risk of ejection method. When the 87% improved containment effectiveness is used, the overall effectiveness would increase from 55% to 68% ($89\%_{sensor}$ x $87\%_{containment}$ x $88\%_{risk\ inside\ vehicle}$ = 68%) for belted partial fatal injuries, assuming side windows are up 69% of the time before side window ejection. With the estimated advanced glazing containment effectiveness, we expect the number of additional lives saved would increase from 241 to 317 (lives) in rollover crashes. With the glazing, the overall number of additional lives saved in rollover and side crashes would increase from 373 to 469 (lives)[220].

(3.2) Costs: In the NPRM, we estimated that if vehicle manufacturers replace a tempered glass with a laminated glass for a standard size front window or rear seat window, the associated unit cost would be about $25 (in 2009 dollars). Anecdotal cost data from glazing manufacturers show that the incremental unit cost would be about $15 per window. 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 $489 million (16.3 million $_{No.\ of\ vehicles}$ x $\$15_{incremental\ unit\ cost}$ x $2_{No.\ of\ windows}$ = $489 million).[221] The agency expects that about 36% of all light vehicles would have fixed (non-removable) windows in the rear passenger (i.e., 3rd row) or cargo

[220] In the benefit chapter, we used both "weighted risk of ejection" and "uniform risk of ejection" approaches for the containment effectiveness. The fatal benefits are based on the "weighted risk of ejection" method. We note that the advanced glazing containment effectiveness values were applied to any rollovers in the target population.
[221] Convertibles were excluded in the 16.3 million vehicles.

compartment.[222] 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 ($507M $_{Curtain}$ + $664M $_{Advanced\ glazing}$ = $1,225M.[223] If the first three rows are covered, including the cargo area behind the second row, the incremental cost would be $1,660M (including $1,153M for advanced glazing).

(3.3) Cost per Equivalent life Saved: With advanced glazing in the first three rows (or the cargo area behind the 3rd row), the number of additional lives saved in rollover and side crashes would[rd] increase from 373 to 469 (lives). Similar to the method used for the fatalities, we estimated that a total of 604 AIS 3-5 injuries would be saved, as shown below.

Table VII-3
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	Conversion Factor[224]	Equivalent Fatalities
Fatalities	*373*		469	1.0000	469
AIS-5	*55*		70	0.6656	46
AIS-4	*124*		158	0.1998	31
AIS-3	*297*		376	0.0804	30
				Total	577

The results in Table VII-3 show that the curtain+glazing ejection mitigation system would save 577 equivalent fatalities.

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[222] Based on MY 2009 sales

[223] Since 100% of vehicles have 1st row windows and 36% 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	$15	16.3M	2	100%	$489M	
3rd row	$15	16.3M	2	36%	$176M	Total: $664M

The $664M is based on an assumption that laminated glazing would be installed in the rear window opening (i.e., 3rd row or cargo behind the 2nd row).

[224] 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.

The discount factors and the discounted fatal equivalents are summarized in Table VII-6.

Table VII-4
Present Discounted Value of Lives Saved for Curtain+Glazing

Fatal Equivalent	Discount Rate	Discounted Fatal Equivalent
577	0.8155 at 3%	457
577	0.6489 at 7%	364

The discounted fatal equivalents in Table VII-4 show that curtain + glazing system would save 457 and 364 equivalent lives when discounted at 3% and 7%, respectively.

Previously we estimated that a total incremental cost of $507 million for covering 1st, 2nd, 3rd row window openings and the cargo area behind 2nd row. With the $1,153 million glazing cost, the total incremental cost increase from $507million to $1,660 million. The $1,660 million total annual cost was divided by the discounted fatal equivalent to produce estimates of the cost per equivalent life saved, as shown in Table VII-5.

Table VII-5
Range of Costs per Equivalent Life Saved
One piece Curtain and Advanced Glazing

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	$1,660	457	364	$3.6	$4.6

The results in Table VII-5 show that the cost per equivalent life saved for the curtain + glazing system would be $3.6 million to $4.6 million at 3% and 7% discount rates, respectively.

(4) Excluding A1 from the test requirements: In the benefits chapter, the potential benefits were estimated based on a premise that vehicle manufacturers would meet the 100 mm displacement requirement at all impact points, including A1. Although the headform test results used in the

FRIA showed that it will be feasible and practicable for A1 to meet the proposed test requirements, we believe that it would be challenging for some vehicles.[225]

We believe that based on the evidence available to us, complete window coverage is critical to the effective performance of the ejection countermeasure. The tests performed with a rollover fixture showed that sometimes the dummy migrates to and can find an opening in the ejection mitigation curtain.[226] As shown in Figure VII-1, excluding A1 as a target point will allow curtains to have 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. In addition, we note that the term "partial curtain" refers to a curtain that has an opening at A1. Nevertheless, we examined the potential safety impact of an impactor 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.

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[225] 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). In addition, we note that the agency impactor test results from the MY 07 Mazda CX9 showed a headform displacement of 76 mm at A1 in the 20 km/h impactor test.

[226] 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."

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).

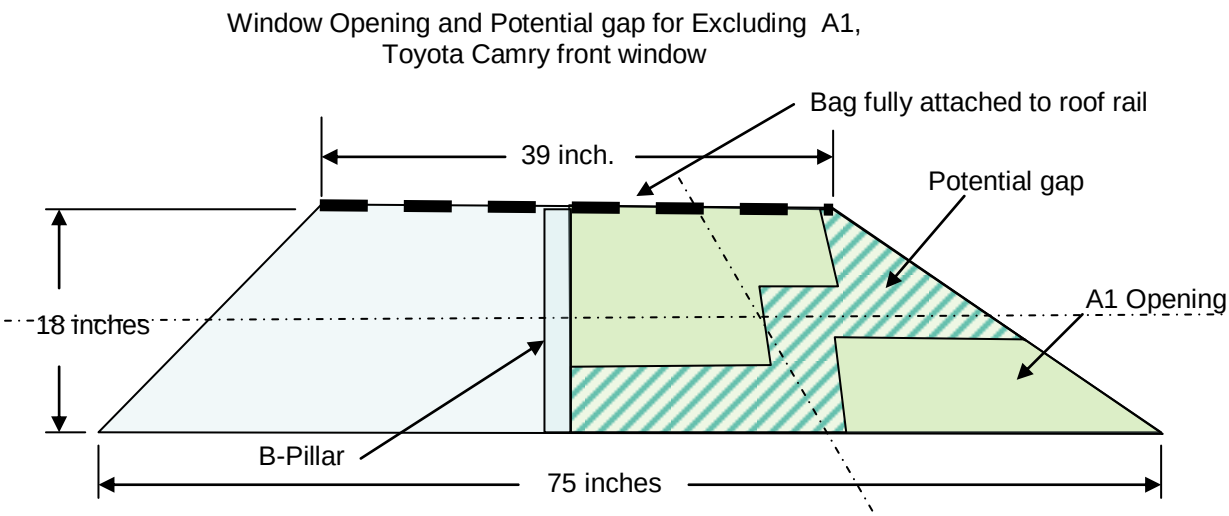


Figure VII-1. Potential gap/opening and A1

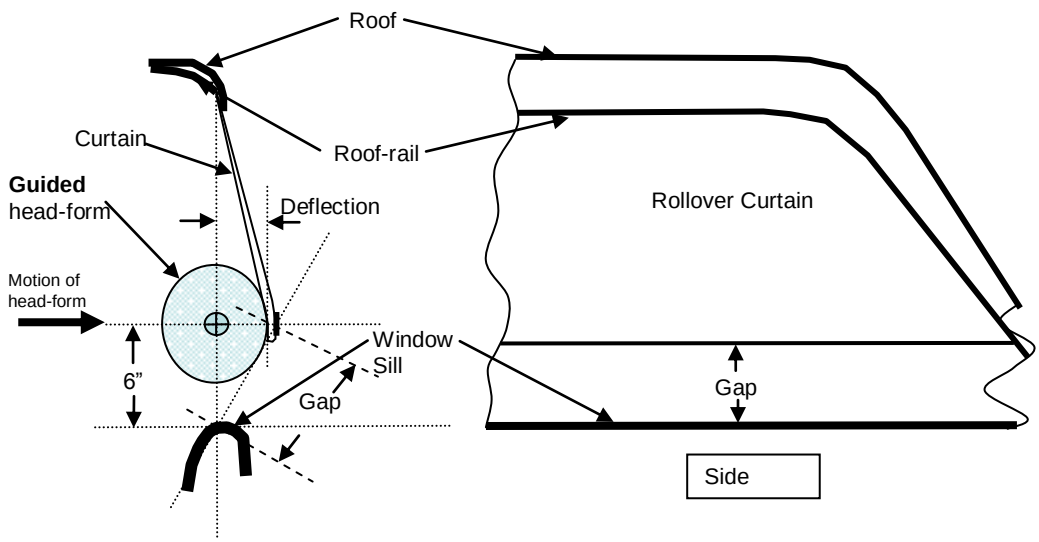


Figure VII-2 Potential Gap in Front Window

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-2) 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%[227] for belted occupants and 16% for unbelted occupants, as shown in Figures VII-3and VII-4.

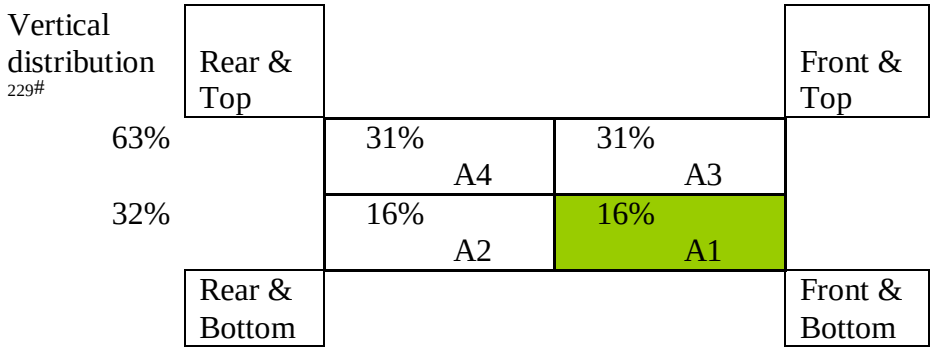
Vertical distribution	Rear & Top			Front & Top
63%		52% A4	10% A3	
31%		26% A2	5% A1	
	Rear & Bottom			Front & Bottom

Total 94%[228] The numbers were rounded to the nearest integer.

Figure VII -3 Belted Occupants, Risk of Ejection through Each Quadrant

[227] 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 6% ejection risk through the sunroof, the risk of ejection through the lower quadrant would be 5% (33%x17%x94%=5%). The percentages were based on the weighted risk of ejection method.

[228] Based on ejections in real world crashes, we assumed that 6% of ejections would occur through the sunroof.



Total 94% The numbers were rounded to the nearest integer.

Figure VII -4 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 potential gap in the lower rearward quadrant (A2) would be approximately 17% (17.3%).[230] Likewise, under the assumption, the risk of ejection through the potential gap in the low forward area would be about 3% (3.3%).[231] 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%$_{\text{fully covered curtain}}$.

[229] Note that, due to limited data, we used the vertical ejection distribution of belted occupants as a proxy for unbelted occupants.
[230] 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%).
[231] 5% of the ejections would occur through the lower forward quadrant.

In the benefit chapter, we determined that the curtain air bag 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). 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 57% effective in preventing belted occupants and 47% effective in preventing unbelted occupants in fatal rollover crashes.

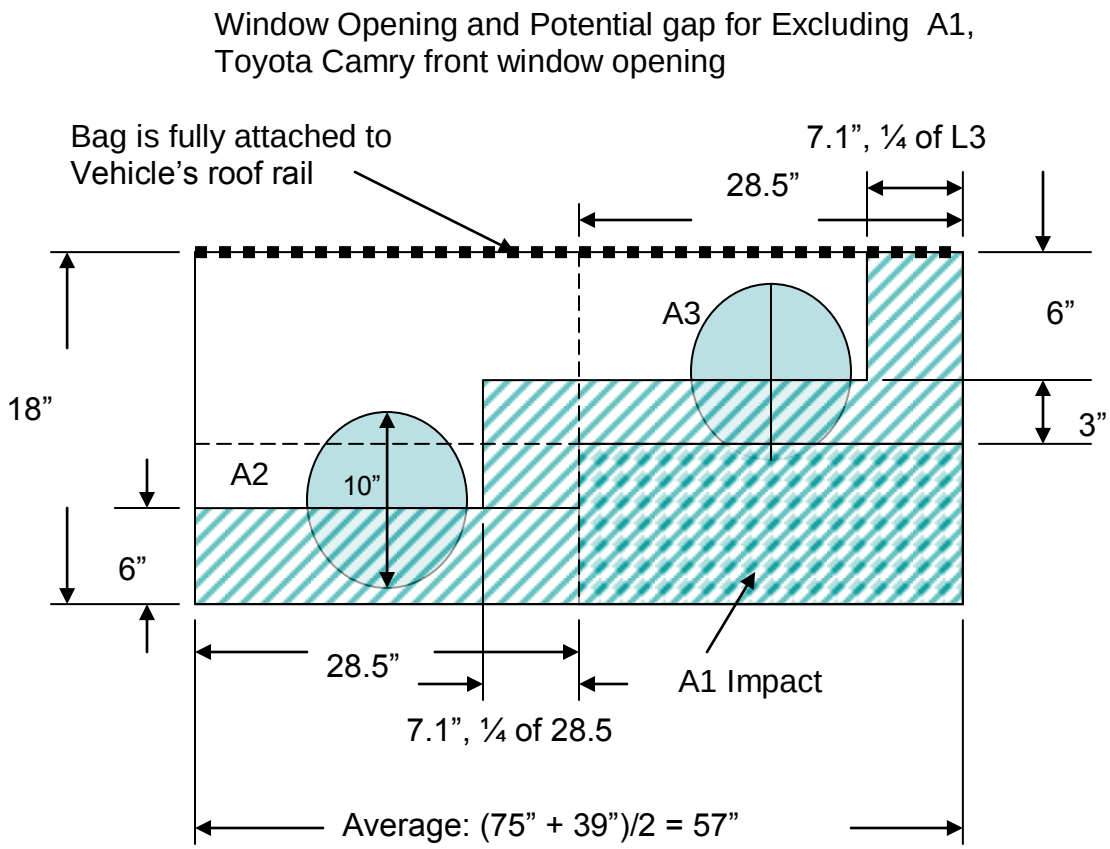


Figure VII-5. Window opening in quadrant form, 2003 MY Toyota Camry

Table VII-6 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	52%	26%	10%	5%
Coverage without testing A1	83%	33.3%	50%	0%
Containment without testing A1	44%	9%	5%	0%
Overall belted containment:				57%

Table VII-7 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	31%	16%	31%	16%
Coverage without testing A1	83%	33.3%	50%	0%
Containment without testing A1	26%	5%	16%	0%
Overall unbelted containment:				47%

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 the bottom of the curtain air bag) when the bag is not completely attached to the structure.

We note that although we only tested a limited 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-6), 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.)

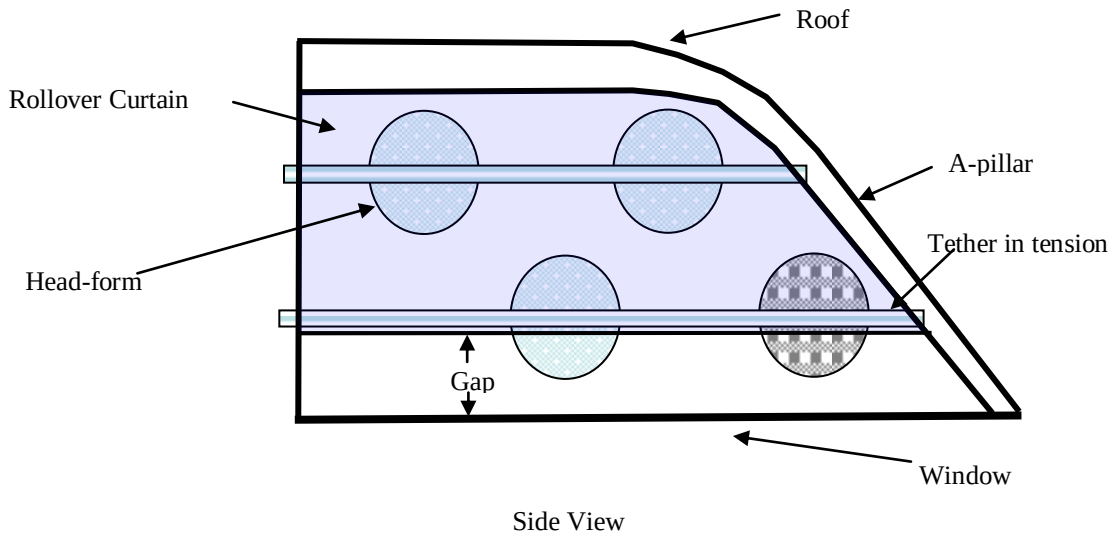


Figure VII-6. Illustration of the tether lines

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 minimum estimate of the potential loss in containment effectiveness if 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 A1 would have significant effects on the containment effectiveness in rollovers. As explained below, for the initial impact to the curtain air bag, the overall system effectiveness would decrease from 55% to 45% for belted partially occupants. For unbelted partially occupants, the system effectiveness would reduce from 50% to 37%.

Tale VII-8
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	55%	45%
Belted Complete	0%	0%
Unbelted Partial	50%	37%
Unbelted Complete	43%	31%

Table VII-9
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	30%	25%
Belted Complete	0%	0%
Unbelted Partial	28%	23%
Unbelted Complete	20%	17%

Table VII-10
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	34%	28%
Belted Complete	0%	0%
Unbelted Partial	31%	23%
Unbelted Complete	23%	17%

Reduction in benefit: Previously in the benefits chapter, we estimated that a total of 524 lives would be saved by the final rule (before adjustments for compliance and installation rates with the weighted risk of injury method). When the overall system effectiveness rates as shown in Tables VII-8 thru VII-10 were applied to the fatal injury population, assuming no compliance, it would result in an upper range estimate[232] of 416 lives saved (compared to 524 lives saved with the full curtain). When A1 is excluded from the test requirements, therefore, it would result in a 20% reduction in fatal saving (108 less, 524 - 416 = 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

[232] 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 system excluding A1 assumes that an unbelted occupant gets multiple chances of going out the gap left by A1, depending on the rollover severity.

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 the figure below.

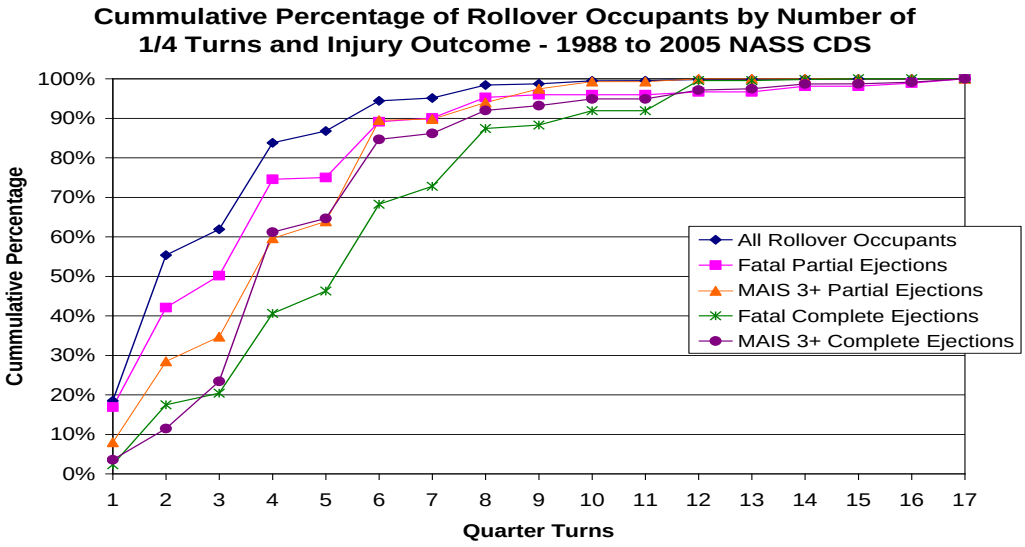


Figure VII-7 Cumulative Percentage of Rollover Occupants by Number of ¼ turns and Injury Outcome

[Do I need to update the calculation with the 2000-2008 data? It would be time-consuming but would not make any difference.]

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-11 shows the population of completely ejected and partially ejected fatalities at each complete vehicle roll break-point.

Table VII-11 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 524 to 416 lives (which was not yet adjusted with the current compliance rate and the expected voluntarily installed rollover bags), as shown below in Table VII-12:

Table VII-12
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 & Sue's	System	Fatalities	lives saved
rollover, no side impacts:						
Belted partial	89%	57%	88%	45%	87	39
Belted complete	89%	0%	75%	0%	0	0
Unbelted partial	89%	47%	88%	37%	125	46
Unbelted complete	89%	47%	75%	31%	535	168
side impacts followed by rollovers:						
Belted partial	89%	57%	49%	25%	6	1
Belted complete	89%	0%	36%	0%	0	0
Unbelted partial	89%	47%	49%	20%	173	35
Unbelted complete	89%	47%	36%	15%	106	16
side impacts, w/ subsequent rollovers, 12-25 mph:						
Belted partial	100%	57%	49%	28%	0	0
Belted complete	100%	0%	36%	0%	8	0
Unbelted partial	100%	47%	49%	23%	0	0
Unbelted complete	100%	47%	36%	17%	63	11
side impacts, no rollovers, 12-25 mph:						
Belted partial	100%	100%	49%	49%	0	0
Belted complete	100%	0%	36%	0%	0	0
Unbelted partial	100%	100%	49%	49%	0	0
Unbelted complete	100%	100%	36%	36%	225	80
side impact, no rollover, children (0-12 YO), include both partial and complete ejections, 12- 25 mph:						
Belted partial	100%	100%	49%	49%	24	12
Belted complete	100%	0%	36%	0%	0	0
Unbelted partial	100%	100%	49%	49%	0	0
Unbelted complete	100%	100%	36%	36%	23	8
				total	1,374	416

After the initial loading of the air bag, some unbelted occupants will move to an opening in the window coverage in lateral rollovers. To estimate the lower end of the range of effectiveness, we assumed that occupants get another chance to be ejected through the opening at 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 went out.) In the previous discussion, for example, we estimated that the partial curtain system would have a containment effectiveness of 47% for unbelted occupant in rollover. Under the assumption, the containment for the occupants would be 22% (47% * 47% = 22%), and 10% (47%*47%*47% = 10%), 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.[233] Under the assumptions of this analysis the partial curtain air bag would save 338 lives (241 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-13 thru - 15

[233] 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-13
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	89%	57%	88%	45%	65	29
Belted complete	89%	0%	75%	0%	0	0
Unbelted partial	89%	47%	88%	37%	94	34
Unbelted complete	89%	47%	75%	31%	246	77
side impacts followed by rollovers:						
Belted partial	89%	57%	49%	25%	4	1
Belted complete	89%	0%	36%	0%	0	0
Unbelted partial	89%	47%	49%	20%	129	26
Unbelted complete	89%	47%	36%	15%	49	7
side impacts, w/ subsequent rollovers, 12-25 mph:						
Belted partial	100%	57%	49%	28%	0	0
Belted complete	100%	0%	36%	0%	3	0
Unbelted partial	100%	47%	49%	23%	0	0
Unbelted complete	100%	47%	36%	17%	29	5
side impacts, no rollovers, 12-25 mph:						
Belted partial	100%	100%	49%	49%	0	0
Belted complete	100%	0%	36%	0%	0	0
Unbelted partial	100%	100%	49%	49%	0	0
Unbelted complete	100%	100%	36%	36%	103	37
side impact, no rollover, children (0-12 YO), include both partial and complete ejections, 12- 25 mph:						
Belted partial	100%	100%	49%	49%	18	9
Belted complete	100%	0%	36%	0%	0	0
Unbelted partial	100%	100%	49%	49%	0	0
Unbelted complete	100%	100%	36%	36%	10	4
				total	752	230

Table VII-14
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	89%	33%	88%	26%	18	5
Belted complete	89%	0%	75%	0%	0	0
Unbelted partial	89%	22%	88%	17%	26	5
Unbelted complete	89%	22%	75%	15%	225	33
side impacts followed by rollovers:						
Belted partial	89%	33%	49%	14%	0	0
Belted complete	89%	0%	36%	0%	0	0
Unbelted partial	89%	22%	49%	10%	36	3
Unbelted complete	89%	22%	36%	7%	44	3
side impacts, w/ subsequent rollovers, 12-25 mph:						
Belted partial	100%	33%	49%	16%	0	0
Belted complete	100%	0%	36%	0%	3	0
Unbelted partial	100%	22%	49%	11%	0	0
Unbelted complete	100%	22%	36%	8%	27	2
side impacts, no rollovers, 12-25 mph:						
Belted partial	100%	100%	49%	49%	0	0
Belted complete	100%	0%	36%	0%	0	0
Unbelted partial	100%	100%	49%	49%	0	0
Unbelted complete	100%	100%	36%	36%	94	34
side impact, no rollover, children (0-12 YO), include both partial and complete ejections, 12- 25 mph:						
Belted partial	100%	100%	49%	49%	5	3
Belted complete	100%	0%	36%	0%	0	0
Unbelted partial	100%	100%	49%	49%	0	0
Unbelted complete	100%	100%	36%	36%	10	3
				total	489	91

Table VII-15
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	89%	19%	88%	15%	3	1
Belted complete	89%	0%	75%	0%	0	0
Unbelted partial	89%	10%	88%	8%	5	0
Unbelted complete	89%	10%	75%	7%	64	4
side impacts followed by rollovers:						
Belted partial	89%	19%	49%	8%	0	0
Belted complete	89%	0%	36%	0%	0	0
Unbelted partial	89%	10%	49%	5%	7	0
Unbelted complete	89%	10%	36%	3%	13	0
side impacts, w/ subsequent rollovers, 12-25 mph:						
Belted partial	100%	19%	49%	9%	0	0
Belted complete	100%	0%	36%	0%	3	0
Unbelted partial	100%	10%	49%	5%	0	0
Unbelted complete	100%	10%	36%	4%	8	0
side impacts, no rollovers, 12-25 mph:						
Belted partial	100%	100%	49%	49%	0	0
Belted complete	100%	0%	36%	0%	0	0
Unbelted partial	100%	100%	49%	49%	0	0
Unbelted complete	100%	100%	36%	36%	27	10
side impact, no rollover, children (0-12 YO), include both partial and complete ejections, 12- 25 mph:						
Belted partial	100%	100%	49%	49%	1	0
Belted complete	100%	0%	36%	0%	0	0
Unbelted partial	100%	100%	49%	49%	0	0
Unbelted complete	100%	100%	36%	36%	3	1
				total	133	17

* The numbers were rounded to the nearest integer.

Previously, we estimated that about 29% (28.8%) of the potential fatal benefits could be achieved with the curtain air bag. When the 29% potential fatal benefits are subtracted from the 338 lives saved, it results in 241 incremental fatal benefits. In the benefits chapter, we estimated 373 incremental fatal benefits with the full curtain. Thus, the incremental fatal benefits decrease from 373 to 241 lives when A1 is excluded. For serious injuries, the injury benefits decrease from 476 to 305 injuries. (See Appendix K for detailed calculation.)

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 \$0.00338 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. When the A1 is excluded from the impactor requirement, we estimate that 729 cm^2 of the window opening would not be covered by a bag. Therefore, with an estimated 16.3 million annual vehicle production excluding convertibles, the exclusion of A1 would result in \$406 M incremental cost with \$24.94 per vehicle. In summary, when the low forward impact point A1 is excluded from the impact requirements, the number of additional lives saved would range from 296 to 241, annually. 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-16
Incremental Costs and Additional Lives Saved for Excluding A1
(with weighted risk of ejection method)

Alternatives	Lives Saved (incremental)	Costs (millions)		
		1st & 2nd rows	3rd row	total
Full Coverage Curtain	373	\$489	\$18	\$507
Excluding A1 (Upper estimate)	296	\$388	\$18	\$406
Excluding A1 (Lower estimate)	241	\$388	\$18	\$406

Table VII-17
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	190	80	35	241		3%	7%
conversion factor	0.0804	0.1998	0.6656	1		0.8155	0.6489
equivalent fatal	15	16	23	241	295	241	192

Table VII-18 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%	$6.1	3%	7%
Excluding A1	241	295	241	192	$406	$1.69	$2.12		$1,062	$762
Full Curtain	373	458	374	297	$507	$1.36	$1.70		$1,773	$1,307

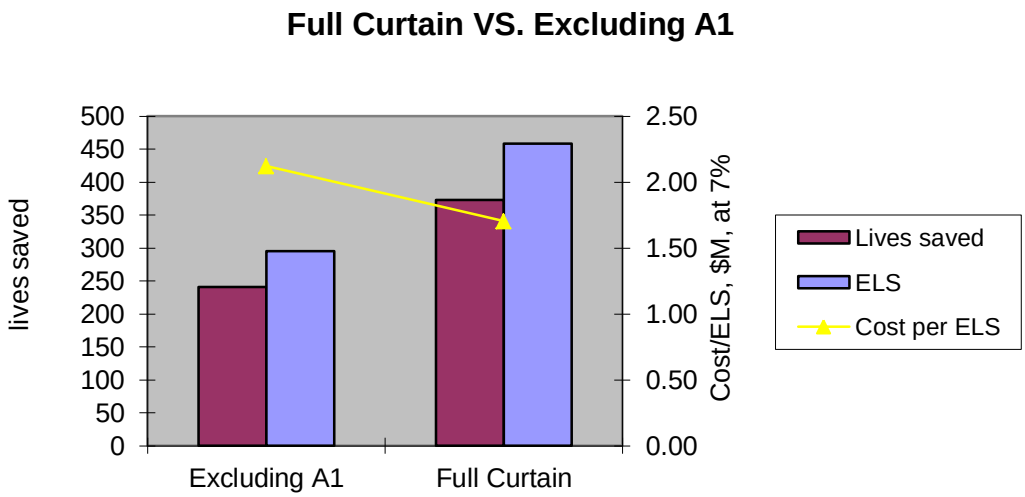


Figure VII-8. Total Lives Saved, ELS, and Cost per ELS (at 7%) for Full Curtain and Excluding A1

We note that the lower estimate (241 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, 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 241 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-19 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	311	221	1.83	2.30

(5) 100% belt use rate: If all observed 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 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 adjusted fatalities would decrease from 1,374 to 888. With the 888 fatalities, the ejection mitigation system would save 241 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, hypothetically, the number of fatalities would decrease from 1,374 to 676. In the target population, there were 1,374 fatalities. Among the 1,374 fatalities, 125 were belted occupants and the remaining 1,249 were unbelted. In the benefits chapter, we estimated that the ejection mitigation would save 41 belted occupants. With the 44 lives saved, the overall system effectiveness would be 35% (44/125 = 0.35). When the 35% effectiveness was applied to the 676 fatalities, it shows that 236 lives would be saved with the ejection mitigation system when all occupants in crashes used safety belts. Hypothetically, if all occupants wear safety belts at all times, 698 lives could be saved if the belt use rate increases from 84%.

(6) Cost benefit for belted versus unbelted occupants:

The section addresses the cost effectiveness of ejection mitigation for belted people as a group compared to unbelted people. If we assume that 85% of the costs apply to belted people, then Table VII-20 shows the distribution of costs.

Table VII-20
Assumed Cost Breakdown between Belted and Unbelted Occupants

Seat belt use rate:	85%
Total incremental cost (in $M):	$507
Incremental cost for belted (in $M)	$431
Incremental cost for unbelted (in $M)	$76

Table VII-21
Benefits for Belted and Unbelted Occupants

Occupants	MAIS 3	MAIS 4	MAIS 5	Fatal	Total	Discounted ELS	
Belted Partial	51	22	2	44	ELS	at 3%	at 7%
Conversion factor	0.0804	0.1998	0.6656	1	saved	0.8155	0.6489
ELS	4.14	4.37	1.19	43.73	53.42	44	35
Occupants	MAIS 3	MAIS 4	MAIS 5	Fatal	Total	Discounted ELS	
Belted Complete	0	0	0	0	ELS	at 3%	at 7%
Conversion factor	0.0804	0.1998	0.6656	1	Saved	0.8155	0.6489
ELS	0.00	0.00	0.00	0.00	0.00	0	0
Occupants	MAIS 3	MAIS 4	MAIS 5	Fatal	Total	Discounted ELS	
Unbelted Partial	46	14	2	79	ELS	at 3%	at 7%
Conversion factor	0.0804	0.1998	0.6656	1	saved	0.8155	0.6489
ELS	3.69	2.75	1.64	78.69	86.76	71	56
Occupants	MAIS 3	MAIS 4	MAIS 5	Fatal	Total	Discounted ELS	
Unbelted Complete	199	89	51	251	ELS	at 3%	at 7%
Conversion factor	0.0804	0.1998	0.6656	1	saved	0.8155	0.6489
ELS	16.04	17.70	33.74	250.57	318.05	259	206

Table VII-22
Cost per Equivalent Life Saved – Belted and Unbelted Occupants

	Costs	Cost per ELS (3%)	Cost per ELS (7%)
Belted	$431 million	$9.9 million	$12.43 million
Unbelted	$76 million	$0.23 million	$0.29 million
Total	$507 million	$1.28 million	$1.71 million

(7) Crashes involving alcohol: In the FMVSS No. 226 PRIA, we estimated that 58% of the fatalities in the PRIA target population are in alcohol related crashes, as shown in Table VII-23.[234]

Table VII-23
Alcohol Used by Driver in Fatal Crashes of the Target Population
(1997-2005 NASS and 2005 FARS)

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		
yes	Driver	No	1	6		
yes	Driver	Unknown	1	11		
yes	Passenger	Yes	36	451		
yes	Passenger	Unknown	2	16	1,797	58%
no	Driver	No	26	159		
no	Driver	Unknown	25	273		
no	Passenger	No	22	557		
no	Passenger	Unknown	32	352	1,341	42%

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-24 Driver Belt Use versus Alcohol Use in Fatal Crashes
(1997-2005 NASS and 2005 FARS)

Occupant Belt Use	Vehicle Driver Used Alcohol		
	yes	no	unknown
No	76%	44%	55%
Yes	24%	56%	45%
total	100%	100%	100%

Subsequent to the alcohol use crash analysis in the PRIA, the agency updated the 1997-2005 NASS with the 2000-2009 NASS crash data. The updated 2000-2009 NASS showed that the

[234] Among the occupant fatalities in crashes where there was a drunk driver, 74% were drivers, 26% were passengers.

percent of alcohol use among the drivers and passengers increased 11% when compared to the 1997-2005 NASS, from 58% to 64%.

In the target population used in the FRIA, there were 1,374 fatalities when the baseline target population was adjusted for 100 percent ESC implementation, 214-potential benefits and increase in belt use rate. When the 64% alcohol involved fatalities were excluded from this target population, it resulted in 874 alcohol related fatalities, as shown below.

Table VII-25 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-25 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
1,374	64%	874	76%	24%	667	207

When all drunk driver related fatalities were excluded from the target population, the fatalities in the target population decreased from 1,374 to 500 (1,374 – 874 = 500). With the decreased number of fatalities in the target population, the potential benefits would decrease from 373 lives saved to 199 lives saved. The cost per equivalent live saved (ELS) ranges were estimated to be $2.5M and $3.2M at 3% and 7% discount rates, respectively, when alcohol related fatalities are excluded from the target population.

Summary of Sensitivity Analyses: 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 rollover sensors, the effectiveness of the rollover sensor and the use of advanced glazing. The three factors affecting benefits (sensor effectiveness, advanced glazing and weighted risk of ejection) showed that the ejection mitigation system could save 494 (additional) lives, annually, in the most favorable conditions (curtain plus advanced glazing and 95% sensor effectiveness). When the least favorable factors were used (89% sensor effectiveness, no advanced glazing and uniform ejection distribution in the window open area), the sensitivity analyses showed at least 364 (additional) lives would be saved, annually, as shown in the figure below.

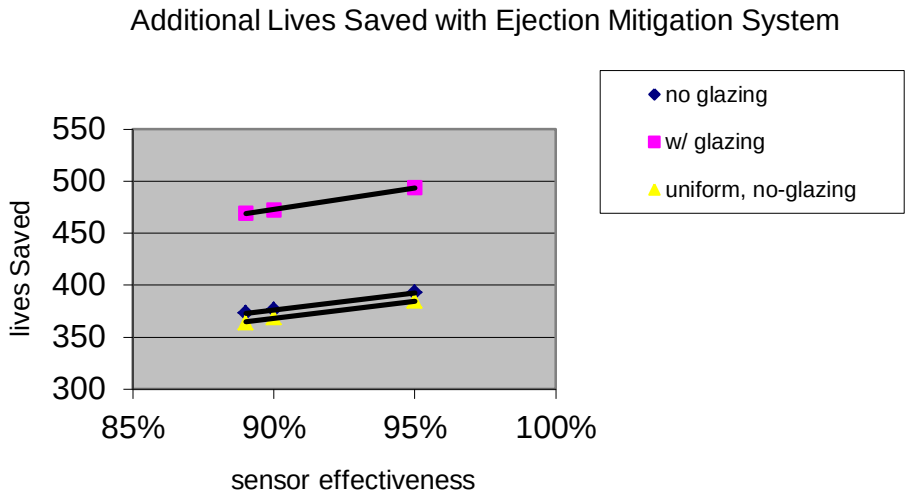


Figure VII-9. Range of estimated benefits with different assumptions used

The middle regression line in Figure VII-9 shows that 20 more lives could be saved by a curtain (only) system if the sensor effectiveness increases from 89% to 95% (393 – 373 = 20 lives). The lower linear regression line shows that a curtain ejection mitigation system (without advanced glazing) could save 364 additional lives, annually, if all ejections through the window opening area were uniformly distributed in rollover crashes. The incremental lives saved with different assumptions used are shown below:

Table VII-26

Window Condition	Sensor Effectiveness		
	89%	90%	95%
Weighted risk of ejection, w/ glazing	469	472	494
Weighted risk of ejection, no glazing	373	376	393
Uniform risk of ejection, no glazing	364	369	385

We note that the use of the uniform risk of ejection method would result in a slightly lower number of additional lives saved (1.6% lower than the use of the weighted risk of distribution). However, when the front lower area, A1 is excluded from meeting the headform requirements, the number of additional lives saved decreased substantially from 373 for the full curtain to 221 for the partial curtain (without advanced glazing).

(8) Replacement costs for air bag deployments:

This section discusses replacement costs for window curtains that are deployed in rollover crashes. There will be a number of rollovers that occur over the lifetime of a model year's fleet in which the vehicle will be repaired, including the window curtain. Those are added lifetime costs for the vehicle. They should be included in the overall costs of the final rule. The agency has not fully analyzed these costs, but has made some estimates for this sensitivity analysis.

There are several factors to consider and estimate. First, how often do rollover crashes occur to a fleet of vehicles over its lifetime. Second, how many of those vehicles are totaled and how many are repaired. Third, what is the incremental cost of repairing those vehicles to repair the window curtains.

Based on NASS-CDS 2000-2009, we found an average of 55,089 vehicles per year involved in ¼ turn rollover crashes (23 percent of all rollovers were ¼ turn events). We focused on ¼ turn crashes for this analysis, because in our review of many crashes we find that when there is a ½ turn of more, there is usually roof intrusion and the vehicle is totaled. Even for many of the ¼ turn rollovers the scenario is that the vehicle was struck by another vehicle on one side and then the vehicle rolls over onto the other side. When both sides of a vehicle are damaged, the vehicle is often totaled (this somewhat depends on the age and value of the vehicle compared to the cost to repair all of the damaged parts). Our educated guess would be that perhaps 80 percent of the ¼ turn rollover vehicles are repaired and 20 percent are totaled. For this sensitivity analysis we examined different replacement rates for those vehicles with ¼ turn, all the way from none of them having the window curtain replaced to all of them having the window curtain replaced. The rollover crashes can occur anytime over the lifetime of a vehicle. We again assume that weighted vehicle miles traveled is a proxy measure for when a crash might occur and the replacement costs are discounted based on that weighted VMT for a 3 percent and 7 percent discount rate.

Replacement costs are assumed for the window curtain fabric itself and for inflators. The rollover sensor would not need to be replaced after a crash. As a rule of thumb, NHTSA typically assumes that repair costs are three times higher than original equipment costs. This takes into account labor for repair costs, storage and distribution of repair parts, etc. Based on just the window curtain and inflator, we estimate the costs for a new vehicle at $246.19 and three times that is $738.57 for the incremental costs of replacing both window curtains and both inflators in a damaged vehicle. If all ¼ rollover crashes were repaired, $40.7 million

(undiscounted) would be spent per year and after discounting those back to present value the estimated incremental replacement costs are $36 million (3% discount rate) or $26 million (7% discount rate). Those are added to the total new vehicle cost of $507 million and compared to the equivalent life saved in Table VII-27 below.

In summary, adding replacement costs into the equations has a small impact on the results. For example, the cost per equivalent life saved for the 3 percent discount rate only changes from 1.36 to 1.45 million. The final rule is still very cost effective, resulting in significant net benefits.

Table VII-27
Effect of Replacement Cost Assumptions

Replace Rate	ELS at 3%	ELS at 7%	Total Cost at 3%	Total Cost at 7%	Cost per ELS in Millions at 3%	Cost per ELS in Millions at 7%	Net Benefit In Millions at 3%	Net Benefit In Millions at 7%
0%	374	297	$ 507	$ 507	$ 1.36	$ 1.71	$ 1,772	$ 1,307
20%	374	297	$ 514	$ 512	$ 1.37	$ 1.73	$ 1,766	$ 1,300
40%	374	297	$ 520	$ 518	$ 1.39	$ 1.75	$ 1,759	$ 1,294
60%	374	297	$ 527	$ 523	$ 1.41	$ 1.77	$ 1,753	$ 1,287
80%	374	297	$ 534	$ 528	$ 1.43	$ 1.79	$ 1,746	$ 1,280
100%	374	297	$ 540	$ 533	$ 1.45	$ 1.82	$ 1,739	$ 1,274

VIII. ALTERNATIVES

There were a number of alternative regulatory approaches the agency considered for this rulemaking. These alternatives included exclusion of the front lower corner of the front side window area (test point A1) and conducting a full-vehicle dynamic test to evaluate a countermeasure's retention capability instead of the headform component test.

The exclusion of the front lower corner of the front side window area was previously discussed in the sensitivity chapter.

For the full-vehicle dynamic test, we have decided against a full-vehicle dynamic test, for the reasons explained in the preamble. The headform test adopted today not only distinguishes between acceptable and unacceptable performance in side curtain air bags, but has advantages over a full vehicle dynamic test. The acceptable (or poor) performance in the laboratory test correlated to the acceptable (or poor) performance in the dynamic test. The component test was able to reveal deficiencies in window coverage of ejection mitigation curtains that resulted in partial or full ejections in dynamic conditions. Incorporating the component test into an ejection mitigation standard would ensure that ejection mitigation countermeasures provide sufficient coverage of the window opening for as long in the crash event as the risk of ejection exists, which is a key component contributing to the efficacy of the system.

Rollover crash tests can have an undesirable amount of variability in vehicle and occupant kinematics. In contrast, the repeatability of the component test has been shown to be good. Moreover, there are many types of rollover crashes, and within each crash type the vehicle speed

and other parameters can vary widely. A curb trip can be a very fast event with a relatively high lateral acceleration. Soil and gravel trips have lower lateral accelerations than a curb trip and lower initial roll rates. Fall-over rollovers are the longest duration events, and it can be difficult to distinguish between rollover and non-rollover events. Viano and Parenteau correlated eight different tests to six rollover definitions from NASS-CDS. Their analysis indicated that the types of rollovers occurring in the real-world varied significantly. Soil trip rollovers accounted for more than 47 percent of the rollovers in the field, while less than 1 percent of real-world rollovers were represented by the 208 Dolly test. 74 FR at 63185.

Occupant kinematics will also vary with these crash types, resulting in different probabilities of occupant contact on certain areas of the side window opening with differing impact energies. Id. A single full vehicle rollover test could narrowly focus on only certain types of rollover crashes occurring in the field. We noted in the NPRM our concern that a comprehensive assessment of ejection mitigation countermeasures through full vehicle dynamic testing may only be possible if it were to involve multiple crash scenarios. Such a suite of tests imposes test burdens that could be lessened by a component test. We also noted that a comprehensive suite of full-vehicle dynamic tests would likely involve many more years of research, which would delay the rulemaking action and the potential for incorporating life-saving technologies. The agency stated that such a delay appears unwarranted, given that NHTSA believes the component test will be an effective means of determining the acceptability of ejection countermeasures. For ejection mitigation, it is unlikely that a single rollover test would be sufficient to address the

many types of rollovers that occur in the field.[235] We would want the dynamic test to assure that an ejection mitigation countermeasure constrains belted and unbelted occupants in all types of rollover crashes. However, at this time there is no archetype rollover crash that can be replicated in laboratory testing.[236]

In this chapter, we discussed two additional alternatives:

Require the impactor test at 24 km/h at 1.5 second at all impact points; and

Require a single impact at the center of the side window opening area.

Each of these is discussed below:

Alternative 1: Require impactor test at 24 km/h at 1.5 second.

The agency considered testing the window opening at 24 km/h. This was proposed by the agency in the NPRM. The agency's examination of field crash data led to the conclusion that the proposed impact test should have a relatively high speed impact shortly after countermeasure deployment. Field data show that crashes with 5 or more ¼-turns result in the majority of complete ejection fatalities. The 1.5 second time delay for the high speed impact corresponds well to the film analysis of vehicles that roll 5 or more ¼-turns in FMVSS No. 208 Dolly tests, for the amount of time it takes for one complete vehicle revolution. Computer simulation of

[235] We have already discussed our determination that the 208 Dolly test is not suitable for ejection mitigation testing. See, e.g., 74 FR at 63185. The 208 Dolly test represents less than 1 percent of real-world rollovers. Further, some recent experience with the 208 Dolly test makes problematic its implementation as a replacement for the impact test or an additional test. During recent tests in our rollover restraints research program, we attempted to subject a MY 2007 Ford Expedition to the 208 Dolly procedure. However, two out of five attempts failed to initiate a roll of even one quarter-turn. We acknowledge that the above was not a typical result of 208 Dolly testing within the agency's experience, but it does highlight testing issues.

[236] A full vehicle dynamic test would presumably involve the use of anthropomorphic test devices (ATDs). There is some question whether the currently available ATDs offer an acceptable level of biofidelity with respect to occupant ejection. For example, the hip articulation for the Hybrid III dummies is limited, which may alter their ability to replicated real word occupant kinematics. An appropriate ATD for use in the test would have to be explored.

three actual rollover crashes indicated maximum head speed into the window openings was 22 km/h.

Additional justification for the 24 km/h impact speed was found in side impact field data. NASS CDS shows that 35% of occupants completely ejected through the side windows in side impact are exposed to impacts with a ΔV greater than 24 km/h. FMVSS No. 201 also uses a 24 km/h impact speed for the upper interior tests.

The six OEM commenters on the issue of impactor speed/energy were VW, AIAM, Alliance, Volvo, Honda and Nissan. Given the fact that there was little or no comment suggesting a modification to the impactor mass, the comments on the impact speed were tied closely to the issue of overall energy of the impact. All six of these commenters wanted the agency to consider reducing the impact speed of the higher speed 24 km/h test; however, the requested levels of reduction varied. All of these commenters expressed concern about the potential adverse effects and unintended consequences of not reducing the impact speed, particular as it relates to side impact protection.

The Alliance was one of several OEM commenters to provide extensive comments on the issue. They requested that the 24 km/h test be reduced to 16 km/h. The Alliance wanted this to be the only test and to be performed at 3.4 seconds after curtain deployment. They justified their position on the basis of impact energy by referring to GM[237] and Ford[238] research.

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[237] O'Brian-Mitchell, Bridget M., Lange, Robert C., "Ejection Mitigation in Rollover Events – Component Test Development," SAE 2007-01-0374.
[238] Docket Nos. NHTSA-2006-26467-0002.

> "Both General Motors (GM) and Ford Motor Company (Ford) have conducted extensive research in this area and have both concluded that the maximum impact energies in the range of 180 – 200 joules were appropriate to address the vast majority of real world rollover events. This energy level was also validated by the agency's own sled test research (referenced in the NPRM – page 63192) simulating both rollover and side impact events which both produced kinetic energies in the range of 180 – 200 Joules. As a result, the Alliance recommends that testing be limited to impact velocities that produce kinetic energies in this range (i.e., 16 km/h)."[239]

Referring to the GM research, the Alliance stated the 16.2 km/h impact speed was "derived from analysis of a series of rollover sensor development tests, in which data was collected in an attempt to quantify the kinetic energy associated with an occupant loading the roof rail airbag system. The 52 tests included both belted and unbelted ATDs, and in all cases, the kinetic energy value associated with the ATD interaction with the roof rail airbag surrogate (referred to in the study as a window membrane) was less than 180 Joules."[240]

The Alliance comments indicated that also very influential in GM's decision to test at 16.2 km/h was the NHTSA sled testing referenced in the NPRM.[241] They explained that "[t]he sled testing representing the rollover condition was conducted at 16 km/h, while the side impact simulation was run at 24 km/h. Once the effective mass was determined, both impact conditions produced a

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[239] NHTSA-2009-0183-0029, p. 11.
[240] NHTSA-2009-0183-0029, p. 11-12.
[241] 74 FR 63192.

kinetic energy between 180 – 200 J. This validates the approach GM had adopted in simulating the occupant kinetic energy in a rollover with an 18 kg impactor at a speed of 16.2 km/h, and shows that the kinetic energy associated with this subsystem test would be applicable to side impact as well."[242]

The Alliance indicated that since they agree with the impactor mass of 18 kg, the appropriated impact "is derived from the equation for linear kinetic energy (KE = $1/2mv^2$; m = mass and v = speed). The Alliance's recommended impact speed is calculated by substituting m = 18 kg and KE = 178 Joules, resulting in a speed of 16 km/h (4.44 m/s)."[243]

In addition, the Alliance makes the following comments on the impactor test speed.

> *"Finally, based on the agency's analysis (PRIA, p. VIII 18), the NPRM proposed impactor speed of 24 km/h corresponds to an initial vehicle velocity of 133 km/h, or 83 mph. While the Alliance supports a regulation that will address a "far reaching population of people in real world rollover crashes", it does not believe that the test metrics should reflect an event in which the vehicle is tripped while traveling at excessive speeds (83 mph)."*

Honda requested that the 24 k/m test be reduced to 17 km/h. They wanted this to be the only test and to be performed at 3.0 seconds after curtain deployment. Honda expounded on the issue of impact energy for lap/shoulder belted occupants.

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[242] NHTSA-2009-0183-0029, p. 12.
[243] NHTSA-2009-0183-0029, p. 21.

> "Our own testing, as summarized in Appendix-1 to this document, demonstrates that the estimated peak head velocity and effective mass, when tested in accordance with FMVSS 208, were also less than 200 J. From these data, we calculated the energy in ejection mitigation measures prescribed by FMVSS 226 should not exceed 200 J. In particular, an occupant properly restrained by lap and shoulder seatbelts, consistent with the restraints required by FMVSS No. 208 for outboard seating positions, the lower torso is restrained by the lap belt and the upper body of the occupant may be propelled toward the outside of the vehicle due to the rotational moment centering on the lumbar portion of the occupant's body (see Appendix-2). Considering these occupant kinematics, Honda believes that energy of 400 J is excessive, and recommends an upper threshold of 200 J. With a peak allowable energy level of 200 J at 16 km/h, there would be no need for testing at 24 km/h."[244]

NHTSA believes the use of the GM energy estimates as a basis for the final rule is problematic because the rollover severity only represents a small minority of the most harmful ejection inducing crashes. Also, the study seems to only measure, or only contain, occupant loading through the head. We would expect shoulder or combined shoulder and head loading to result in higher energy estimates. The Ford modeling study also has limited usefulness given that lack of specificity and detail provided about the modeling.

The agency reanalyzed the sled testing used to develop the mass of the impactor. We estimated that the minimum energy and effective mass for the 24 km/h test (so called side impact configurations) were 294 J and 13.0 kg, respectively.

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[244] NHTSA-2009-0183-0034, p. 2-3.

In a rollover configuration, a 400 J energy level with 23.7 kg of effective mass would be achieved at an impact speed of 20.9 km/h (5.81 m/s). However, a reanalysis of the DRF videos found peak head and shoulder speeds between 15 and 16 km/h (4.17 and 4.44 m/s). Assuming an effective mass of 6.45 kg and 17.3 kg for the head and torso (23.75 kg combined), respectively, the resultant impact energy would be 225 J. Using these effective mass values along with the head and torso speeds of 20 km/h and 16 km/h, respectively, from previous agency simulations results in a 270 J energy value.

Based on our analysis, we decided to decrease the impact test speed to 20 km/h. We conclude that this is more representative of what the ejection countermeasure will typically be exposed to in the field, particularly in rollovers. We also believe this will greatly enhance the practicability of the final rule with a relatively small loss in benefits.

To determine how the reduction in headform impact speed from 24 km/h to 20 km/h affects the potential benefits, we initially considered two approaches.

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”). For example, if the injured occupants are separated by five speed bins with an equal ΔV rang of 4 mph (i.e., 0 - 4 km/h, 5 - 9 km/h, 10 - 14 km/h, 15 - 20 km/h,

and 21 - 24 km/h), the first approach results in 20% reduction in potential benefits. Although the first approach would produce a simple estimation of the loss, the agency does not have any field or laboratory data to support the assumption used in the analysis.

For the second approach, we estimated the loss based on real world crashes and computer simulations. The real world rollover crash data, including both ejection and non-ejection causing rollovers, showed that almost all vehicles rolled 10 ¼-turns or less and that the number of vehicles decreases drastically as the number of quarter turns increases. When the rollovers were separated by ½-turn, it showed that almost all vehicles rolled 5 ½-turns or less, as shown below. Therefore, for the analysis, it would be reasonable to assume that all vehicles would roll 5 ½-turns or less in rollovers.

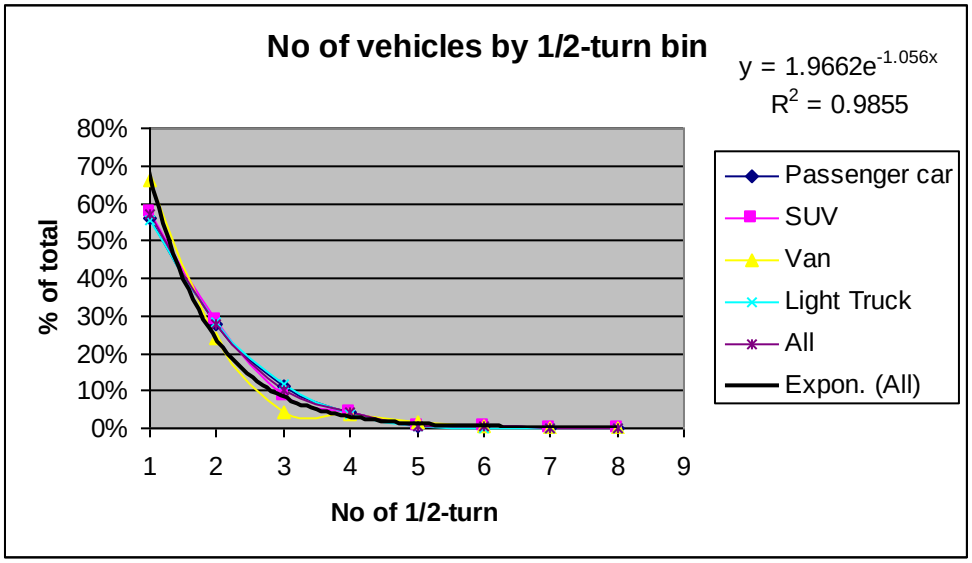

Figure VIII-1. Number of vehicles in rollovers by ½-turn, 1999-2007 NASS CDS

Table VIII-1
Vehicles in lateral rollovers separated by number of rolls, 1999-2007 NASS CDS

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%	

A series of simulations were performed by the agency to recreate three NASS investigated rollover crashes with relatively high initial speeds prior to rollover. The three vehicles used for the simulation were Toyota pickup, Toyota Corolla and VW Jetta. Originally, the 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.

In the Toyota pickup crash, the vehicle was traveling at 96 km/h and went into a sharp turn and yaw, which resulted in a 12 ¼-turn rollover. In the case of the Corolla, 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 Corolla rolled 6 1/4 –turns. 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. The Volkswagen rolled 4 ¼-turns.

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. The computer simulation showed that a higher initial vehicle speed would result in a higher occupant-to-glazing speed and 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), as shown below.

Table VIII-2
Head and Torso Velocities of a Hybrid III 50th Percentile Male Dummy in 3 Rollover Simulations

Vehicle	Vehicle initial speed, km/h	Vehicle ¼ Turns	¼ Turns at Complete Ejection	Restraint Use	Head to Glazing, km/h	Avg. Head to Glazing, km/h	Occupant speed by % of vehicle speed
Toyota PU	96	12		Yes	20		
			1	No	20		
Toyota Corolla (86)	96	6		Yes	15		
			6	No	13	17	18%
Volkswagen Jetta (85)	88	4		Yes	14		
			4	No	18	16	18%

In addition, based on the MADYMO simulation, we assumed that the occupant-to-glazing speed is proportional to the vehicle's initial speed. In the PRIA, we stated that the rationale for the 24 km/h is that when a curtain air bag meets the proposed 100 mm displacement requirement at a linear impact speed of 24 km/h the air bag system would capture all potential benefits. With the 18% vehicle-to-occupant ΔV conversion in rollovers, we estimated that a vehicle initial speed of 133 km/h would result in an occupant-to-glazing speed of 24 km/h with 10 ¼-turns in a rollover, with the following equation:

$$\begin{aligned} Vehicle\,initial\,speed &= C_4 C_5 \sqrt{5} \quad where\, C_4 = 1/0.18, C_4 = 5.56,\ C_5 = 10.733 \\ &= 133\ km/h \quad (83\ mph),\ ten\ 1/4 - turn\ rolls \quad -(1) \end{aligned}$$

In other words,

Vehicle initial speed = (conversion factor)*(head-to-glazing speed),

$= C_4 * C_5\sqrt{5}$, at 10 ¼-turns

$C_4 = 1/18\%$ (i.e., $C_4 = 5.56$), based on the MADYMO simulation

Head-to-glazing speed = $C_5\sqrt{5}$ at 10 ¼-turns,

$C_5\sqrt{5} = 24$ km/h at 10 ¼-turns

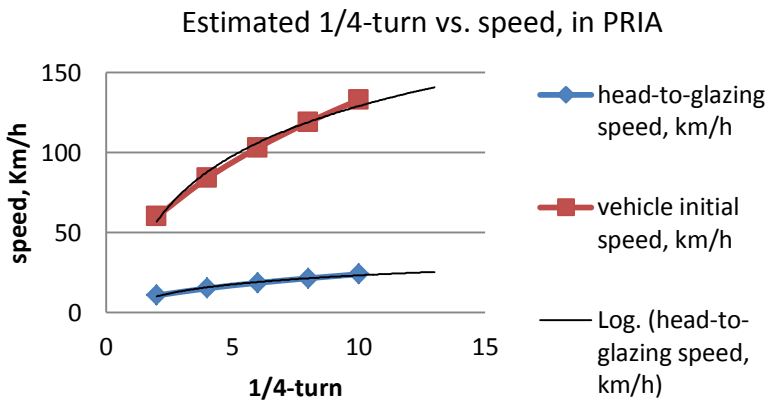

Figure VIII-2. Vehicle's initial speed vs. Occupant-to-glazing Approaching Speed used in PRIA

As shown above, in the PRIA, we used the results of the three rollover computer simulations to determine a relationship between occupant window impact speed and number of ¼ turns. The calculation above shows that it would require a vehicle velocity of 133 km/h (83 mph) to achieve the proposed 24 km/h impact speed in a 10 ¼-turn rollover. However, according to National Forensic Engineers, the number of rolls of the three vehicles (Toyota, Corolla and Volkswagen) was relatively high when compared to real world crashes.[245] In other words, the computer simulation based on three vehicles would underestimate the number of ¼-turns at a given vehicle's trip velocity. For example, according to the submitted crash data, the initial vehicle velocity would be 65 km/h with 10 ¼-turns. The 65 km/h initial speed is much lower than the 133 km/h speed predicted by the computer simulation. We note that some rollovers in the figure

[245] Based on a report "Automotive Side Glazing for Primary and Secondary Occupant retention", SAE 2007-01-1546, submitted on January 21, 2010.

have very high ¼-turns. However, although the crash data show very high ¼-turn rollovers, as shown in Table 2, the NASS data showed that almost all rollovers were 10 ¼-turns or less.

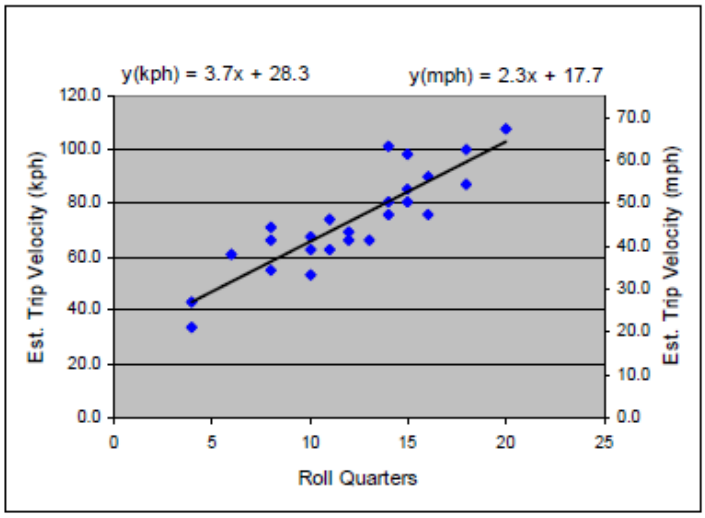

Figure VIII-3. Submitted real world crash data: Estimated trip velocity vs. roll quarters for reconstructed accidents.

The MADYMO simulation showed that 18% of the initial vehicle velocity would be converted into the occupant-to-glazing speed. If we assume that 18% of the initial velocity would be converted into the occupant-to-glazing speed, we could determine the maximum occupant-to-glazing speed based on the previously derived conversion equation (1) and the submitted real world crash data, as shown below.

Vehicle initial speed = (conversion factor)*(occupant-to-glazing speed);

Where,
Vehicle initial speed = 65.3 km/h at 10 ¼-turns in real world crashes
Conversion factor, $C_4 = 5.56$ (i.e., $C_4 = 1/18\%$)
Occupant-to-glazing speed, $C_5\sqrt{5}$ at 10 ¼-turns, unknown

Thus,

Occupant-to-glazing speed, $C_5\sqrt{5} = (65.3 \text{ km/h})_{\text{vehicle initial speed}} / (5.56)_{\text{conversion factor}}$
$C_5\sqrt{5} = 11.7$ km/h,

Thus,

$C_5 = 5.26$

Vehicle initial speed = (5.56)*(5.26)*(√no. of ½-turns)

Occupant-to-glazing speed = (5.26)*(√no. of ½-turns)

The calculation above showed that the occupant-to-glazing speed at a vehicle speed of 65.3 km/h (40.6 mph) would be 11.7 km/h if 18% of the initial vehicle velocity would be converted into the occupant-to-glazing speed. The number of ¼-turn vs. vehicle speed and occupant-to-glazing speed with the assumed 18% conversion factor are shown below.

Table VIII-3
Vehicle initial and Head-to-glazing Speeds with 18% Vehicle Speed to Occupant Speed Conversion Factor

No. of 1/4-turns	% of total ¼ turn	No. of 1/2-turns	vehicle initial speed, km/h	head-to-glazing speed, km/h	vehicle initial speed, mph	head-to-glazing speed, mph
2	57%	1	29	5	18	3
4	28%	2	41	7	26	5
6	10%	3	51	9	31	6
8	4%	4	58	11	36	7
10	1%	5	65	12	41	7
12	< 1%	6	72	13	44	8
14	<1%	7	77	14	48	9
16	<1%	8	83	15	51	9

The results in the table above show that the occupant speeds are relatively low even in extremely high ¼-turn rollover crashes. For example, the table shows that the occupant-to-glazing speed would be about 15 km/h at a vehicle initial speed of 83 km/h in a 16 ¼-turn rollover crash. However, the crash film analysis, computer simulations and Dynamic Rollover Fixture (DRF) performed by the agency showed that the occupant speed would be much higher than the speeds estimated with the 18% conversion factors, including 12 km/h with 10 ¼-turns, as shown below.

Table VIII-4
Occupant-to-glazing speed by NHTSA performed rollover test[246]

Test	Occupant head speed, km/h
Film analysis	18 km/h
Computer modeling	22 km/h
DRF	15.8 km/h

It appears that the discrepancy in occupant speed is due to inaccuracy of the 18% conversion factor used in the calculation. In other words, the real world crash data showed that the occupant-to-glazing speed would be higher than 18% of the vehicle initial speed.

As mentioned, the three vehicles (Toyota PU & Corolla and VW Jetta) used in the computer simulations had much higher initial speeds when compared to the real world crashes. For example, the Toyota PU had 12 ¼-turns with an initial vehicle speed of 96 km/h, whereas the real world crash data show 73 km/h at the same 12 ¼-turns. In other words, the three vehicles used in the computer simulations had a smaller amount of the kinetic energy associated with the initial vehicle speed dissipated through vehicle's roll motion and, consequently, a higher amount of the energy was dissipated through other motions or structural deformation at the beginning of the trip motion. Since a lower amount of the initial kinetic energy would be converted to a roll motion, one could conclude that the three vehicles used in the simulation would have a lower initial angular velocity <u>at a given initial vehicle speed</u> when compared to vehicles in real world rollovers. Conversely, vehicles in real world rollover crashes would have a higher angular velocity when compared to the three vehicles used in the simulation. Since a higher angular velocity would result in a higher occupant-to-glazing speed, it would be reasonable to assume that a higher amount of the initial vehicle velocity in real world crashes would be converted into

[246] FMVSS No. 226 NPRM

the occupant-to-glazing speed when compared to the three vehicles used in the computer simulations.

As an alternative to the approach above, we could assume that 24 km/h headform speed covers all rollovers as we did in the PRIA. Under the assumption, the real world crash data show that the adjustment constant C_4 would be 2.72, instead of 5.56 used in the formula (1) above. The 2.72 factor shows that 37% of the vehicle's initial speed would be converted to the occupant-to-glazing speed in lateral rollovers. In other words, the real world crashes data showed that 37% of the initial velocity would be converted into the occupant-to-glazing speed, whereas the MADYMO simulation showed that 18% of the initial velocity would be converted into the occupant-to-glazing speed, as shown below:

Vehicle initial speed = (conversion factor)*(head-to-glazing speed);

Where,

Vehicle initial speed = 65.3 km/h at 10 ¼-turns based on the real world data submitted,

Head-to-glazing speed = $C_5\sqrt{5}$ at 10 ¼-turns,

$C_5\sqrt{5}$ = 24 km/h at 10 ¼-turns, as assumed

$$\boxed{\begin{aligned} &Vehicle\,initial\,speed = C_4 C_5 \sqrt{5} \quad where\, C_5 = 9.97 \\ &\qquad\qquad\qquad\qquad = 65.3\, km/h \quad (43\, mph),\, ten\ 1/4 - turn\ rolls \\ &C_4 = 2.72, \quad 1/C_4 = 37\% \end{aligned}}$$

The occupant-to-glazing speed can be calculated from the vehicle initial speed with the constants C_4 and C_5, as shown below:

Table VIII-5
Number of ¼-turn vs. vehicle & occupant-to-glazing speed, with newly submitted data

No. of 1/4-turns	No. of 1/2-turns	head-to-glazing speed, km/h	vehicle initial speed, km/h	% of total no. of rolls
2	1	10	27	57%
4	2	14	38	28%
6	3	17	47	10%
8	4	20	54	4%
10	5	22	61	1%
			Total	100%

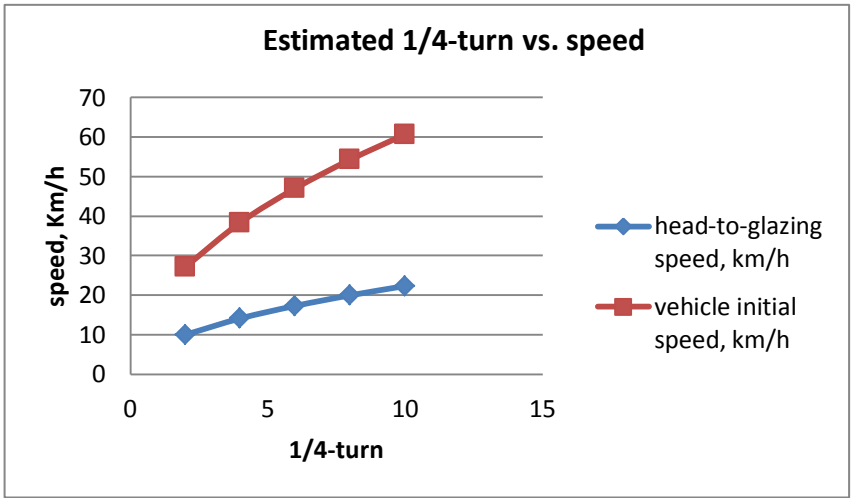

Figure VII-4. Number of ¼-turn vs. vehicle & occupant-to-glazing speed, with real world crash data

In the previous discussion above, we estimated the occupant speed at a given vehicle speed with two different approaches. For the first approach, we assumed that the maximum occupant speed would be 18% of the vehicle's initial speed. However, the real world crash data and NHTSA's full vehicle rollover testing and computer simulation results showed that the approach would under estimate the occupant-to-glazing speed. For the second approach, we assumed that the proposed 24 km/h would cover all occupant-to-glazing speed in rollovers. The approach showed that the maximum occupant-to-glazing speed is 37% of the vehicle's initial speed. Since we do not have actual crash data to show how fast a person moves toward the side window in real

world crashes, we attempted to validate the results from the second approach by comparing the estimated occupant speeds to the speeds measured during Agency's rollover film analysis.

In the film analysis, twenty three full scale rollover tests were reviewed to find any cases of occupant / side glazing impact. In seven of these tests, the occupant was observed striking the side glazing with either the head or shoulder. Film analysis was conducted to measure the velocity of the impacts.

The impact speeds for the first five tests were measured using the rear seat camera and calibrating the motion data using the known dimensions of the dummy's head. The measurements assume that the dummy's motion occurs within a single plane perpendicular to the camera's line of sight. This assumption should produce reasonably accurate measurements. The final two tests involved pickup trucks, which had no rear seat camera. For these tests, the time from the start of the dummies motion until impact was measured. This time was used along with the distance between the dummies head and the window, measured pretest, to calculate an average velocity. In all of the seven tests presented here, the dummy struck the window prior to impact with the ground.

Table VIII-6
NHTSA Full Vehicle Rollover Testing Film Analysis, Occupant Striking Side Glazing
(Measurements conducted in April 1993)

Test #	Make	Model	Test Type	Test Speed (km/h)	Impact Speed (km/h)	Contact Point	No. of 1/4-turn
878	Honda	Accord	RTD	33.80	7.97	Shoulder	2
*	Dodge	Aires	Guardrail	96.56	15.95	Head	16[247]
888	Chevrolet	Celebrity	RTD	37.02	6.51	Shoulder	4
*	Ford	Pinto	Dolly	27.36	2.54	Head	No data
*	Dodge	Reliant	RTD	33.80	4.51	Shoulder	No data
1520	Ford	Ranger	RTD	48.28	5.84	Head	2
1522	Nissan	Pickup	Pole	48.28	16.96	Head	No data

* The test numbers are not available for these vehicles. Note that some of the ¼-turn data were missing.

In the Dodge guardrail test, an occupant-to-glazing speed of 15.96 km/h was measured when the vehicle impacted the guardrail at a vehicle of 96.56 km/h resulting in a conversion factor of 16.5% (15.95/96.56 = 16.5%). The Pinto dolly and the Ford Ranger RTD tests showed similar conversion factors, 9.3% and 12.1%, respectively. The Nissan Pickup pole test resulted in a rather large conversion factor, 41%. Overall, the test results showed an average head-to-glazing speed of 10.3 km/h and an average conversion factor of 20%. The 20% conversion factor measured in the test is very similar to the 18% conversion factor estimated in the computer simulation. As discussed, we suspect that the 20% conversion factor would be too small when compared to the real world crashes.

Although the occupant head impact test results are valuable, we did not use the ¼-turn data for the analysis since the test data are too limited. Instead, we examined the entire ¼-turns measured in the tests to determine the average number of ¼-turns and vehicle speed, as shown below.

[247] The RTD test is a FMVSS No. 208 Dolly test, but with the vehicle raised higher to maximize roof crush.

Table VIII-7
NHTSA Full Vehicle Rollover Testing Film Analysis, report dated September 2009

Test No.	Make	Model	Veh. Speed km/h	Test Type	No. of 1/4 - turns
878	Honda	Accord	33.8	RTD	2
888	Chevrolet	Celebrity	37	RTD	4
920	Dodge	Omni	37	RTD	2
939	Mercury	Zephyr	37	RTD	2
1255	Ford	Bronco	37	RTD	2
1266	Dodge	Caravan	48.3	RTD	1
1267	Chevrolet	Pickup	48.3	RTD	4
1274	Nissan	Pickup	48.3	RTD	6
1289	Nissan	Pickup	48.3	RTD	2
1391	Dodge	Caravan	48.3	RTD	8
1392	Ford	Bronco	48.3	RTD	8
1393	Nissan	Pickup	48.3	RTD	4
1394	Nissan	Pickup	48.3	RTD	4
1395	Pontiac	Grand Am	48.3	RTD	2
1471	Dodge	Colt	48.3	RTD	2
1520	Ford	Ranger	48.3	RTD	2
1521	Dodge	Ram	48.3	RTD	4
1530	Dodge	Caravan	96.6	Guardrail	1
1531	Nissan	Pickup	96.6	Guardrail	4
1546	Plymouth	Reliant	33.8	RTD	6
1851	Volvo	240	48.3	RTD	6
1852	Volvo	740	48.3	RTD	8
1925	Nissan	Pickup	48.3	RTD	8
1929	Nissan	Pickup	48.3	RTD	6
2141	Nissan	Pickup	48.3	RTD	8
2270	Nissan	Pickup	48.3	RTD	8
2514	Ford	Explorer	48.3	208	11
2553	Ford	Explorer	48.3	208	10
3012	Ford	Explorer	48.3	208	11
3635	Ford	Explorer	48.3	208	12

Table VIII-8
Average Number of ¼-turns and Vehicle Speed, NHTSA Full Vehicle Rollover Testing Film Analysis

Test Type	Guardrail	208 dolly	RTD	All
No. of tests	2	4	24	30
% of total no. of test	7%	13%	80%	100%
Weighted average, 1/4-turn:	0.17	1.47	3.63	5.3
Avg. speed, km/h:	96.6	48.3	45.2	*
Weighted average speed, km/h:	6.4	6.4	36.2	49.0

* If a simple average is used, the three test types would result in an average speed of 63.4 km/h. However, for the analysis, we used the 49 km/h weighted average.

The above table shows that on average the vehicles turned 5.3 ¼-turns and had a vehicle test speed of 49 km/h when all test results were combined. To determine whether the revised speed model more closely represents real world rollovers than the model used in the PRIA, we compared the vehicle test results to the vehicle and occupant speeds estimated with the models. For the head-to-glazing speed, both models predict a slightly higher occupant-to-glazing speed. At 5.3 ¼-turn, the NHTSA film results showed an occupant-to-head speed of 10.3 km/h whereas the models showed a head-to-glazing speed of 18.0 km/h. However, the vehicle test results showed that the revised model (i.e., ¼-turn vs. speed model developed with the submitted real world crash data) fits more closely than the model used in the PRIA, as shown in the figures below.

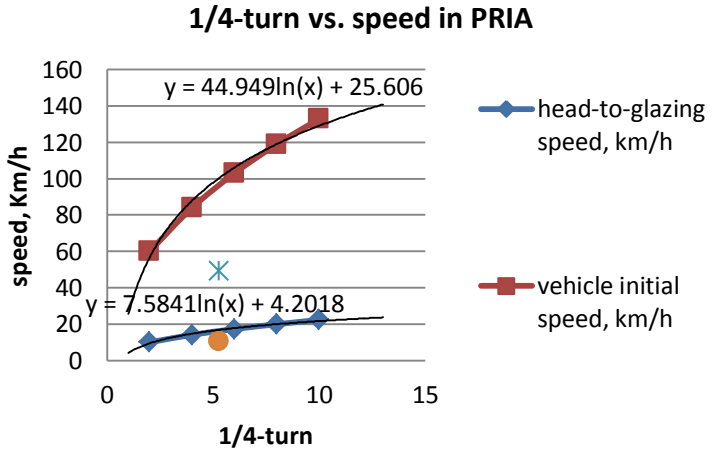

Figure VIII-5. Number of ¼-turn vs. vehicle & occupant-to-glazing speeds, used in PRIA, with NHTSA Rollover Vehicle Data

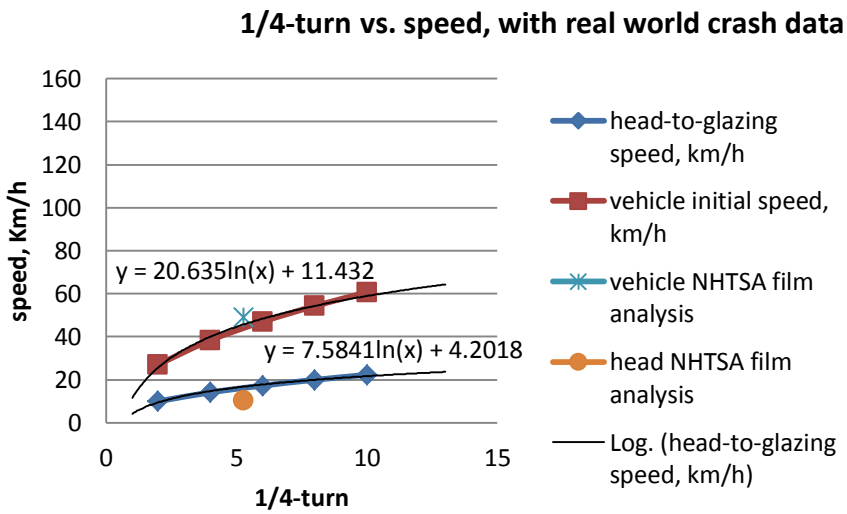

Figure VIII-6. Number of ¼-turn vs. vehicle & occupant-to-glazing speeds, with real world crash data, with NHTSA Rollover Vehicle Data

The revised model in the figure above shows that an occupant-to-glazing speed of 24 km/h would occur at a vehicle initial speed of 65 km/h in a 14 ¼-turn rollover crash. Likewise, an occupant-to-glazing speed of 20 km/h would occur at a vehicle initial speed of 54 km/h in an 8 ¼-turn rollover crash.

In summary, to estimate the reduction in potential benefit when the headform speed decreases from 24 km/h to 20 km/h, we developed two vehicle-occupant speed models. Since agency's laboratory and computer simulation showed that the revised model would more closely represent real world rollovers than the model used in the PRIA, we used the revised model to analyzed real world crashes. The real world crash data showed that 91.4% of AIS 3+ occupant ejections occurred with 8 ¼-turns or less and that 99.1% of AIS 3+ occupant ejections occurred with 14 ¼-turns or less, as shown below.

Table VIII-10
Rollover ejection partial + complete, 1997 - 2008 NASS & FARS

No. of ¼-turns (Occupant speed)	Fatal	MAIS 3+	All Cumulative Percent
1	208	217	5.4%
2	566	513	19.0%
3	139	518	27.2%
4	668	1689	56.9%
5	128	176	60.7%
6	611	1025	81.3%
7	107	60	83.4%
8 (20 km/h)	368	265	91.4%
9	25	81	92.7%
10	79	83	94.8%
11	0	0	94.8%
12	173	93	98.1%
13	0	12	98.3%
14 (24 km/h)	20	45	99.1%
15	4	2	99.2%
16	7	16	99.5%
17	10	33	100.0%

Although the kinetic energy associated with the headform decreases sizably from 400 J to 278 J when the impact speed decreases from 24 km/h to 20 km/h, the results in the table above show that MAIS 3+ injuries resulting from initial vehicle speeds higher than 20 km/h would be small. The table above shows that the reduction in headform speed from 24 km/h to 20 km/h would reduce the target population and the potential benefits by 8% (99.1% - 91.4% = 7.7%). In addition, the table above shows that 91.4% of all lateral rollovers would have an occupant-to-glazing speed of 20 km/h or less with eight or less ¼-turns. Therefore, the ejection mitigation curtain air bag would not be effective for 9% of lateral rollovers (100% - 91.4% = 8.6%).

Side crashes:

When the headform impact speed decreases from 24 km/h to 20 km/h, it may affect the performance of curtain air bags installed in a vehicle since curtain air bags are designed to

deploy for both rollovers and side impacts. To investigate any potential adverse effects resulting from the reduction in speed, we analyzed the minimum performances of a curtain air bag that is designed to meet the FMVSS No. 214-oblique pole test requirements.

As part of FMVSS No. 214 "Side Impact Protection" rulemaking, the agency estimated that the occupant ΔV would be 77% of vehicle ΔV. In other words, 77% of the initial vehicle ΔV would be converted into the occupant ΔV. The 77% conversion factor showed that, when compared to rollovers, a higher percentage of the kinetic energy associated with the initial vehicle speed goes to the occupant's glazing approaching speed in side impacts.

If we assume that 77% of the initial vehicle ΔV would be converted to the occupant-to-glazing ΔV in side impacts, we could calculate the occupant-to-glazing ΔV as a function of vehicle ΔV in side impacts, as shown below.

Table VIII-11
Effectiveness of Curtain Bag in Side Impacts

vehicle speed, mph	vehicle speed, km/h	occupant speed, km/h
12	20	15
15	24	18
16	26	20
17	28	22
19	30	23
20	32	25
21	34	26

The results in Table VIII-11 show that, for example, when a side impact crash occurs at a vehicle ΔV of 26 km/h the head of an occupant in the outboard seating position would move toward to the side of the vehicle at 20 km/h. Likewise, the table shows that a vehicle ΔV of 32 km/h would result in an occupant ΔV of 25 km/h.

As discussed in the FMVSS No. 214-FRIA, the 214-side air bag would be effective in protecting vehicle occupants at a vehicle ΔV range of 19 km/h to 40 km/h (12 mph to 25 mph). In other words, the side air bag would not bottom out at an occupant ΔV rang of 15 km/h to 31 km/h. In the FMVSS No. 226 NPRM, the agency estimated that an occupant's effective mass would be represented by 13 kg for side impact configuration and 18 kg a rollover configuration. In the final rule preamble we reassessed this data and found the side impact and rollover effective mass values to be 13 kg and 24 kg, respectively. In the FMVSS No. 214 oblique impact FRIA, we estimated that a side curtain air bag that is in compliance with the FMVSS No. 214 HIC requirement would not bottom out at an occupant-to-glazing speed of 8.6 m/s (31 km/h occupant-to glazing speed). Therefore, with the 13 kg effective mass, a side curtain air bag would withstand 481 J at an occupant-to-glazing speed of 31 km/h (8.6 m/s) without bottoming out. The 481 J is higher than the kinetic energy associated with the 18 kg headform traveling 24 km/h (400 J) or 20 km/h (278 J). In other words, a curtain air bag meeting the FMVSS No. 214 HIC requirement would bottom out at a relatively higher occupant-to-glazing speed of 26 km/h. Therefore, the reduction in headform impact speed from 24 km/h to 20 km/h would not affect the potential benefits as long as the air bag system is in compliance with the 214-oblique pole requirements and the window opening is completely covered with a curtain air bag.

In summary, when the headform impact speed decreases from 24 km/h to 20 km/h, it would result in 9% reduction in rollover potential benefits. However, the reduction in impact speed would not affect the side impact potential benefits. In the FMVSS No. 226 PRIA, we estimated that 76% of the overall benefits were resulting from protecting occupants in rollovers and the

remaining 24% were from side impacts. Therefore, the 9% reduction in rollover benefits would result in 7% reduction in overall benefits, as shown below.

Table VIII-12
Overall Percent Reduction in Benefits if Headform Impact Speed Decreases From 24 km/h to 20 km/h

Crash Type	% Reduction	% of estimated benefits	Overall % reduction
Rollover	9%	76%	7%
Side impact	0%	24%	0%
total	N/A	100%	7%

If a rollover curtain air bag is designed to meet the 20 km/h impactor test requirement, in order to meet the 24 km/h impactor requirement, manufacturers would increase the internal pressure or the volume of the air bag. The energy associated with the 18 kg headform impactor is 278 joules and 400 joules with an impact speed of 20 km/h (5.56 m/s) and 24 km/h (6.67 m/s), respectively. The energy calculation showed 56% increase in kinetic energy between the 24 km/h and 20 km/h impactor tests. If we assume the air bag has the same headform contact area in the impactor test, the work done by the headform is proportional to the internal pressure for the travel distance L, as shown below:

$$\begin{aligned} Work &= \int Force * dl \\ &= \int Pressure * (contact\ area) * dl \\ &= Pressure * (contat\ area) \int dl = Pressure * (contact\ area) * L \end{aligned}$$

If the work done by the headform increases by 56%, the equation above shows that the internal pressure need be increased by 56% when compared to the internal air bag pressure of the 20 km/h air bag, for the same headform contact area and the air bag thickness (i.e., distance traveled). Alternatively, according to the ideal gas law (PV = MRT, P: pressure; V: volume; M&R: constants; T: temperature), the volume of the 24 km/h air bag would be increased by 56%

if the pressure remains the same when compared to the 20 km/h air bag. (Later in the discussion, we call this option as "low pressure bag" option.)

In the benefit chapter, we estimated that the inflator (casing plus the propellant) of a 214-curtain air bag would be $8.86 per vehicle in 2009 economics ($7.61 per vehicle in 2003 economics). In addition, we estimated that the rollover curtain air bag would cover 28% larger area when compared to the 214-side curtain air bag. Accordingly, the inflator cost of a rollover air bag which covers 28% larger window opening compared to the 214-curtain air bag would be $11.37 ($8.8647*(1+0.2825) = $11.37. In the cost chapter, we estimated that the 1st and 2nd rows combined window opening area would be 6,619 cm^2. Thus, we could say that the unit cost would be $0.001718/$cm^2$ per vehicle, 6,619 cm^2 * $0.001718/$cm^2$ = $11.37 per vehicle). If we assume that the width of the air bag remains the same, hypothetically, the 56% increase in volume (that could be compressed to generate gas pressure for the 24-km/h air bag) could cover 56% larger area (when the gas pressure in the 20 km/h air bag remains unchanged). Therefore, the incremental inflator (casing and propellant) cost to inflate the air bag to cover 56% larger area would be $6.38 per vehicle ($11.37*0.56 = $6.38). In other words, when the volume of the air bag increase by 56%, the incremental cost associated with the casing and propellant would be $6.38 per vehicle. Inversely, when the internal pressure is increased by 56% with the same air bag volume, the inflator incremental cost would be $6.38 per vehicle.

There are several design approaches that manufacturers could use to meet the 24-km/h impactor requirement, as discussed below:

Approach A: For the 1st and 2nd row window openings, manufacturers would simply increase the pressure of the rollover curtain air bag (i.e., high pressure bag). With estimated 16.3 million vehicles (excluding convertibles), the incremental cost would be \$103.94M (\$6.38*16.3M $_{\text{vehicles}}$ = \$103.94M). We note that the size of the high pressure bag would be the same as the 20 km/h air bag. Therefore, the material cost for the (air bag) cloth would be the same.

Approach B: For the 1st and 2nd row window openings, manufactures could maintain the internal pressure (of the 20 km/h air bag) but increase the width of the air bag (i.e., low pressure bag). Although the internal pressure would be the same, the volume (thus, the size) of the low pressure air bag would be greater than the 20 km/h air bag. Therefore, the low pressure air bag (i.e., 24 km/h air bag) would have a higher material cost for the (air bag) cloth and also the inflator. In the cost chapter, we estimated that the unit cost for the air bag cloth would be \$0.003381/cm^2 per vehicle. Combined with the incremental inflator cost, the unit incremental cost for the low pressure bag would be \$18.93 per vehicle (\$0.001718/cm^2 +\$0.003381/cm^2)*6,619 cm^2 * 0.56 = \$18.93) and the total incremental cost would be \$308.52M.

Approach C: For the 3rd row opening, manufactures could use the high pressure bag. If we assume that the size of the 3rd window opening is ½ of the 1st and 2nd window openings combined, the incremental unit cost would be \$3.19 per vehicle (1/2 * 6,619 cm^2 * \$0.001718/cm^2 * 0.56 = \$3.19 per vehicle). With estimated 5.9 million vehicles with the 3rd row window, the incremental cost was estimated to be \$18.68M to cover the 3rd row only.

Approach D: For the 3rd row opening, manufacturers could use the low pressure bag. With larger inflator and larger air bag, the unit incremental cost would be $9.46 per vehicle (1/2 * 6,619 cm^2 * ($0.001718/$cm^2$ + $0.003381/$cm^2$)*0.56 = $9.46 per vehicle. With estimated 5.9 million vehicles with the 3rd row window, the incremental cost was estimated to be $55.45M to cover the 3rd row only.

Approach E: For the 3rd row opening, manufacturers might need to use additional inflators. As discussed in the cost chapter, additional inflator (one for each side) would be $46.33 per vehicle. With the large (air bag) cloth and the additional inflator, the unit incremental cost would be $52.61 per vehicle. With estimated 5.9 million vehicles with the 3rd row window, the total incremental cost of $308.22M to cover the 3rd only.

With the potential approaches above, the incremental cost to meet the 24 km/h test requirement ranges from $123M to $364M. and the total incremental cost ranges from $320M to $1,124M with the cost per equivalent life saved ranges from $1.97 to $3.51 (discounted at 7%), as shown below:

Table VIII-13
Equivalent Life Saved (ELS) for 20 km/h and 24 km/h Impact Speeds

Impact Speed	Lives saved	ELS	Discounted ELS		Cost ($M)	Cost per ELS	
			3%	7%		3%	7%
With 20-km/h rollover curtain air bag	373	458	374	297	$507	$1.36	$1.70
With 24-km/h rollover curtain air bag, lowest	401	493	402	320	$629	$1.57	$1.97
With 24-km/h rollover curtain air bag, highest	401	493	402	320	$1,124	$2.80	$3.51

<u>Alternative 2</u>: Effects of requiring a single impact in each side window opening area.

In the cost chapter, we estimated that the manufacturing cost burden on manufacturers to install a rollover curtain air bag would be much smaller when compared to the testing cost. Therefore, when the number of impacts is reduced in the opening area, it would not substantially reduce the overall incremental cost. However, when the number of impacts is reduced, it would significantly reduce the potential benefits, as shown below.

2.A. Reduction in containment effectiveness: In the benefits chapter we estimated potential benefits when the window opening area is impacted by the impactor at four different points. As an alternative, we examined the effects of requiring a single impact test in the window opening. If a rollover curtain air bag were required to meet the 100 mm 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 benefits chapter, a rollover curtain air bag that is capable of meeting the impactor displacement 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 ($52.2\%_{\text{upper rear}} + 10.4\%_{\text{upper front}} = 62.6\%$).[248] 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

[248] Using the more conservative uniform distribution would give lower effectiveness.

ejection by 3% for belted and 10% for unbelted occupants.[249] When the risk of ejection through the front potential gap is considered, it resulted in 59% effectiveness for belted and 53% for unbelted occupants in rollovers. When weighted with the belt use rate (13% and 87% for belted and unbelted, respectively) in the target population, it resulted in 54% (53.8%) containment effectiveness in rollovers. (Note that 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.) 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.[250] 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.

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[249] 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 0.94 = 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.

[250] 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.

2.B. Reduction in benefit: In the adjusted target population, we found that 1,102 fatalities in rollover crashes. Among the 1,102 fatalities, 747 were from rollover without any side crashes, 284 were from side crashes followed by rollovers in all but 19 – 40 km/h, and the remaining 71 were from side crashes followed by rollovers in 19 – 40 km/h. 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 524 lives saved to 364 (about 31% reduction). Previously, we estimated that about 29% of the potential fatal benefits could be achieved with voluntarily installed curtain air bags, 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 test requirement. Based on the impactor test data, we suspect that the majority of current ejection bags would meet the single impact test requirement. For the analysis, therefore, we assumed that all currently available ejection mitigation air bags would meet the single impactor test requirement. Under the assumption, about 51% of the potential benefits could be achieved with currently available curtain air bags, with 55% MY 2011 installation rate. When the 51% potential fatal benefits are subtracted from the 364 lives saved, it result in 177 incremental fatal benefits [364_{lives} x (1-0.51) = 177 $_{incremental\ fatal\ benefits}$]. Therefore, the <u>incremental</u> fatal benefits would decrease from 373_{lives} to 177_{lives} when a single headform impact test is required in the window opening.[251]

We note that, for the benefit estimate, we assumed that <u>most of adult occupants</u> would not slide to the opening during a roll motion. A dimensional analysis of the curtain and the window

[251] 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 <u>decrease substantially</u> as the occupant slides over the bag after the initial impact.

opening area indicates that a very large gap (about 10 inches, 249 mm) can be formed between the window sill and the curtain, even if the 100 mm deflection requirement remains unchanged.[252]

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-14
Incremental Costs Associated with Single Impact Headform Test
(With MY 2011 Baseline Head/Side Air Bag, per vehicle in 2009 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	$39	$0	$0	$39	$282
Combo	1%	Roll sensor, curtain and thorax bag	$39	$180	$79	$203*	$33
Total veh.	16.3M(1)						
214-Combo bag cost		($94)	*$39+$180+$79-$94 = $203			Total	$315

(1) Excluding convertibles. (2) The numbers were rounded to the nearest integer.

[252] 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:

As an alternative to the required 20 km/h impactor tests, we analyzed safety impacts of testing ejection mitigation rollover curtain air bags at 24 km/h. In addition, we analyzed potential benefits and associated costs for requiring a single impact test in the window opening area. These two alternatives were compared with the estimated costs and benefits of meeting the impactor requirements in the final rule, as shown below:

Table VIII-15
Incremental Costs and Additional Lives Saved for Alternatives

Alternatives	Lives Saved (incremental)	Costs (millions)
Proposed Rule (4 impacts)	373	$507
Testing at 24 km/h (4 impacts)	401	$629 - $1,124
Single Impact	177	$315

* Similar to the assumption used for 3rd row vehicles or vehicles with a cargo area behind 2nd row, we assumed that a single 214-curtain air bag covers the first three rows and the cargo area.

The results in Table VIII-15 show that the impactor test in the final rule would result in 373 lives saved, annually, when the window opening is tested at four impact points at the two impact speeds and times (20 km/h-1.5 seconds and 16 km/h-6 seconds). When the window opening is required to be tested at 24 km/h, it would result in 401 lives saved (7% reduction). The estimated benefits and costs show that testing the window opening at 24 km/h would result in a moderate impact on the overall system benefit. The analysis of the second alternative shows that a rollover curtain air bag that is designed to withstand an impact only at the geometric center of the window opening would also provide sizable benefits (177 incremental lives saved). However, we are uncertain how this relatively small bag interacts with an occupant in rollovers. In addition, we note that the headform 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 one point in each of the three side windows 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 headform test. As shown in the sensitivity chapter, when the front lower corner of the front side window area (test point A1) is excluded from the FMVSS No. 226 requirements, the incremental fatal benefits decrease from 373 to 241 lives. For serious injuries, the injury benefits decrease from 476 to 305 injuries.

IX. 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 an 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 or final rule will not have a significant impact on a substantial number of small entities. The head of the agency has made such a certification with regard to this final rule.

The factual basis for the certification (5 U.S.C. 605(b)) is set forth below. Although NHTSA is not required to issue a final RFA, as a means of venting the issues we discuss below many of the issues that a final 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. Description of the reason why action by the agency is being considered

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. Objectives of, and legal basis for, the rule

This rule adopts a new Federal Motor Vehicle Safety Standard (FMVSS) No. 226, "Ejection mitigation." Under the standard, the side window openings of light vehicles will be tested with a featureless headform impactor by impacting various areas in the window opening at specific impact speeds. To meet the test requirements, vehicle manufacturers will need to assure that the side window openings are fully covered by a countermeasure that prevents the headform from moving more than 100 mm beyond the plane of the window. The rule will lead to the installation of new technologies, such as large curtain air bags with rollover sensors, which are

capable of preventing occupants from full or partial ejection in rollover. The curtain air bag system installed to meet the impactor requirements of the final rule will also reduce fatalities and injuries caused by complete ejections through side windows in side crashes. In addition, the curtain air bag system would prevent ejection of children through the side windows in side impacts.

NHTSA is requiring these changes under the authority of 49 U.S.C. 322, 30111, 30115, 30117, 30128, 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 rule is also being issued pursuant to the "Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users." 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." The Act directs the agency to issue a final rule on this subject. 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. <u>Description and estimate of the number of small entities to which the final rule will apply</u>

The final rule will apply to small entities that are motor vehicle manufacturers, multi-stage manufacturers, and alterers. It will also affect air bag manufacturers and rollover sensor manufacturers, but these are not considered small businesses. Business entities are 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 analyzed the impact of the final rule on these small manufacturers as a whole and not individually. As explained below, the impact is not expected to be significant.

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 .

4.1. Reporting & Recording Impacts:

For the headform test, the agency is requiring a phase-in schedule starting the first September 1 two years from the date of publication of a final rule. Assuming that a final rule would be issued January 31, 2011, the phase-in would be implemented in accordance with the following schedule. Credits will be allowed for early compliance during the phase-in period, applicable to the 25 percent, 50 percent, 75 percent, and 100 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	25 percent of a manufacturer's light vehicles
September 1, 2014 to August 31, 2015	50 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	100 percent of all light vehicles, credits may be used
On or after September 1, 2017	All light vehicles, without advance credits
On or after September 1, 2017	Small manufacturers and limited carline manufacturers
On or after September 1, 2018	Alterers, multistage manufacturers

As with previous rules, the agency will allow small manufacturers (an original vehicle manufacturer that produces or assembles fewer than 5,000 vehicles annually for sale in the U.S.) and limited line manufacturers (a manufacturer that sells three or fewer car lines in the U.S. during a production year) the option of achieving full compliance when the phase-in is completed. Furthermore, vehicles manufactured in two or more stages and altered vehicles do not have to comply until one year after the phase-in is completed. This substantial lead time

provides a great amount of flexibility to small manufacturers to allocate their resources to meet the standard and enables them to produce their vehicles without having to compete with large manufacturers for the business of side curtain air bag and rollover sensor suppliers. At the same time, by including vehicles produced by small manufacturers under the standard, ultimately individuals driving or riding in those vehicles will be afforded the protection of ejection mitigation countermeasures should the vehicle become involved in a rollover or side crash.

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. The certification information developed by the manufacturer is comparable to that required by other Federal motor vehicle safety standards to which the manufacturers already certify compliance.

4.2. Compliance Impacts:

(a) 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 less than 1,000 employees.

The rule will directly affect motor vehicle manufacturers. However, we believe that the rule will not have a significant economic impact on small vehicle manufacturers. We believed that 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 final rule accounts for this limitation by allowing small manufacturers and 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 entities.

We also believe that the rulemaking will 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 impactor test 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 system will have much, if any, effect on vehicle sales.

If a vehicle is equipped with a side impact curtain air bag without rollover sensor, the incremental cost to modify the FMVSS No. 214-curtain system is estimated to cost $51.68 per vehicle. If a vehicle is equipped with a side impact curtain air bag with rollover sensor, the incremental cost would be $12.26 per vehicle. If a vehicle is equipped with a combo air bag

system, the cost would be $213.04 per vehicle. We believe that these price increases will be passed on to the final customer. Compared to the least expensive vehicle in Table VIII-2, the cost is insignificant.

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, effect on vehicle sales. Based on this analysis, the agency believes that the final rule will not have a significant economic impact on these 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 final rule. These manufacturers buy incomplete vehicles to finish as complete vehicles or modify previously-certified vehicles. Many of these latter vehicles are van conversions, but there are a variety of vehicles affected.

To produce a vehicle, a final-stage manufacturer can either stay within the incomplete vehicle document (IVD) furnished by the incomplete vehicle manufacturer (which are typically large vehicle manufacturers, such as GM or Ford), or the final-stage manufacturer can work with incomplete vehicle manufacturers to enable the final-stage manufacturer to certify to the new

standard.[253] The final-stage manufacturer can also certify to the standard using due care based on an assessment of the information available to the manufacturer.

We believe that the majority of incomplete vehicles will be equipped with the ejection mitigation curtain bag that meets the impactor test requirements. It would be a feasible matter to produce a completed vehicle using an incomplete vehicle that has a rollover curtain and sensor system already installed. We anticipate that final-stage manufacturers will base their vehicles on incomplete vehicles that already have the ejection mitigation countermeasure installed rather than install the side curtain air bags and rollover sensor themselves.[254]
The standard adopted today does not specify any requirements for the rollover sensor. In the compliance test, we manually deploy the ejection mitigation side curtain air bags with the stationary vehicle set up in the test laboratory. All modifications of which we are aware that final-stage manufacturers or alterers make to the vehicle can be made without disabling the ability of the agency to manually deploy the side curtain air bags in the laboratory test.

To lessen the impacts of this rule on multi-stage manufacturers and alterers, we have excluded vehicles whose original roof was removed, in part or in total, by final-stage manufacturer or alterer. That exclusion addresses designs that will specifically affect side curtain air bag

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[253] For a discussion of NHTSA's certification regulations for final stage manufacturers, see 71 FR 28168, May 15, 2006, Docket No. NHTSA-2006-24664, Response to petitions for reconsideration of a final rule implementing regulations pertaining to multi-stage vehicles and to altered vehicles. The Background section of that document provides concepts and terminology relating to the certification of multi-stage vehicles.
[254] Incomplete vehicles that were designed to meet the FMVSS No. 214 pole test requirements with the FMVSS No. 214 seat-mounted air bags will need extensive modification to meet the FMVSS No. 226 test requirements. To install rollover curtain air bags and a sensor on these vehicles, final-stage manufacturers would likely need to use the combined engineering judgment of the incomplete vehicle manufacturer, rollover curtain air bag supplier, and their own judgment to certify compliance with FMVSS No. 226. Possibly some exemplar tests could be performed to show compliance.

coverage or inflators for which pass-through guidance might not be available. We have also excluded from the standard law enforcement vehicles, correctional institution vehicles, taxis and limousines, if they have a fixed security partition separating the 1st and 2nd or 2nd and 3rd rows and if they are produced by more than one manufacturer or are altered (within the meaning of 49 CFR 567.7). Thus, while there are a substantial number of multi-stage manufacturers impacted by the final rule, we have reduced the impacts on those entities. The certification alternatives available to small entities, e.g., using incomplete vehicles that have an ejection mitigation system already installed, are reasonable and practicable. For the above reasons, this final rule will not have a significant impact on a substantial number of small entities.

(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 final rule is expected to have a positive impact on their business.

We expect additional business for air bag manufacturers and rollover sensor manufacturers. The final rule will require the use of more air bags and rollover sensors. In each case, the final 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 final rule.

6. 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.

The only alternatives available for small entities relate to the lead time phase-in discussed above. There are no other alternatives that can achieve the stated objectives without installing countermeasures into the vehicle.

X. 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 2009 results in $134 million (109.615/81.536 = 1.34). The assessment may be included in conjunction with other assessments, as it is here.

A final 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 $561 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 final rule have a variety of costs ranging from an average of at least $31 per vehicle for 16.3 million vehicles excluding convertibles, it will exceed $507 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 Final 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 final component test is conducted in a well controlled test environment, which results in an acceptable amount of variability. In addition, the final 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 test the side window area at 24 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 analyzed several test data and real world crashes. The analysis showed that the reduction in impact speed from 24 km/h to 20 km/h would result in 7% reduction in benefit. As for the second alternative, a curtain ejection mitigation system designed to meet the 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			
Dodge Durango	A-pillar	B-Pillar	Side Rail	Upper Roof
	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:								28.78%
Belted	Partial	90%	70%	88%	55%	35	48	34
Belted	Complete	90%	0%	75%	0%	0	0	0
Unbelted	Partial	90%	64%	88%	51%	46	63	45
Unbelted	Complete	90%	64%	75%	43%	167	231	164
side impacts followed by rollovers:								
Belted	Partial	90%	70%	49%	31%	1	2	1
Belted	Complete	90%	0%	36%	0%	0	0	0
Unbelted	Partial	90%	64%	49%	28%	35	48	35
Unbelted	Complete	90%	64%	36%	20%	16	22	15
side impacts, w/ subsequent rollovers, 12-25 mph:								
Belted	Partial	100%	70%	49%	34%	0	0	0
Belted	Complete	100%	0%	36%	0%	0	0	0
Unbelted	Partial	100%	64%	49%	31%	0	0	0
Unbelted	Complete	100%	64%	36%	23%	10	14	10
side impacts, no rollovers, 12-25 mph:								
Belted	Partial	100%	100%	49%	49%	0	0	0
Belted	Complete	100%	0%	36%	0%	0	0	0
Unbelted	Partial	100%	100%	49%	49%	0	0	0
Unbelted	Complete	100%	100%	36%	36%	58	80	57
side impact, no rollover, children (0-12 YO), include both partial and complete ejections, 12- 25 mph:								
Belted	Partial	100%	100%	49%	49%	9	12	8
Belted	Complete	100%	0%	36%	0%	0	0	0
Unbelted	Partial	100%	100%	49%	49%	0	0	0
Unbelted	Complete	100%	100%	36%	36%	6	8	6
						381		376

95% sensor without glazing

Crashes		Sensor	Containment	Winnicki's	System	Fatalities w/ ESC	Benefits Lives	incremental Adj. Factor 28.78%
rollover, no side impacts:								
Belted	Partial	95%	70%	88%	58%	87	51	36
Belted	Complete	95%	0%	75%	0%	0	0	0
Unbelted	Partial	95%	64%	88%	53%	125	67	48
Unbelted	Complete	95%	64%	75%	46%	535	244	173
side impacts followed by rollovers:								
Belted	Partial	95%	70%	49%	32%	6	2	1
Belted	Complete	95%	0%	36%	0%	0	0	0
Unbelted	Partial	95%	64%	49%	30%	173	51	36
Unbelted	Complete	95%	64%	36%	22%	106	23	16
side impacts, w/ subsequent rollovers, 12-25 mph:								
Belted	Partial	100%	70%	49%	34%	0	0	0
Belted	Complete	100%	0%	36%	0%	8	0	0
Unbelted	Partial	100%	64%	49%	31%	0	0	0
Unbelted	Complete	100%	64%	36%	23%	63	14	10
side impacts, no rollovers, 12-25 mph:								
Belted	Partial	100%	100%	49%	49%	0	0	0
Belted	Complete	100%	0%	36%	0%	0	0	0
Unbelted	Partial	100%	100%	49%	49%	0	0	0
Unbelted	Complete	100%	100%	36%	36%	225	80	57
side impacts, no rollovers, children, 12-25 mph:								
Belted	Partial	100%	100%	49%	49%	24	12	9
Belted	Complete	100%	0%	36%	0%	0	0	0
Unbelted	Partial	100%	100%	49%	49%	0	0	0
Unbelted	Complete	100%	100%	36%	36%	23	8	6
						1,374		393

89% sensor with glazing

Crashes		Sensor	Containment	Winnicki's	System	Fatalities w/ ESC	Benefits Lives	incremental Adj. Factor 28.78%
rollover, no side impacts:								
Belted	Partial	89%	87%	88%	68%	87	59	42
Belted	Complete	89%	0%	75%	0%	0	0	0
Unbelted	Partial	89%	85%	88%	66%	125	83	59
Unbelted	Complete	89%	85%	75%	57%	535	303	216
side impacts followed by rollovers:								
Belted	Partial	89%	87%	49%	38%	6	2	2
Belted	Complete	89%	0%	36%	0%	0	0	0
Unbelted	Partial	89%	85%	49%	37%	173	64	45
Unbelted	Complete	89%	85%	36%	27%	106	28	20
side impacts, w/ subsequent rollovers, 12-25 mph:								
Belted	Partial	100%	87%	49%	42%	0	0	0
Belted	Complete	100%	0%	36%	0%	8	0	0
Unbelted	Partial	100%	85%	49%	41%	0	0	0
Unbelted	Complete	100%	85%	36%	30%	63	19	14
side impacts, no rollovers, 12-25 mph:								
Belted	Partial	100%	100%	49%	49%	0	0	0
Belted	Complete	100%	0%	36%	0%	0	0	0
Unbelted	Partial	100%	100%	49%	49%	0	0	0
Unbelted	Complete	100%	100%	36%	36%	225	80	57
side impacts, no rollovers, children, 12-25 mph:								
Belted	Partial	100%	100%	49%	49%	24	12	8
Belted	Complete	100%	0%	36%	0%	0	0	0
Unbelted	Partial	100%	100%	49%	49%	0	0	0
Unbelted	Complete	100%	100%	36%	36%	23	8	6
						1,374		469

89% sensor uniform distribution without glazing

Crashes		Sensor	Containment	Winnicki's	System	Fatalities w/ ESC	Benefits Lives	incremental Adj. Factor 28.78%
rollover, no side impacts:								
Belted	Partial	89%	63%	88%	46%	87	43	30
Belted	Complete	89%	0%	75%	0%	0	0	0
Unbelted	Partial	89%	63%	88%	49%	125	61	44
Unbelted	Complete	89%	63%	75%	42%	535	224	159
side impacts followed by rollovers:								
Belted	Partial	89%	63%	49%	27%	6	2	1
Belted	Complete	89%	0%	36%	0%	0	0	0
Unbelted	Partial	89%	63%	49%	27%	173	47	33
Unbelted	Complete	89%	63%	36%	20%	106	21	15
side impacts, w/ subsequent rollovers, 12-25 mph:								
Belted	Partial	100%	63%	49%	31%	0	0	0
Belted	Complete	100%	0%	36%	0%	8	0	0
Unbelted	Partial	100%	63%	49%	31%	0	0	0
Unbelted	Complete	100%	63%	36%	22%	63	14	10
side impacts, no rollovers, 12-25 mph:								
Belted	Partial	100%	100%	49%	49%	0	0	0
Belted	Complete	100%	0%	36%	0%	0	0	0
Unbelted	Partial	100%	100%	49%	49%	0	0	0
Unbelted	Complete	100%	100%	36%	36%	225	80	57
side impacts, no rollovers, children, 12-25 mph:								
Belted	Partial	100%	100%	49%	49%	24	12	8
Belted	Complete	100%	0%	36%	0%	0	0	0
Unbelted	Partial	100%	100%	49%	49%	0	0	0
Unbelted	Complete	100%	100%	36%	36%	23	8	6
						1,374		364

Fatal Benefits with Single Impact at Geometry Center of Window Opening

Crashes		Sensor	Containment	Winnicki's	System	Fatalities w/ ESC	Benefits Lives	incremental Adj. Factor 51.29%
rollover, no side impacts:								
Belted	Partial	89%	59%	88%	46%	87	40	20
Belted	Complete	89%	0%	75%	0%	0	0	0
Unbelted	Partial	89%	53%	88%	41%	125	52	25
Unbelted	Complete	89%	53%	75%	35%	535	189	92
side impacts followed by rollovers:								
Belted	Partial	89%	59%	49%	26%	6	1	1
Belted	Complete	89%	0%	36%	0%	0	0	0
Unbelted	Partial	89%	53%	49%	23%	173	40	19
Unbelted	Complete	89%	53%	36%	17%	106	18	9
side impacts, w/ subsequent rollovers, 12-25 mph:								
Belted	Partial	100%	59%	49%	29%	0	0	0
Belted	Complete	100%	0%	36%	0%	8	0	0
Unbelted	Partial	100%	53%	49%	26%	0	0	0
Unbelted	Complete	100%	53%	36%	19%	63	12	6
side impacts, no rollovers, 12-25 mph:								
Belted	Partial	100%	100%	49%	49%	0	0	0
Belted	Complete	100%	0%	36%	0%	0	0	0
Unbelted	Partial	100%	100%	49%	49%	0	0	0
Unbelted	Complete	100%	0%	36%	0%	225	0	0
Side impacts, no rollover, children 12-25 mph								
Belted	Partial	100%	100%	49%	49%	24	12	6
Belted	Complete	100%	0%	36%	0%	0	0	0
Unbelted	Partial	100%	100%	49%	49%	0	0	0
Unbelted	Complete	100%	0%	36%	0%	23	0	0
						1,374	364	177

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	1,158	928	1,239	10%	20%	28%
	PU	1,236	812	793	11%	18%	18%
	SUV	1,881	858	907	17%	19%	20%
	Van	324	147	188	3%	3%	4%
	Other	12	2	0	0%	0%	0%
	Subtotal	4,612	2,747	3,127	41%	61%	70%
	Vehicle	MAIS 1-2	MAIS 3-5	Fatal	MAIS 1-2	MAIS 3-5	Fatal
Partial Ejections	Car	1,429	971	660	13%	21%	15%
	PU	2,515	375	190	22%	8%	4%
	SUV	1,590	402	350	14%	9%	8%
	Van	1,133	44	103	10%	1%	2%
	Other	13	0	17	0%	0%	0%
	Subtotal	6,680	1,792	1,320	59%	39%	30%
	Vehicle	MAIS 1-2	MAIS 3-5	Fatal	MAIS 1-2	MAIS 3-5	Fatal
Total Ejections	Car	2,588	1,899	1,899	23%	42%	43%
	PU	3,751	1,187	983	33%	26%	22%
	SUV	3,471	1,260	1,257	31%	28%	28%
	Van	1,457	192	291	13%	4%	7%
	Other	25	2	17	0%	0%	0%
	Total	11,292	4,540	4,447	100%	100%	100%

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 1,374 observed fatalities in the target population. According to the model developed by the agency, the use rate among potential fatal crashes (UPFC) would be 70% when the average observed usage rate is 84%, as shown below:[255]

Table H-1
Use rate among Potential Fatal Crashes (UPFC) with 84% observed usage rate

Average observed usage rate	84%
Use rate among Potential Fatal Crashes (UPFC)	70%
Safety belt effectiveness	77%
Potential fatality	3,005
Lives saved by belt	1,631

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	77%
Potential fatality	3,005
Lives saved by belt	2,118

Tables H-1 and H-2 show that additional 487 lives in the 1,374 observed fatal target population would be saved if the belt use rate increase by 16% from 84% to 100%.[256] When the 487 lives saved are subtracted from the 1,374 fatalities in the target population, it results in 888 fatalities. In the FRIA, we estimated that the ejection mitigation system would save 373 lives among 1,374 fatalities. It resulted in an overall effectiveness of 27% (373/1,374 = 27%). When the 27%

[255] The UPFC equation is from DOT HS 809 639, Table 10, Model 2
[256] 2,065 lives saved by 100% belt use – 1,535 lives saved by 82% belt use = 530 net lives saved.

overall effectiveness was applied to the 888 fatalities, it resulted in 241 lives saved, as shown below:

Table H-3
Additional Lives Saved by Increase in Belt Use Rate

Fatalities with 84% belt use rate	1,374
Estimated additional lives saved with 84% belt use rate	373
Overall ejection mitigation system effectiveness	27%
Estimated fatalities with 100% belt use rate	888
Estimated additional lives saved with 100% belt use rate	241

The table above shows that the number of lives saved by the ejection mitigation system would decrease from 373 to 241 lives with a 100% belt use rate. In other words, 16% increase in belt use rate would result in a 35% reduction in ejection mitigation fatal benefits. However, the increase in belt use rate would result in 487 lives saved. 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.[257]

[257] L. Blincoe and J. Wang, report DOT HS 809 639.

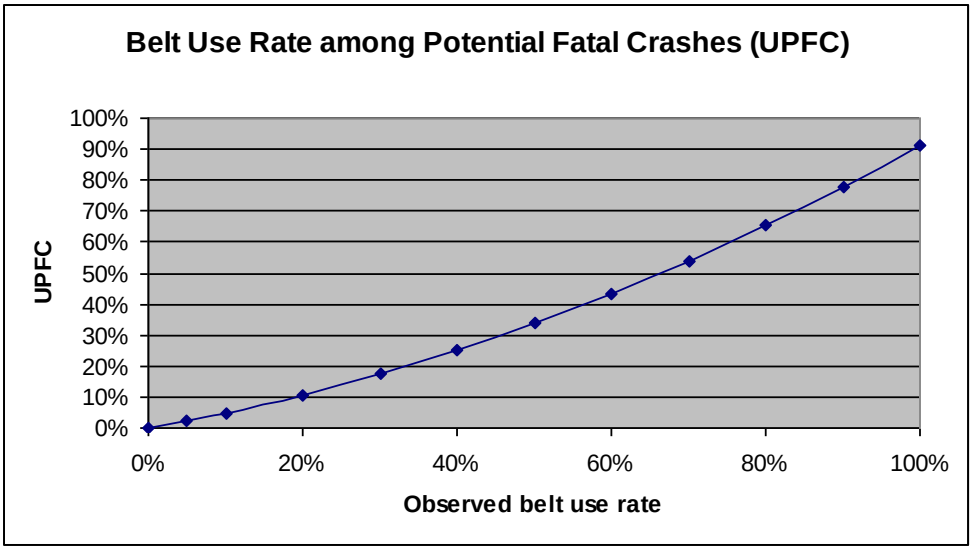

Figure H-1. Observed belt use rate vs. Belt use rate among potential fatal crashes

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 476 to 307 (AIS 3-5) injuries. When the 241 lives saved and 307 serious injuries prevented are converted into Equivalent Life Saved (ELS), it results in 241 and 192 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
84% used in FRIA	N/A	373	373
100%	487	241	728

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 $1,307M with 84% belt use rate to $665M with 100% belt use rate, when all light vehicles are equipped with the 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%
84%	373	458	374	297	6.1	$2,279	$1,814	$507	$1,773	$1,307
100%	241	296	241	192	6.1	$1,472	$1,171	$507	$965	$665

Appendix I

ELS and Net Benefits for Excluding Alcohol Related Fatalities

Alcohol	Equ. Lives Saved			$ per life (in $M)	Benefits (in $M)		Cost (in $M, 2009$)	Net Benefits ($M)	
	no discount	at 3%	at 7%		at 3%	at 7%		at 3%	at 7%
included	458	374	279	6.1	$2,279	$1,814	$507	$1,773	$1,307
excluded	244	199	159	6.1	$1,216	$968	$507	$709	$461

Alcohol Used by Driver in Fatal Crashes of Ejected Occupants in Rollover or Side Impact Ejection Path through Row 1 or 2 Side Window
(1997-2005 NASS, no adjustments)

Alcohol Used in Crash	Occupant Role	Alcohol Used by Driver of this Vehicle	Sample Count	Annual Estimated	Total	% of total
yes	Driver	Yes	176	1,009		
yes	Driver	No	5	15		
yes	Driver	Unknown	2	7		
yes	Passenger	Yes	53	320		
yes	Passenger	Unknown	3	9	1,360	54%
no	Driver	No	56	207		
no	Driver	Unknown	39	238		
no	Passenger	No	26	364		
no	Passenger	Unknown	49	331	1,140	46%

Alcohol Used by Driver in Fatal Crashes of Ejected Occupants in Rollover or Side Impact Ejection Path through Row 1 or 2 Side Window
(2000-2009 NASS, no adjustments)

Alcohol Used in Crash	Occupant Role	Alcohol Used by Driver of this Vehicle	Sample Count	Annual Estimated	Total	% of total
yes	Driver	Yes	222	1,014		
yes	Driver	No	4	13		
yes	Driver	Unknown	2	3		
yes	Passenger	Yes	65	321		
yes	Passenger	No	3	12		
yes	Passenger	Unknown	5	11	1,374	60%
no	Driver	No	66	252		
no	Driver	Unknown	40	200		
no	Passenger	No	30	169		
no	Passenger	Unknown	46	294	915	40%

Appendix J
ELS Broken-Out by Belt Use and Level of Ejection

The final ejection mitigation standard would save 373 lives and prevent 476 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 458, 374 and 297 ELS at no discount, 3% discount and 7% discount, respectively. Among the 458 ELS at no discount, 53 are from partially ejected belted occupants, 87 are from partially ejected unbelted occupants and the remaining 318 are from completely ejected unbelted occupants, as shown below. 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	117	37.3%	44	253	29.7%	75	53	44	35
Belted complete	8	0.0%	0	40	0.0%	0	0	0	0
Unbelted partial	298	26.4%	79	245	25.4%	62	87	71	56
Unbelted complete	951	26.3%	251	865	39.2%	339	318	259	206
Total	1,374		373	1,403		476	458	374	297

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 $M, 2009$)	Net Benefits ($M)	
	no discount	at 3%	at 7%		at 3%	at 7%		at 3%	at 7%
Belted partial	53	44	35	6.1	$266	$211	$507	$139	$85
Belted complete	0	0	0	6.1	$0	$0		-$127	-$127
Unbelted partial	87	71	56	6.1	$432	$343		$305	$217
Unbelted complete	318	259	206	6.1	$1,582	$1,259		$1,455	$1,132

Note: For the net benefits, the cost ($507M) were evenly divided into the four groups (by belt use & level of ejection)

Full curtain – for up to 9 ¼-turns

	AIS 3	AIS 4	AIS 5	Fatal	total	discounted equ, fatal		cost ($M)	cost per equ. Life saved		stat. Value	Net Saving	
Additional benefits	297	124	55	373		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	24	25	37	373	458	374	297	$507	1.36	1.70		$1,773	$1,307

Excluding A1– for up to 9 ¼-turns

	AIS 3	AIS 4	AIS 5	Fatal	total	discounted equ, fatal		cost ($M)	cost per equ. Life saved		stat. Value	Net Saving	
Additional benefits	190	80	35	241		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	15	16	23	241	295	241	192	$406	1.69	2.12		$1,062	$762