UPDATED REVIEW OF POTENTIAL TEST PROCEDURES FOR FMVSS NO. 208

Prepared By The

OFFICE OF VEHICLE SAFETY RESEARCH

WILLIAM T. HOLLOWELL
HAMPTON C. GABLER
SHELDON L. STUCKI
STEPHEN SUMMERS
JAMES R. HACKNEY, NPS

OCTOBER 1999

People Saving People
http://www.nhtsa.dot.gov

TABLE OF CONTENTS

Executive Summary

Background

The objective of a crash test for Federal Motor Vehicle Safety Standard (FMVSS) No. 208 is to measure how well a passenger vehicle would protect its occupants in the event of a serious real world frontal crash. This is sometimes referred to as the crashworthiness of a vehicle. This report reviews potential test procedures for evaluating frontal crashworthiness.

Structural design for crashworthiness seeks to mitigate two adverse effects of a crash – (1) rapid deceleration of the occupant compartment, and (2) crush of the occupant compartment survival space. In a severe crash, the speed of a vehicle often decreases from its travel speed to zero in a hundred thousandths of a second. One important way to minimize the injury consequences of this abrupt change in velocity is to extend the amount of time necessary to slow the vehicle down – the less abrupt the change in velocity, the lower the crash forces on the occupant. The front end of vehicles are designed to crumple in a controlled manner in a collision to give their occupants the necessary additional time to safely decelerate in a crash.

Note that the controlled crush or crumple of the front-end, a safety positive feature, is totally different from the crush or collapse of the actual occupant compartment – which is to be avoided. At a minimum, partial collapse of the structural cage which surrounds the occupant allows vehicle parts (e.g., the engine or steering mechanism) to "intrude" into the occupant space and strike the occupant causing injury. In extremely severe collisions, the occupant compartment may suffer a catastrophic collapse, and allow the occupant to be crushed.

The degradation of the occupant compartment survival space is measured by intrusion. The occupant compartment deceleration severity is measured by the amplitude and time duration of the deceleration time history. The deceleration time history is sometimes called the crash pulse. Both effects have the potential for causing injury.

Objectives

The ideal frontal crash test procedure will be able to evaluate occupant protection while ensuring that the vehicle will not jeopardize its crash "friendliness" with its collision partners. The test conditions (e.g., impact speed, impact angle, and test device) must be representative of the frontal crash environment to which passenger vehicles are exposed on the highway. Finally, to provide assurance of protection in potentially serious injury crashes, the test procedures must be severe enough to represent a crash in which occupants could be seriously injured or killed.

This report examines several potential frontal crash test procedures, and evaluates how well each candidate frontal test procedure meets these objectives. Specifically, this report evaluates (1) the full frontal fixed barrier test, (2) the oblique frontal fixed barrier test, (3) the generic sled test, (4) the frontal fixed offset deformable barrier test, (5) the perpendicular moving deformable barrier (MDB) test, (6) the oblique moving deformable barrier test and (7) the full frontal fixed deformable barrier (FFFDB) test. Each procedure is compared with the 48 kph fixed rigid barrier test and the generic sled test currently prescribed in FMVSS No. 208.

Approach and Findings

Based on actual crash tests and computer simulations of real world crashes, each test procedure has been categorized with respect to its crash pulse and expected intrusion level. The crash responses of the vehicles that were similar to the rigid barrier test responses were categorized as stiff, whereas the crash responses that were similar to the generic sled pulse were categorized as soft. In examining the deceleration levels from the crash tests and simulations, the “soft” responses are generally characterized by longer duration pulses and lower acceleration levels. The “stiff” pulses are characterized by shorter duration pulses and higher acceleration levels. In examining the resulting velocity profiles from these pulses during the first 50 to 60 milliseconds (the time at which occupants begin to interact with the air bag), it is observed that the “soft” pulses result in a velocity change of the occupant that is roughly half that experienced by occupants inside vehicles subjected to a stiff pulse. In examining both the crash test and the simulation results, the occupants of vehicles subjected to the soft pulses experienced lower injury levels than would have occupants of vehicles subjected to stiff pulses.

In addition to characterizing the crash pulse response, the expected intrusion outcome was determined from crash test measurements and simulations. The intrusion outcome was divided into two categories - (1) intrusion level of 0 to 15 cm, and (2) intrusion greater than 15 cm. The results from these efforts are shown in the table below. Analysis of U.S. crash statistics has shown that in crashes where the intrusion exceeds 15 cm, the probability of injury is substantially higher than in crashes with lower amounts of intrusion.

Table ES-1: Test Procedure: Expected Outcomes

Test Procedure	Impact Direction	Crash Pulse	Intrusion (est.)
Rigid Wall/ Full frontal	Perpendicular	Stiff	0 - 15 cm
Rigid Wall/ Full frontal	Oblique	Soft	> 15 cm
FFFDB/ Full frontal	Perpendicular	Soft	0 - 15 cm
Offset-Barrier (EU Test)	Perpendicular	Soft	> 15 cm
Vehicle-MDB/ Full-Frontal	Perpendicular	Stiff	0 - 15 cm
Vehicle-MDB/ Overlap # 55%	Perpendicular	Soft	> 15 cm
Vehicle-MDB/ Overlap > 55%	Perpendicular	Stiff	> 15 cm
Vehicle-MDB/ Overlap # 33%	Oblique	Soft	> 15 cm
Vehicle-MDB/ Overlap > 33%	Oblique	Stiff	> 15 cm
Sled Test	Perpendicular	Soft	Not Applicable

Passenger vehicles will be exposed to a wide spectrum of real world crash types when introduced into the vehicle fleet. The strategy in selecting a test procedure is to identify tests that have the potential to improve the crash protection provided across a broad range of real-world impact conditions. The crash test conditions for each procedure, e.g., impact speed, impact angle, test devices and configurations, must be carefully selected to be representative of the frontal crash environment to which passenger vehicles are generally exposed on the highway.

The National Automotive Sampling System (NASS) files for 1988-97 were analyzed in order to characterize the frontal crash environment. The study investigated approximately 3,770 vehicles, or drivers, with airbags which were involved in frontal crashes, of which 847 had injuries classified as moderate or greater, 408 serious or greater injuries, and 89 fatal injuries. These were “weighted” in NASS to represent 97,585, 32,143 and 4,437 moderate, serious and fatal injuries, respectively. By grouping drivers into specific test conditions based on the crash severity, assumed to be defined by crash pulse and intrusion, an estimate of the target crash populations for each test configuration can be predicted. The target populations based on exposure and based on serious-to-fatal injuries for drivers with air bags were computed. The major finding was that a MDB-to-vehicle test, both left and right offset, would address the largest target population of drivers exposed to frontal crashes – approximately 64 percent of drivers and about 59 percent of those receiving serious to fatal injuries. The full, fixed rigid barrier test at 0 to 30 degrees impact angle would address a lower target population -- about 44 percent of the drivers and about 40 percent of those receiving serious to fatal injuries. All other potential tests would address substantially lower target populations.

Although the emphasis of the rigid barrier test is clearly on occupant protection, an important constraint on the test procedure is that it should not lead to designs which jeopardize the vehicles crash “friendliness” in collisions against other vehicles. One concern that has been raised by many safety researchers in industry, government, and academia is that some tests currently not in use – most notably the frontal offset-barrier test – may drive vehicle designs away from being crash “friendly” and it must be ensured that any tests that are required do not drive vehicle designs in that direction.

Mitigation of intrusion and crash pulse require competing design modifications. To reduce intrusion, the common remedy is to strengthen or ‘stiffen’ the vehicle structure both surrounding and including the occupant compartment. To lessen deceleration severity, the conventional approach is to soften the vehicle structure forward of the occupant compartment. The ideal test procedure would be one which leads designers to (1) soften the front structure for control of deceleration severity and (2) strengthen the structure surrounding the occupant compartment to control intrusion. Currently, the rigid barrier test acts as a constraint on over-stiffening of the front vehicle structure. The frontal-oblique MDB test, or a combination of the rigid full frontal barrier test and a frontal-offset test forces designers to produce a vehicle which limits intrusion while simultaneously limiting deceleration severity. However, less rigorous tests which produce neither intrusion nor high deceleration, e.g, the FFFDB or the sled test, provide essentially no constraint on front structure stiffness, and would permit the manufacture of a new generation of stiffer, more aggressive passenger vehicles.

Options for Consideration

Analysis of each of the candidate test procedures with respect to their lead time, target populations, body regions addressed, and effect on compatibility leads to the following four options available for consideration for the evaluation of a vehicle’s frontal crash protection. The generic sled test is not one of the options. Unlike a full scale vehicle crash test, a sled test does not, and cannot, measure the actual protection an occupant will receive in a crash. The sled test does not replicate the actual timing of air bag deployment, does not replicate the actual crash pulse of a vehicle, does not measure the injury or protection from intruding parts of the vehicle, and does not measure how a vehicle performs in actual angled crashes. Finally, the generic sled test has a substantially smaller target population when compared to the options discussed below.

Option 1 - Combination of Perpendicular and Oblique Rigid Barrier Tests: The first option is the unbelted rigid barrier test of impact speed 0 to 48 kmph and impact angle 0 to 30º. This option has a target population which is substantially larger than the generic sled test, and is immediately available for implementation. The perpendicular rigid barrier test primarily evaluates crash pulse severity while the oblique rigid barrier test primarily evaluates intrusion. Likewise, the perpendicular rigid barrier test is expected to evaluate head, chest, neck and upper leg injury potential, but generally indicates no lower leg injury unless coupled with the oblique barrier test. With regard to compatibility, the perpendicular rigid barrier test acts as a constraint on over-stiffening the front structure.

Option 2: Combination of the Perpendicular Rigid Barrier Test and an Offset-Barrier Test:
The second option is a combination of the rigid barrier test with an offset-barrier test similar to the procedure used in Europe. This option combines the crash pulse control provided by the perpendicular rigid barrier test with the intrusion control provided by the offset-barrier test. The target population for the combined procedure equals the target population for the combination of the perpendicular and oblique rigid barrier tests. In addition to evaluating the protection of the head, chest, and neck of the occupant, the combined procedure also evaluates leg protection against intrusion. With regard to compatibility, the combined procedure, like the rigid barrier test alone, acts as a constraint on over-stiffening the front structure, but would allow strengthening of the occupant compartment to avoid intrusion.

Option 3 - Moving Deformable Barrier (MDB)-to-Vehicle Test: The third option is the frontal-MDB test. Of all candidate test procedures, this option has one of the largest target populations, but also has the need for a longer lead time (2-3 years) to complete research and development. The frontal-MDB test combines, in a single test, the crash pulse control provided by the perpendicular rigid barrier test with the intrusion control provided by the offset-barrier test. For lighter vehicles, this procedure provides the incentive to produce designs which are more crash compatible with heavier collision partners. The procedure provides no incentive to either stiffen or soften larger vehicles, thereby allowing the automakers the design flexibility to build compatibility into heavier vehicles. Design modifications made to take advantage of this could lead to poorer performance in single vehicle crashes.

Option 4 - Combination of Perpendicular Rigid Barrier and Moving Deformable Barrier (MDB)-to-Vehicle Test: The fourth option is the combination of the frontal rigid barrier and the MDB test. Of all candidate test procedures, this option has the largest target population. These tests combine the crash pulse control provided by the perpendicular rigid barrier test with the intrusion control provided by the offset-barrier test. For lighter vehicles, this procedure provides the incentive to produce designs which are more crash compatible with heavier collision partners. The combined procedures prevent larger vehicles from becoming too stiff, thereby pointing the automakers toward designs that build compatibility into heavier vehicles. The research and development related to this procedure will require a lead time of 2-3 years to complete.

Recommendations

On March 19, 1997, NHTSA published a final rule that adopted an unbelted sled test protocol as a temporary alternative to the fixed barrier test for unbelted occupants. The agency took this action to provide an immediate, interim solution to the problem of the fatalities and injuries that current air bag systems are causing in relatively low speed crashes to a small, but growing number of children and occasionally to adults. It was the understanding at that time, and it is reiterated in this study, that the sled test does not meet the need for effectively evaluating vehicle protection systems. The advanced air bag rulemaking actions that are being proposed provide adequate lead time to assure proper designs for occupant protection that must be evaluated under appropriate test conditions. Therefore, it is recommended for this rulemaking to eliminate the sled test procedure and to consider the aforementioned options that are available within the rulemaking time frame. Additionally, it is recommended that research be continued in developing and evaluating the moving deformable barrier test for future agency consideration for upgrading FMVSS No. 208.

CHAPTER 1. INTRODUCTION

The National Highway Traffic Safety Administration (NHTSA) strives to establish test procedures in regulatory requirements that lead to improvements in real world safety, often in connection with performance standards. In Federal Motor Vehicle Safety Standard (FMVSS) No. 208, "Occupant Crash Protection," a rigid barrier crash test was applied. Historically, this test has applied to both belted and unbelted 50th percentile male anthropomorphic dummies for impact conditions from 0 to 48 kmph and impact angles from 0 to 30 degrees.

As a result of problems of injuries and fatalities associated with air bags and out-of-position child passengers, out-of-position adult drivers (usually unbelted), and infants in rear-facing child safety seats, NHTSA published a final rule on March 19, 1997, that temporarily amended FMVSS No. 208 to facilitate the rapid redesign of air bags so that they inflate less aggressively. More specifically, the agency adopted an unbelted sled test protocol as a temporary alternative to the full scale unbelted barrier crash test requirement. The agency took this temporary action to provide an immediate, yet partial, solution to the problem of the fatalities and injuries that current air bag systems are causing in relatively low speed crashes to a small, but growing number of children and occasionally to adults. In the final regulatory evaluation published in conjunction with the issuance of the final rule, the agency estimated that if manufacturers depowered their air bag systems on average by 20 to 35 percent, 47 children's lives could be saved from the estimated 140 children who otherwise would be killed over the lifetime of one model year's fleet. Furthermore, based on limited test results, projections were made regarding the disbenefits to adult occupants that would occur in high severity crashes as a result of depowering the air bag systems. The estimated disbenefit was that 45 to 409 driver and passenger adult fatalities would result from depowering the air bag systems by 20 to 35 percent.[1]

While the agency adopted the sled test alternative to facilitate the quick redesign of air bags, the agency recognized that the sled test does not evaluate full vehicle system performance, particularly crash sensing. Therefore, the agency included a sunset provision for this alternative. The sunset provision would eliminate the sled test at the time that the agency believed advanced air bag technology would be

---

[1] The agency has revised both the benefits and disbenefits of the redesigned air bag systems as a result of the review of significant data obtained regarding redesigned air bag systems. The large potential increase in chest acceleration as seen in the agency's testing of prototype depowered systems for unbelted passengers in 30 and 35 mph testing has not materialized in Model Year (MY) 1998 vehicles, with the exception of one vehicle. The agency does not know the reason why. It could be that vehicles were not depowered as much as the prototype systems and thus did not have as large of an effect. It could be that manufacturers changed their systems from the prototypes to lessen the effect to the extent possible; or some combination of the two. Based on minimal data, the MY9 1998 redesigned air bags along with increases in belt use and moving kids to the rear seat together appear to have reduced the low speed out-of-position fatalities by about 70 percent or up to 83 mostly unbelted passenger fatalities. However, between 8 and 49 lives might not be saved in high speed crashes by MY 1998 air bags compared to pre-NY 1998 air bags. [1]

available. The recently enacted "National Highway Traffic Safety Administration Reauthorization Act of 1998" requires that a final rule for advanced air bag systems be made effective in phases as rapidly as possible, beginning not earlier than September 1, 2002, and provides that the sled test option shall remain in effect unless or until changed by this rule. Nevertheless, comments received by the agency regarding the March 19, 1997 rule, and the sunset provision included extensive discussions of the relevance of the full barrier test requirements and sled test protocol.

This report has been written to provide an assessment of potential frontal impact test procedures.[2] To achieve this goal, a multifaceted approach was undertaken. In Chapter 2, a review of the types of testing that have been utilized in the past for evaluating vehicle safety performance is presented. Candidate test procedures are identified, and a general description and an assessment of the state of development for each test procedure is presented. In Chapter 3, the frontal crash environment is characterized using the National Automotive Sampling System (NASS) file. Target populations for crashes and for serious injury-producing crashes are presented for the crash modes represented by the candidate test procedures. Furthermore, the predominant body regions for which injury potential is evaluated by each of the candidate test procedures are identified. In Chapter 4, a study is presented that addresses whether potential test procedures would necessarily and unavoidably result in vehicle designs that on balance would have a negative impact on motor vehicle safety. In Chapter 5, a study is presented that identifies the candidate test procedures as being rigid barrier-like (or "stiff") or sled-like (or "soft"). The procedures also are characterized according to their anticipated level of intrusion in the vehicles tested. These outcomes were used for characterizing the crash environment in Chapter 3. The final section, Chapter 6, summarizes the major findings from the individual studies, and then provides recommendations resulting from these findings. Appendices A-C provide technical background for these chapters.

REFERENCES

1. ____, "Preliminary Economic Assessment, SNPRM, FMVSS No. 208, Advanced Air Bags," National Highway Traffic Safety Administration, September 1999.

---

[2] In preparing for the advanced air bag regulation, several potential crash test procedures have been explored by the agency. These include the offset deformable barrier test as specified by the European Union in Directive 96/79/EC, the moving deformable barrier crash test that is being evaluated in NHTSA's advanced frontal research programs, and a 48 kmph full frontal fixed deformable barrier (FFFDB) crash test. The supporting rationale provided for any one of these tests may include the belief that the crash pulse is similar to that experienced in real world vehicle crashes, the use of the crash test will result in improvements in vehicle structures to prevent intrusion and/or improved restraint system designs to reduce loads on the occupants, and the use of the test will improve vehicle compatibility between passenger cars and light trucks and vans. Conversely, it may be argued that any one of these tests may not represent vehicle crash pulses, will lead to improper air bag/restraint system designs, and will lead to structural designs that increase incompatibility between vehicle types and weights.

CHAPTER 2. CANDIDATE TEST PROCEDURES

This section examines candidate test procedures for evaluation of frontal crash protection. The discussion describes each test procedure, provides the status of each procedure, the agency's experience with each procedure, the experience of the crash safety community with each procedure, and the lead time necessary to complete research for each procedure.

2.1 Approach

The objective of a crash test for Federal Motor Vehicle Safety Standard (FMVSS) No. 208 is to measure the crashworthiness of a passenger vehicle. The standard specifies performance requirements for the protection of vehicle occupants in crashes. Historically, this has encouraged improvements to the vehicle structure and restraint systems to enhance occupant crash protection. Structural design for crashworthiness seeks to mitigate two adverse effects of a crash – (1) degradation of the occupant compartment survival space and (2) the occupant compartment deceleration severity. Both effects have the potential to cause injuries – first, because of the increase in probability of occupant contact with intruding vehicle components, and, second, because of the potential for internal injuries to occupants. The degradation of the occupant compartment survival space is measured by intrusion, while occupant compartment deceleration severity is measured by the amplitude and time duration of the crash pulse.

The ideal frontal crash test procedure will evaluate the potential for occupant injury from both deceleration severity and from intrusion. Furthermore, in addition to occupant protection, the ideal test procedure will not lead to designs which jeopardize the vehicles' crash compatibility with its collision partners. Finally, the test conditions (i.e., impact speed, impact angle, and impact partner) must encompass and be representative of the frontal crash environment to which passenger vehicles are exposed on the highway.

This report examines several frontal crash test procedures, and evaluates how well each procedure meets these objectives. Specifically, this report evaluates (1) the full frontal fixed rigid barrier test, (2) the oblique frontal fixed rigid barrier test, (3) the generic sled test, (4) the offset frontal fixed deformable barrier test, (5) the perpendicular moving deformable barrier (MDB) test, (6) the oblique moving deformable barrier test and (7) the full frontal fixed deformable barrier (FFFDB) test. Each procedure is compared with the 48 kph rigid barrier test and the generic sled test.

2.2 Overview of Experience

A number of test types have been used in the past to evaluate vehicle performance in frontal crashes.

Over the years, the agency has conducted car-to-car, car-to-fixed barrier, moving barrier-to-car, and car-to-narrow object crash tests. Additionally, the agency has routinely conducted sled tests to evaluate restraint system performance. Figure 2-1 shows an example of an oblique offset car-to-car test. These car-to-car crashes generate a wide range of crash responses. In Figure 2-2, two crash response characteristics are cross-plotted (average acceleration vs. time to velocity change) for car-to-car tests and for the two test procedures specified in FMVSS No. 208--the rigid barrier test and the generic sled test. In car-to-car tests, the vehicles differ in their change in velocity, with the lighter vehicle experiencing a greater velocity change than the heavier vehicle. In rigid barrier tests, there is a lesser vehicle-to-vehicle variation in the velocity change. In order to compare the crash pulses of car-to-car tests with those in other tests, it is necessary to isolate the velocity change in the car-to-car test that corresponds to the velocity change in the test being evaluated, and then compare the time necessary taken to make the change. In the tests evaluated for this report, a 48 kmph velocity change was selected as a measure of comparison. Clearly in terms of the crash pulse, the generic sled tests are not representative of car-to-car tests.

The 48 kmph velocity was used since it is the upper bound for the velocity change in the generic sled pulse. The time for the 48 kmph velocity change in the car-to-car tests ranges from 64 to 168 msec, with the vast majority being in the 75 to 125 msec range. Figure 2-3 compares the time of the peak chest acceleration for the driver dummy in FMVSS No. 208 rigid barrier tests conducted for model year 1990 - 1998 vehicles and 18 vehicles crashed in the 60 percent overlap collinear car-to-car tests. Out of the 215 rigid barrier tests analyzed, 97.6 percent of the driver dummies measured peak chest acceleration prior to 100 msec. The time duration over which these peak chest accelerations occur compares well with the time duration over which most of the vehicles tested against the rigid barrier reached the 48 kmph velocity change. Also, it is seen that this compares well with the time duration over which the peak chest accelerations occur in the car-to-car tests. Returning to Figure 2-2, it is seen that the generic sled pulse (GSP) falls both at the lower end of the average acceleration and at the longer end of the time duration. Furthermore, it is seen that most of the car-to-car tests fall within the time range for the rigid barrier tests, (with the few outliers at the longer time duration representing vehicles substantially heavier than their crash partner in the test).

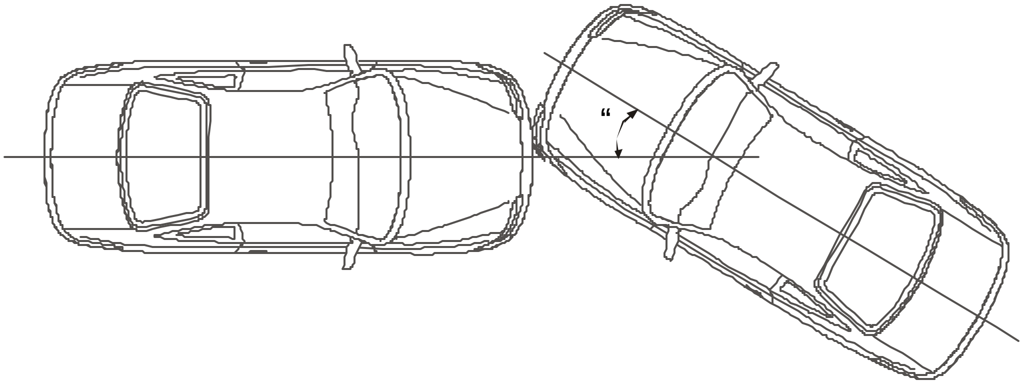


Figure 2-1. Car-to-Car Crash Test

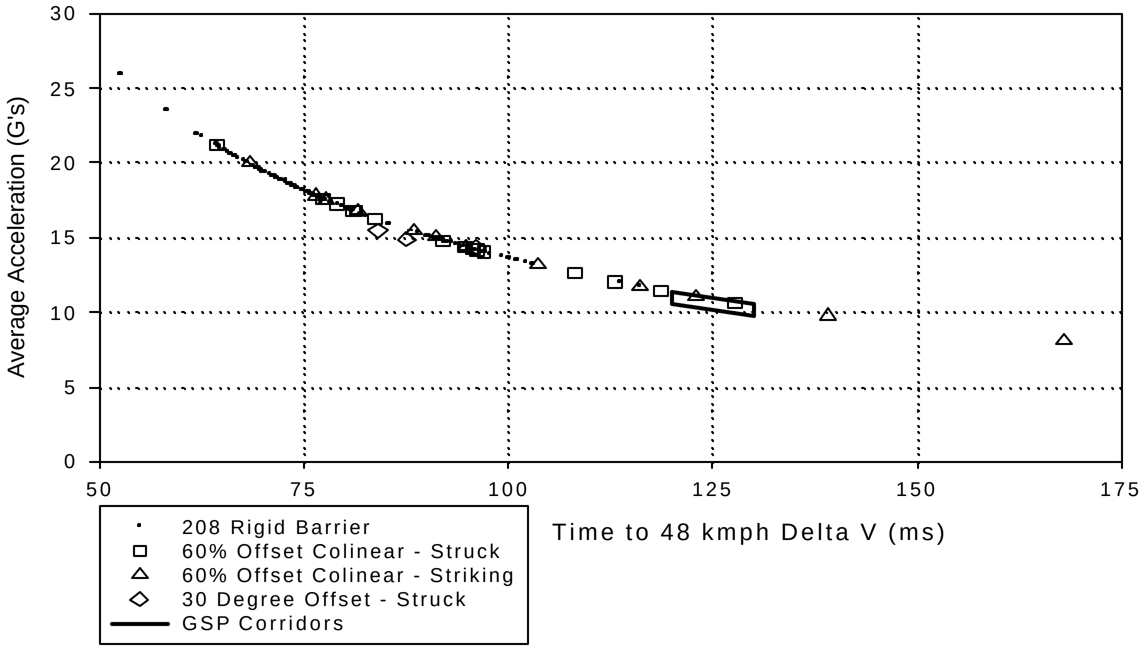


Figure 2-2. Comparison of Crash Pulse Characteristics for Car-to-Car tests

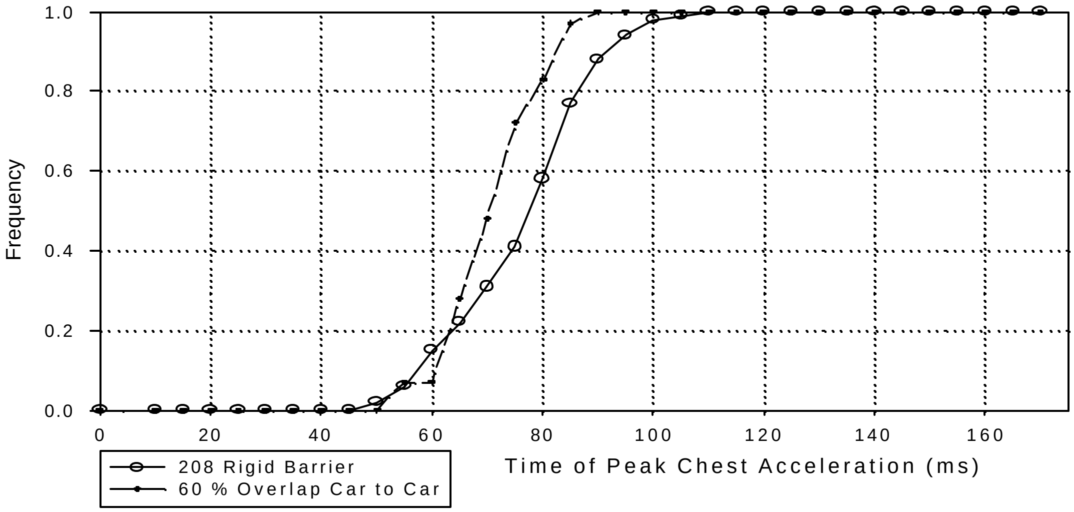


Figure 2-3. Cumulative Frequency Distribution of the Time for Peak Driver Chest Acceleration in the FMVSS No. 208 Rigid Barrier Tests and 60% Overlap Colinear Car to Car tests

The car-to-car and the car-to-narrow object testing are not among the potential test procedures that will be utilized. The following notes the rationale for these determinations. Using a specified production vehicle as an impactor, or bullet vehicle, has never been considered as a compliance test procedure by the agency. However, such an approach has been implemented in test procedures specified for the evaluation of highway safety features [2]. The agency has not included this as part of the test procedures that would be proposed in this rulemaking out of concern regarding the future availability of a current vehicle specified for use as an impactor precluded this approach from consideration as a candidate test procedure. Also, the large variety of equipment configurations (e.g., engine, transmission, air conditioning) available for a production vehicle would introduce unwieldy complexity in the test procedure. Finally, conducting a car-to-car crash test could raise repeatability issues.

A second type of test is vehicle-to-narrow objects, e.g., trees and poles. Collisions between vehicles and fixed narrow objects result in a significant number of fatalities. Car collisions with trees and poles account for approximately one-third of all fatalities in fixed object collisions. Offset barrier testing, addressed below, is a reasonable surrogate for car-to-narrow object tests. Car-to-narrow object crash testing has shown crash pulses which are quite similar to the European Union (EU) and the Insurance Institute for Highway Safety (IIHS) fixed deformable offset barrier tests.

Finally, the car-to-fixed barrier and the moving barrier-to-car crash tests are two test types that have been used extensively for compliance testing as well as for testing in the agency's research programs. Furthermore, the agency has experience in using these test types in which the front of the tested vehicle is fully engaged (i.e., full frontal test) or only a portion of the front of the tested vehicle is engaged (i.e., frontal offset test). Also, the agency has conducted these types of tests under conditions in which the line of travel of the tested vehicle is perpendicular to the fixed barrier or is in line, i.e., parallel, with the line of travel of the moving barrier (i.e., head-on). Additionally, the agency has conducted tests under conditions in which the tested vehicle's line of travel is at an angle to the perpendicular with the fixed barrier or to the line of travel of the moving barrier (i.e., oblique). Table 2-1 provides a summary of the type of testing the agency has conducted to represent these crash types. As can be seen from an examination of the relevant frontal crash test found in this table, the agency has experience in all test configurations with the exception of a moving rigid barrier in the frontal crash mode.

Table 2-1. Agency Experience with Vehicle Crash Test Types

	BARRIER							
TYPE	Fixed		Moving					
Direction	Frontal		Frontal		Side		Rear	
Stiffness	Rigid	Flexible	Rigid	Flexible	Rigid	Flexible	Rigid	Flexible
In-line	FMVSS 208 barrier	Simulations Only		Frontal Research Program	Side Research Program	EU, FMVSS 214	FMVSS 301	Fuel System Research Program
Oblique	FMVSS 208 barrier					Side Research Program		
Offset In-line	Frontal Research Program	EU, IIHS, Frontal Research Program		Frontal Research Program				Fuel System Research Program
Offset Oblique				Frontal Research Program				

2.3 Overview of Potential Candidate Test Procedures

The following section examines each of the viable candidate test procedures for evaluation of frontal crash protection. Following a brief summary, a review is presented of the status of each procedure, the agency's experience with each procedure, the experience of external organizations with each procedure, and the expected lead time that would be necessary to complete the research and implement each procedure.

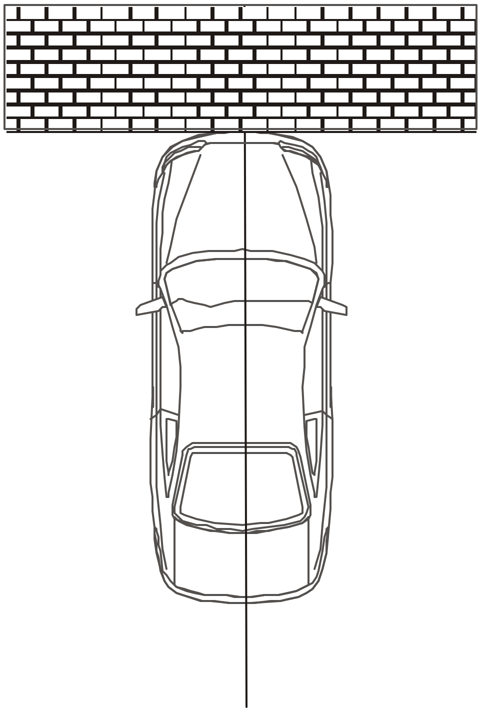


Figure 2-4. Full Frontal Fixed Barrier

2.3.1. Full Frontal Fixed Barrier

2.3.1.a Head-on Full Frontal Fixed Barrier

The Full Frontal Fixed Barrier Crash test (or Rigid Barrier test) represents a vehicle-to-vehicle full frontal engagement crash with each vehicle moving at the same impact velocity. A schematic of the test configuration is shown in Figure 2-4. The test is intended to represent most real world crashes (both vehicle-to-vehicle and vehicle-to-fixed object) with significant frontal engagement in a perpendicular impact direction. For FMVSS No. 208, the impact velocity is 0 to 48 kmph (0 to 30 mph), and the barrier rebound velocity, while varying somewhat from car to car, typically ranges up to 10 percent of the impact velocity for a change in velocity of up to 53 kmph. Note that although the rebound velocity varies somewhat from vehicle to vehicle, it is small compared to the impact speed, and the rigid barrier test therefore exposes the belted or unbelted occupant to approximately the same change in velocity (48 kmph plus the rebound velocity) for any vehicle. It is a full systems test which evaluates the protection provided by both the energy-absorbing vehicle structure and the occupant restraint system. Together with performance requirements, it ensures that the vehicle provides the same minimum level of protection in single vehicle crashes also regardless of the vehicles mass or size.

In the rigid barrier test, the vehicle changes velocity very quickly upon hitting the barrier. The crash produces a high deceleration crash pulse of short time duration – frequently referred to as a “stiff” pulse. Figure 2-5 shows a plot of the pulse duration against the average deceleration for rigid barrier tests of model years 1990 through 1998. (The average acceleration was determined by dividing the change in velocity of the vehicle during the test by the duration of the crash pulse.) The data are plotted for both the FMVSS No. 208 rigid barrier tests conducted at 48 kmph and for the New Car Assessment Program (NCAP) tests conducted at 56 kmph.. A reference curve based on theory is included, assuming a change velocity of the impact speed plus a 10 percent rebound velocity for each of the two data sets. Figure 2-5 also shows the required corridors for the generic sled test. A comparison of car-to-car tests in Figure 2-2 with the rigid barrier tests in Figure 2-5 demonstrate that rigid barrier tests produce crash pulses which are representative of car-to-car tests. Once again, we note that the generic sled pulse is representative of neither car-to-car tests nor rigid barrier tests. The agency has used the rigid barrier test for many years, and estimates that 4,758 lives have been saved by October 1, 1999, by air bag equipped vehicles designed to meet the FMVSS No. 208 [3]. Should the generic sled test become the sole requirement for frontal crash protection evaluation, the benefits will become significantly reduced.

In the rigid barrier tests conducted by NHTSA, only minimal intrusion has been measured in the testing vehicles of the U.S. fleet. Prior to the mandatory requirements of FMVSS No. 208 and of NCAP, in the late 1970s and early 1980s, extensive intrusion, particularly of the steering columns in light trucks, was a common occurrence. The kinetic energy of the crash ($\frac{1}{2} MV^2$) is dissipated by crush of vehicle and rebound velocity. To minimize the delta-V, structural designs attempt to minimize the residual rebound velocity away from the wall.   As noted above, the rebound velocity varies somewhat from vehicle to vehicle, and therefore the variation is small compared to the impact speed. Hence, approximately the same amount of kinetic energy per kilogram of vehicle mass will be dissipated for each tested vehicle when tested at the same speed.

The rigid barrier test is used in crashworthiness standards in the U.S., Canada, Japan, and Australia. The test is widely accepted as repeatable and reproducible [4]. In the U.S., until the recent adoption of the alternative sled test, the test (including the oblique test) was the only basis for the occupant protection standard FMVSS No. 208 (S.5.1) for unbelted and belted occupants. In Canada, Japan, and Australia, the test is used with belted occupants only. In addition, several other U.S. standards are also based upon the results of this test including FMVSS No. 204, Steering Control Rearward

Displacement (48 kmph only), FMVSS No. 212, Windshield Mounting (0 to 48 kmph), FMVSS No. 219, Windshield Zone Intrusion (0 to 48 kmph), and FMVSS No. 301, Fuel System Integrity (0 to 48 kpmh).

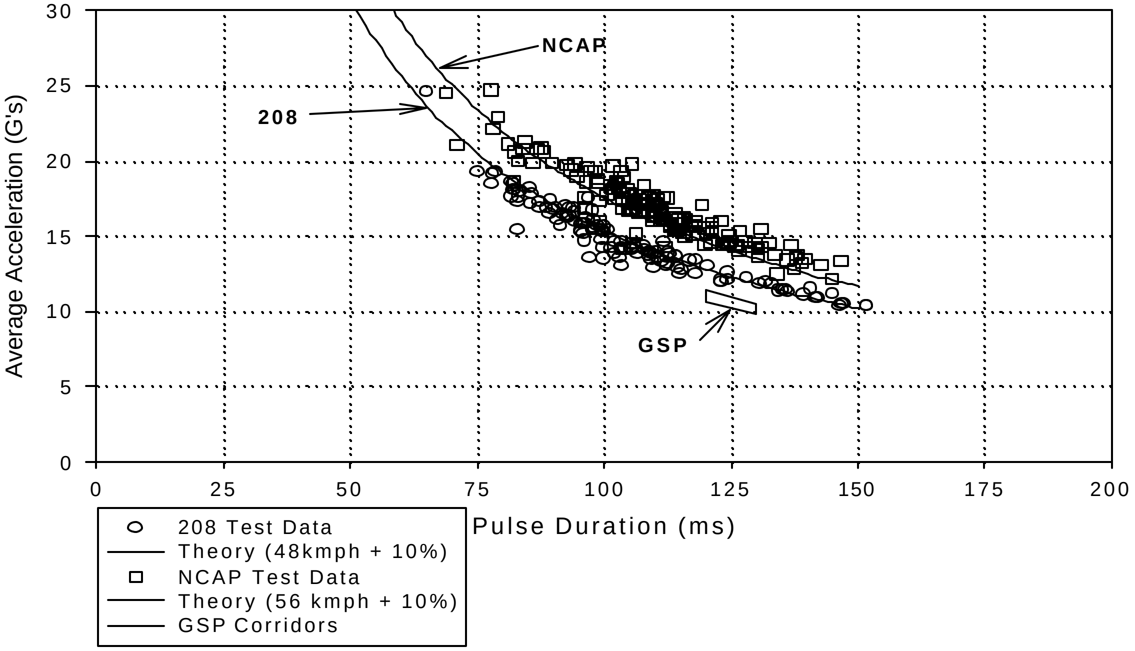


Figure 2-5. FMVSS 208 and NCAP rigid barrier test data for model years 1990-1998

The rigid barrier test is used in the New Car Assessment Programs (NCAP) of the U.S., Japan, and Australia. Unlike the FMVSS No. 208 rigid barrier test, the NCAP test is applied to belted occupants only at a speed of 56 kmph. Along with FMVSS No. 208 rigid barrier test, NCAP testing has led to designs with reduced intrusion and softer crash pulses for both cars and light trucks and vans (LTVs) [5]. Comparison of NCAP results with real world crash statistics, prior to the introduction of air bags, show that rigid barrier tests have resulted in improved occupant protection [6]. A report to Congress on the effectiveness of air bags confirmed that vehicle systems developed according to this test are effective in reducing injuries and fatalities in the U.S. crash environment [7].

<u>Performance of New Model Vehicles with Redesigned Air Bag Systems in Rigid Barrier Tests</u>: In 1997, the generic sled test was introduced as a temporary alternative to the rigid barrier test to allow automakers to rapidly install less aggressive air bags. To check the performance of these redesigned air bags in the new vehicle models, NHTSA has completed a series of FMVSS No. 208 rigid barrier tests in thirteen production vehicles with unbelted 50th percentile male dummies in the driver and right front

passenger seating positions. Additionally, three of the vehicle models were tested with unbelted 5th percentile female dummies in the driver and right front seating positions. The results of these tests are provided in Appendix A, Tables A-1 through A-4.

The test results for the 50th percentile male driver dummy are summarized in Table A-1. As reflected in this table, the driver dummy in the 1999 Honda Acura RL exceeded the maximum femur load requirement. This was the only injury assessment reference value (IARV) exceeded for the driver dummy in these tests. It should be noted that the injury measures for the chest displacement, head injury criterion, and neck injury criterion were below 90 percent of the IARVs for each of the thirteen tested vehicles, with most below the 80 percent level. However, in examining the results for the chest Gs, it is seen that two vehicles (i.e., the 1999 Dodge Intrepid and Honda Acura RL) were within the 90 to 100 percent IARV range.

The test results for the 50th percentile male passenger dummy are summarized in Table A-2. As reflected in this table, the passenger dummy in the 1998 Dodge Neon exceeded the IARV for the chest G. This was the only injury assessment reference value (IARV) exceeded for the passenger dummy in these tests. It should be noted that the injury measures for the chest displacement, head injury criterion, neck injury criterion, and femur load requirement were below 90 percent of the IARVs for each of the thirteen tested vehicles, again with most below the 80 percent level. However, in examining the results for the chest Gs, it is seen that one vehicles (i.e., the 1999 Dodge Intrepid) was within the 90 to 100 percent IARV range

The test results for the 5th percentile female driver dummy are summarized in Table A-3. As reflected in this table, three vehicles were tested--the 1999 Saturn SL, Dodge Intrepid, and Toyota Tacoma. The driver dummy injury measures in the Saturn were all below the 80 percent level of the IARVs. Whereas, the driver dummy in the Intrepid exceeded the IARVs for the chest displacement and the neck injury criteria. Furthermore, the chest G measurement was within the 90 to 100 percent IARV range. For the Tacoma, the chest displacement and the femur load measurements were in the 90 to 100 percent IARV range, while the chest G measurement was in the 80 to 90 percent IARV range. Note that each of the vehicles had head injury criterion measurements that were below the 80 percent level of the IARVs.

The test results for the 5th percentile female passenger dummy are summarized in Table A-4. As was the case with the driver dummy, the Saturn passenger dummy injury measures also were all below the 80 percent level of the IARVs. The passenger dummy in the Intrepid exceeded the IARVs for chest Gs. For the Tacoma, the passenger dummy exceeded the IARVs for the neck injury criterion. Note that each of the vehicles had chest displacement and head injury criterion measurements that were below the 80 percent level of the IARVs.

Status: NHTSA and the auto industry have extensive experience with this test procedure using the 50th percentile male dummy. The challenge will be in meeting the requirements for the 5th percentile female dummy. From the agency's limited test results, meeting these requirements is achievable in the time frame of this rulemaking. Lead time: No lead time required to resume implementation of this procedure.

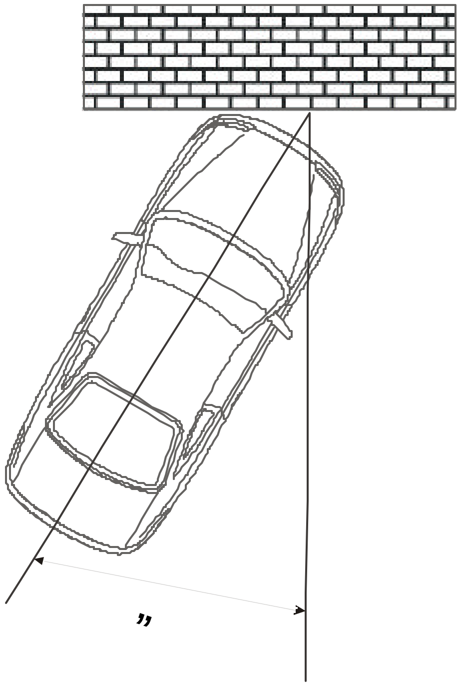


Figure 2-6 Oblique Frontal Fixed Barrier
(shown at 30º Impact Angle)

2.3.1.a Oblique Frontal Fixed Barrier

The frontal barrier crash test of FMVSS No. 208 requires a rigid barrier test of up to 48 kmph, at angles from the perpendicular to the line of travel of up to 30 degrees. A schematic of the test configuration is shown in Figure 2-6 Oblique Frontal Fixed Barrier tests result in a lower acceleration crash pulse of longer duration than the full frontal fixed barrier tests – frequently referred to as a soft crash pulse. Figure 2.7 plots the pulse duration against the average longitudinal acceleration for 30 degree rigid barrier tests. The test data has a longer duration and lower average acceleration than the 0 degree barrier test. The oblique frontal fixed barrier test is intended to represent most real world crashes with less frontal engagement-more oblique with change in velocity up to approximately 53 kmph (noting that the barrier rebound velocity is typically up to 10% of the impact velocity).

The angled barrier test exposes the belted or unbelted occupants to the same change in velocity (approximately 0 to 53 kmph) for any vehicle. Like the perpendicular barrier test, it is a full systems test which evaluates the protection provided by both the energy-absorbing vehicle structure and the occupant restraint system. It ensures that the restraint system provide the same level of protection in single vehicle crashes regardless of vehicle mass/size. Figure 2-7 demonstrates that the generic sled pulse roughly approximates the oblique frontal fixed barrier test at 30 degrees – a very benign test of vehicle restraint systems.

In contrast to the perpendicular rigid barrier test, the angled barrier test evaluates air bags/passive restraints to ensure occupant protection in other than longitudinal motions of the occupant. It also evaluates the protection offered by the air bag designs in preventing serious head contact with A-pillars, roof headers, and other components of the upper interior structure of the occupant compartment. Unlike the perpendicular test, the angled test provides some measure of the resistance of the occupant compartment to intrusion. The angled barrier test provides some ability to evaluate the degree of lower limb protection afforded by the compartment to localized intrusion.

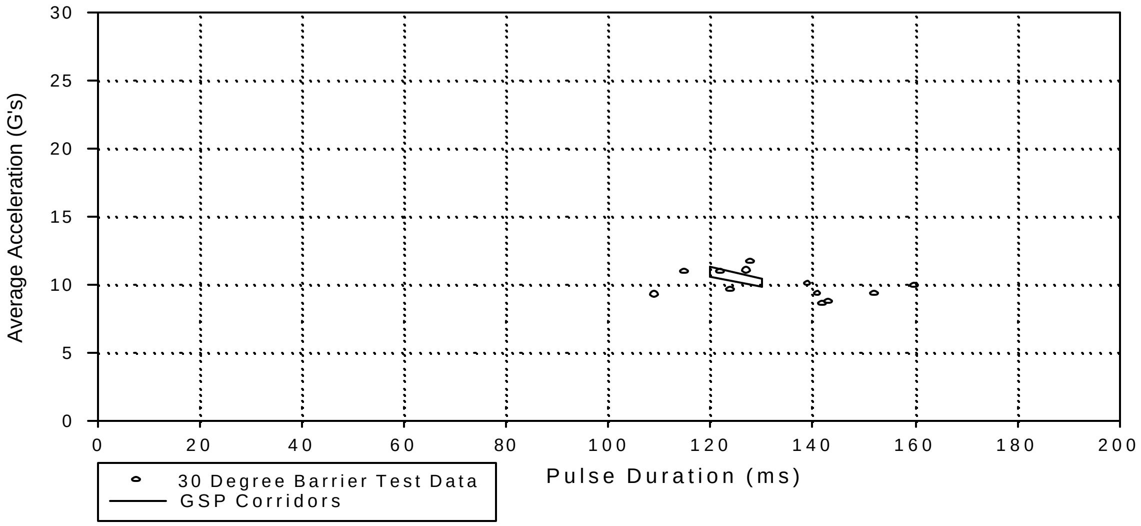


Figure 2-7 30 Degree Rigid Barrier Test Data

The kinetic energy of the crash (½ MV^2) is dissipated by crush of vehicle, residual final velocity, and vehicle rotation. To minimize the delta-V, structural designs attempt to minimize the residual rebound velocity away from the wall. Although the rebound velocity frequently varies somewhat from vehicle to vehicle, it is small compared to the impact speed. Hence, approximately the same amount of kinetic energy per kilogram of vehicle mass will be dissipated in the vehicle structure.

The angled barrier test is a component of crashworthiness standards in the U.S., Canada, Japan, and Australia. In the U.S., the test is a part of the occupant protection standard FMVSS No. 208 (Section

5.1) for unbelted and belted occupants. In Canada, Japan, and Australia, the test is used with belted occupants only. In addition, one other U.S. standard is based upon the results of this test--FMVSS No. 301, Fuel System Integrity.

Status: The auto industry has extensive experience with this test procedure. This procedure is available for use without additional research. However, only minimum testing with the angled barrier has been conducted at NHTSA (one test in recent years, a few early NCAP tests) – primarily because the soft pulse of the angled barrier test makes it a less severe test of the occupant restraint system. No lead time required to resume implementation of this procedure.

2.3.2. Sled Test for Unbelted Occupants

The generic sled test was intended as a temporary measure to allow rapid introduction of redesigned air bags. Unlike a full scale vehicle crash test, a sled test does not, and cannot, measure the actual protection an occupant will receive in a crash. The current sled test measures limited performance attributes of the air bag, but not the performance provided by the vehicle occupant crash protection system or even the full air bag system. Several inherent flaws prevent the generic sled test from being an adequate measure of frontal crash protection.

First, the sled test does not replicate the actual timing of air bag deployment. Deployment timing is a critical component of the safety afforded by an air bag. If the air bag deploys too late, the occupant may already have struck the interior of the vehicle before deployment begins. Air bag deployment timing is determined by parts of the air bag system which are not tested during a sled test, i.e., the crash sensors and computer algorithm. While this performance is tested in a barrier test, there is no crash involved in a sled test to trigger air bag deployment based on the performance of the crash sensors and computer algorithm. Instead, the air bag is simply deployed at a predetermined time during a sled test. The time is artificial – it may have nothing to do with the time when the air bag would deploy during an actual real world crash of the same vehicle

Second, the current generic sled pulse does not replicate the actual crash pulse of a vehicle. The actual crash pulse of a vehicle is a critical factor in occupant protection. The pulse takes into account the specific manner in which the front of the vehicle deforms during a crash, thereby absorbing energy. However, the current sled test uses an identical crash pulse to test all vehicles, which is somewhat typical of the crash pulse of a large passenger car. Light trucks and smaller cars typically have much "stiffer" crash pulses than that of the sled test. This means that deceleration occurs more quickly than is indicated by the sled test. Thus, the sled test result may falsely portray the occupant protection characteristics of a vehicle.

Third, a sled test does not measure protection and harm from actual vehicle systems, e.g., steering wheel intrusion into the driver, or pillar or toe-board intrusion and related injuries to the driver or a passenger that may result. Since a sled test does not involve any kind of crash, it does not test for such intrusions in crashes. Thus, the sled test may falsely indicate that a vehicle provides good protection based on dummy injury criteria when, in actuality as a result of steering wheel or other intrusion, the vehicle provides poor protection.

Fourth, the sled test does not measure how a vehicle performs in oblique crashes. It only tests a perpendicular impact. Real world frontal crashes occur at varying angles, resulting in occupants moving toward the steering wheel and instrument panel in a variety of trajectories. The angle test component of the barrier test requirement ensures that a vehicle is tested under these real world conditions.

Status: The generic sled pulse test is currently being used by NHTSA and the automakers. Lead time: No lead time required for continued use of this procedure.

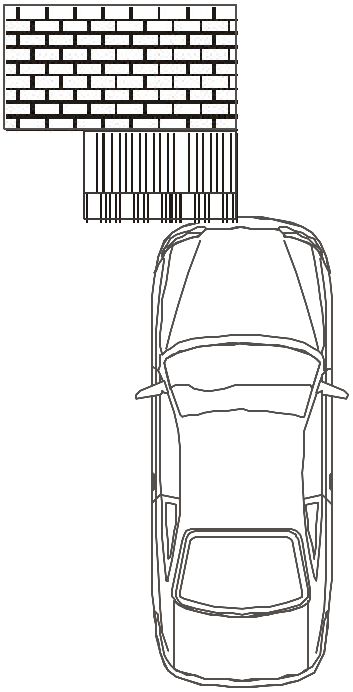


Figure 2-8 Frontal Offset Deformable Barrier

2.3.3. Frontal Fixed Offset Deformable Barrier

The Frontal Fixed Offset Deformable Barrier Test, often called the offset barrier test, subjects the vehicle/occupant restraint system to partial engagement of the front structure with a crushable barrier face. For all vehicles, this test exposes the belted or unbelted occupant to approximately the same change in velocity for any vehicle – regardless of vehicle mass/size. The offset barrier test produces a lower acceleration crash pulse of longer time duration than the full frontal fixed rigid barrier test –

frequently characterized as a "soft" pulse. It is a full systems test which evaluates the response of the energy-absorbing vehicle structure and the occupant restraint system to a low severity crash pulse. Figure 2-9 plots the pulse duration and average acceleration for 40 and 60 kmph offset deformable barrier tests. The average acceleration levels for the 40 kmph cases are lower than the 60 kmph cases, and roughly approximate the generic sled pulse in average amplitude. To obtain the same level of protection as the full frontal rigid barrier test, the offset barrier test must either be run at a higher speed, or coupled with the full frontal rigid barrier test.

The offset barrier test is intended to represent most real world crashes with less frontal engagement-in perpendicular impacts with change in velocity up to approximately 56-60 kmph based upon an impact speed of 56 kmph. This test frequently results in significant occupant compartment intrusion in current production vehicles. The test is intended to evaluate air bags/passive restraints to assure occupant protection in more than just the longitudinal direction. It requires that vehicle designs prevent serious head contact with A-pillars, roof headers, and other components of the upper interior structure of the occupant compartment. The test provides the capability to evaluate upper and lower leg protection due to localized intrusion. In Europe, it is the only proposed test for evaluating frontal occupant protection.

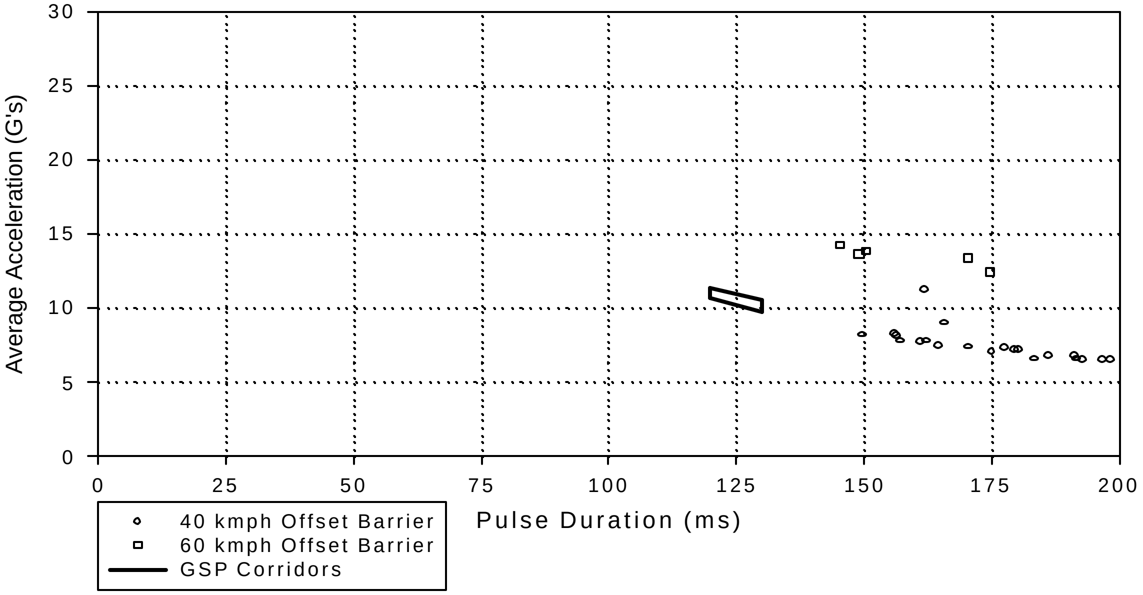


Figure 2-9. Frontal 40 % offset deformable barrier test data

The kinetic energy of the crash is dissipated by crush of vehicle, crush of the deformable barrier, any residual rebound velocity, and vehicle rotation. The kinetic energy of a crash is equal to ½MV^2 where M is the mass of the vehicle and V is the impact velocity of the vehicle. To minimize the delta-V, structural designs attempt to minimize the residual rebound velocity away from the wall. Because the deformable barrier bottoms-out in all tests which NHTSA has analyzed, the barrier face absorbs a fixed quantity of the crash energy. Hence, the relative kinetic energy (KE) dissipated by a given vehicle will vary significantly.

$$\text{Percent KE Absorbed by the Vehicle} = (\tfrac{1}{2}\,MV^2 - \text{KE absorbed by the Barrier}) / (\tfrac{1}{2}\,MV^2) \times 100$$

The offset barrier test has been proposed for European Union Directive for belted occupants at a speed of 56 kmph. This test has potential as an alternative to the FMVSS No. 208 full barrier test for unbelted occupants. Adoption of this test for FMVSS No. 208 would establish harmonization with the EU, and would provide the ability to evaluate lower limb injuries more effectively than with the rigid perpendicular or rigid oblique barrier test. As part of a research program on air bag crash protection, Transport Canada has conducted a large series of 40 kmph (25 mph) 40 percent offset deformable barrier tests. The tests have used belted 5th percentile female and 50th percentile male dummies.

In September 1996, the U.S. Congress directed NHTSA to conduct a feasibility study toward establishing a FMVSS for frontal offset crash testing. Congress stated that these activities should reflect ongoing efforts to enhance international harmonization of safety standards. In response to this Congressional directive, NHTSA has recently completed a series of five (5) offset barrier crash tests. In these tests, the vehicle was impacted at 60 kmph into a fixed deformable barrier that overlaps 40 percent of the front of the vehicle. The tests used belted 5th percentile female dummies and 50th percentile male dummies [8].

The offset barrier test is used in NCAP in Europe, Australia, and US (IIHS). These NCAP offset barrier tests use a higher speed - 64 kmph and are restricted to belted occupants only. The IIHS tests have demonstrated excessive intrusion in many current production vehicles. IIHS has shown that better performing vehicles, i.e., those with less intrusion, can and often do have softer crash pulses as measured in full barrier test indicating that such tests do not necessarily need to lead to more aggressive frontal structure designs [9]. Real world Australian study correlates results to improved occupant protection [10].

Status: At the time of the first publication of this study (i.e., September 1998), the use and assessment to date had been focused on belted occupants. Since that time, the agency has conducted research to evaluate the possible extension of this test procedure to unbelted occupants and an array of dummy sizes. While this research has provided limited test data, the results indicate the feasibility of meeting the performance requirements associated with such a test. The major challenge that would be faced by the automakers would be in the development of improved crash sensing that provide timely deployment of the air bag. However, the improved sensing for this crash condition has the potential of increased deployments in lower severity crash events. Lead time: It is now assumed that no additional lead time is required for implementation of this test procedure.

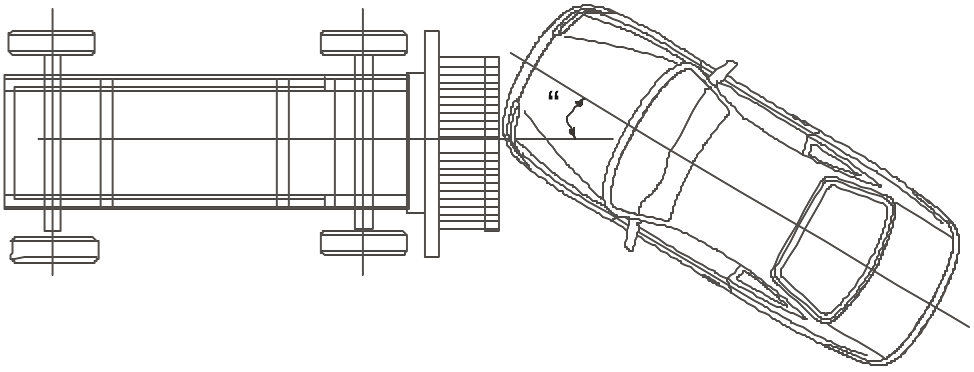


Figure 2-10. Oblique Moving Deformable Barrier (MDB) Test

2.3.4. Oblique Moving Deformable Barrier Test

The Oblique Moving Deformable (MDB) Test is intended to represent severe oblique real world crashes with significant frontal engagement and significant intrusion. The frontal-oblique MDB test produces a high deceleration crash pulse of short time duration – frequently referred to as a “stiff” pulse. Crash tests conducted by NHTSA indicate that this procedure produces significant intrusion in the smaller, lighter vehicles. This test is being investigated by NHTSA for improved frontal protection. NHTSA research projects that even after a full implementation of air bags throughout the U.S. fleet, over 10,000 fatalities will still occur each year in frontal crashes [1]. The Frontal Oblique test is designed to encourage implementation of crash protection beyond that necessary to meet current frontal test procedures. Results from this research program are currently focused on belted occupants.

The test is intended to simulate an oblique vehicle to vehicle crash with each vehicle moving at 50-60 kmph or with one vehicle moving at 100-120 kmph. The MDB could represent the average weight of a car in the fleet, but this is a decision that requires further consideration. The present deformable face is the same as used in FMVSS No. 214, Side Impact Protection. Lower weight vehicles would experience higher changes in velocity than heavy vehicles (i.e., small compact cars may see a change in velocity much greater than heavier sports utility vehicles). The delta V’s in these small cars are significantly higher than those obtained in an FMVSS No. 208 perpendicular rigid barrier test, but are representative of the delta V’s which a smaller vehicle would experience in real world crashes with heavier vehicles, e.g., light trucks and vans (LTVs). The test exposes occupants in the smaller vehicles to severe upper and lower body loads - both from crash pulse deceleration and intrusion. The level of protection required in single vehicle crashes would vary depending on vehicle mass.

The kinetic energy of the crash ($\frac{1}{2} M_1V^2 + \frac{1}{2} M_2V^2$ if both MDB and vehicle or moving at velocity V and $\frac{1}{2} M_1V^2$ if only the MDB is moving) is dissipated by crush of vehicle, crush of MDB, rebound, vehicle(s) rotation, and vehicle(s) residual velocity. Because the deformable barrier absorbs an essentially fixed share of the crash energy, the relative kinetic energy dissipated by a given vehicle will vary significantly.

Percent KE Absorbed by the Vehicle = (½ MV^2 - KE absorbed by the MDB) / (½ MV^2) x 100

<u>Status</u>: Experience with this test is limited. The repeatability and reproducibility of this procedure are being addressed in RD programs. The assessment to date has been focused on belted occupants. Any extension to unbelted occupants and to an array of dummy sizes will require additional study. Lead time: Completion of research using this test is estimated to require 2-3 years.

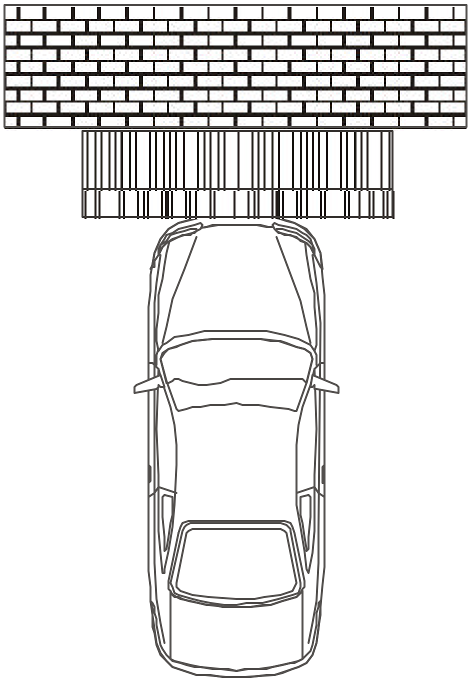


Figure 2-11. Full Frontal Fixed Deformable-face Barrier (FFFDB)

2.3.5. Full Frontal Fixed Deformable-face Barrier (FFFDB)

The Full Frontal Fixed Deformable-face Barrier (FFFDB) test extends the concept of the deformable offset barrier test to full engagement of the vehicle structure. In this test, a vehicle is crashed into a rigid barrier equipped with a deformable face. The front structure of the vehicle is fully engaged. This test exposes the belted or unbelted occupant to approximately the same change in velocity of 0 to 53 kmph (noting that the rebound velocity varies from vehicle to vehicle, but is typically 10% of the impact velocity). It is a full systems test which evaluates the protection provided by both the energy-absorbing vehicle structure and the occupant restraint system. Depending on the design of the deformable face, the test can be designed to require approximately the same level of protection in single vehicle crashes regardless of vehicle mass/size.

The FFFDB test produces a lower deceleration crash pulse of longer time duration – commonly referred to as a "soft" pulse. As the more severe rigid barrier test at 48 kmph produces no intrusion, likewise, the less severe FFFDB test could be expected to also produce no intrusion in vehicles of the current U.S. fleet.

The kinetic energy of the crash (½ MV^2) is dissipated by crush of vehicle, crush of the deformable barrier, and any residual rebound velocity. The relative kinetic energy dissipated by a given vehicle is determined as shown below:

$$\text{Percent KE Absorbed by the Vehicle} = (½\, MV^2 - \text{KE absorbed by the Barrier}) / (½\, MV^2) \times 100$$

<u>Status</u>: This test procedure has not been run by the agency. No data are available to assess repeatability or reproducibility. The agency's experience with the offset deformable barrier would apply here. However, the exact characteristics of the full deformable barrier would need further study. Furthermore, an oblique version of this test would require development and evolution. Lead time: 1-2 years to complete research using this test procedure.

2.4. Summary

This section provides an examination of the candidate test procedures available for evaluation of frontal crash protection through crash testing. The discussion has provided the status of each procedure with respect to regulatory testing, NCAP testing, and research testing. Included have been both the agency's and external organizations' experience with each procedure, and the expected lead time necessary to complete research for each procedure in a revised FMVSS No. 208. From this review, it has been determined that the rigid barrier, the oblique rigid barrier, the frontal offset deformable barrier, and sled test procedures are available immediately. The full frontal fixed deformable-face barrier may take 1-2 years to complete research and the moving deformable barrier test may take 2-3 years.

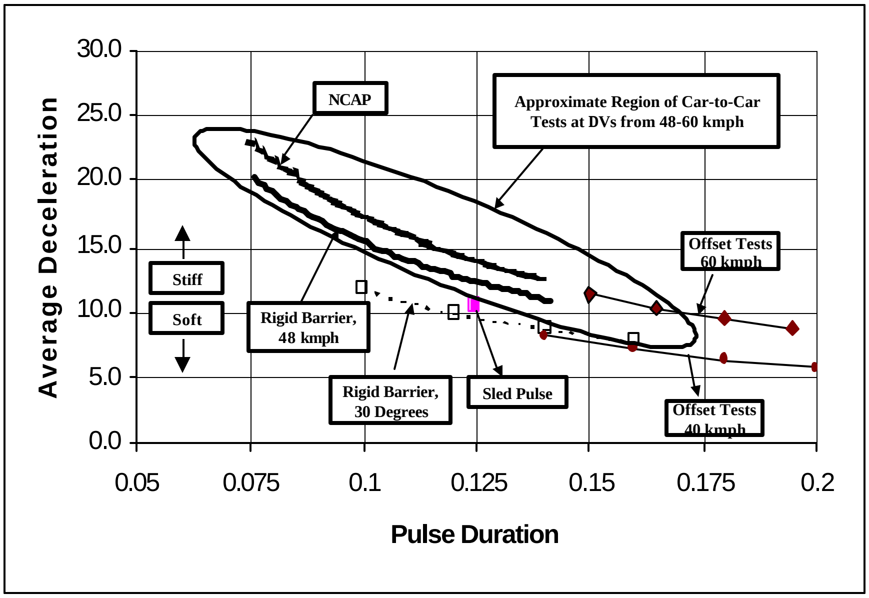


Figure 2.12 Comparison of Test Methods

As part of the analysis undertaken for this section, the vehicle crash response characteristics of the car-to-car tests were compared to those of the candidate test procedures. Figure 2.12 above provides a composite plot showing the characteristics from each of these test procedures along with the approximated region represented by car-to-car crash tests. Here it is seen that, while some of the car-to-car tests result in "soft" crash pulses, a majority of these tests are characterized by a "stiff" pulse. The circled area in Figure 2-12 shows the approximate region of the car-to-car crash tests with delta Vs between 48 and 60 kmph. In these delta-velocity ranges, the test procedure which is most representative of car-to-car tests is the full frontal rigid barrier test. The generic sled pulse is clearly not representative of these car-to-car crashes.

2.5. References

1. ____, "Preliminary Economic Assessment, FMVSS No. 208, Advanced Air Bags," National Highway Traffic Safety Administration, September 1998.

2. Ross, H. E., Sicking, D. L., Zimmer, R. A., and Michie, J. D., "Recommended Procedures for the Safety Performance Evaluation of Highway Features," NCHRP Report 350, Transportation Research Board, Washington, D.C., 1993.

3. ____, "Fourth Report to Congress: Effectiveness of Occupant Protection Systems and Their Use (Draft)" National Highway Traffic Safety Administration, June 1998.

4. Mackey, John M. and Gauthier, Charles L., "Results, Analysis, and Conclusions of NHTSA's 35 MPH Frontal Crash Test Repeatability Program," SAE Paper No. 840201, 1984.

5. Hackney, James R. and Kahane, Charles J., "The New Car Assessment Program: Five Star Rating System and Vehicle Safety Performance Characteristics," SAE Paper No. 950888, SAE International Congress and Exposition, Detroit, MI, 1995.

6. Kahane, Charles J., Hackney, James R., and Berkowitz, Alan M., "Correlation of Vehicle Performance in the New Car Assessment Program with Fatality Risk in Actual Head-on Collisions," 14th International Technical Conference on the Enhanced Safety of Vehicles, Munich, Germany, May 1994.

7. ____, "Third Report to Congress: Effectiveness of Occupant Protection Systems and Their Use," National Highway Traffic Safety Administration, Report No. DOT HS 537, December 1996.

8. Park, B., Morgan, R. M., Hackney, J. R., Lee, J., Stucki, S. L., and Lowrie, J.C., "Frontal Offset Crash Test Study Using 50th Percentile Male and 5th Percentile Female Dummies", 16th International Technical Conference on the Enhanced Safety of Vehicles, Windsor, Canada, June 1998.

9. Meyerson, S., Zuby, D., and Lund, Adrian, "Repeatability of Frontal Offset Crash Tests," 15th International Technical Conference on the Enhanced Safety of Vehicles, Melbourne, Australia, May 1996.

10. Fildes, Brian, Deery, Hamish, Lenard, Jim, Kenny, David, Edwards-Coghill, Kate, and Jacobsen, Simon, "Effectiveness of Air Bags in Australia," 16th International Technical Conference on the Enhanced Safety of Vehicles, Windsor, Canada, June 1998.

CHAPTER 3. NASS ANALYSIS OF FRONTAL IMPACTS

3.1. Introduction

To assess the relationship between the various test procedures and real world crashes, a methodology for estimating the target population for each test type was developed. The procedure estimates the number of drivers exposed to crashes as well as the number exposed to MAIS$3 injuries, by various frontal test procedures, in a future fleet where all the vehicles are equipped with frontal air bags. The analysis was limited to drivers since NASS data on passengers with air bags is still quite limited. Hence, this analysis provides a means of ranking different tests based solely on the “target” crash populations addressed by the test.

Data from the 1988 through 1997 NASS-CDS files are used in these analyses [1]. For NASS years 1988 to 1997 there are about 3,770 air bag equipped vehicles involved in frontal crashes, of which 847 of the drivers had moderate and greater injuries (MAIS$2), 408 drivers had serious and greater injuries (MAIS$3), and 89 drivers had fatal injuries. Frontal impacts were defined as follows: non-rollover and principal direction of force (DOF1) = 11, 12, or 1 o’clock positions or DOF1 = 10 or 2 o’clock positions with the crash damage forward of the A-pillar.

NASS cases are assigned a weighting factor which is used to formulate a national estimate from the sampled data. These factors produce “weighted” estimates of 97,585 drivers in frontal crashes with moderate and greater injuries, 32,143 drivers in frontal crashes with serious and greater injuries, and 4,437 drivers in frontal crashes with fatal injuries. All calculations used in these analyses are based on the NASS-CDS weighted national estimates. The details of this methodology and resulting estimated annual target populations for each test are presented in Section 3.3.

Section 3.2 provides some background information on several analyses related to frontal crashes. Included in these analyses are 1) crash descriptions considering crash modes based solely on crash pulse and a combination of crash pulse and intrusion and 2) an analysis of deltaV for several intrusion levels and injury level. This section distinguishes frontal crashes by general impact type: full barrier and left and right offset without specifically identifying what the test will be to address these type of impacts.

See Section 5, of the report, for a discussion of the frontal crash pulse stiffness (soft and stiff) definitions used in this section.

3.2. General Findings on Frontal Crash Modes

This section provides background analyses, which presents to the reader data to put the later analysis in context. Type of crash mode analysis, i.e., crash pulse only or crash pulse combined with intrusion, an analysis of the size of the frontal crash exposure, and an analysis of deltaV's is presented.

3.2.1 Crash Description - Effect of Crash Pulse With and Without Intrusion

In a paper presented at the 16th International Technical Conference on the Enhanced Safety of Vehicles, Stucki, et. al., presented a method of grouping impact conditions [2]. Drivers in frontal crashes with air bags are grouped into different crash modes based on impact direction (collinear or oblique), degree of overlap, and object struck (other vehicle or fixed object). As noted in Section 2, two adverse results of a crash are occupant compartment deceleration severity and survival space degradation. For analytical purposes, assuming that the driver injury is a result of crash severity and that the crash pulse and impact intrusion define the severity, the impact conditions which may be represented by a full barrier, and left or right offset, or other impact modes are shown in Table 3-1. Table 3-1 presents the distribution of frontal crashes, serious injury crashes, and fatal crashes.

Table 3-1. Crash Description and Driver Exposure, Serious Injury and Fatality for Frontal Crash Modes Considering Crash Pulse and Intrusion (1988-1997 NASS-CDS)

Crash Mode	Crash Description (Pulse/Intrusion)	Percentage of		
		Frontals	MAIS $3 $Serious Injury	Fatalities
Full Barrier	1. All distributed damage, collinear impacts 2. Distributed damage, oblique, fixed object	22	34	14
Left Offset	1. All left offset 2. Distributed damage, oblique, vehicle-to-vehicle	34	36	53
Right Offset	1. All right offset 2. Distributed damage, oblique, vehicle-to-vehicle	35	23	18
Other	Other	9	7	15
Total	Total	100	100	100

Assuming that crash pulse alone is a sufficient indicator of crash severity; the resulting driver exposure, serious injury, and fatal injury distributions are shown in Table 3-2. If it is assumed that intrusion is not important then many of the offset impact crash pulses may be similar to the full barrier pulse. The role of intrusion and crash pulse will be evaluated later in the section.

Table 3-2. Crash Description and Driver Exposure, Serious Injury and Fatality for Frontal Crash Modes Considering Crash Pulse Only (1988-1997 NASS-CDS)

Crash Mode	Crash Description (Pulse Only)	Percentage of		
		Frontals	MAIS $ 3 $Serious Injury	Fatalities
Full Barrier	1. Collinear,. Overlap> 55% 2. Oblique, Overlap>33%	57	67	45
Left Offset	1. Left collinear, Overlap #55% 2. Oblique, Overlap #33%	12	17	27
Right Offset	1. Right collinear, Overlap #55% 2. Oblique, Overlap #33%	14	9	13
Other	Other	17	7	15
Total	Total	100	100	100

3.2.2 Injuries by Crash Mode

As described in reference 1, the annual number of injuries and fatalities to drivers in frontal impact modes can be estimated based on data from the Agency's Preliminary Economic Assessment on Advanced Air Bags [3]. These estimates for two different levels of injuries and fatalities are presented in Table 3-3.

Table 3-3, Estimated Annual Injuries and Fatalities by Crash Mode, Drivers in Frontal Crashes (1988-1997 NASS-CDS)

Crash Mode	MAIS >= 2	MAIS >= 3	Fatalities
Full Barrier	31,200	11,900	1,190
Left Offset	43,200	12,600	4,505
Right Offset	37,200	8,050	1,530
Other	8,400	2,450	1,275
Total	120,000	35,000	8,500

3.2.3 DeltaV Analysis of Frontal Crashes

Historically, FMVSS No. 208 test requirements included and are proposed to include impact speeds up to 48 kmph (30 mph), including crash modes which will address full barrier or offset impacts. The percentage of driver injuries and fatalities in frontal crashes up to and including a velocity change (deltaV) of 48 kmph and over 48 kmph for full barrier and left offset crash modes are shown in Table 3-4 for the crashes involving air bag equipped vehicles.

Table 3-4. Proportion of Injuries/Fatalities Below and Above DeltaV's of 48 kmph by Crash Mode, Frontal Impacts with Air Bag Equipped Vehicles (1988-1997 NASS-CDS)

Test Mode	Injury Level	#48 Kmph DeltaV	>48 Kmph DeltaV
Full Barrier	MAIS$2	79% (78 cases)	21% (46 cases)
	MAIS$3	75% (34 cases)	25% (32 cases)
	Fatalities	6% (2 cases)	94% (6 cases)
Left Offset	MAIS$2	88% (203 cases)	12% (36 cases)
	MAIS$3	85% (85 cases)	15% (24 cases)
	Fatalities	68% (17 cases)	32% (8 cases)

Figure 3-1 presents the cumulative percentage of drivers in frontal crashes by deltaV for categories of intrusion. For intrusions up to 15 centimeters essentially all incidents are below 48 kmph while for intrusions over 15 centimeters about 90 percent occurred below 48 kmph. Vehicle intrusion is assessed by using the highest magnitude of intrusion for a single compartment component.

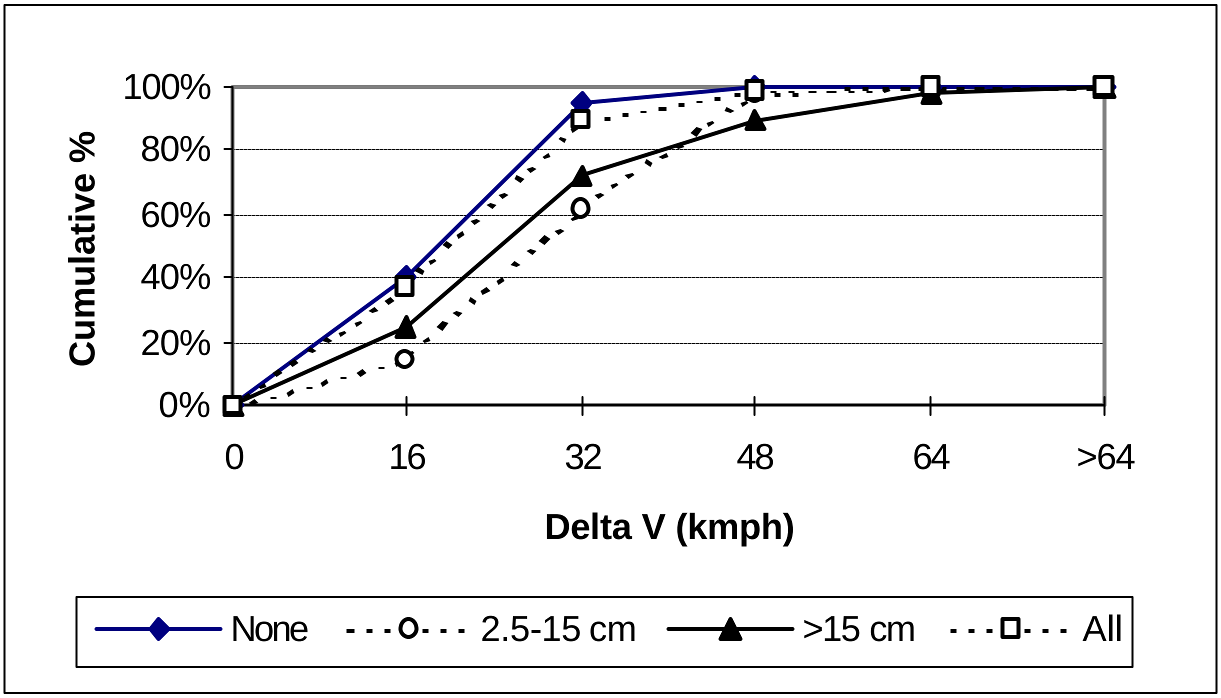


Figure 3-1. Cumulative Percent of All Drivers in Frontal Crashes by Delta V for Different Intrusion Amounts

For the limited number of crashes with air bag equipped vehicles available in the NASS CDS 1988-1997, almost 100 percent of drivers are involved in frontal crashes that have deltaV's below 48 kmph. About 80 percent of the drivers with serious injuries are in impacts with deltaV's below 48 kmph, see Figure 3-2.

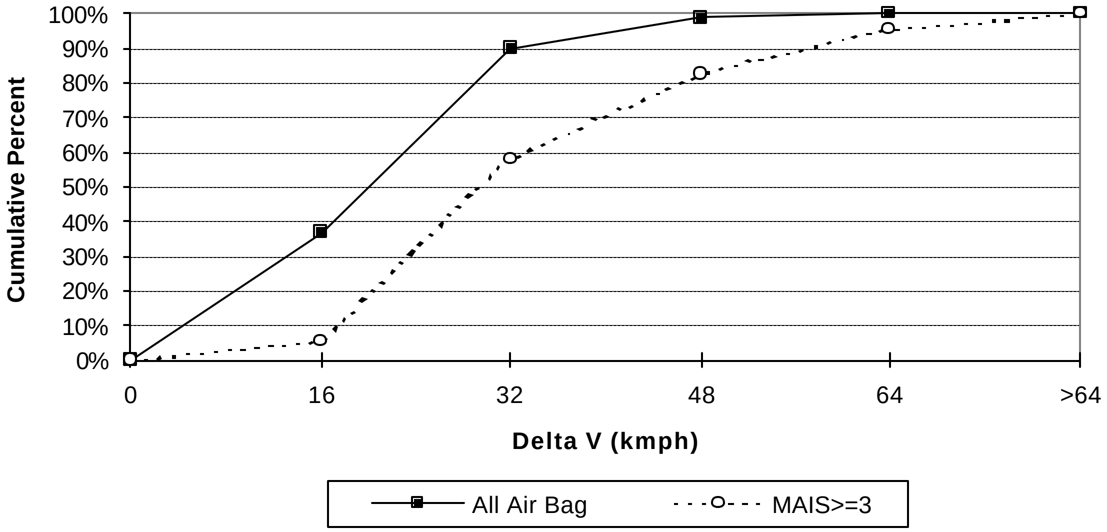


Figure 3-2. Cumulative Percent of Drivers with Air Bags in Frontal Crashes by Delta V for all Exposures and MAIS$3 Injury

3.3. Analysis of NASS Crash Data by Crash Mode, Pulse Type, and Intrusion to Predict Target Populations for Potential Tests

This section documents a procedure to estimate the number of drivers exposed to crashes as well as the number exposed to MAIS$3 injuries, by various frontal test procedures, in a future fleet where all the vehicles are equipped with frontal air bags. Further, it uses this procedure to predict the number of crashes related to each test procedure.

Frontal crashes with a deltaV of 48 kmph and less are segregated by impact mode (full barrier and left and right offset), by crash pulse (stiff or soft, as defined in Section 2), and by three levels of intrusion (none, up to 15 centimeters, and over 15 centimeters) into appropriate groups based on the test parameters of each potential test. Vehicle intrusion is assessed by using the highest magnitude of intrusion for a single compartment component.

The annual distribution of vehicle (or driver) involvement (exposure) by the crash parameters, described above, is assumed to be the same for a future air bag fleet as for the current fleet for all vehicles. The annual exposure for each specified impact type (barrier, left or right offset), intrusion amount and stiff or soft crash pulse is computed. The likelihood of drivers in vehicles with air bags receiving serious or greater injury (MAIS$3) in frontal collisions is also computed for these crash variables. The MAIS$3 injury likelihood for drivers with air bags for each specified combination of the crash variables is then applied to the corresponding exposure to estimate the number of seriously injured drivers for each specific crash condition. These injured drivers are then apportioned into the tabular cells of crash mode, pulse type, and intrusion amount. The candidate tests are defined by their crash mode, pulse type, and intrusion amount; and the appropriate cells in the exposure and MAIS$3 injury tables are apportioned to the specific test accordingly.

The analysis is separated by drivers with belts "as used", i.e., with no discrimination of belt use, and by drivers without belts, since the proposed test procedures are for unbelted occupants. However, as shown in the following Tables 3-5 and 3-6 the unweighted numbers of drivers with air bags and MAIS$3 injuries are infrequent. Although the driver MAIS$3 incidences within the table cells are probably not sufficient for valid conclusions, the proportions for each test procedure appear to be similar as for the "as used' observations. Because of the limited incidences in certain table cells for the unbelted driver population the remaining discussions and analysis will address the population of drivers with belts "as used."

Table 3-5 shows the intrusion distributions of all vehicles in frontal impacts for deltaV's of 48 kmph or less by type of impact and crash pulse (soft or stiff), from NASS-CDS years 1988 to 1997. By design of NASS, these data should approximately represent national estimates of vehicles, or drivers, in crashes with deltaV's of 48 kmph or less over a period of ten years (1988 through 1997.) However, since deltaV is unknown in about 50 percent of cases, overall, the data must also be adjusted for these missing values. The annual estimate of drivers in frontals with deltaV equal or less than 48 kmph shown in Table 3-5 is then the total estimate divided by the ten years of NASS and multiplied by a factor of two to adjust for cases of unknown deltaV. This analysis produces an annual estimate of 1,456,619 drivers (or vehicles) in frontal crashes with a deltaV of 48 kmph or less.

The number of drivers with serious or greater injuries (MAIS$3) in frontal crashes with deltaV's less than or equal to 48 kmph, and the number in each cell as a percent of all drivers for that cell (labeled "Risk%"), is shown in Table 3-6 by crash pulse type and intrusion amount.

Except for crash pulses with intrusions of 2.5 to 15 centimeters, drivers in crashes with "stiff " crash pulses have a slightly higher likelihood of MAIS$3 injuries than those with "soft" pulses. See Figure 3-3. The likelihood of a driver with an air bag receiving a MAIS$3 injury to the

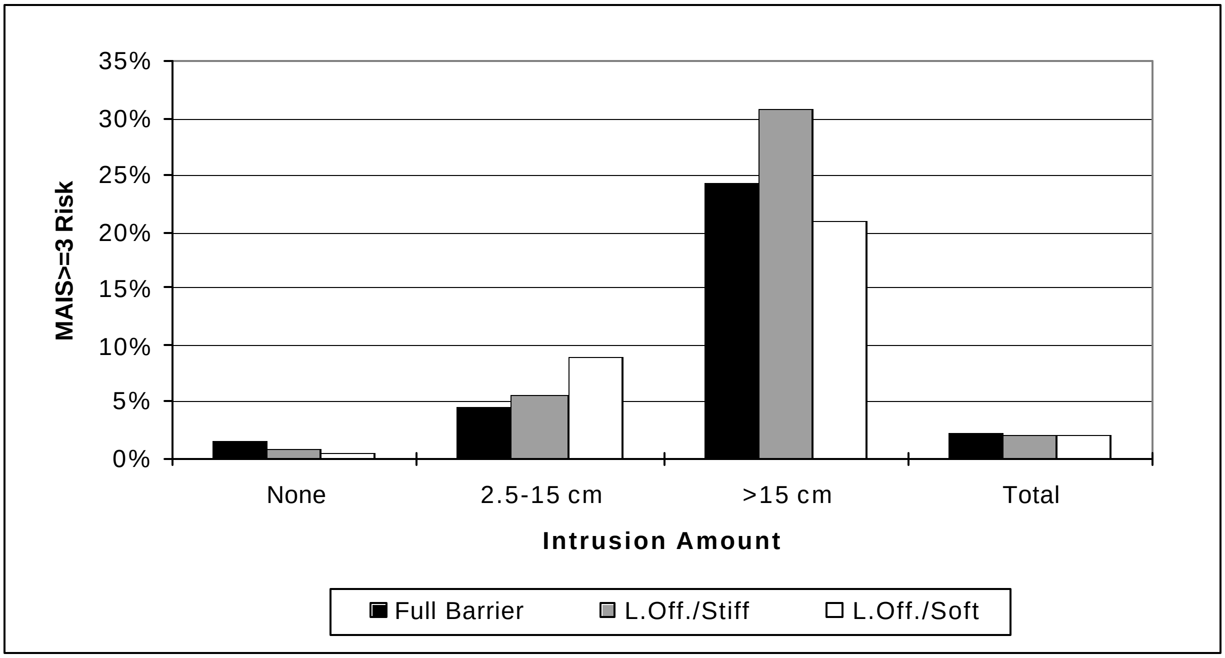


Figure 3-3. MAIS$3 Likelihood by Intrusion and Crash Pulse Type, Delta V#48 Kmph, Drivers with Air Bags in Frontal Crashes, 1988-1997 NASS

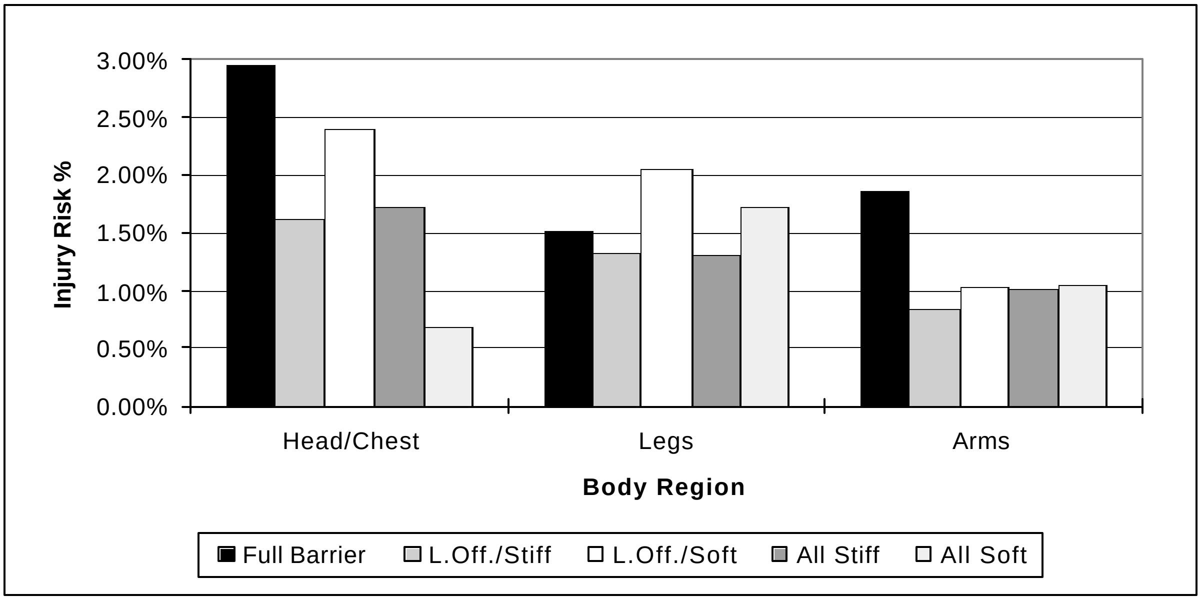


Figure 3-4. AIS$3 Likelihood by Crash Pulse Type, Body Region AIS=MAIS, Delta V#48 Kmph, Drivers with Air Bags in Frontal Crashes, 1988-1997 NASS

head/chest, leg and body regions is shown in Figure 3-4, for crash mode and crash pulse type (stiff or soft). The highest likelihood of MAIS$3 head or chest injuries, occur in full barrier impacts with stiff crash pulses. Serious leg injuries, not life-threatening, occur at a higher rate in offset crashes. Thus, the general finding is that stiff pulses produce more head and chest injuries while soft crashes produce more leg injuries.

The annual counts of all drivers and for drivers with MAIS$3 injuries are computed for the different crash pulses and intrusion magnitude. For exposure, the annual count is simply the percent of all frontals (% of Front) in each cell of Table 3-5 multiplied by the estimated annual number of drivers with air bags in frontal impacts (1,456,619) in the same table. The results are shown in Table 3-7. For example, for the full barrier with no intrusion and belts “as used”, the estimate is: 1,456,619 * 16.42% =239,154 drivers.

For annual estimates of drivers with serious to fatal injuries, the annual numbers of MAIS$3 injuries is estimated by taking the risk in each cell of Table 3-6 and applying it to the estimated annual number of exposed drivers in each cell of Table 3-5. The drivers with MAIS$3 injury in each cell is “Risk%" for the cell multiplied by the annual count for the corresponding cell. Again, these results are shown in Table 3-7.

The number of drivers in frontal crashes, both exposed and with MAIS$3 injuries, addressed by each of the test types can be estimated by selecting the appropriate cells in Table 3-7 which represent the crash pulse and intrusion. Designs which comply with the specific test and provide adequate protection at the conditions specified would also provide protection at lower severities, i.e., lower deltaV and less intrusion, but not at higher severities. For example, vehicles designed to meet the EU test, which is a soft crash pulse with intrusions over 15 centimeters, would also provide adequate protection for less than 15 centimeters intrusion but not for stiffer crash pulses. For each test type, the associated crash pulse type, intrusion amount, cells addressed in Table 3-7, and cells addressed if the offset test also includes right overlap, are shown in Table 3-8. The number of drivers in the cells specified for each of the tests are summed to give the estimate of the annual number of drivers, either exposed or MAIS$3 injuries, with air bags in frontal impacts. The results are shown below in Table 3-9.

Note that the annual counts include only left offset impacts (where appropriate) while the expanded count includes both right and left offset impacts as a percentage of all driver exposures and MAIS$3 injuries in frontal crashes. It also should be noted that the test procedures overlap, i.e., the full barrier oblique impact has a soft crash pulse similar to an offset pulse with over 15 centimeters intrusion, which is also included in the vehicle-to-MDB offset test. This procedure of defining the crash population which applies to each test based on the crash pulse type and the intrusion of the test creates the overlap of crash data.

Table 3-5. All Vehicles, 1988-1997 NASS Frontal Crashes, Delta V#48 Kmph

Intrusion	Row Header	Full Barrier	Left Offset		Right Offset		Other Offset	Total	
		Stiff	Stiff	Soft	Stiff	Soft	Soft	Stiff	Soft
Belts "As Used"									
None	Raw#	2720	2870	1317	2887	1452	1066	8477	3835
	Wt.#	1195768	1140863	729648	1150882	769905	549791	3487513	2049344
	% of Front	16.42%	15.66%	10.02%	15.80%	10.57%	7.55%	47.89%	28.14%
	Annual #	239154	228173	145930	230176	153981	109958	697503	409869
2.5 to 15 cm	Raw#	626	750	376	559	397	284	1935	1057
	Wt.#	124134	186995	90250	137230	176724	642113	448359	909087
	% of Front	1.70%	2.57%	1.24%	1.88%	2.43%	8.82%	6.16%	12.48%
	Annual #	24827	37399	18050	27446	35345	128423	89672	181817
>15 cm	Raw#	390	457	358	397	299	263	1244	920
	Wt.#	47287	55276	68028	99936	58798	59466	202499	186292
	% of Front	0.65%	0.76%	0.93%	1.37%	0.81%	0.82%	2.78%	2.56%
	Annual #	9457	11055	13606	19987	11760	11893	40500	37258
Total	Raw#	3736	4077	2051	3843	2148	1613	11656	5812
	Wt.#	1367189	1383134	887926	1388048	1005427	1251370	4138371	3144723
	% of Front	18.77%	18.99%	12.19%	19.06%	13.80%	17.18%	56.82%	43.18%
	Annual #	273438	276627	177585	277610	201085	250274	827674	628945
Total Frontal	Raw#	17468							
	Wt.#	7283094							
Estimated Annual Crashes Adjusted for Unknown Delta V (~50%): (7,283,094/10)*2 =									1456618.8
Belts Not Used									
None	Raw#	1100	948	429	1060	524	257	3108	1210
	Wt.#	405188	286335	206811	334899	185086	117283	1026422	509180
	% of Front	19.86%	14.03%	10.14%	16.41%	9.07%	5.75%	50.30%	24.95%
	Annual #	81038	57267	41362	66980	37017	23457	205284	101836
2.5 to 15 cm	Raw#	358	332	162	268	201	94	958	457
	Wt.#	52639	70918	32295	52535	84010	24342	176092	140647
	% of Front	2.58%	3.48%	1.58%	2.57%	4.12%	1.19%	8.63%	6.89%
	Annual #	10528	14184	6459	10507	16802	4868	35218	28129
>15 cm	Raw#	238	219	182	234	170	119	691	471
	Wt.#	29367	24493	39041	40121	22960	32218	93981	94219
	% of Front	1.44%	1.20%	1.91%	1.97%	1.13%	1.58%	4.61%	4.62%
	Annual #	5873	4899	7808	8024	4592	6444	18796	18844
Total	Raw#	1696	1499	773	1562	895	470	4757	2138
	Wt.#	487194	381746	278147	427555	292056	173843	1296495	744046
	% of Front	23.88%	18.71%	13.63%	20.95%	14.31%	8.52%	63.54%	36.46%
	Annual #	97439	76349	55629	85511	58411	34769	259299	148809
Total Frontal	Raw#	6895							
	Wt.#	2040541							
Estimated Annual Crashes Adjusted for Unknown Delta V (~50%): (2040541/10)*2 = 408,108									408108

Table 3-6. Drivers with Air Bags, MAIS$3, 1988-1997 NASS Frontal Crashes, Delta V# 48 Kmph

Intrusion	Row Header	Full Barrier	Left Offset		Right Offset		Other Offset	Total	
		Stiff	Stiff	Soft	Stiff	Soft	Soft	Stiff	Soft
Belts "As Used"									
None	MAIS>=3 Raw#	10	12	7	21	8	6	43	21
	MAIS>=3 Wt.#	2475	1436	507	1683	547	313	5594	1367
	Drivers Raw#	287	381	169	405	224	167	1073	560
	Drivers Wt.#	151228	154999	100331	155781	127837	72456	462008	300624
	Risk%	1.64%	0.93%	0.51%	1.08%	0.43%	0.43%	1.21%	0.45%
2.5 to 15 cm	MAIS>=3 Raw#	12	14	10	9	3	3	35	16
	MAIS>=3 Wt.#	989	818	850	674	83	478	2481	1411
	Drivers Raw#	61	103	50	64	48	39	228	137
	Drivers Wt.#	21535	14473	9384	19049	21162	11020	55057	41566
	Risk%	4.59%	5.65%	9.06%	3.54%	0.39%	4.34%	4.51%	3.39%
>15 cm	MAIS>=3 Raw#	12	25	17	8	10	13	45	40
	MAIS>=3 Wt.#	749	1400	1096	390	746	704	2539	2546
	Drivers Raw#	29	67	43	41	26	43	137	112
	Drivers Wt.#	3092	4568	5252	22420	3061	8396	30080	16709
	Risk%	24.22%	30.65%	20.87%	1.74%	24.37%	8.38%	8.44%	15.24%
Total	MAIS>=3 Raw#	34	51	34	38	21	22	123	77
	MAIS>=3 Wt.#	4213	3654	2453	2747	1376	1495	10614	5324
	Drivers Raw#	377	551	262	510	298	249	1438	809
	Drivers Wt.#	175855	174040	114967	197250	152060	91872	547145	358899
	Risk%	2.40%	2.10%	2.13%	1.39%	0.90%	1.63%	1.94%	1.48%
Total MAIS>=3: 10614+5324									15938
Total Number of Drivers: 547145+358899									906044

Table 3-6 (Continued)

Intrusion	Row Header	Full Barrier	Left Offset		Right Offset		Other Offset	Total	
		Stiff	Stiff	Soft	Stiff	Soft	Soft	Stiff	Soft
Belts Not Used									
None	MAIS>=3 Raw#	5	1	1	8	6	0	14	7
	MAIS>=3 Wt.#	166	38	48	1192	258	0	1396	306
	Drivers Raw#	57	53	26	70	57	18	180	101
	Drivers Wt.#	18617	19359	14001	19187	16945	3759	57163	34705
	Risk%	0.89%	0.20%	0.34%	6.21%	1.52%	0.00%	2.44%	0.88%
2.5 to 15 cm	MAIS>=3 Raw#	3	6	4	4	3	2	13	9
	MAIS>=3 Wt.#	575	107	189	216	83	471	898	743
	Drivers Raw#	20	24	14	26	15	10	70	39
	Drivers Wt.#	2968	2774	1123	3674	3872	2882	9416	7877
	Risk%	19.37%	3.86%	16.83%	5.88%	2.14%	16.34%	9.54%	9.43%
>15 cm	MAIS>=3 Raw#	5	8	6	7	6	1	20	13
	MAIS>=3 Wt.#	509	538	547	371	634	350	1418	1531
	Drivers Raw#	11	25	13	16	11	8	52	32
	Drivers Wt.#	1210	1585	1275	2373	1133	4259	5168	6667
	Risk%	42.07%	33.94%	42.90%	15.63%	55.96%	8.22%	27.44%	22.96%
Total	MAIS>=3 Raw#	13	15	11	19	15	3	47	29
	MAIS>=3 Wt.#	1250	683	784	1779	975	821	3712	2580
	Drivers Raw#	88	102	53	112	83	36	302	172
	Drivers Wt.#	22795	23718	16399	25234	21950	10900	71747	49249
	Risk%	5.48%	2.88%	4.78%	7.05%	4.44%	7.53%	5.17%	5.24%
Total MAIS>=3: 3,712+2,580									6292
Total Number of Drivers : 71,747+49,249									120996

Table 3-7. Annual Estimates, Drivers with Air Bags, Exposed and MAIS$3, 1988 through 1997 NASS-CDS Frontal Crashes, Delta V<= 48 kmph

	Full Barrier	**Left Offset**		**Right Offset**		**Other Offset**	**Total**	
Intrusion	**Stiff**	**Stiff**	**Soft**	**Stiff**	**Soft**	**Soft**	**Stiff**	**Soft**
Belts "As Used"								
EXPOSED								
None	239154	228173	145930	230176	153981	109958	697503	409869
2.5 to 15 cm	24827	37399	18050	27446	35345	128423	89672	181817
>15 cm	9457	11055	13606	19987	11760	11893	40500	37258
Total	273438	276627	177585	277610	201085	250274	827674	628945
MAIS>=3								
None	3914	2114	737	2487	659	475	8515	1871
2.5 to 15 cm	1140	2114	1635	971	139	5570	4225	7344
>15 cm	2291	3388	2839	348	2866	997	6027	6702
Total	7345	7616	5212	3806	3663	7043	18767	15918

Table 3-8. Crash Conditions Simulated by Test Type

Test	Crash Pulse	Intrusion	Cell Location in Table 3-7	Expanded Test Cell Location in Table 3-7
Rigid Wall/ Full Frontal	Stiff	0 to 15 cm	Column - "Full Barrier" Rows - "None" & "2.5-15"	Same as Previous Column
Rigid Wall/ Full Frontal Oblique	Soft	> 15 cm	Column - "Left and Right Offset - Soft" Rows - "Total"[1]	Same as Previous Column
FFFDB/ Full Frontal	Soft	0 to 15cm	Column -"Left and Right Offset-Soft" Rows - "None" & "2.5-15"[1]	Same as Previous Column
Offset-Barrier EU Test	Soft	>15 cm"	Column - "Left Offset - Soft" Rows - "Total"	Column - "Left and Right Offset - Soft" Rows - "Total"
Vehicle-MDB Full Frontal	Stiff	0 to 15 cm	Column - "Full Barrier" Rows - "None" & "2.5-15"	Same as Previous Column
Vehicle-MDB Inline, Overlap > 55%	Stiff	>15 cm	Column - "Left Offset - Stiff" & "Left Offset - Soft" Rows - "Total"	Column - "Left and Right Offset - Stiff & Soft" Rows - "Total"
Vehicle-MDB Inline, Overlap # 55%	Soft	>15 cm	Column - "Left Offset - Soft" Rows - "Total"	Column - "Left and Right Offset - Soft" Rows - "Total"
Vehicle-MDB Oblique, Overlap > 33%	Stiff	>15 cm	Column - "Left Offset - Stiff" & "Left Offset - Soft" Rows - "Total"	Column - "Left and Right Offset - Stiff & Soft" Rows - "Total"
Vehicle-MDB Oblique, Overlap #33%	Soft	>15 cm	Column - "Left Offset - Soft" Rows - "Total"	Column - "Left and Right Offset - Soft" Rows - "Total"
Sled Test	Soft	NA	Column - "Left and Rt Offset - Soft" Rows - "None"[1]	Same as Previous Column

[1] These tests do not "fit" the cells from NASS specifically but represents the nearest fit.

Table 3-9. Drivers Exposed and Drivers with MAIS$3 Injuries by Test Conditions with Air Bags

Possible Tests #	Test Description	Specific Test Configuration	Crash Pulse	Intrusion	Annual Counts[1] (Table 3-7)			Annual Counts Expand[1] Test (Table 3-7)	
					Exposed Drivers	Drivers with MAIS$3	Predominant Body Regions Addressed[2]	Exposed Drivers	Drivers with MAIS$3
1	**FMVSS 208 AND Rigid Barrier Test**	**Rigid Wall/ Full Frontal**	Stiff	0 to 15cm	263,981	**5,054**	**Head, Chest**	263,981	**5,054**
		Rigid Wall/ Frontal Oblique	Soft	>15 cm	378,670	**8,875**	**Legs**	378,670	**8,875**
2	**FFFDB/ Full Frontal**	**FFFDB/ Full Frontal**	Soft	0 to 15cm	353,306	**3,170**	**Legs**	353,306	**3,170**
3	**Offset-Barrier EU Test**	**Offset-Barrier EU Test**	Soft	>15 cm	177,585	**5,212**	**Legs**	378,670	**8,875**
4	**Vehicle-MDB Full Frontal**	**Vehicle-MDB Full Frontal**	Stiff	0 to 15cm	263,981	**5,054**	**Head, Chest**	263,981	**5,054**
5	**Vehicle-MDB Offset - Stiff OR**	**Vehicle-MDB Inline, Overlap>55%**	Stiff	>15 cm	454,212	**12,828**	**Head, Chest, Legs**	932,907	**20,297**
	Vehicle-MDB Offset - Stiff	**Vehicle-MDB Oblique, Overlap>33%**	Stiff	> 15 cm	454,212	**12,828**	**Head, Chest, Legs**	932,907	**20,297**
6	**Vehicle-MDB Offset - Soft OR**	**Vehicle-MDB Inline, Overlap#55%**	Soft	> 15 cm	177,585	**5,212**	**Legs**	378,670	**8,875**
	Vehicle-MDB Offset - Soft	**Vehicle-MDB Oblique, Overlap#33%**	Soft	> 15 cm	177,585	**5,212**	**Legs**	378,670	**8,875**
7	**FMVSS 208 Sled Test**	**Sled Test**	Soft	NA	299,911	**1,396**		299,911	**1,396**

[1] Annual Counts includes left offset and full-overlap crashes; while Annual Counts Expanded includes right offset as well as the left offset and full-overlap crashes.

[2] Analysis of body region by crash mode and pulse type, shows "stiff" pulses result in higher rates of head/chest injury and offset resulted in more leg injuries

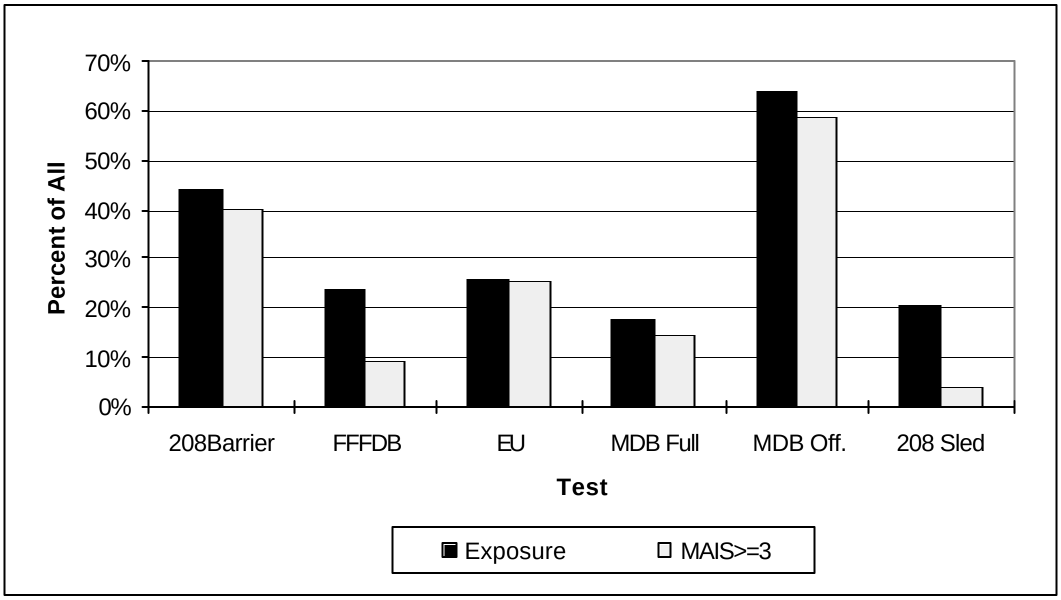


Figure 3-5. Estimated Driver Exposure and MAIS$3 Injuries for Selected Test Types as Percentage of all Frontal Occurrences

3.4. Summary

Some general conclusions are that drivers of vehicles equipped with air bags in stiff pulse frontal crashes have a higher frequency and risk of serious to fatal injuries than those in crashes with soft pulses. Stiff crash pulses produce more AIS$3, life-threatening, head/chest injuries; while offset crashes, with stiff and soft pulses, produce more leg injuries.

By grouping drivers into specific test conditions based on the crash severity, defined by the crash pulse and intrusion, an estimate of the target crash populations for each test can be predicted.

Figure 3-5 presents the exposure and serious-to-fatal injuries for drivers of vehicles with air bags for the various test types. A MDB-to-vehicle test, both left and right offset, would address the largest target population for both exposure and MAIS$3 injured drivers (about 64 percent of drivers in frontal crashes and about 58 percent of those with MAIS$3 injuries.) The full, fixed barrier test would address a lower target population (about 45 percent of drivers in frontal crashes and about 40 percent of those with MAIS$3 injuries). All other potential tests would address significantly lower target populations.

The MDB-to-vehicle test addresses head, chest, and leg injuries while the full barrier test addresses head and chest injuries, predominantly. Of the remaining tests, those which produce stiff pulses and low intrusion address mainly head and chest injuries, while those with soft pulses and substantial intrusion address mainly leg injuries.

3.5. References

1. National Automotive Sampling System - Crashworthiness Data System, 1988-1997), National Center for Statistics and Analysis, National Highway Traffic Safety Administration.

2. Stucki, Sheldon L., Hollowell, William T., and Fessahaie, Osvaldo, “Determination of Frontal Offset Test Conditions Based on Crash Data,” Sixteenth International Technical Conference on Enhanced Safety of Vehicles, Windsor, Canada, June, 1998.

3. “Preliminary Economic Assessment, FMVSS No. 208, Advanced Air Bags,” National Highway Traffic Safety Administration, September, 1998.

CHAPTER 4. CRASH COMPATIBILITY

4.1 Introduction

This report has addressed tests that assess the crashworthiness of a vehicle – the capability of a vehicle to protect its occupants in a collision. This is one aspect of crash compatibility. The other aspect of crash compatibility is aggressivity – the tendency of a vehicle to injure the occupants of the other vehicle in a vehicle-to-vehicle collision. This chapter examines the impact of each of the candidate test procedures on crash compatibility – particularly in frontal crashes. The specific objective is to determine whether the candidate test procedures would invariably result in a significant negative impact on safety that cannot be mitigated in a reasonable manner.

In general, lack of crash compatibility arises from three factors:

- Mass Incompatibility
- Stiffness Incompatibility
- Geometric Incompatibility

The first factor is an incompatibility in mass. The conservation of momentum in a collision places smaller vehicles at a fundamental disadvantage when the collision partner is a heavier vehicle. For an inelastic head-on collision, a vehicle which is half the mass of its collision partner will experience a change in velocity double that of its collision partner. Joksch has estimated that a vehicle of half the mass of its collision partner will experience a fatality risk 10 times greater than its heavier collision partner [1].

The second factor is an incompatibility in stiffness. In a frontal collision between two vehicles of the same mass but with a mismatch in stiffness, the bulk of the crash energy would be absorbed by the less stiff vehicle resulting in greater deformation of the less stiff vehicle. If the deformation of the less stiff vehicle is sufficiently large, occupant compartment intrusion may occur with an increase in injury potential to the vehicle’s occupants. From a compatibility perspective, the preferred scenario would be for both vehicles to share the crash energy rather than forcing one of the collision partners to absorb the bulk of the energy in the crash.

The third factor is geometric incompatibility such as might arise when a sports utility vehicle strikes a car. In a frontal impact, geometric incompatibility, e.g, a ride height mismatch, can lead to the misalignment of the structural load paths, and may prevent effective interaction of the two vehicle structures in a collision so that crash energy is absorbed by vehicle structures designed to absorb it. In a side impact, a mismatch in ride height can allow the vehicle with greater ground clearance to override the door sill of the lower vehicle, and contribute to the intrusion of a side-impacted vehicle.

The following discussion focuses on the influence each of the candidate test procedures will have on crash compatibility in frontal impacts. The effect of stiffness on crash compatibility is discussed for all candidate procedures. Note that the effects of mass incompatibility cannot be assessed for fixed barrier tests, as fixed barrier tests simulate a vehicle colliding with a vehicle of identical mass. In contrast, moveable barrier tests can and do measure the influence of mass mismatch to some extent – particularly when the vehicle being tested is lighter than the moveable barrier. Other than in misalignments between a deformable barrier face and a vehicle front structure, none of the candidate tests evaluate geometric compatibility.

Crash Tests vs. Stiffness Compatibility

Test procedures which produce a stiff crash pulse generally tend to encourage the design of softer front structures and /or more effective restraint systems. Procedures which result in extensive intrusion generally tend to encourage designers to strengthen the vehicle frontal structure, the structure surrounding the occupant compartment, or both.

Both design approaches may affect the extent to which the vehicle is compatible with its crash partners. Viewed from the perspective of a vehicle being hit by the subject vehicle, softening the frontal structure for crash pulse attenuation makes the subject vehicle less aggressive. On the other hand, if a manufacturer elected to reduce the potential for intrusion by stiffening the vehicle structure, such changes would tend to make the vehicle more aggressive.

However, as previously noted, the use of the full barrier test in FMVSS No. 208 has led to a vehicle fleet that includes vehicles that do not have aggressive structures and do not have high intrusion as measured in the tests. Also, in contrast to possible adverse design effects, the offset test results from IIHS indicate that the better performing vehicles relative to excessive intrusion are vehicles with less aggressive front structures.

4.2. Crash Compatibility of Vehicles Designed to FMVSS No. 208 Rigid Barrier Test

Under the FMVSS No. 208 rigid barrier test, vehicle crashworthiness is evaluated by conducting a frontal crash test into a rigid barrier at an impact speed up to 48 kmph (30 mph). The auto industry has criticized this full frontal rigid barrier test using unbelted dummies claiming that it requires overly aggressive air bag designs. Their claim is that in order to meet this FMVSS No. 208 requirement, particularly with light trucks and vans (LTVs), they are forced to stiffen their vehicle front structures, which they assert would make these vehicles more aggressive in vehicle-to-vehicle collisions. It has been suggested that replacing the rigid barrier test with a more benign test, e.g., the Full Frontal Fixed Deformable Barrier (FFFDB) test, would lead to softer LTVs that would do less damage to another vehicle in a crash.

If necessary to reduce crash deceleration severity of a rigid barrier test, the designer could modify the front structure of the vehicle and/or the occupant restraints in order to absorb crash energy, and cushion the load on the occupants. As shown in Figure 4-1 and tabulated in Table C-1, overall the automakers have exercised great design latitude in how the rigid barrier requirement is met. Drawing on NHTSA New Car Assessment Program crash test results, the linear stiffness of a selection of LTVs and cars was estimated using the following relationship:

$$k = (mv^2) / x^2$$

where m is the mass of the vehicle, v is the initial velocity of the vehicle, and x is the maximum dynamic crush of the vehicle. Because NCAP impact speeds are 5 mph higher than the FMVSS No. 208 barrier test, the NCAP tests encompass and provide an excellent estimate of the vehicle structural response which would be measured in the lower speed 208 test. Note that all of the vehicles on this chart have passed FMVSS No. 208 requirements. In general stiffness increases with weight, but for any given weight there is a wide range of average frontal stiffness values. For today's vehicles, excessive compartment intrusion is rarely observed by the agency in the full frontal rigid barrier compliance test. Therefore, FMVSS No. 208 rigid barrier test provides absolutely no incentive to stiffen the vehicle structure.

As shown in Figure 4-2 and tabulated in Table C-1, for a given vehicle weight, vehicles display a substantial variation in the amount of crush, or front-end crumple, designed into the front structure. In general, LTVs crumple much less than a passenger car of the same weight. The result is that LTVs are substantially stiffer, and less forgiving in a crash, than are passenger cars of the same weight.

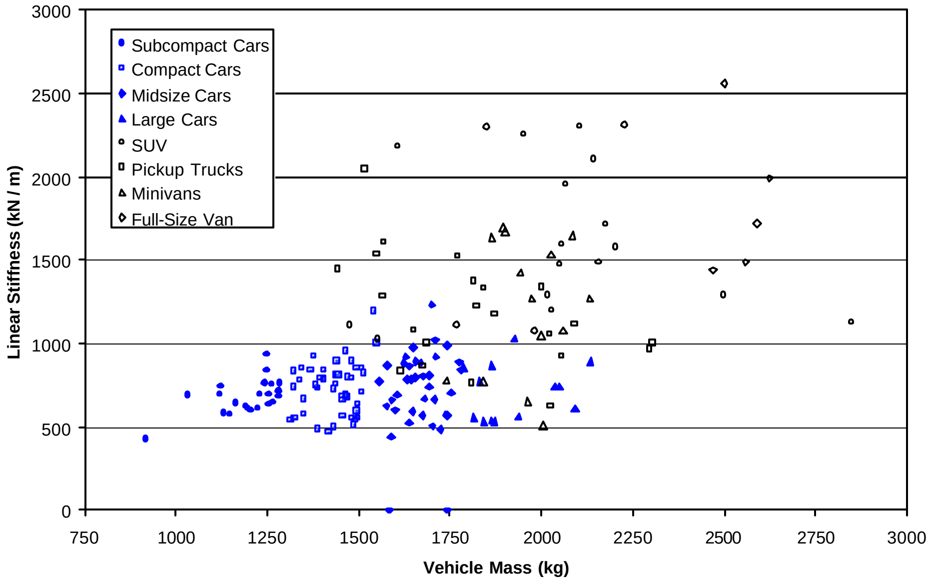


Figure 4-1. Relationship between Frontal Stiffness and Vehicle Mass as determined from NCAP Rigid Barrier Crash Tests.

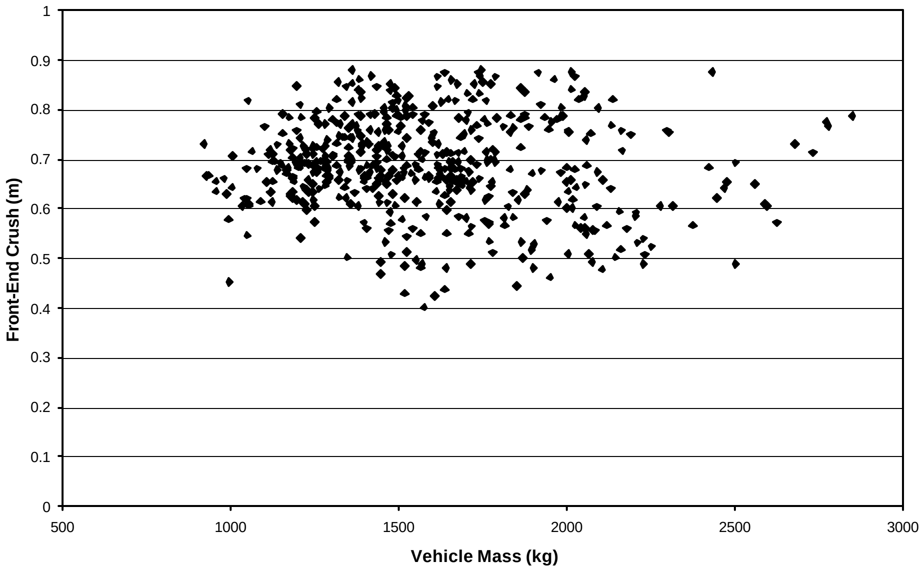


Figure 4-2. Relationship between Vehicle Mass and Front Structure Crush Distance (NCAP 1979-97)

Another concern that has been expressed is that the rigid barrier test forces LTVs to be stiffer in order to meet FMVSS No. 208. The claim is that since LTVs weigh more on average than passenger cars, and have more kinetic energy to be dissipated in a crash, LTV structures need to be made stiffer in order to absorb this extra energy.

To evaluate this claim, the frontal stiffness of a passenger car was compared with the stiffness of an LTV of equal mass. Figure 4-3 compares the frontal stiffness of a 1996 Ford Taurus with a 1995 Ford Ranger pickup truck. Both vehicles were certified to the FMVSS No. 208 barrier test, and both vehicles are of approximately the same mass (1750 kg). However, note that the Ranger is substantially stiffer than the Taurus. At 250 mm of crush, the Taurus exerts approximately 250N of force while the Ranger exerts approximately 720 kN – nearly three times higher than the Taurus. Accordingly, there is no merit to the claim that LTVs must be stiffer because of their mass. The Taurus and Ranger are of equal mass, yet the Ranger design is decidedly stiffer and thus more aggressive. LTVs <u>not</u> made stiffer because of the FMVSS 208 rigid barrier test. In fact, examination of NCAP results shows that LTVs with less aggressive structures perform better in the NCAP full frontal rigid barrier test [2].

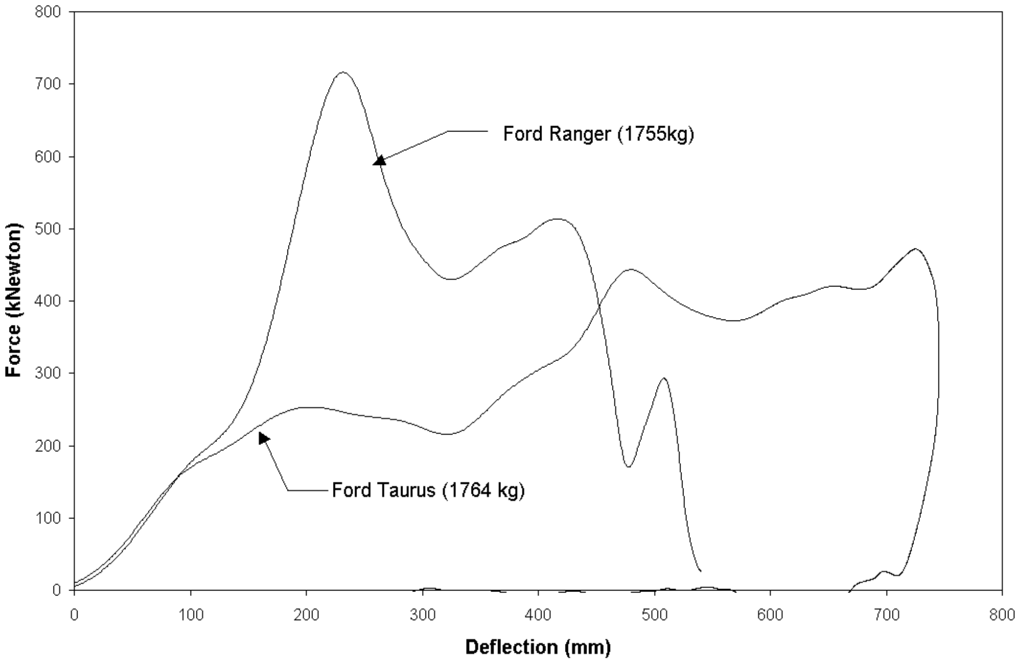


Figure 4-3. Frontal Stiffness:
Small Pickup (Ford Ranger, Test 2207)
vs. Midsize Car (Ford Taurus, Test 2312)

4.3. Potential Consequences of Test Procedure Options

This section examines the potential consequences, in terms of stiffening/softening of the front end, of the test procedure options discussed below and earlier in this report.

4.3.1 Effect of the Generic Sled Test on Compatibility

As discussed earlier, the perpendicular rigid wall test produces a stiff pulse without excessive intrusion. This test would encourage designs which soften the front structure or enhance restraints for high severity events. The sled test is based upon a soft pulse, and by its nature produces no intrusion. Vehicles which currently pass the rigid-barrier test can readily pass the generic sled test, and this test requires no design modifications.

4.3.2 Effect of the Frontal-Offset Test and Oblique Frontal Fixed Barrier on Compatibility

Unlike the full frontal barrier crash test, the Frontal-Offset test may produce large amounts of occupant compartment intrusion depending on a large number of factors, e.g., impact velocity. Although these tests generally indicate little risk to the occupant from head and chest injuries, the tests do suggest the potential for lower limb injury. To perform well in some of these offset tests, vehicle designers may choose to limit intrusion by stiffening the front structure of a vehicle. The concern is that in making their vehicle less prone to leg injuries, the automakers may be make their vehicles stiffer and more aggressive.

However, as previously noted, the use of the full barrier test in FMVSS No. 208 including oblique tests has not led to a vehicle fleet that is, in general, aggressive or that suffers substantial intrusion as measured in the tests. Also, in contrast to possible adverse design effects, the offset test results from IIHS indicate that the better performing vehicles relative to excessive intrusion are vehicles with less aggressive front structures.

4.3.3 Effect of the FFFDB test on Crash Compatibility

In the Full Frontal Fixed Deformable Barrier (FFFDB) test, the deformable barrier acts as a crash energy absorber. As there is a fixed total amount of crash energy, energy which is absorbed by the honeycomb barrier is energy that does not have to be absorbed by the vehicle. If the deformable barrier face stiffness is less than the stiffness of the tested vehicle, the result is that with a FFFDB-type test the vehicle structure does not need to be designed to absorb the entire energy load.

Because the deformable barrier absorbs crash energy and effectively ‘softens’ and extends the duration of the impact, the FFFDB test produces little incentive to soften the car or LTV structure. If the FFFDB test were chosen, vehicle designers could actually choose to stiffen the structure of a vehicle that passed the rigid barrier test of FMVSS No. 208, and be able to pass the FMVSS No. 208 dummy requirements in the FFFDB test.

4.3.4 Effect of the MDB test on Crash Compatibility

Unlike the barrier tests, the two MDB test options provide a test of mass compatibility as well as stiffness compatibility. In a collision between a heavier and lighter vehicle, the lighter vehicle undergoes the greater change of velocity and hence is subjected to a more severe crash event. Hence, in an MDB test, vehicles which are lighter than the MDB would need to be designed to protect the occupant in this more severe crash environment.

As the crushable front of the current MDB typically crushes fully or “bottoms out”, the MDB absorbs a fixed amount of crash energy. Vehicles near the mass of the MDB would therefore absorb more crash energy than they would absorb in a perpendicular rigid barrier test. Like the offset barrier test, which also exhibits the same bottoming-out effect, vehicle designers may choose to limit excessive intrusion by stiffening the front structure of a vehicle. However, in the case of the MDB test, any increase in stiffness to limit intrusion will be constrained by the requirement to limit crash pulse severity. Note also that although the current MDB face bottoms out in a crash, the MDB face could be made thicker to avoid bottoming out.

As LTVs are typically heavier than cars (and heavier than the current MDB mass of 3000 pounds), this test would have the effect of requiring smaller cars to have restraint systems and frontal structures capable of improved protection for the occupant in LTV-to-car collisions. Light trucks, on the other hand, would be subjected to a less severe event. However, as increasing vehicle weight, in an MDB test, decreases crash severity, both LTV and car designers would have an incentive to increase vehicle mass in order to improve test results.

The frontal-oblique MDB test produces both a severe crash pulse as well as significant intrusion. Mitigation of these two threats to the occupant would tend to lead to both softer frontal structures to reduce deceleration severity and strengthening of the structure surrounding the occupant compartment to reduce intrusion. Designing to meet both of these objectives will produce vehicles which produce enhanced crashworthiness and improved compatibility.

Table 4-1 summarizes the potential consequences, in terms of stiffening/softening of the front end, of the test procedure options discussed above and earlier in this report.

Table 4-1. Test Procedure:
Potential Consequences for Frontal Crash Protection and Effect on Stiffness Compatibility

Test Procedure	Impact Direction	Potential Consequences on Design
Rigid Wall/ Full frontal	Perpendicular	Soften Front and/or Improve Restraints
Rigid Wall/ Full frontal	Oblique	Stiffen front structure or structure surrounding occupant compartment
Full Frontal Fixed Deformable Barrier (FFFDB)	Perpendicular	None
Offset-Barrier: IIHS / EU Test	Perpendicular	Stiffen front structure or structure surrounding occupant compartment
Vehicle-MDB/ Full frontal	Perpendicular	1) Stiffen lighter vehicles 2) Neutral for heavy veh.
Vehicle-MDB/ Overlap # 55%	Perpendicular	Stiffen front structure
Vehicle-MDB/ Overlap > 55%	Perpendicular	1) Soften front structure. 2) Lighter cars must also strengthen compartment
Vehicle-MDB/ Overlap # 33%	Oblique	Stiffen front structure.
Vehicle-MDB/ Overlap > 33%	Oblique	1) Soften front structure. 2) Lighter cars must also strengthen compartment.
Generic Sled Test	Perpendicular	None

4.4. Summary

Currently, the FMVSS No. 208 perpendicular rigid barrier test acts as a constraint on over-stiffening of the front vehicle structure. The frontal-oblique MDB test, or a combination of the rigid full frontal barrier test and a frontal-offset test would lead to vehicles which limit intrusion while simultaneously limiting deceleration severity. However, less rigorous tests, e.g, the FFFDB or the sled test, would effectively waive or weaken the limit associated with the rigid barrier deceleration severity, and would facilitate the manufacture of a new generation of stiffer, more aggressive passenger vehicles.

4.5. References

1. Joksch, H., Massie, D., and Pichler, R., "Vehicle Aggressivity: Fleet Characterization Using Traffic Collision Data", DOT HS 808 679, February 1998.

2. Hackney, James R. and Kahane, Charles J. "The New Car Assessment Program: Five Star Rating System and Vehicle Safety Performance Characteristics", SAE Paper No. 950888, SAE International Congress and Exposition, Detroit, MI, 1995.

CHAPTER 5. EVALUATION OF TEST CONFIGURATIONS

A variety of test configurations have been investigated for evaluating a vehicle's crashworthiness. This section examines these test configurations and compares them in terms of deceleration and intrusion responses. The tests are categorized according to how well the test configurations resemble car-to-car or car-to-fixed object crashes. Vehicle test data are augmented with computer simulated tests to provide a complete analysis of the proposed test configurations. The test configurations are characterized according to the deceleration and intrusion responses in vehicle crash tests.

The deceleration responses were categorized as either "rigid barrier like" ("stiff") or "sled like" ("soft"). Crash pulses were identified that were similar to the rigid barrier deceleration/velocity crash responses. Additionally, the remaining crash pulses were characterized as similar to the deceleration/velocity pulse used for the generic sled pulse, GSP. The rigid barrier like pulses were labeled as stiff due to the high velocity an unrestrained occupant would experience relative to the interior of the vehicle. An unrestrained occupant in a barrier like test would experience high impact speeds with the interior surfaces and corresponding higher injury measures. The sled like pulses were labeled as soft due to the lower velocity an unrestrained occupant would experience relative to the interior of the vehicle and the corresponding lower injury measures. Figures 5-1 through 5-3 are provided to demonstrate this effect. In Figure 5-1, the vehicle deceleration responses are plotted for the generic sled pulse as well as for a rigid barrier test of a Dodge Neon. Here, it is seen that the sled pulse is longer in duration and lower in magnitude than that for the rigid barrier test. Figure 5-2 provides a plot of the vehicle velocity responses resulting from the crash pulses. Here, it is seen that the change in velocity in the rigid barrier test occurs much more rapidly than in the sled test. Finally, Figure 5-3 provides a plot of the velocity of the occupant relative to the interior of the vehicle. As seen in this plot, at 60 milliseconds (the time at which occupants generally engage a deploying air bag) the velocity of the occupant in the rigid barrier test is almost twice that of the sled test.

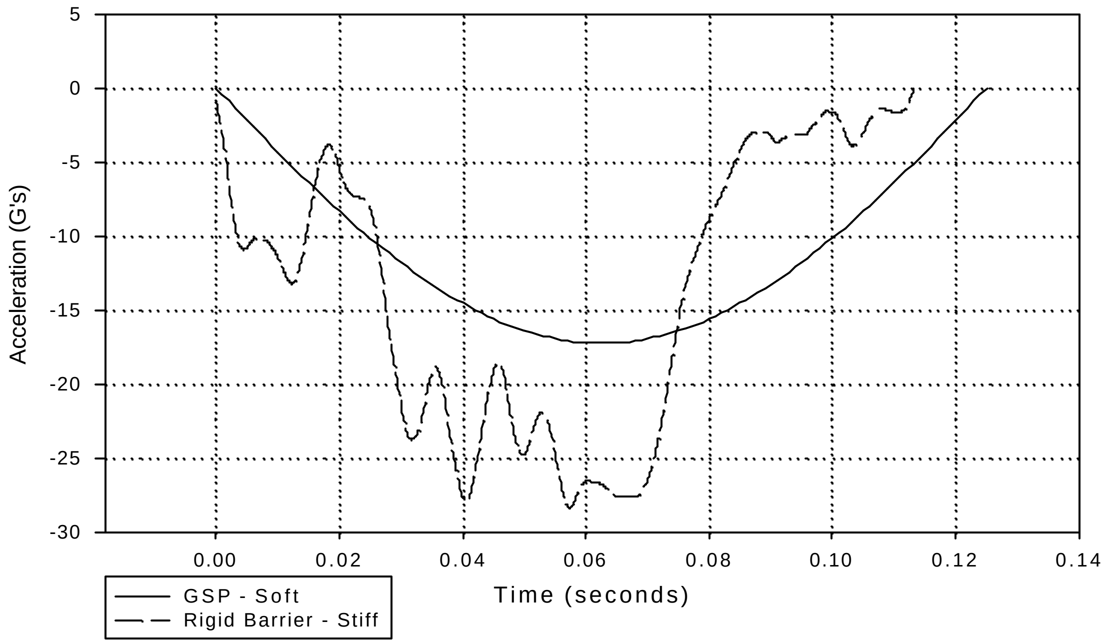


Figure 5-1: Typical Occupant Compartment Acceleration Profiles

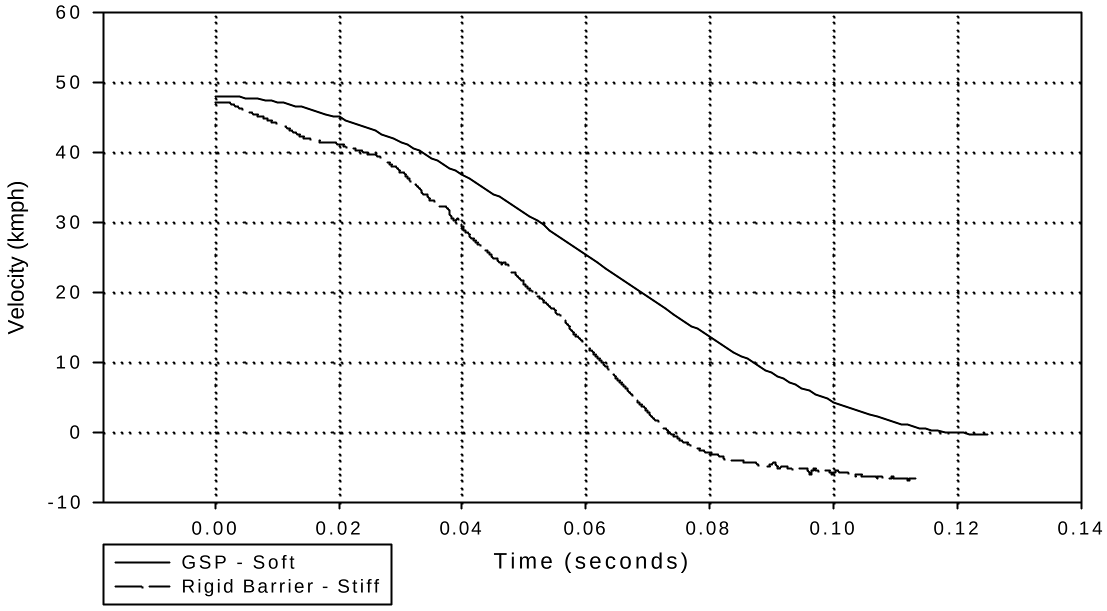


Figure 5-2: Typical Occupant Compartment Velocity Profiles

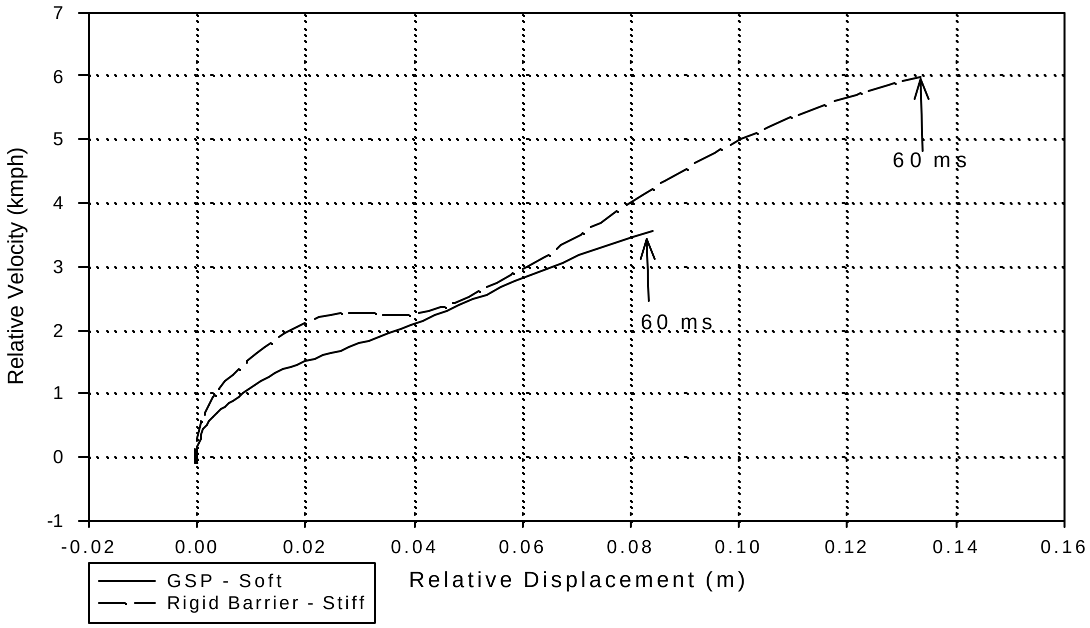


Figure 5-3: Typical Relative Displacement and Velocity for the Driver Chest

Two levels of intrusion were considered, those in the range of 0 to 15 cm and those above 15 cm. From an analysis of the National Automotive Sampling System data, these intrusion levels were found to have substantially different probabilities of serious injury. Intrusion data from full scale crash tests will be used and augmented with intrusion measurements from simulated test configurations. As a final comparison, the simulated test configurations are evaluated based on the energy absorbed by the vehicle structure during the crash event.

5.1 Crash Responses

Using the above characterizations, a variety of test conditions are evaluated in terms of the crash response, or the deceleration and velocity profiles experienced by the vehicle. This evaluation is focused on the effects of the rate of increase and magnitude of the crash loading on the vehicle structure. The evaluation uses vehicle tests, but will augment the test data with additional simulated test configurations.

5.1.1 Vehicle Test Data

As part of its research program to explore improved frontal crash protection, the agency has conducted a number of tests using the Honda Accord as the striking (or bullet) vehicle and the Chevrolet Corsica as the subject (or struck) vehicle. In this test series, collinear, moving car-to-car crash tests at partial overlaps of 50, 60, and 70 percent of the Corsica have been conducted. Also, a 30 degree oblique, car-to-car impact with 50 percent overlap on the Corsica has been conducted. The car-to-car tests were conducted with both cars moving at about 60 kmph. In addition to the test series, the agency also has conducted an NCAP test (i.e., a 56 kmph, full frontal, rigid barrier test) using the Corsica. The Corsica's longitudinal compartment deceleration crash pulses measured during the aforementioned tests are shown in Figure 5-4 and the corresponding velocity profiles are shown in Figure 5.5. The collinear 60 percent overlap and the oblique 50 percent overlap crash tests show almost identical velocity profiles to the full barrier up to about 60 milliseconds and deviate by about 10 to 15 percent beyond that time; however, the collinear, 50 percent crash test produces wider variations throughout the crash event and, generally, about twice the deviation from the full barrier test as the other offset tests. Based on these comparisons, the collinear impacts with overlaps ranging from somewhere between 50 and 60 percent (say 55 percent) to full overlap were classified as "full barrier-like" crashes.

Oblique car-to-car impact tests have been conducted only at nominally 50 percent overlap impact conditions. As discussed above, this test produced a somewhat similar velocity profile to the full barrier test and as shown in Figure 5-4 the oblique crash test produces a compartment deceleration crash pulse with similar magnitude and duration as the NCAP full barrier test, at similar impact speeds for the Corsica.

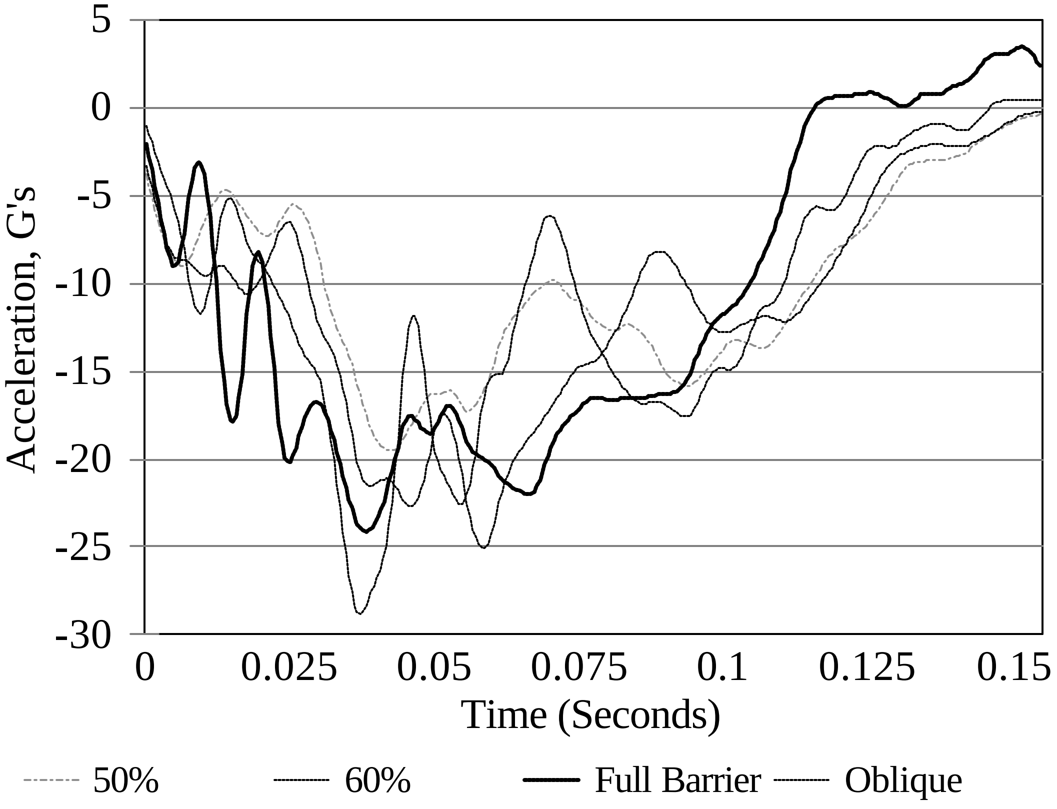


Figure 5-4: Longitudinal Crash pulses by Overlap for Chevrolet Corsica, Struck by Honda Accord, About 56 Kmph

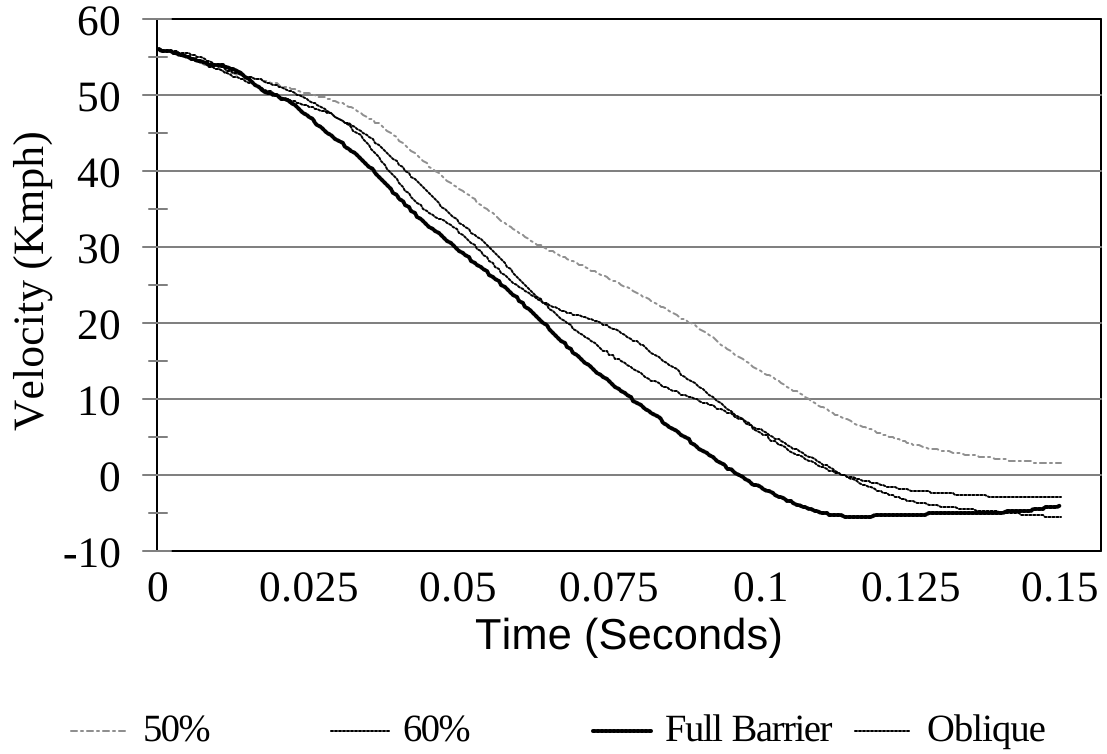


Figure 5-5: Velocity Profiles by Overlap for Chevrolet Corsica, Struck by Honda Accord, About 56 Kmph

In addition to the test series with the Corsica, another test series was conducted using the Ford Taurus. This test series included a Taurus-to-Taurus test and a Moving Deformable Barrier (MDB)-to-Taurus. Both of these tests were conducted at a 30 degree oblique impact with a nominal 50 percent overlap of the subject Taurus vehicle. For these tests, each vehicle had an initial speed around 56 kmph. Also, the agency has conducted an NCAP test of the Taurus. A comparison of the crash pulses from these tests is shown in Figures 5-6 and 5-7. Both of the oblique crash pulses are observed to be more severe than the NCAP crash pulse, based on peak deceleration. Comparison of the velocity profiles in Figure 5-7 shows corresponding velocity profiles up until about 80 msec and deviations from 15 to 20 percent afterwards.

From a review of the test results from the Taurus test series along with those from the Corsica test series, it has been determined that the oblique impact is more severe due in part to higher peak deceleration. The oblique test engages more of the vehicle structure simultaneously, wheel, frame rail, and engine. Thus, in the absence of additional tests with varying proportions of overlap, it is assumed that oblique frontal offset crash pulses at overlaps of one-third (**a**) and greater are similar to those in the full barrier tests. Although all of the partial overlap crash tests produce longer duration crash pulses on the Chevrolet Corsica (by 25 to 40 milliseconds), the pulse signature is similar throughout most of the event (up to about 100 milliseconds.) The oblique Taurus tests have a shorter duration crash pulse than the corresponding NCAP test, resulting in a higher deceleration and greater potential for injury.

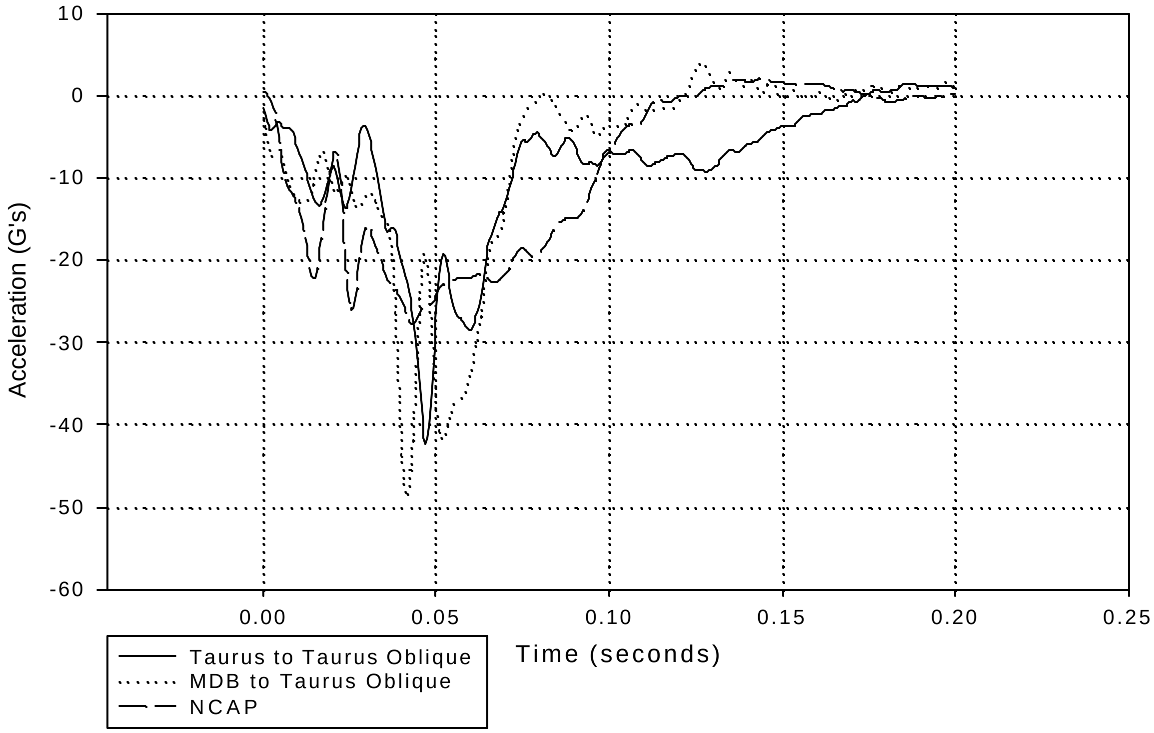


Figure 5-6: Ford Taurus 30 Degree, Oblique, 50 Percent Overlap Crash Pulses Compared to NCAP

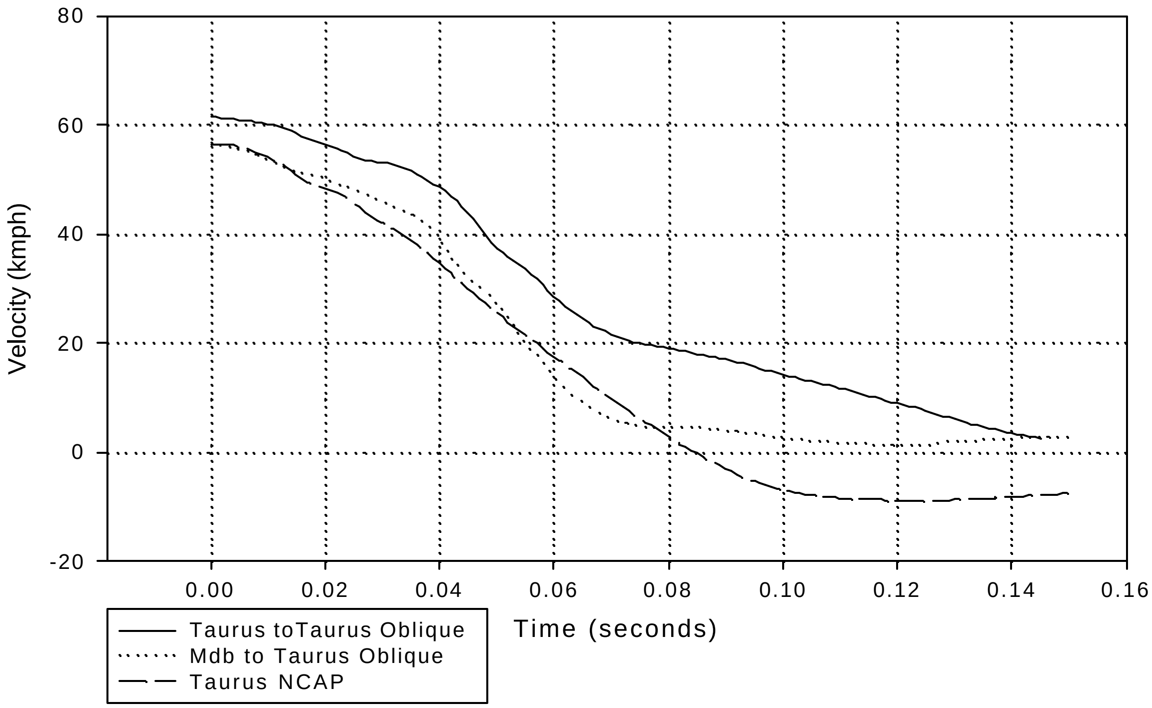


Figure 5-7: Ford Taurus 30 Degree, Oblique, 50 Percent Overlap Crash Pulses

Another test series was conducted by the agency to explore the potential for harmonizing with the frontal offset test procedure specified by the European Union. Two of the tests in this series involved the Dodge Neon and the Ford Taurus. Figures 5-8 and 5-9 compare the deceleration and the velocity pulses for two 1996 Dodge Neon and two 1996 Ford Taurus tests. Each vehicle was tested using both the NCAP test program, 56 kmph, 0 degree rigid wall, and by using the European Union offset test procedure at 60 kmph. The comparison of the crash pulses shows that, even though the offset tests were conducted at higher test speeds, the onset of the deceleration is much slower for the offset test procedure. The slow onset of deceleration leads to a lower occupant to interior contact velocities and a less severe environment for occupant restraint systems. Both test procedures produce approximately equivalent changes in velocities as shown in Figure 5-9.

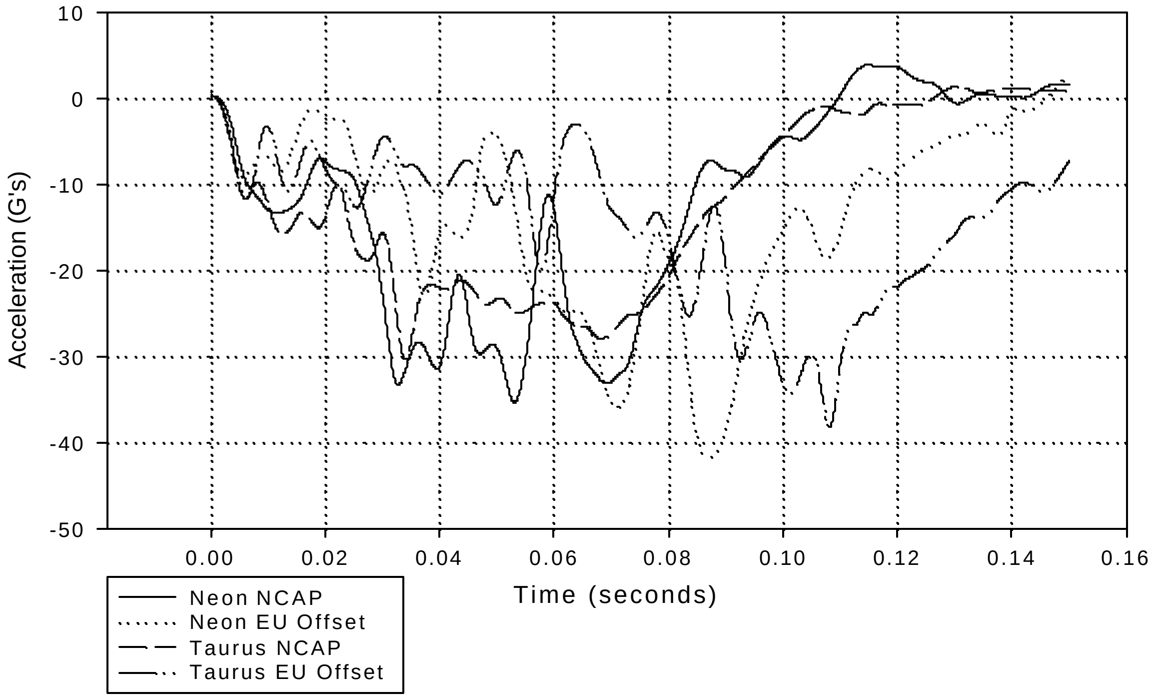


Figure 5-8: Comparison of NCAP and 60 kmph EU Offset crash pulses

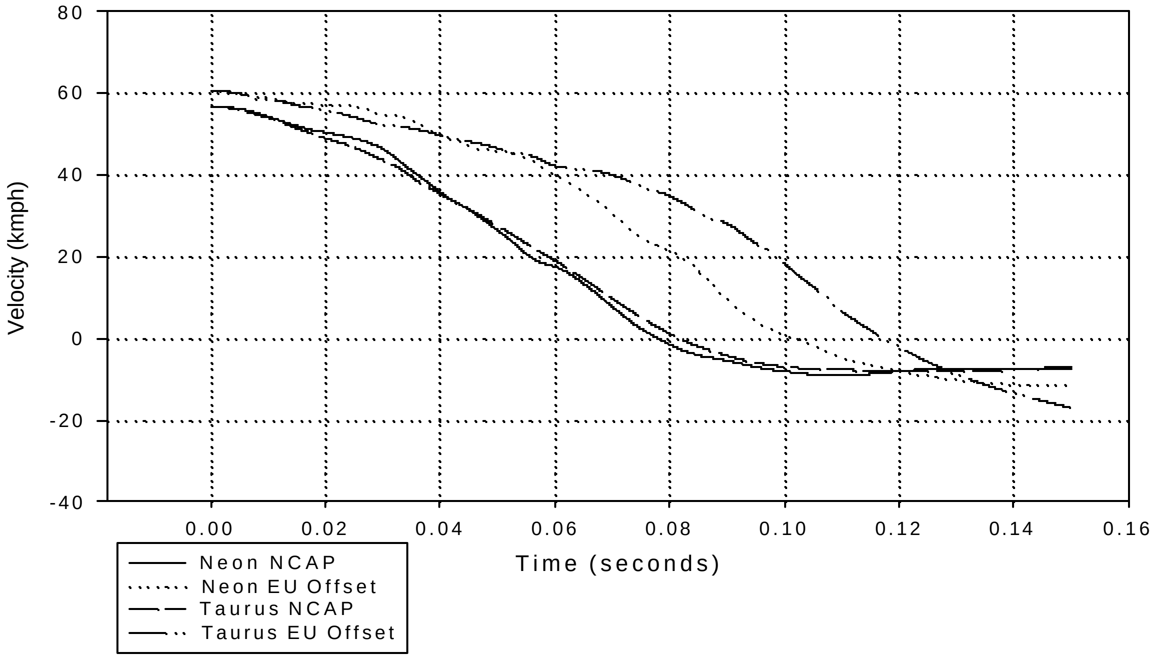


Figure 5-9: Comparison of NCAP and 60 kmph EU Offset crash pulses

5.1.2 Simulated Crash Responses

In order to provide additional crash response data, a series of finite element simulations using an available Dodge Neon model as the baseline vehicle was conducted. These simulations were run for a matrix of test methods and crash configurations so that a comparative analysis can be undertaken. All of the simulations were conducted using LS-DYNA version 9.40. These included simulating 48 kmph (30 mph) full frontal rigid wall tests at angles of 0, 15, and 30 degrees. Also included were simulations of a fixed full frontal deformable barrier. Finally, vehicle-to-vehicle collisions were simulated. These included both full frontal and oblique, frontal offset crash simulations of the Neon into a Chevrolet CK 2500 pickup truck. The matrix for the finite element simulation study is shown in Table 5-1. The validation and detailed results for these simulations are discussed in Appendix B.

Table 5-1: Matrix for Finite Element Simulations

Vehicle	Speed	Configuration
Neon	48 kmph	0 Degree Rigid Wall
Neon	48 kmph	15 Degree Rigid Wall
Neon	48 kmph	30 Degree Rigid Wall
Neon	48 kmph	Fixed Full Frontal Deformable Barrier (FFFDB)
Neon-CK	48 kmph	Full Frontal engagement
Neon-Neon	48 kmph	Full Frontal engagement
Neon-CK	48 kmph	30 Degree Oblique 50% Offset

Figures 5-10 and 5-11 show the deceleration profiles for all of the Neon simulations. The 208 rigid barrier deceleration and the generic sled pulse are used as references for comparison. Figure 5-10 plots the deceleration profiles that are classified as “soft” or “sled-like”. Figure 5-11 plots the profiles that are considered “stiff” or “Barrier-like.” Notice that the rigid barrier deceleration very closely resembles the Neon to Neon simulation. This correlation is dependent upon the symmetry of the Neon structure. The generic sled pulse does not resemble the deceleration profile for any of the test configurations. The GSP has a longer pulse width and lower peak deceleration than the 208 barrier. The FFFDB and the 30 degree barrier similarly had longer deceleration pulse widths and lower peaks than the 208 barrier. The fixed full frontal deformable barrier, FFFDB, has generally low deceleration profile from 40 to 60 milliseconds. The peak deceleration for the FFFDB occurs significantly later, (78 ms), than any of the other test configurations, except the 30 degree angled barrier impact. Note the longitudinal deceleration of the Neon was plotted for all of the deceleration profiles. The offset oblique Neon - CK simulation produced a longer deceleration profile with a significantly lower peak deceleration than was produced by the inline Neon - CK simulation. The Neon-CK oblique offset simulation did not produce the high deceleration levels, relative to the 208 rigid barrier test procedure, that were observed in the Taurus test series.

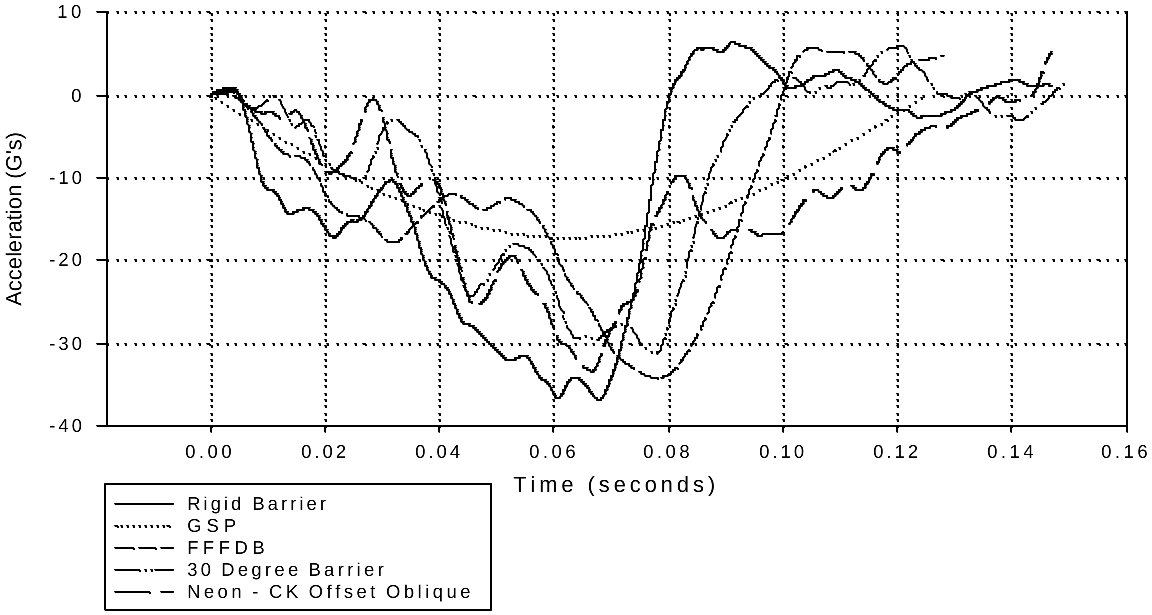


Figure 5-10: Comparison of “Soft” Acceleration Profiles for Neon Simulations

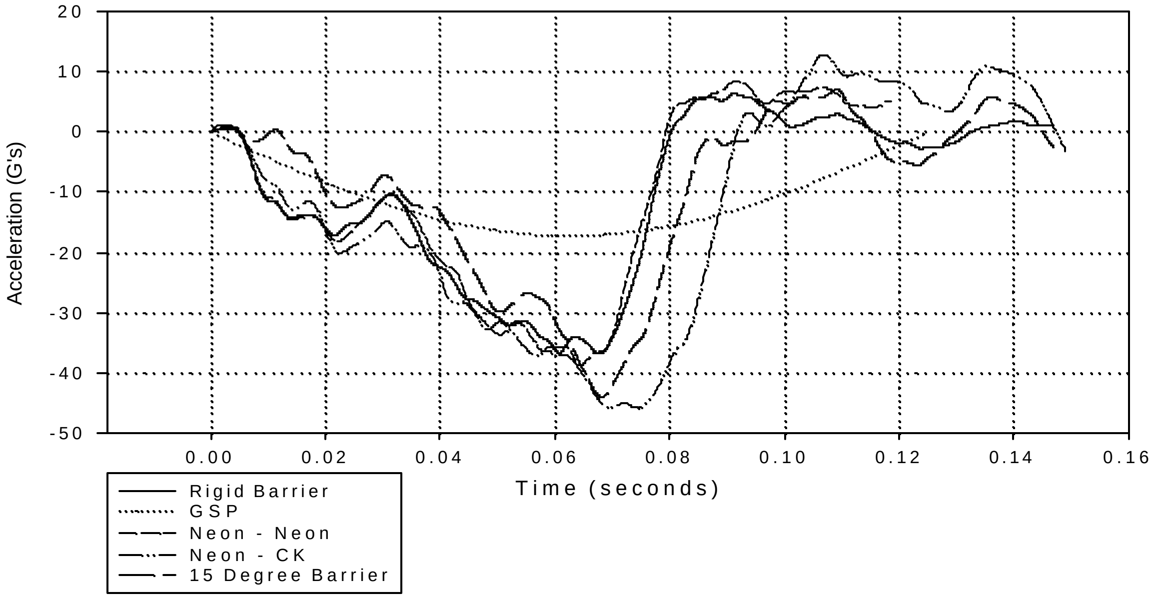


Figure 5-11: Comparison of “Stiff” Acceleration Profiles for Neon Simulations

Figures 5-12 and 5-13 shows the velocity profiles for the "soft" and "stiff" simulated test configurations respectively. Between 20 ms and 70 ms the velocity profiles can be lumped into two general groups. The stiff velocity profiles have a sharp slope and follow the behavior of the rigid barrier test. The soft velocity profiles have a much lower slope. Again the rigid barrier velocity profile very closely resembles the Neon-Neon simulation. The Neon - CK simulation initially resembles the rigid barrier profile, but has a much higher change in velocity after 70 ms.

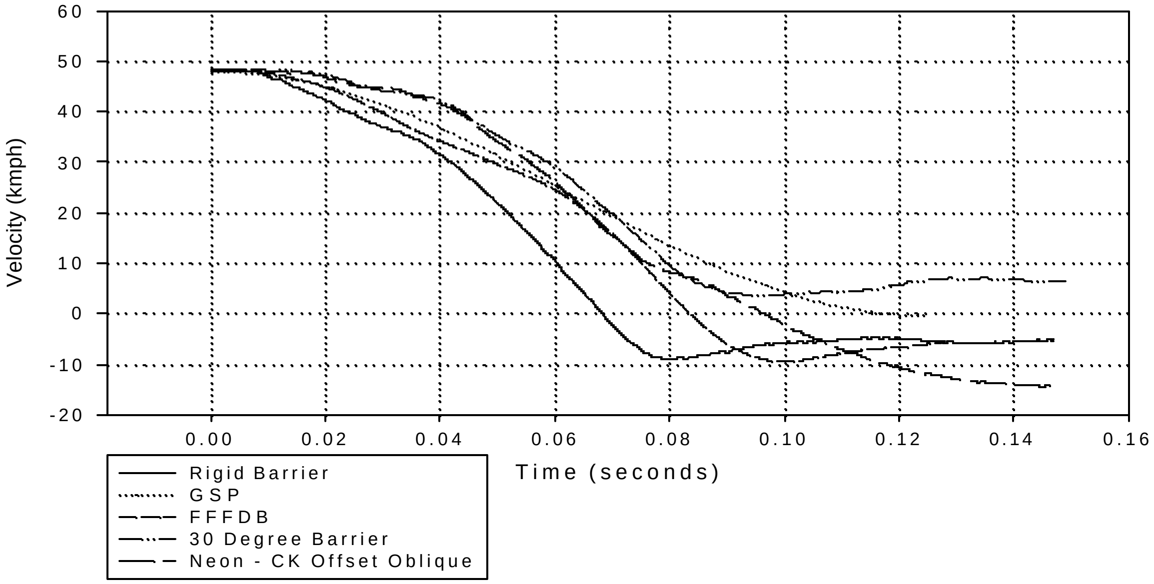


Figure 5-12: Comparison of Velocity Profiles for "Soft" Neon Simulations

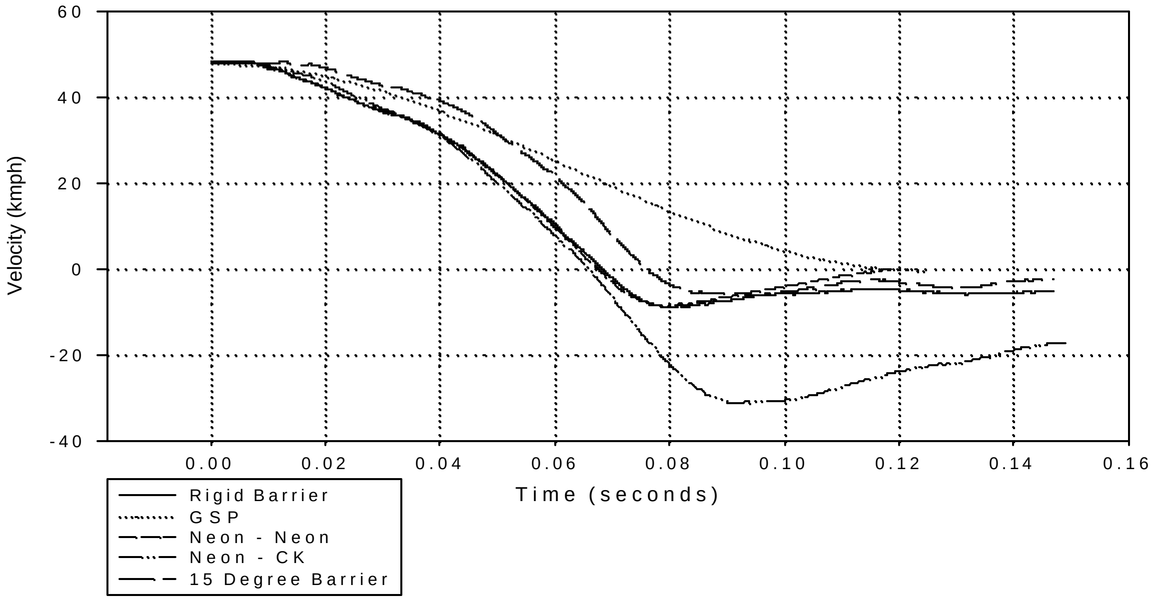


Figure 5-13: Comparison of Velocity Profiles for "Stiff" Neon Simulations

5.2 Occupant Injury

The characterization of the crash response as either “stiff” or “soft” only has significance if the two pulses lead to different levels of occupant injury potential. This section will analyze the test and simulation crash responses to compare the potential for occupant injury in each of the configurations.

Table 5-2 lists the injury criteria for a series of offset crash tests [1]. This table uses the definition of Tibia Index from SAE J1727. Table 5-2 shows that the oblique offset test conditions produce injury criteria that are slightly lower than for the rigid barrier. The EEVC fixed deformable barrier test produced injury criteria that were significantly lower than the rigid barrier test.

Table 5-2: Driver Injury Criteria for Offset Crash Tests

Test Condition	HIC	Chest Gs	Femur (N)	Tibia Index
Taurus-to-Taurus, Inline, 50% overlap, 56 kmph	530	45.4	5654	1.0
Taurus-to-Taurus, 30 degree, 55% overlap, 62 kmph	411	51	5824	1.7
MDB-to-Taurus, 30 degree, 53% overlap, 57 kmph	461	54.8	6708	2.4
MDB-to-Taurus, 45 degree crabbed 65% overlap, 105 kmph (MDB)	363	44.9	7223	1.6
Taurus-to-EEVC Fixed Deformable Barrier, 50% overlap, 64.2 kmph	178	38.5	6154	0.6
Taurus NCAP rigid barrier	524	53	7313	N / A

The finite element crash simulations are used to evaluate the occupant compartment deceleration and velocity profiles as well as the intrusion for the various test configurations . The deceleration profiles from the finite element simulations were used to drive MADYMO articulated mass models. The MADYMO models will evaluate the potential for occupant injury in the test configurations. Detailed occupant compartment data for the 1996 Neon was not available, so a generic MADYMO occupant compartment model was used. The relative locations of the windshield, knee bolster, front and side headers were adjusted to match the interior configuration of the Neon. The generic model shown in Figure 5-14 below, was used to evaluate the response of an unbelted hybrid III dummy. A generic air bag model was used with an initiation time of 15 milliseconds, the initiation time measured in the FMVSS 208 rigid barrier compliance test.

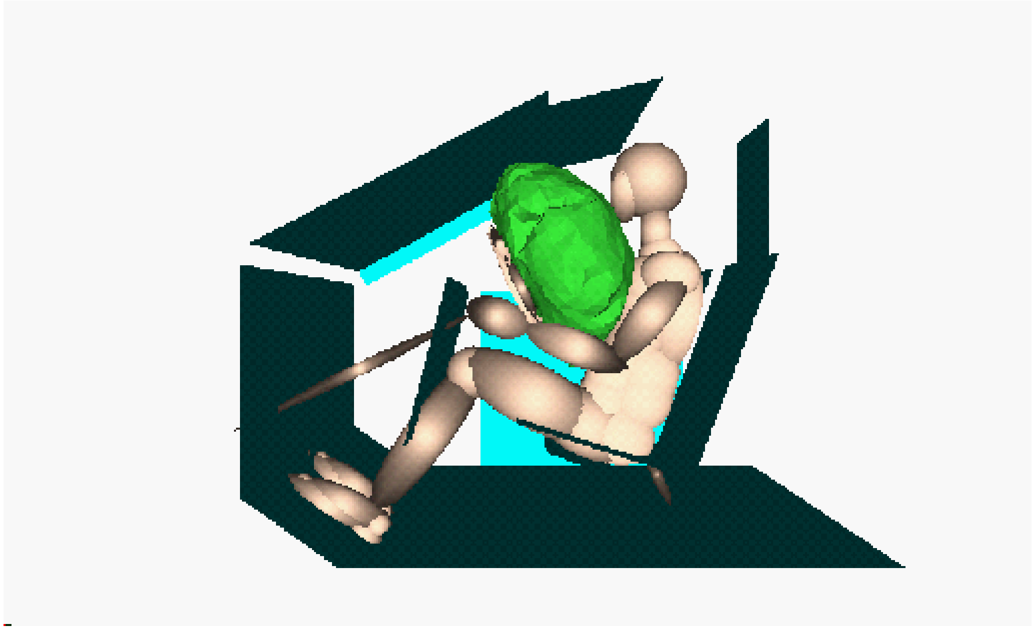


Figure 5-14: MADYMO model for the generic occupant compartment

Since the occupant compartment model is generic and developed specifically for the Neon, the computed injury criteria have been normalized relative to the baseline 48 kmph zero degree rigid barrier test data. The injury criteria for all of the test configurations are shown in Table 5-3.

Table 5-3: Injury Criteria from MADYMO Driver simulations

Test	HIC	Chest G's	Chest Defl.
FMVSS 208 Rigid Barrier	100%	100%	100%
Generic Sled Pulse (GSP)	48%	65%	76%
FFFDB	80%	92%	103%
Neon-Neon	90%	119%	99%
Neon-CK Inline	207%	142%	155%
15 Degree Barrier	78%	90%	111%
30 Degree Barrier	67%	64%	72%
Neon-CK 30 Degree 50% Offset	80%	64%	79%

Table 5-3 indicates the test configurations that were identified as "soft", the GSP, FFFDB, 30 degree barrier, and Neon - CK oblique all have HIC's that are 80% or below of the rigid barrier test configuration. The chest acceleration shows a somewhat narrower differentiation between the test configurations with the FFFDB having an acceleration 92% of the FMVSS 208 test configuration. The chest displacement measurements do show the same grouping of test procedures. The FFFDB has approximately the same chest deflection as the FMVSS 208 test configuration, while the other "soft" configurations have chest deflections below 80% of the FMVSS 208 test configuration.

5.3 Occupant Compartment Intrusion

Studies of the NASS data have shown that crashes with greater than 15 cm of intrusion have a higher probability of serious injury. This section will evaluate the test configurations in terms of the measured intrusion.

The intrusion measurements for the full vehicle tests of the Ford Taurus and Chevrolet Corsica are shown in Tables 5-4 and 5-5. For the tables, only the maximum intrusion into the occupant compartment is considered. For the various test configurations, intrusion measurements were made for the toepan, instrument panel, and steering column. The intrusion measurements were broken down into two groups, less than and greater than 15 cm of intrusion. For the Taurus series all of the angled impacts generated intrusions greater than 15 cm, while all the tests with full engagement of the front structure produced less than 15 cm of intrusion. The Corsica test series consisted of a series of oblique and collinear offset tests, in which all tests that recorded intrusion measured greater than 15 cm of intrusion. The oblique tests all produced intrusion greater than 15 cm.

Table 5-4: Intrusion measurements for Taurus Test Series

TAURUS INTRUSION BY TEST TYPE				
TEST TYPE	SPEED, kmph	OVERLAP, %	0-15 cm	≥ 15 cm
#1 Car-to-car collinear	56	50	x	
#2 Car-to-car collinear	59	50		x
Car-to-car oblique	62	50		x
MDB-to-car oblique	59	50		x
EU Directive	64	50	x	
EU Directive	64	40	x	

EU Directive	60	40	x	
#1 NCAP Rigid Barrier	56	100	x	
#2 NCAP Rigid Barrier	59	100	x	
#1 FMVSS 208 Rigid Barrier	48	100	x	
#2 FMVSS 208 Rigid Barrier	48	100	x	

Table 5-5: Intrusion measurements for Corsica Test Series

CORSICA INTRUSION BY TEST TYPE				
TEST TYPE	SPEED, kmph	OVERLAP, %	0-15 cm	≥ 15 cm
#1 Car-to-car oblique	66	80		x
#2 Car-to-car oblique	62	50		x
MDB-to-car oblique	66	50		x
Car-to-car oblique	53	50		x
#1 Car-to-car collinear	59	50		x
#2 Car-to-car collinear	58	60		x
#3 Car-to-car collinear	59	70		x
DOT# 1585 NCAP Rigid Barrier	56	100	N/A	N/A
DOT #2124 208 Rigid Barrier	48	100	N/A	N/A

Note: Data not available for NCAP and 208 Corsica tests

Similarly the measurements for the simulations are shown in Table 5-6. Only the simulations for the 208, Neon-Neon, and FFFDB test configurations had maximum intrusions of less than 15 cm. All of the angled simulations produced maximum intrusions of greater than 15 cm..

Table 5-6: Neon Intrusion By Test Type

Neon INTRUSION BY TEST TYPE			
TEST TYPE	SPEED kph	0-15 cm	≥ 15 cm
FMVSS 208 Rigid Barrier	48	x	
FFFDB	48	x	
Neon - Neon	48	x	
CK-to-Neon oblique	48		x
Angled Barrier 30 Degree	48		x
CK-to-Neon collinear	48		x

5.4 Evaluation of Energy Absorption

The finite element simulations provide the ability to evaluate the energy absorbed by the structure of the Neon during the various crash simulations. Similar to the intrusion measurement, the energy absorption can indicate the likely extent of damage to the vehicle in the various test configurations.

Figure 5-15 shows the time histories of the internal energy in the Neon structure. The test configurations display a large range of energy absorption rates. The rigid wall and CK pickup full frontal engagements show the highest energy absorption rates. The 30 degree impacts and the FFFDB show the lowest energy absorption rates. The total or final energy absorbed by the Neon is reached relatively early in the crashes, from 80 to 100 milliseconds. Table 5-7 shows the final energy absorbed as a ratio of the energy absorbed in the FMVSS 208 rigid barrier test. For the test configurations shown, the internal energy varies from 61 percent to 159 percent of the internal energy in the standard FMVSS 208 test procedure. The FFFDB and the angled rigid barrier tests all display significant reductions in the absorbed energy, supporting their classification as “soft” test configurations. However, the oblique offset Neon-CK simulation has 119 % of the absorbed energy of the FMVSS No. 208 impact. This indicates that while the deceleration profile and injury criteria may not be severe, the structural deformation and intrusion are very significant.

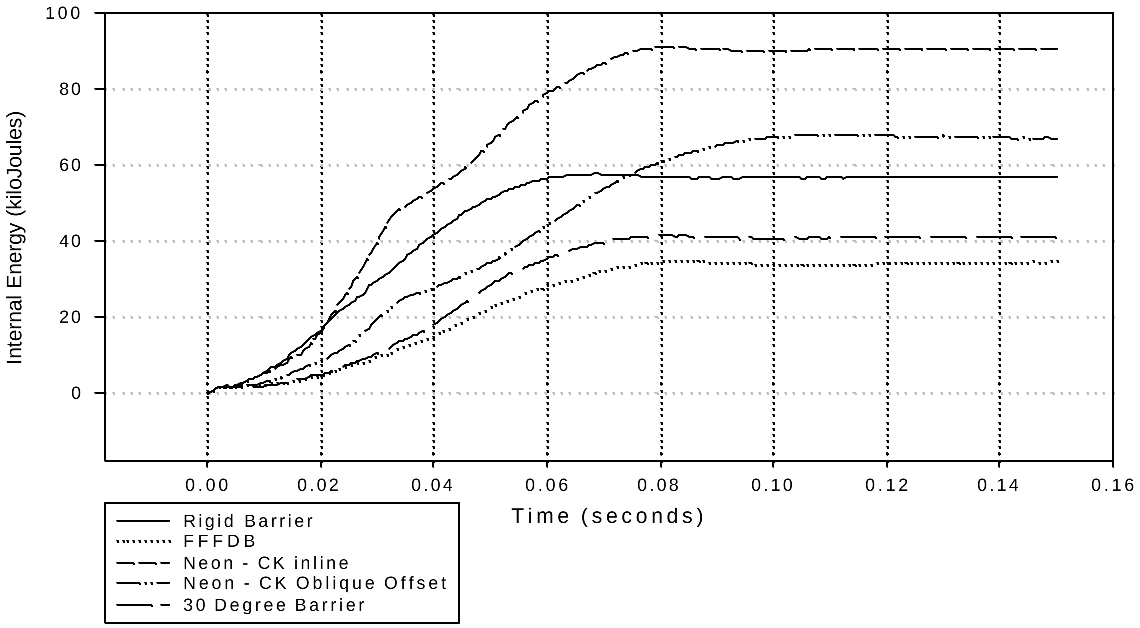


Figure 5-15: Comparison of the Energy Absorbed by the Neon Structure in various test configurations

Table 5-7: Internal Energy Ratios, normalized to the FMVSS 208 Rigid Barrier simulation

Test Type	Peak Internal Energy Ratio
Rigid Barrier, Neon	1.0
FFFDB, Neon	0.61
Neon - CK inline	1.59
Neon-CK Oblique Offset	1.19
30 Degree Barrier, Neon	0.72

5.5 Summary and Discussion

Based on the test and simulation data presented, the test procedures have been categorized with respect to the crash pulse and the intrusion outcomes. The crash responses that were similar to the rigid wall tests (or barrier-like) were categorized as stiff, whereas the crash responses that were similar to the generic sled pulse were categorized as soft. In examining the acceleration levels from the crash tests and simulations, the “soft” responses are generally characterized by the longer duration pulses (approximately 125 msec and longer) and lower peak deceleration levels (approximately 18-20 Gs).

The “stiff” pulses are characterized by the shorter duration pulses (below 110 millisecond) and higher peak deceleration levels (approximately 25 Gs). In examining the resulting velocity profiles from these pulses during the first 50 to 60 milliseconds (the time at which occupants begin to interact with the air bag), it is observed that the “soft” pulses result in velocity changes that are roughly half of those experienced by vehicles subjected to a stiff pulse. In examining both the crash test and the simulation results, it is seen that the vehicles subjected to the soft pulses experienced lower injury levels as compared to the vehicles subjected to stiff pulses. Furthermore, in examining the energy absorbed by the Neon’s frontal structure as calculated through finite element analyses, it was observed that the stiff pulses resulted in substantially greater energy absorption. The energy absorption resulting from a soft pulse was 70 percent (and lower) of that absorbed by a stiff pulse.

In addition to characterizing the crash response, the expected intrusion outcome was determined. The expected intrusion outcome was divided into two categories as well. The first was an expected intrusion level of 0 to 15 cm. The second was for intrusion that is expected to exceed 15 cm. These intrusion levels were chosen based on the probability of injury as observed in the NASS files (See Chapter 3.). The results from these efforts are shown in Table 5-8.

Table 5-8: Test Procedure: Expected Outcomes.

Test Procedure	Impact Direction	Crash Pulse	Intrusion (est.)
Rigid Wall/ Full frontal	Perpendicular	Stiff	0 - 15 cm
Rigid Wall/ Full frontal	Oblique	Soft	> 15 cm
FFFDB/ Full frontal	Perpendicular	Soft	0 - 15 cm
Offset-Barrier: (IIHS / EU Test)	Perpendicular	Soft	> 15 cm
Vehicle-MDB/ Full-Frontal	Perpendicular	Stiff	0 - 15 cm
Vehicle-MDB/ Overlap # 55%	Perpendicular	Soft	> 15 cm
Vehicle-MDB/ Overlap > 55%	Perpendicular	Stiff	> 15 cm
Vehicle-MDB/ Overlap # 33%	Oblique	Soft	> 15 cm
Vehicle-MDB/ Overlap > 33%	Oblique	Stiff	> 15 cm
Sled Test	Perpendicular	Soft	Not Applicable

5.6 References

1. Stucki, Sheldon L. and Hollowell, William T., “NHTSA’s Improved Frontal Protection Research Program”, Fifteenth International Technical Conference on Enhanced Safety of Vehicles, Melbourne, Australia, May 1996

CHAPTER 6. SUMMARY AND RECOMMENDATIONS

The National Highway Traffic Safety Administration has undertaken a priority effort to minimize the fatalities and reduce the severity of the injuries to out-of-position occupants resulting from aggressive air bag deployment in low speed crashes, and also, simultaneously, to preserve the benefits for normally seated restrained and unbelted adults in high severity crashes. As part of this effort, the agency has undertaken a study to evaluate a number of test procedures that could be used to evaluate the safety performance of vehicles in frontal crashes. For this special study, a multifaceted approach was undertaken. In Chapter 2, a review of the candidate test procedures is presented, and a general description and an assessment of the state of development for each test procedure are discussed. In Chapter 3, the frontal crash environment is characterized using the National Automotive Sampling System (NASS) file. Target populations for crashes and for serious injury-producing crashes are presented for the candidate test procedures. Furthermore, the predominant body regions which are addressed by the candidate test procedures are identified. In Chapter 4, a study is presented regarding the design directions that would result from each of the candidate test procedures. An evaluation is made regarding the effects of the test procedures toward compatibility in vehicle-to-vehicle crashes. In Chapter 5, a study is presented that identifies the candidate test procedures as being rigid barrier-like (“stiff) or sled-like (“soft”), the test procedures that are currently part of FMVSS No. 208. Comparisons of the crash responses are made with responses from vehicle-to-vehicle crashes (using test or simulation data) in order to ascertain whether the candidate test procedures are representative of real world crashes. Furthermore, the procedures are characterized based on their anticipated level of intrusion. This final section summarizes the major findings from the individual studies, and then provides recommendations resulting from these findings.

6.1 Summary of Findings

This section provides highlights of the findings from each of the analyses undertaken for this study. For the convenience of the reader, Table 6.1 summarizes these findings.

As mentioned, Chapter 2 provides a review of the types of testing that have been utilized in the past and that could be used in the future by the agency for evaluating vehicle safety performance. During this review, car-to-car and car-to-narrow object testing were eliminated as candidate test procedures. Included as candidate test procedures were the rigid barrier test (both full frontal and full frontal oblique), a full frontal fixed deformable barrier test, a moving deformable barrier-to-vehicle test, and a sled test. A general description and an assessment of the state of development for each test procedure is presented. Additionally, the status of each procedure with respect to regulatory testing, NCAP testing, and research testing was discussed. Included within the discussion are the agency’s and external organizations’ experience with each procedure as well as the expected lead time necessary to complete the research related to each procedure. From this review, it has been determined that the rigid barrier, the oblique rigid barrier, the frontal offset deformable barrier, and the sled test procedures are available for use without additional research. The moving deformable barrier test may require 2-3 years to complete the research.

In Chapter 3, the frontal crash environment is characterized using the National Automotive Sampling System (NASS) file. Target populations for all frontal crashes and for serious injury-producing crashes are presented for the candidate test procedures. Furthermore, the predominant body regions which are addressed by the candidate test procedures are identified. Some general conclusions are that drivers with air bags involved in frontal crashes subjected to a stiff crash pulse have a higher frequency and risk of serious-to-fatal injuries than drivers in crashes subjected to a soft crash pulse. Crashes characterized by a stiff crash pulses produce more AIS$3, life-threatening, head and chest injuries. Offset crashes, with either a stiff and soft crash pulses, produce more leg injuries.

By grouping drivers into specific test conditions based on the crash severity, assumed to be characterized by the crash pulse and level of intrusion, an estimate of the target crash populations is projected. An MDB-to-vehicle test, using both left and right offset test procedures, would address the largest target population for both the exposure and for seriously injured drivers (i.e., drivers with injuries of severity MAIS$3). The results from the study indicated the target population is about 80 percent of the drivers in frontal crashes and about 70 percent of those with serious-to-fatal injuries. The full frontal fixed barrier test would address a lower target population, about 55 percent of drivers in frontal crashes and about 45 percent of those with MAIS$3 injuries. All other potential tests would address substantially lower target populations. The MDB-to-vehicle test addresses head, chest, and leg injuries; while the full frontal fixed barrier test addresses head and chest injuries, predominantly. The remaining tests which produce stiff pulses and low intrusion address mainly head and chest injuries, while those tests with soft pulses and substantial intrusion mainly address leg injuries. The body regions addressed by the sled test with a soft pulse and no intrusion is not apparent from the method used to evaluate the crashes contained in the NASS file.

In Chapter 4, a study is presented regarding the design directions that would result from each of the candidate test procedures. An evaluation is made regarding the effects of the test procedures toward compatibility in vehicle-to-vehicle crashes. Test procedures which produce a stiff crash pulse tend to encourage the design of softer front structures and /or more effective restraint systems. Procedures which replicate the intrusion seen in real world crashes, tend to encourage designers to strengthen the vehicle structure. Both design modifications affect the extent to which the vehicle is compatible with its crash partners. Stiffening the frontal structure of a vehicle for intrusion protection makes the vehicle more aggressive while softening the frontal structure for crash pulse protection makes the vehicle less aggressive. The ideal design balances the need for crash and intrusion control while limiting aggressivity.

Currently, the rigid barrier test acts as a constraint on over-stiffening of the front vehicle structure. The frontal-oblique MDB test, or a combination of the rigid full frontal barrier test and a frontal-offset test forces designers to produce a vehicle which limits intrusion while simultaneously limiting deceleration severity. However, less rigorous tests, e.g, the FFFDB or the sled test, would effectively waive or weaken this limit on deceleration severity, and possibly could permit the manufacture of a new generation of stiffer and, therefore, more aggressive passenger vehicles.

In Chapter 5, a study is presented that identifies the candidate test procedures as being barrier-like ("stiff) or sled-like ("soft"). Comparisons of the crash responses are made with responses from vehicle-to-vehicle crashes (using test or simulation data) in order to ascertain whether the candidate test procedures are representative of real world crashes. Furthermore, the procedures are characterized regarding their anticipated level of intrusion. Based on the test and simulation data presented, the test procedures have been categorized with respect to the crash pulse and the intrusion outcomes. The crash responses that were similar to the rigid wall tests (or barrier-like) were categorized as stiff, whereas the crash responses that were similar to the generic sled pulse were categorized as soft. In examining the acceleration levels from the crash tests and simulations, the "soft" responses are generally characterized by the longer duration pulses and lower peak acceleration levels). The "stiff" pulses are characterized by the shorter duration pulses and higher acceleration levels. In examining the resulting velocity profiles from these pulses during the first 50 to 60 milliseconds (the time at which occupants begins to interact with the air bag), it is observed that the "soft" pulses result in velocity changes that are roughly half of those experienced by vehicles subjected to a "stiff" pulse. In examining both the crash test and the simulation results, it is seen that the occupants of vehicles subjected to soft pulses experienced lower injury levels than the occupants of vehicles subjected to stiff pulses. Furthermore, in examining the energy absorbed by the frontal structure as calculated through finite element analyses, it was observed that the test procedures resulted in substantially different energy absorption. For example, the energy absorption resulting from the FFFDB test procedure was less than or equal to 70 percent of that absorbed by the vehicle in the rigid barrier test.

In addition to characterizing the crash response, the maximum occupant compartment intrusion was determined at the toeboard, dashpanel, and steering column. The expected intrusion outcome was divided into two categories as well. The first was an expected intrusion level of 0 to 15 cm. The second was for intrusion that is expected to exceed 15 cm. These intrusion levels were chosen based on the probability of injury as observed in the NASS files.

Table 6.1. Test Procedure Expected Outcomes

Test #	Test Description	Specific Test Configuration	Crash Pulse	Intrusion	Annual Counts			Annual Counts Expanded Test		Design Directions	Lead Time
					Exposed Drivers	Drivers with MAIS$3	Predominant Body Regions Addressed[1]	Exposed Drivers	Drivers with MAIS$3		
1	FMVSS 208 Rigid Barrier Test (Past and Planned)	Rigid Wall/ Full Frontal (0-15°)	Stiff	0 to 15cm	263,981	5,054	Head, Chest	NA	NA	Soften front and/or improve restraints	Now
		Rigid Wall / Frontal Oblique (15-30°)	Soft	>15 cm	378,670	8,875	Legs	378,670	8,875	Stiffen front structure	Now
2	FFFDB/ Full Frontal	FFFDB/ Full Frontal	Soft	0 to 15cm	353,306	3,170	Legs	NA	NA		1-2 yrs
3	Offset-Barrier EU Test	Offset-Barrier EU Test	Soft	>15 cm	177,585	5,212	Legs	378,670	8,875	Stiffen front structure	Now
4	Vehicle-MDB Full Frontal	Vehicle-MDB Full Frontal	Stiff	0 to 15cm	263,981	5,054	Head, Chest	NA	NA	Stiffen lighter vehicles; neutral for heavy vehicles	2-3 yrs
5	Vehicle-MDB Offset - Stiff *(Option 1)*	Vehicle-MDB Inline Overlap>55%	Stiff	>15 cm	454,212	12,828	Head, Chest, Legs	932,907	20,297	Soften front structure; Lighter vehicles also must strengthen compartment	2-3 yrs
	Vehicle-MDB Offset - Stiff *(Option 2)*	Vehicle-MDB Oblique Overlap >33%	Stiff	> 15 cm	454,212	12,828	Head, Chest, Legs	932,907	20,297	Soften front structure; Lighter vehicles also must strengthen compartment	2-3 yrs

6	Vehicle-MDB Offset - Soft *(Option 1)*	Vehicle-MDB Inline Overlap#55%	Soft	> 15 cm	177,585	5,212	Legs	378,670	8,875	Stiffen front structure	2-3 yrs
	Vehicle-MDB Offset - Soft *(Option 2)*	Vehicle-MDB Oblique Overlap#33%	Soft	> 15 cm	177,585	5,212	Legs	378,670	8,875	Stiffen front structure	2-3 yrs
7	FMVSS 208 Sled Test	Sled Test	Soft	NA	299,911	1,396		NA	NA	-	Now

[1] Analysis of body region by crash mode and pulse type, shows "stiff" pulses result in higher rates of head/chest injury and offset resulted in more leg injuries

6.2 Options for Consideration

Analysis of each of the candidate test procedures with respect to their lead time, target populations, body regions addressed, and effect on compatibility leads to the following four options available for consideration for the evaluation of a vehicle's frontal crash protection. The generic sled test is not one of the options. Unlike a full scale vehicle crash test, a sled test does not, and cannot, measure the actual protection an occupant will receive in a crash. The sled test does not replicate the actual timing of air bag deployment, does not replicate the actual crash pulse of a vehicle, does not measure the injury or protection from intruding parts of the vehicle, and does not measure how a vehicle performs in actual angled crashes. Finally, the generic sled test has a substantially smaller target population when compared to the options discussed below.

<u>Option 1 - Combination of Perpendicular and Oblique Rigid Barrier Tests</u>: The first option is the unbelted rigid barrier test of impact speed 0 to 48 kmph and impact angle 0 to 30°. This option has a target population which is substantially larger than the generic sled test, and is immediately available for implementation. The perpendicular rigid barrier test primarily evaluates crash pulse severity while the oblique rigid barrier test primarily evaluates intrusion. Likewise, the perpendicular rigid barrier test is expected to evaluate head, chest, neck and upper leg injury potential, but provides no evaluation of lower leg injury unless coupled with the oblique barrier test. With regard to compatibility, the perpendicular rigid barrier test acts as a constraint on over-stiffening the front structure. However, in vehicle-to-vehicle collisions, it is equivalent to a frontal-to-frontal collision with a vehicle like itself. Hence, this procedure does not lead to compatibility with either lighter or heavier collision partners.

<u>Option 2: Combination of the Perpendicular Rigid Barrier Test and an Offset Deformable Barrier Test</u>: The second option is a combination of the rigid barrier test with an offset deformable barrier test similar to the procedure used in Europe. This option combines the crash pulse control provided by the perpendicular rigid barrier test with the intrusion control provided by the offset-barrier test. The target population for the combined procedure equals the target population for the combination of the perpendicular and oblique rigid barrier tests. In addition to evaluating the protection of the head, chest, and neck of the occupant, the combined procedure also evaluates leg protection against intrusion. With regard to compatibility, the combined procedure, like the rigid barrier test alone, acts as a constraint on over-stiffening the front structure, but would allow strengthening of the occupant compartment to avoid intrusion. However, like Option 1, it is equivalent to a frontal collision with a vehicle like itself. Hence, this procedure does not lead to compatibility with either lighter or heavier collision partners.

<u>Option 3 - Moving Deformable Barrier (MDB)-to-Vehicle Test</u>: The third option is the frontal-MDB test. Of all candidate test procedures, this option has one of the largest target populations, but also has the need for a longer lead time (2-3 years) to complete research and development. The frontal-MDB test combines, in a single test, the crash pulse control provided by the perpendicular rigid barrier test with the intrusion control provided by the offset-barrier test. For lighter vehicles, this procedure provides the incentive to produce designs which are more crash compatible with heavier collision

partners. The procedure provides no incentive to either stiffen or soften larger vehicles, thereby allowing the automakers the design flexibility to build compatibility into heavier vehicles. This option leads to crash compatible designs. On the negative side, if a barrier weight is selected that represents the median weight of the fleet, the vehicles that weigh more than the selected MDB would experience a softer crash pulse than that experienced in a rigid barrier test. Design modifications made to take advantage of this could lead to poorer performance in single vehicle crashes.

<u>Option 4 - Combination of Perpendicular Rigid Barrier and Moving Deformable Barrier (MDB)-to-Vehicle Test</u>: The fourth option is the combination of the frontal rigid barrier and the MDB test. Of all candidate test procedures, this option has the largest target population. These tests combine the crash pulse control provided by the perpendicular rigid barrier test with the intrusion control provided by the offset-barrier test. For lighter vehicles, this procedure provides the incentive to produce designs which are more crash compatible with heavier collision partners. The combined procedures prevent larger vehicles from becoming too stiff, thereby pointing the automakers toward designs that build compatibility into heavier vehicles. Of all the candidate test procedures, this option leads to most crash-compatible designs. This combination eliminates the negative side of an MDB test alone; that is, it would not allow design modifications that could lead to poorer performance in single vehicle crashes. The research and development related to this procedure will require a lead time of 2-3 years to complete.

6.3 Recommendations

On March 19, 1997, NHTSA published a final rule that adopted an unbelted sled test protocol as a temporary alternative to the fixed barrier test for unbelted occupants. The agency took this action to provide an immediate, interim solution to the problem of the fatalities and injuries that current air bag systems are causing in relatively low speed crashes to a small, but growing number of children and occasionally to adults. It was the understanding at that time, and it is reiterated in this study, that the sled test does not meet the need for effectively evaluating vehicle protection systems. The advanced air bag rulemaking actions that are being proposed provide adequate lead time to assure proper designs for occupant protection that must be evaluated under appropriate test conditions. Therefore, it is recommended for this rulemaking to eliminate the sled test procedure and to consider the aforementioned options that are available within the rulemaking time frame. Additionally, it is recommended that research be continued in developing and evaluating the moving deformable barrier test for future agency consideration for upgrading FMVSS No. 208.

6.4 References

1. Kahane, Charles J., Hackney, James R., and Berkowitz, Alan M., “Correlation of Vehicle Performance in the New Car Assessment Program with Fatality Risk in Actual Head-on Collisions,” 14th International Technical Conference on the Enhanced Safety of Vehicles, Munich, Germany, May 1994.

2. ____, "Third Report to Congress: Effectiveness of Occupant Protection Systems and Their Use," National Highway Traffic Safety Administration, Report No. DOT HS 537, December 1996.

3. Hackney, James R. and Kahane, Charles J., "The New Car Assessment Program: Five Star Rating System and Vehicle Safety Performance Characteristics," SAE Paper No. 950888, SAE International Congress and Exposition, Detroit, MI, 1995.

APPENDIX A

LEGEND for TABLES A-1 through A-4

0 to 80 Percent of Injury Assessment Reference Value
80 to 90 Percent of Injury Assessment Reference Value
90 to 100 Percent of Injury Assessment Reference Value
Exceeds Injury Assessment Reference Value

TABLE A-1. UNBELTED DRIVER 50th PERCENTILE MALE

TABLE A-2. UNBELTED PASSENGER 50th PERCENTILE MALE

TABLE A-3. UNBELTED DRIVER 5th PERCENTILE FEMALE

TABLE A-4. UNBELTED PASSENGER 5th PERCENTILE FEMALE

TABLE A-1. UNBELTED DRIVER 50th PERCENTILE MALE

		Test #	Chest G IARV = 60.0	Chest disp. IARV = 63.0 mm	HIC15 IARV = 700	Nij ver. 9 IARV = 1.0	Maximum Femur (N) IARV = 10,008 N
30 mph Rigid Barrier	MY99 Intrepid	V3126	54.4	44.8	403	0.52	7,786 (R)
	MY99 Tacoma	V3128	43.7	48.4	176	0.33	8,839 (L)
	MY99 Acura RL	V3125	56.9	31.8	154	0.29	**13,349** (L)
	MY99 Saturn SC1	V3127	36.8	46.8	128	0.41	5,288 (R)
	MY99 Econoline	V3123	52.1	37.1	87	0.32	6,198 (L)
	MY99 Expedition	V3124	46.7	28.1	178	0.41	6,612 (R)
	MY98 Taurus	V2832	47.2	21.9	181	0.38	5,556 (L)
	MY98 Neon	V2838	43.5	24.9	166	0.47	7,336 (R)
	MY98 Camry	V2837	51.8	38.1	231	0.45	6,115 (L)
	MY98 Accord	V2836	36.7	45.8	51	0.27	7,623 (R)
	MY98 Explorer 4L	V2839	44.4	32.3	272	0.30	6,033 (R)
	MY98 Voyager	V2773	48.0	54.7	350	0.47	7,309 (L)
	MY98 Cherokee	V2830	46.1	41.6	189	0.53	7,366 (L)
25 mph Rigid Barrier	MY99 Intrepid	V3147	40.1	33.0	194	0.41	7,824 (R)
	MY99 Tacoma	V3146	42.9	46.1	97	0.34	7,280 (L)
	MY99 Acura RL	V3145	35.0	35.7	63	0.24	5,912 (L)
35 mph 40% Offset Deformable Barrier	MY99 Intrepid	V3143	57.8	42.3	350	**1.39**	5,558 (R)
	MY99 Tacoma	V3148	38.0	46.2	150	0.42	4,844 (L)
30 mph 30ERight Barrier	MY99 Intrepid	V3144	34.4	23.5	53	0.35	5,623 (R)
30 mph 30E Left Barrier	MY99 Intrepid	V3117	43.0	32.0	210	0.37	5,666 (L)

TABLE A-2. UNBELTED PASSENGER 50th PERCENTILE MALE

		Test #	Chest G IARV = 60.0	Chest disp. (mm) IARV = 63.0 mm	HIC15 IARV = 700	Nij ver. 9 IARV 1.0	Maximum Femur (N) IARV = 10,008 N
30 mph Rigid Barrier	MY99 Intrepid	V3126	54.1	25.7	223	0.40	7,890 (R)
	MY99 Tacoma	V3128	35.6	23.5	173	0.69	6,372 (R)
	MY99 Acura RL	V3125	49.8	11.6	367	0.44	7,676 (R)
	MY99 Saturn SC1	V3127	40.2	9.2	200	0.50	6,374 (L)
	MY99 Econoline	V3123	45.8	7.3	226	0.35	8,039 (R)
	MY99 Expedition	V3124	51.0	19.6	132	0.34	6,975 (R)
	MY98 Taurus	V2832	48.5	8.8	191	0.43	5,697 (L)
	MY98 Neon	V2838	**61.4**	16.0	297	0.59	6,606 (L)
	MY98 Camry	V2837	35.1	16.7	236	0.26	5,273 (R)
	MY98 Accord	V2836	45.0	13.1	160	0.39	4,677 (L)
	MY98 Explorer4L	V2839	48.2	10.3	186	0.31	6,341 (R)
	MY98 Voyager	V2773	53.4	20.3	249	0.48	8,025 (R)
	MY98 Cherokee	V2830	49.2	12.2	84	0.49	7,921 (R)
25 mph Rigid Barrier	MY99 Intrepid	V3147	48.1	18.3	83	0.39	9,016 (L)
	MY99 Tacoma	V3146	23.5	15.6	82	**1.15**	5,236 (R)
	MY99 Acura RL	V3145	32.8	17.3	119	0.44	6,215 (R)
35 mph 40% Offset Deformable Barrier	MY99 Intrepid	V3143	53.2	19.5	197	0.57	7,592 (L)
	MY99 Tacoma	V3148	39.4	23.4	208	0.57	4,591 (L)
30 mph 30E Right Barrier	MY99 Intrepid	V3144	34.7	6.0	234	0.43	5,179 (L)
30 mph 30E Left Barrier	MY99 Intrepid	V3117	45.5	18.9	288	0.44	6,267 (L)

TABLE A-3. UNBELTED DRIVER 5th PERCENTILE FEMALE

		Test #	Chest G IARV = 60.0	Chest Disp. (mm) IARV = 52.0	HIC15 IARV = 700	Nij ver. 9 IARV = 1.00	Maximum Femur (N) IARV = 6,805
30 mph, 0 Degree Rigid Barrier	MY99 Saturn SL1	V3113	37.0	31.1	106	0.37	3,566 (L)
	MY99 Intrepid	V3118	56.6	**52.8**	139	**1.52**	4,778 (R)
	MY99 Tacoma	V3119	52.3	51.5	201	0.48	6,172 (R)
25 mph, 0 Degree Rigid Barrier	MY99 Intrepid	V3122	40.5	32.1	99	0.35	4,674 (R)
	MY99 Tacoma	V3115	50.5	40.5	239	0.62	4,712 (L)
35 mph 40% Offset Deformable Barrier	MY99 Intrepid	V3121	51.5	40.9	472	**1.94**	2,927 (R)
	MY99 Tacoma	V3120	44.4	36.9	354	0.57	3,466 (L)
	MY99 Saturn SL1	TBD	33.6	**55.1**	99	0.36	3,612 (L)
30 mph, 30 Degree Left Angular Barrier	MY99 Intrepid	V3116	44.5	27.6	87	**1.69**	4,249 (R)
30 mph, 30 Degree Right Angular Barrier	MY99 Intrepid	TBD (retest)	TBD	TBD	TBD	TBD	TBD
35 mph, 30 Degree Right Angular Barrier	MY99 Intrepid	V3114	35.2	25.8	62	**1.39**	4,189 (R)

TABLE A-4. UNBELTED PASSENGER 5th PERCENTILE FEMALE

		Test #	Chest G IARV = 60.0	Chest Disp. (mm) IARV = 52.0	HIC15 IARV = 700	Nij ver. 9 IARV = 1.00	Maximum Femur (N) IARV = 6,805
30 mph, 0 Degree Rigid Barrier	MY99 Saturn SL1	V3113	44.9	15.2	277	0.73	3,259 (R)
	MY99 Intrepid	V3118	**62.1**	13.1	303	0.62	5,078 (L)
	MY99 Tacoma	V3119	42.3	4.2	380	**2.65**	5,974 (L)
25 mph, 0 Degree Rigid Barrier	MY99 Intrepid	V3122	35.2	4.6	121	0.52	4,324 (R)
	MY99 Tacoma	V3115	35.0	3.7	143	**2.06**	5,419 (L)
35 mph 40% Offset Deformable Barrier	MY99 Intrepid	V3121	**77.7**	12.3	368	**1.70**	4,450 (L)
	MY99 Tacoma	V3120	41.7	1.1	164	0.61	3,373 (L)
	MY99 Saturn SL1	TBD	24.0	5.7	45	0.31	3,701 (L)
30 mph, 30 Degree Left Angular Barrier	MY99 Intrepid	V3116	51.0	5.8 [1]	124 [2]	0.48	5,396 (L)
30 mph, 30 Degree Right Angular Barrier	MY99 Intrepid	TBD (retest)	TBD	TBD	TBD	TBD	TBD
35 mph, 30 Degree Right Angular Barrier	MY99 Intrepid	V3114	58.0	11.3	295	0.64	6,158 (L)

[1] = VRTC noted that passenger chest displacement is suspicious.
[2] = VRTC noted that z head acceleration was noisy and HIC computations did not include it.

Compliance Margins:

To date, NHTSA has tested thirteen vehicles with redesigned air bags in unbelted 48 km/h rigid barrier tests. All but one driver Hybrid III dummy and all but one passenger Hybrid III dummy met the requirements of FMVSS No. 208's current injury criteria. The one driver failure was a femur load (13,349 N) and the passenger failure was the chest Gs (61.3) The vehicles tested represent a range of passenger car sizes, a minivan, a full size van and two sports utility vehicles. In general, chest Gs are the injury measures which will most be affected by redesigned air bags. Chest Gs for driver and passenger Hybrid III's in these tests are shown in Table A-5 and Figures A-1 and A-2. (Of these thirteen vehicles, NHTSA has tested twelve of the pre-redesigned models.) A comparison of the test results of redesigned air bags to FMVSS No. 208 compliance tests of 1996 and 1997 model year vehicles and manufacturers certification of 1997 vehicles with pre-redesigned air bags is presented in Figure A-3 for drivers and passengers. This figure shows chest Gs in terms of margin of compliance with the 60 G requirement, i.e., 48 Gs would be 20 percent. From this figure (and the complete listing in Tables A-6 and A-7), it can be seen that the scatter for redesigned air bags is similar to that for pre-redesigned air bags.

TABLE A-5: Resultant Chest Gs in 208 Barrier Tests, Unbelted 50th% HIII Dummy

	Pre-'98 Driver	'98 Driver	'99 Driver	Pre-'98 Pass	'98 Pass	'99 Pass
Taurus	50.4	47.2	NA	45.6	48.5	NA
Explorer	53.2	44.4	NA	44.6	48.2	NA
Neon	47.3	43.5	NA	46.1	61.4	NA
Camry	49	51.8	NA	47.3	35.1	NA
Caravan	47.5	48.0	NA	39	53	NA
Accord	40.2	36.7	NA	40.2	45	NA
Intrepid	40.6	NA	54.4	52.4	NA	54.1
Saturn	33	NA	36.8	41.6	NA	40.2
Acura RL	45	NA	56.9	45.9	NA	49.8
Econoline	47.3	NA	52.1	44.6	NA	45.7
Expedition	42.2	NA	46.7	43.7	NA	51
Tacoma	46.4	NA	43.7	46	NA	35.6
Average	46.1	45.3	48.4	44.8	48.5	46.1

208 Crash Test Results

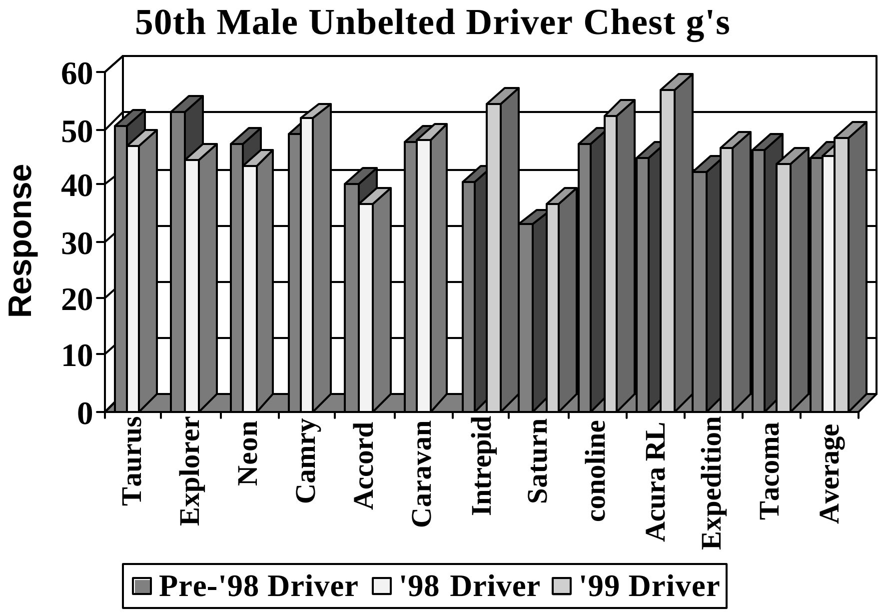


Figure A-1. Driver Resultant Chest Gs , Unbelted 50th Percentile HIII Dummies in FMVSS No. 208, 48 Kmph Barrier Test

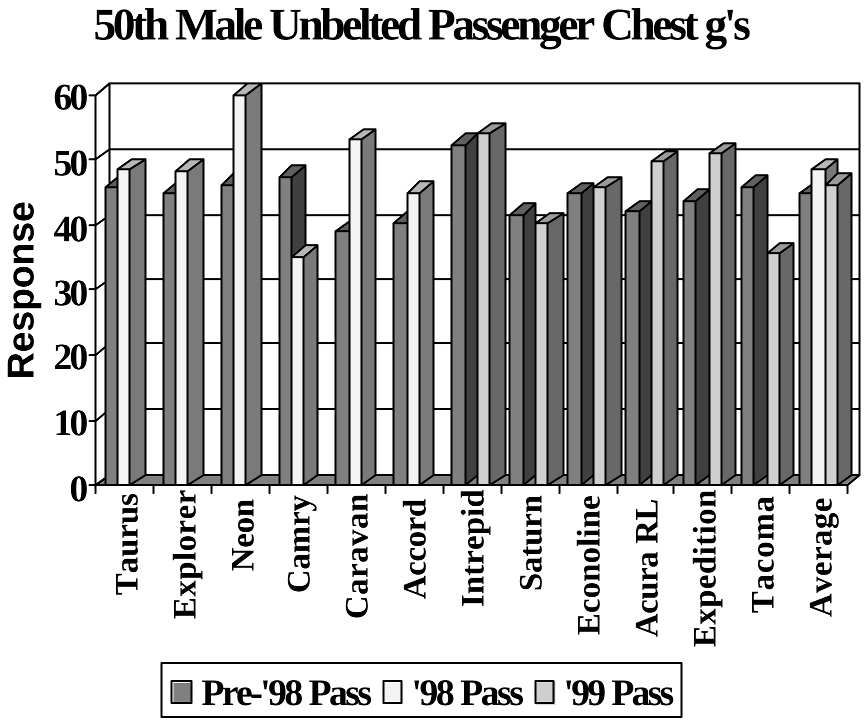
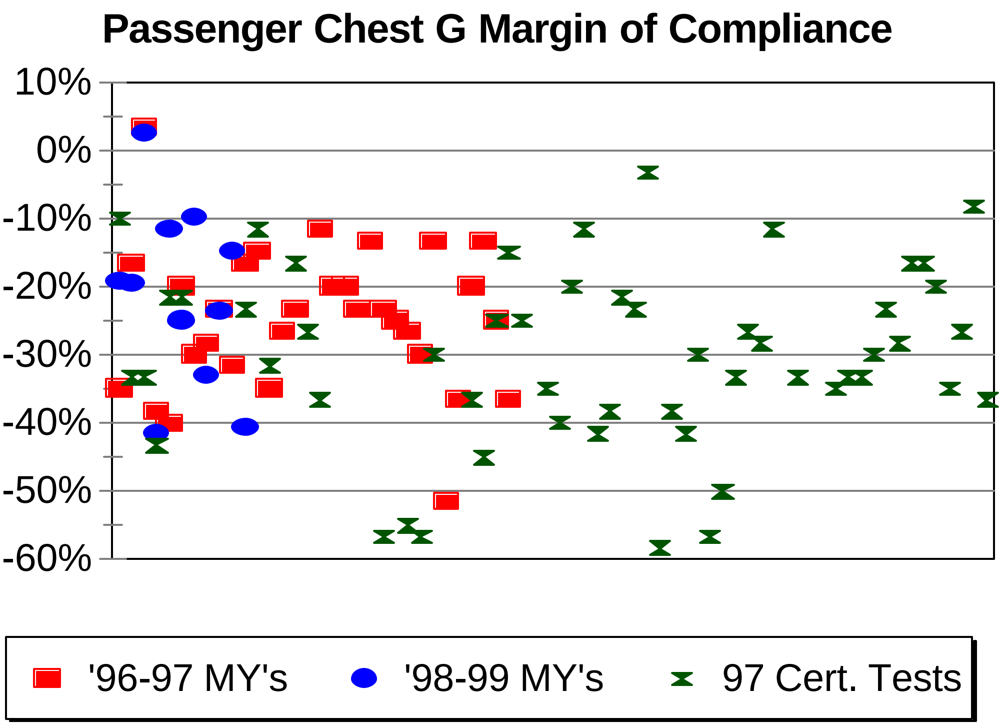


Figure A-2. Passenger Resultant Chest Gs , Unbelted 50th Percentile HIII Dummies in FMVSS No. 208, 48 Kmph Barrier Test



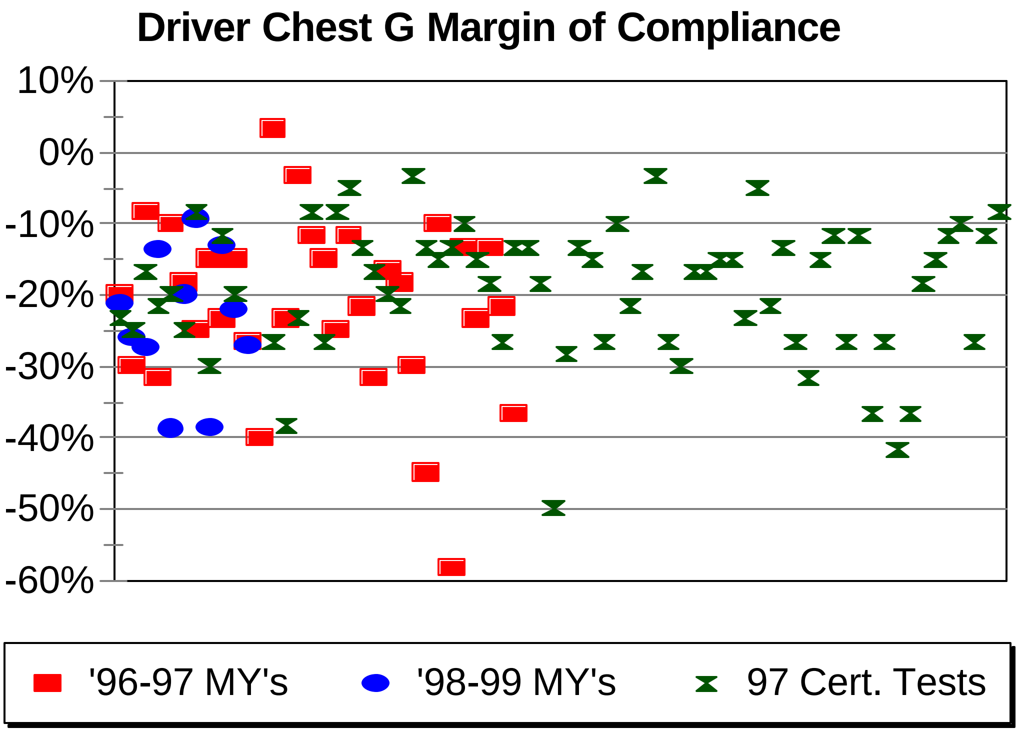


Figure A-3. Comparison of Margin of Compliance, Unbelted 50th Percentile HIII Dummies in FMVSS No. 208, 48 Kmph Barrier Test

Manufacturers stated that to be comfortable with their vehicle certification they have established a 20 percent margin of compliance and that anything less would indicate a problem with certification. Drivers with redesigned air bags (98 and 99 model year's) had a margin less than 20 percent of the 60 G criteria (above 48 Gs) in 33 percent (4 of 12) NHTSA tests, while drivers with pre-redesigned air bags (96 and 97 model years) had less than 20 percent margins in 47 percent (15 of 32) of the compliance tests and 56 percent (38 of 68) in the certification tests. For passengers, the percentage having less than a 20 percent margin was 58 percent (7 of 12) with redesigned air bags and 26 percent (8 of 31) with pre-redesigned air bags in compliance tests and 19 percent (10 of 54) in the certification tests. These results indicate that with regard to compliance margins for chest Gs redesigned air bags provide similar performance, albeit higher percentages with less than 20 percent margin of compliance for passengers but lower percentages for drivers.

Table A-6. FMVSS No. 208, 48 Kmph, Rigid Barrier Test with Unbelted 50th Percentile Hybrid III Dummies, Chest Gs and Compliance Margin (NHTSA Compliance Tests)

Year Make Model	Driver Chest Gs	Margin	Passenger Chest Gs	Margin
1996 Dodge Caravan	48	20.0%	39	35.0%
1996 Pontiac Bonneville	42	30.0%	50	16.7%
1996 Mitsubishi Mirage	55	8.3%	62	-3.3%
1996 Lincoln Towncar	41	31.7%	37	38.3%
1996 Volvo 850	54	10.0%	36	40.0%
1996 Jeep Cherokee	49	18.3%	48	20.0%
1996 Subaru Impreza	45	25.0%	42	30.0%
1996 Honda Civic	51	15.0%	43	28.3%
1996 Toyota Tacoma	46	23.3%	46	23.3%
1996 Hyundai Accent	51	15.0%	41	31.7%
1996 Saab 900	44	26.7%	50	16.7%
1996 Isuzu Rodeo	36	40.0%	51	15.0%
1996 Hyundai Sonata	62	-3.3%	39	35.0%
1996 Toyota Celica	46	23.3%	44	26.7%
1996 Toyota 4Runner	58	3.3%	46	23.3%
1996 Nissan	53	11.7%		
1996 Nissan Pathfinder	51	15.0%	53	11.7%
1996 Isuzu Trooper	45	25.0%	48	20.0%
1996 BMW 318ti	53	11.7%	48	20.0%
1996 Dodge Neon	47	21.7%	46	23.3%
1996 Dodge Intrepid	41	31.7%	52	13.3%
1996 Ford Taurus	50	16.7%	46	23.3%
1997 Ford F-150	49	18.3%	45	25.0%
1997 Ford Expedition	42	30.0%	44	26.7%
1997 Saturn SL	33	45.0%	42	30.0%
1997 Pont. GrandAm	54	10.0%	52	13.3%
1997 Lincoln Mk VIII	25	58.3%	29	51.7%
1997 Mitsubishi Galant	52	13.3%	38	36.7%
1997 Cad. Eldorado	46	23.3%	48	20.0%
1997 Chrysler Sebring	52	13.3%	52	13.3%
1997 Ford Econoline	47	21.7%	45	25.0%
1997 Chevrolet S-10	38	36.7%	38	36.7%
Averages	47.0625	21.6%	45.16129	24.7%

Table A-7. FMVSS No. 208, 48 Kmph, Rigid Barrier Test with Unbelted 50th Percentile Hybrid III Dummies, Chest Gs and Compliance Margin (Manufacturers' Certification Tests)

Make Model	Driver Chest Gs	Margin	Passenger Chest Gs	Margin
Chrysler Sebring Convertible	46	23.3%	54	10.0%
Jeep Wrangler	45	25.0%	40	33.3%
Jeep Wrangler	50	16.7%	40	33.3%
Ford E-150	47	21.7%	34	43.3%
Ford Escort	48	20.0%	47	21.7%
Ford Escort	45	25.0%	47	21.7%
Ford Expedition	55	8.3%		
Ford Expedition	42	30.0%		
Ford Expedition	53	11.7%		
Ford Expedition	48	20.0%		
Ford Expedition			46	23.3%
Ford Expedition			53	11.7%
Lincoln Mk VIII	44	26.7%	41	31.7%
Buick Century	37	38.3%		
Buick Park Avenue	46	23.3%	50	16.7%
Cadillac DeVille	55	8.3%	44	26.7%
Cadillac Eldorado	44	26.7%	38	36.7%
Chevrolet S10 Blazer	55	8.3%		
Chevrolet S10 Blazer	57	5.0%		
Chevrolet S10 Blazer	52	13.3%		
Chevrolet S10 Blazer	50	16.7%		
Chevrolet Van	48	20.0%	26	56.7%
Chevrolet Van	47	21.7%		
Chevrolet Van	58	3.3%	27	55.0%
Chevrolet Van	52	13.3%	26	56.7%
Chevrolet Venture	51	15.0%	42	30.0%
Geo Tracker	52	13.3%		
Geo Tracker	54	10.0%		
Pontiac Firebird	51	15.0%	38	36.7%
Pontiac Firebird	49	18.3%	33	45.0%
Pontiac Grand AM	44	26.7%	45	25.0%
Pontiac Grand Prix	52	13.3%	51	15.0%
Pontiac Sunfire	52	13.3%	45	25.0%
Pontiac Sunfire	49	18.3%		
Saturn Sedan	30	50.0%	39	35.0%
Saturn Coupe	43	28.3%	36	40.0%
Hyundai Elantra	52	13.3%	48	20.0%
Hyundai Elantra	51	15.0%	53	11.7%
Kia Sephia	44	26.7%	35	41.7%

Land Rover Discovery	54	10.0%	37	38.3%
Mercedes C Class	47	21.7%	47	21.7%
Mercedes C Class	50	16.7%	46	23.3%
Mercedes E Class	58	3.3%	58	3.3%
Mitsubishi Galant	44	26.7%	25	58.3%
Mitsubishi Mirage	42	30.0%	37	38.3%
Mitsubishi Mirage	50	16.7%	35	41.7%
Mitsubishi Mirage	50	16.7%	42	30.0%
Mitsubishi Mirage	51	15.0%	26	56.7%
Mitsubishi Mirage	51	15.0%	30	50.0%
Mitsubishi Montero	46	23.3%	40	33.3%
Nissan Infiniti Q45	57	5.0%	44	26.7%
Nissan Altima	47	21.7%	43	28.3%
Nissan Quest	52	13.3%	53	11.7%
Saab 9000	44	26.7%		
Saab 9000	41	31.7%	40	33.3%
Suzuki Sidekick	51	15.0%		
Suzuki X-90	53	11.7%		
Toyota Lexus ES300	44	26.7%	39	35.0%
Toyota Lexus LS400	53	11.7%	40	33.3%
Toyota Lexus SC300	38	36.7%	40	33.3%
Toyota Camry	44	26.7%	42	30.0%
Toyota Camry	35	41.7%	46	23.3%
Toyota Land Cruiser	38	36.7%	43	28.3%
Toyota RAV4	49	18.3%	50	16.7%
Toyota RAV4	51	15.0%	50	16.7%
Toyota RAV4	53	11.7%	48	20.0%
Toyota RAV4	54	10.0%	39	35.0%
Toyota RAV4	44	26.7%	44	26.7%
Toyota RAV4	53	11.7%	55	8.3%
Volkswagen Passat	55	8.3%	38	36.7%
Averages	**48.5**	**19.2%**	**41.8**	**30.4%**

APPENDIX B

B - VALIDATION OF SIMULATED CRASH CONDITIONS

B.1 Finite Element Simulations

Under the Partnership for a New Generation of Vehicles (PNGV) research program, NHTSA is currently developing a series of finite element vehicle models. One of the first vehicle models to be developed under this program is a model of the 1996 Dodge Neon. This model has been developed with a high degree of detail and was chosen as the baseline vehicle for this simulation study. The vehicle model consists of 311 materials, 295,000 nodes and, 270,000 elements. The Neon model has been validated for frontal and frontal offset conditions. Additional work is currently underway to evaluate the model performance in side and rear impact simulations. A simulation of an FMVSS 208 rigid barrier test took one week to complete on 4 processors of an SGI Power Challenge parallel computer. The simulation was run for 150 milliseconds. Plots of the vehicle profile at the beginning and end of the simulation are shown in Figures B-1 and B-2

.

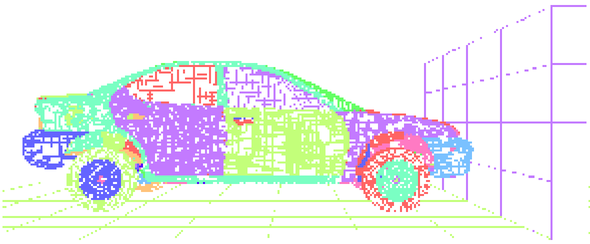


Figure B-1: FMVSS No. 208 Simulation, 0 ms

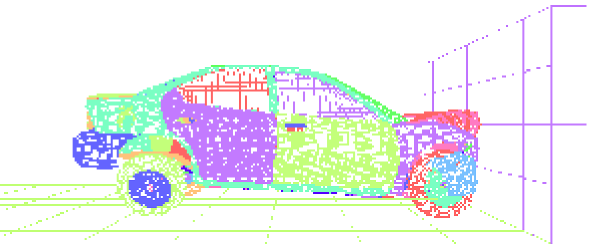


Figure B-2: FMVSS No. 208 Simulation, 150 ms

Figures B-3 and B-4 show the simulation computed accelerations of the driver and passenger seat cross members plotted against data from NHTSA test number 2434, a FMVSS No. 208 compliance test of the Dodge Neon. The test data for the driver seat has a anomalous negative data spike around 95 milliseconds, but otherwise the data were deemed useable. The driver seat simulation computed acceleration shows a good correlation to the measured test acceleration. Similarly, the passenger seat simulation computed acceleration shown in Figure B-4 also shows good correlation with the test data. For the rest of the simulations, the driver seat data were used for comparison, however for the test data validation, the passenger data is shown due to the spike in the driver data. Differences between the right and left seat accelerations are generally minor, due to asymmetries in the vehicle structure. Figures B-5 and B-6 compare the corresponding velocity profiles for the driver and passenger seat data. Again the correlations are good, though the spike in the driver's test data causes a significant deviation in the velocity profile after 90 milliseconds.

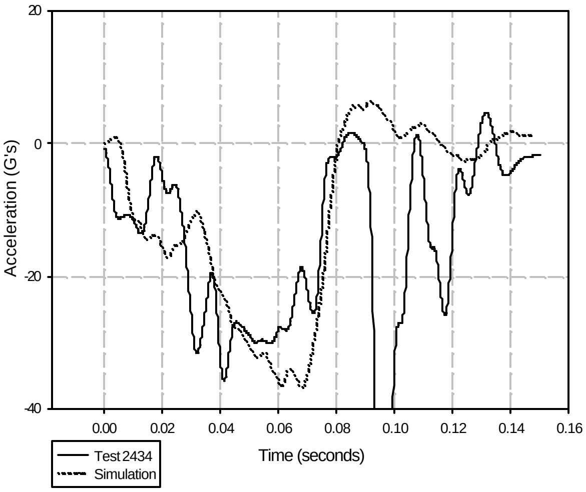


Figure B-3: 208 Simulation - Driver Seat Cross member

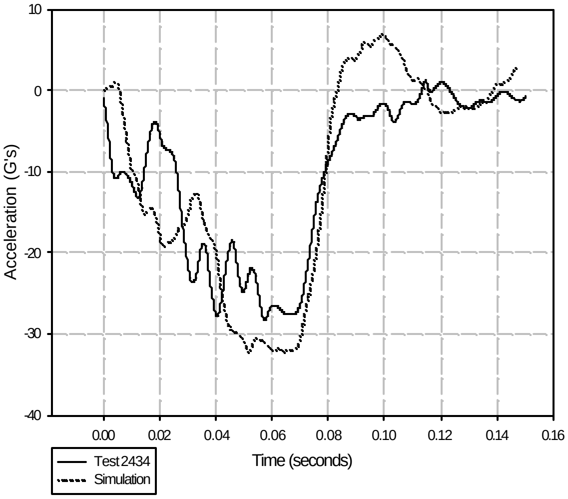


Figure B-4: 208 Simulation - Passenger Seat Cross member

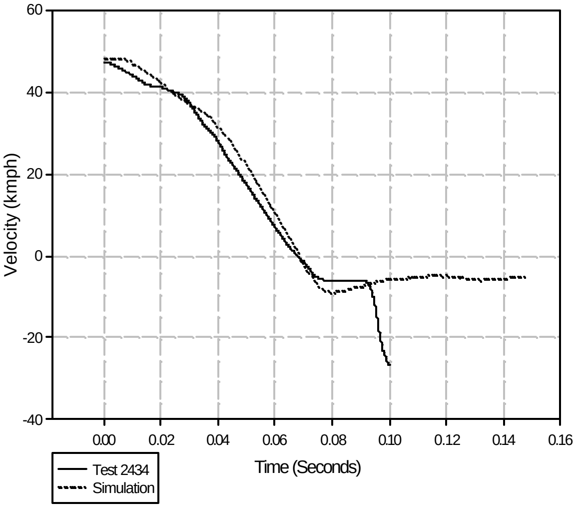


Figure B-5: 208 Simulation - Driver Seat Cross Member

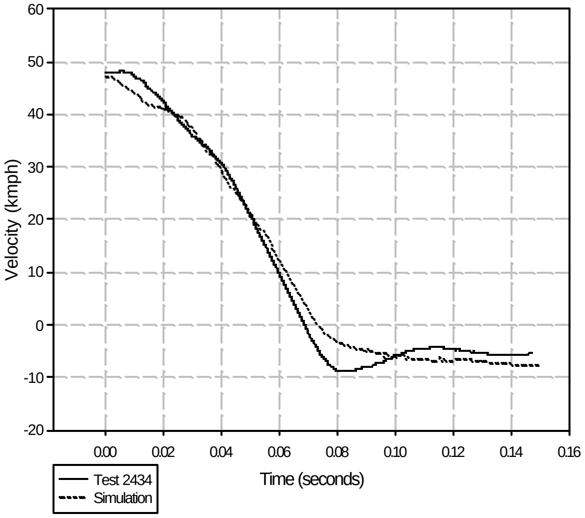


Figure B-6: 208 Simulation - Passenger Seat Cross Member

B.1.1 Fixed Full Frontal Deformable Barrier Simulations

A full frontal fixed deformable barrier, FFFDB, was modeled by extending the length of an existing model for the EEVC frontal offset barrier. This barrier face, as shown in Figure B-7, is similar to the honeycomb face used on the FMVSS No. 214 moving deformable barrier. A 48 kmph simulation was run for the Neon model into the FFFDB. Figures B-8 and B-9show the final configuration at 150 milliseconds. The bumper of the Neon moved forward 380 mm, (14.96 in), after initial contact of the barrier face.

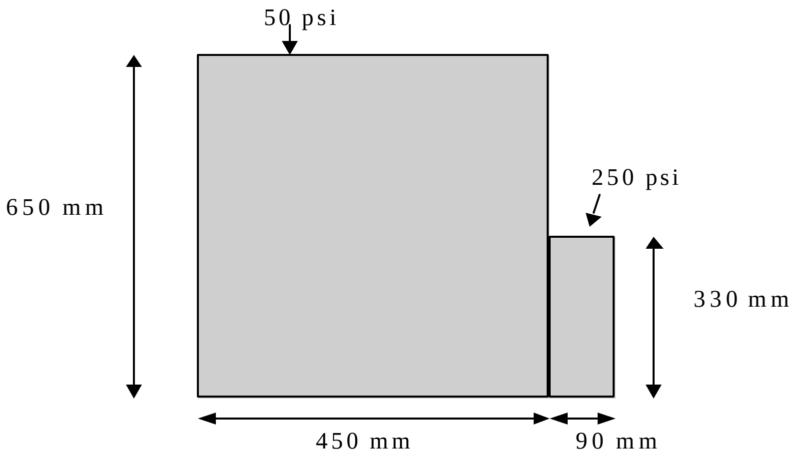


Figure B-7: European Frontal Offset Deformable Barrier Face

Table B-1 lists the energy dissipation computed for the FFFDB simulation. Over 50 percent of the initial kinetic energy was absorbed in the body structure of the neon. An additional 35 percent was absorbed in the honeycomb structure. The 11 percent simulation error is due to “shortcuts” taken to reduce the simulation time. The high deformation of the honeycomb material reduces the allowable time step required for an accurate solution. To properly simulate the large deformations in the honeycomb could take over a month to compute; therefore, the minimum time step was limited to 1 microsecond.

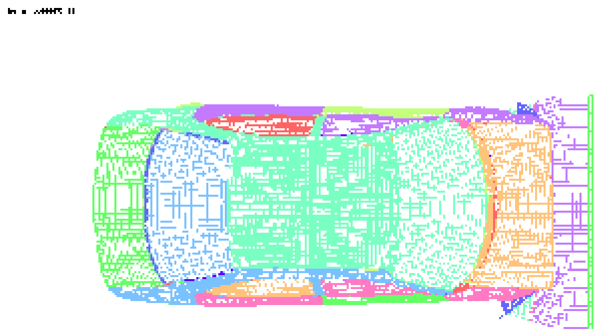


Figure B-8: Neon into FFFDB, 150 ms

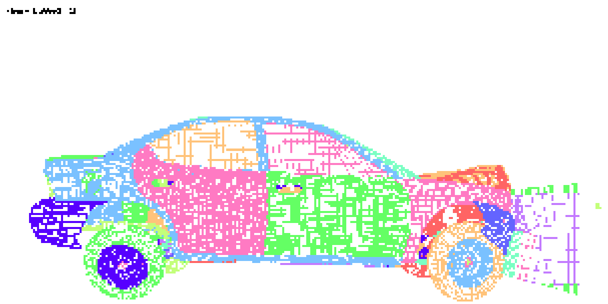


Figure B-9: Neon into FFFDB, 150 ms

Table B-1: Energy Dissipation in FFFDB simulation

Neon Structure	50.49 %
50 psi Honeycomb	31.15 %
250 psi Honeycomb	5.94%
Final Kinetic Energy	1.60 %
Simulation Error	10.83%
Total Energy	99.99 %

B.1.2 Inline Vehicle-to-Vehicle Simulations

For comparison purposes, two 30 mph vehicle-to-vehicle simulations were/are being conducted. The first was a Neon-to-Neon full frontal engagement simulation. Both Neon models were initially moving at 48 kmph. The second vehicle to vehicle simulation used a Chevrolet CK2500 pickup truck model. The pickup truck model is substantially less complex than the Neon model, consisting of 211 materials, 62,000 nodes, and 50,000 elements. Figures B-10 and B-11 show the configuration for the inline Neon into CK simulation, each vehicle initially moving at 48 kmph.

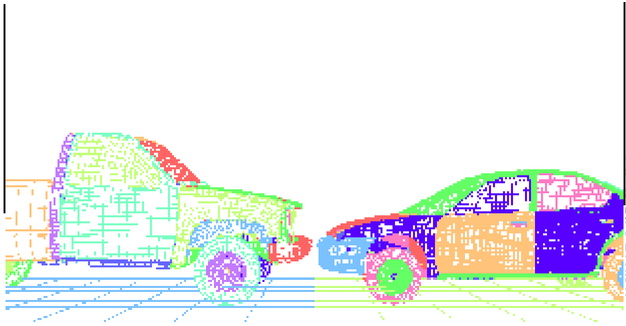


Figure B-10: Neon - CK, 0 ms

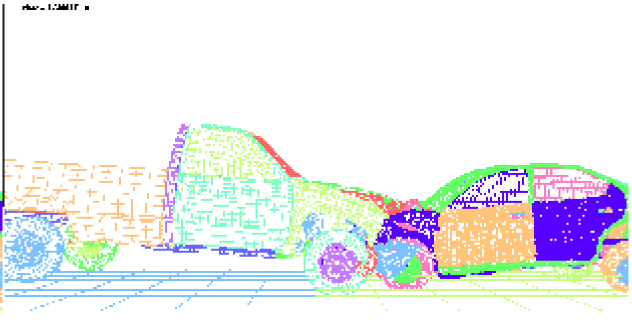


Figure B-11: Neon - CK, 150 ms

B.1.3 Angled Barrier Simulations

Four simulations were conducted using the Neon model to evaluate the effect of angled barrier impacts. The Neon model was impacted against 30 degree and 15 degree angled barriers at both 48 kmph and 40 kmph, Figures B-12 through B-15 show the configurations for the 30 degree and 15 degree simulations, respectively.

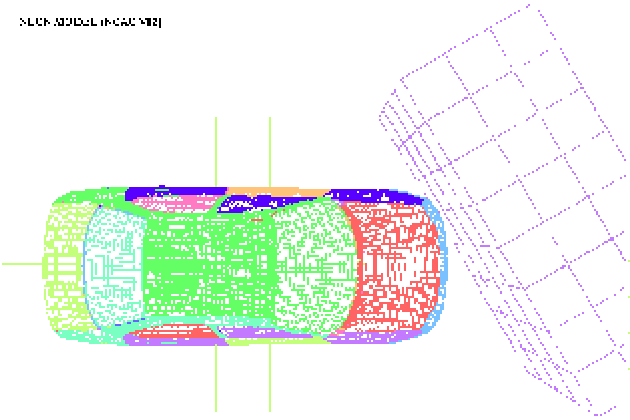


Figure B-12: 30 Degree, 48 kmph, 0 ms

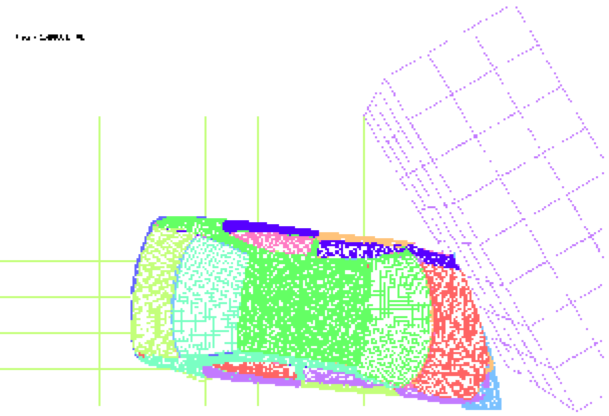


Figure B-13: 30 Degree, 48 kmph, 150 ms

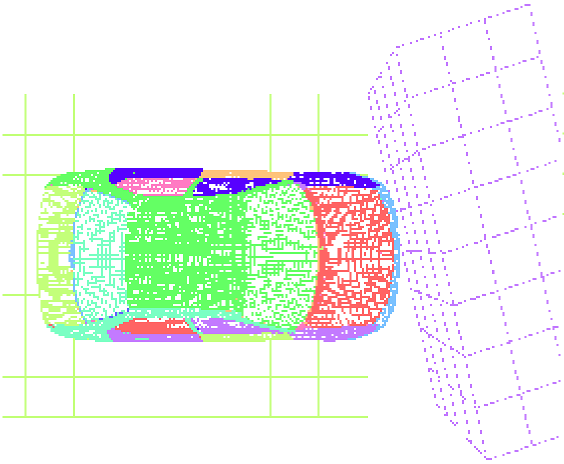


Figure B-14: 15 degree, 48 kmph, 0 ms

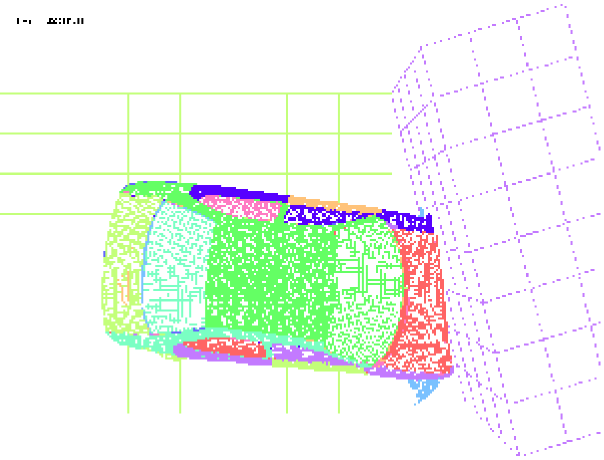


Figure B-15: 15 degree, 48 kmph, 150 ms

Figure B-16 compares the acceleration profiles for 48 and 40 kmph at both 15 and 30 degrees. The 15 degree impacts have significantly higher peak accelerations than the corresponding 30 degree impacts. Lowering the impact velocity from 48 kmph to 40 kmph reduced the peak decelerations by 15.1 and 7.8 G's for the 15 and 30 degree simulations respectively. Note that these figures are for the longitudinal measurements, the 30 degree impacts have a significant lateral acceleration, which raises the peak resultant acceleration 34.9 G's for the 48 kmph simulations and to 27.4 G's for the 40 kmph simulation. For comparison, Figures B-16 and B-17 shows the generic sled pulse which produced a lower and longer acceleration pulse than any of the angled barrier tests.

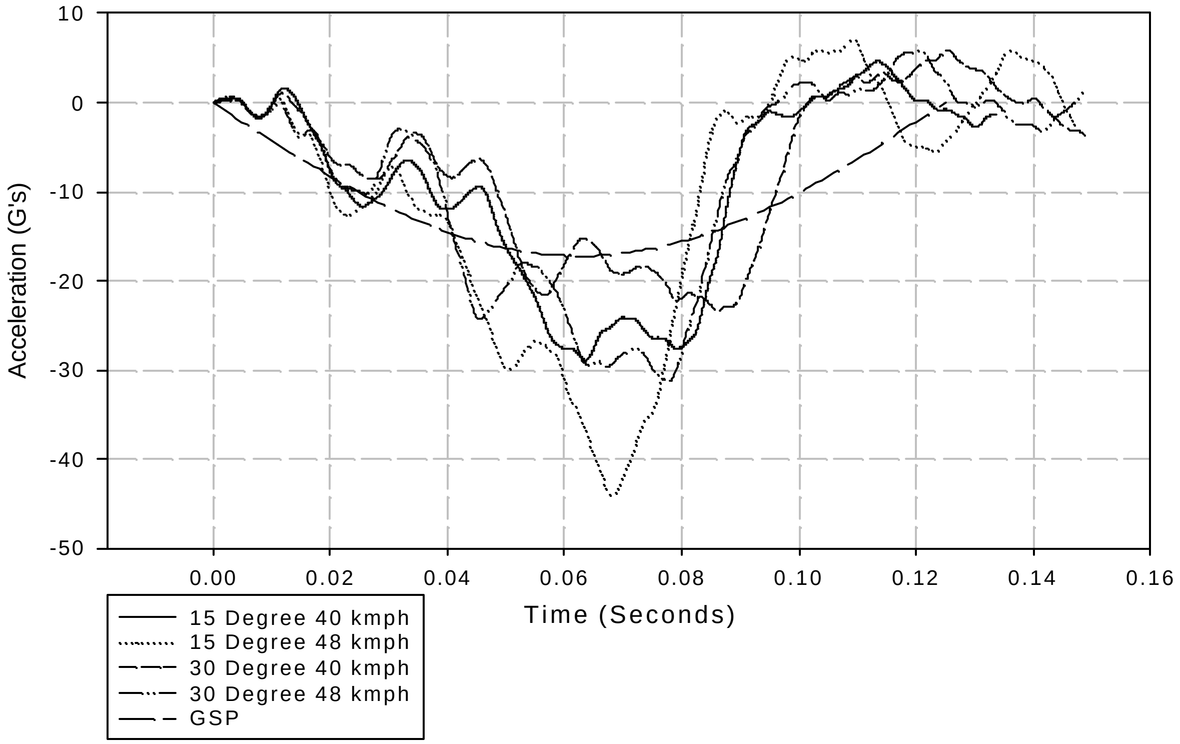


Figure B-16: Longitudinal Accelerations for Angled Barrier Simulations and the Generic Sled Pulse

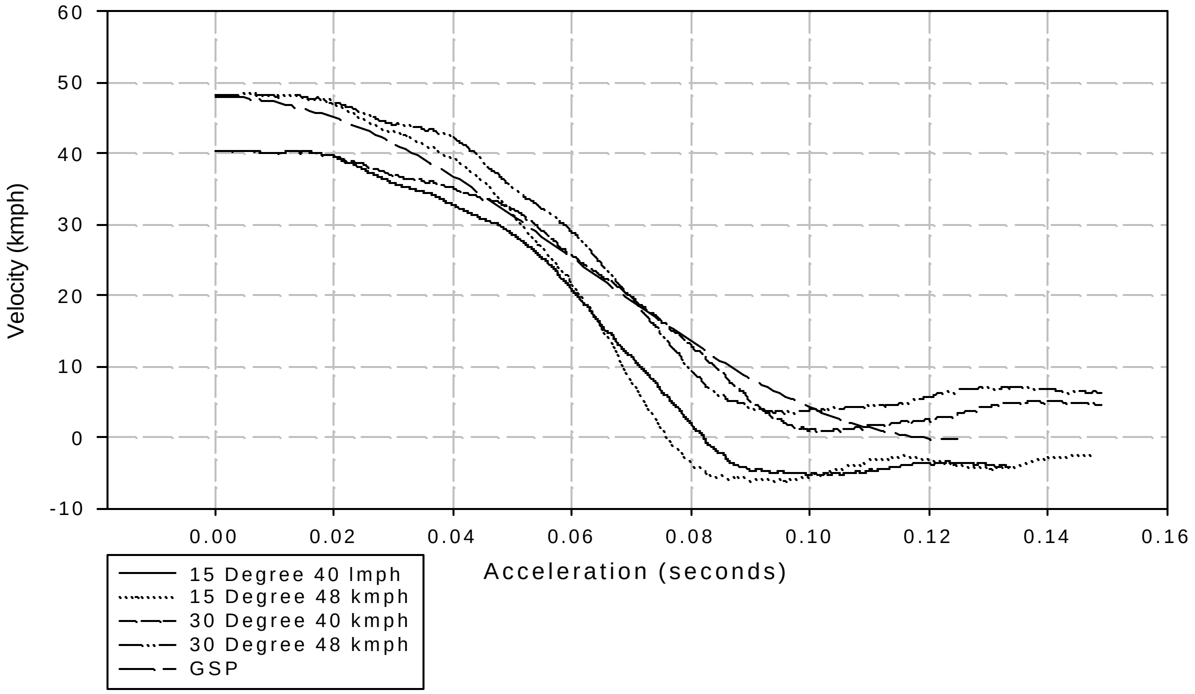


Figure B-17: Longitudinal Velocities for Angled Barrier Simulations and the Generic Sled Pulse

B.1.4 Oblique Offset Impact Simulations

An Oblique offset simulation for the CK pickup into the Neon has been conducted. For this simulation each vehicle had an initial velocity of 48 kmph, with an angle of 30 degrees between the line of travel of the two vehicles. Figures B-18 and B-19 show the initial and final profiles for this configuration. The Neon experienced severe deformation and occupant compartment intrusion.

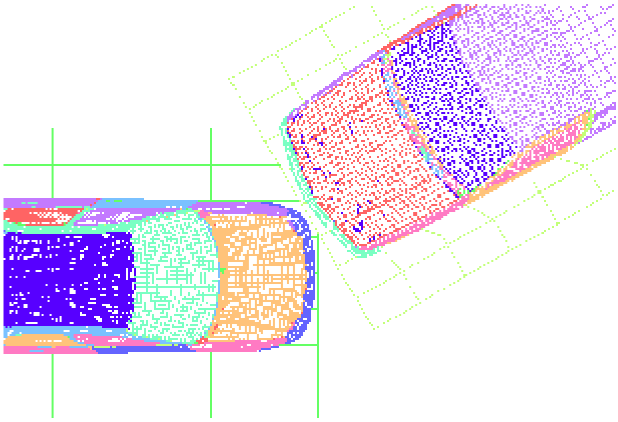


Figure B-18: Neon - CK 30 Degree 50% Offset, 0 ms

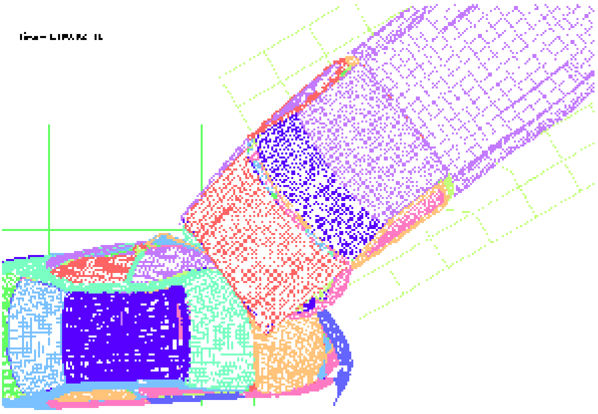


Figure B-19: Neon - CK 30 Degree 50% Offset, 150 ms

B.2 Intrusion Measurements

Eight of the simulations were selected for analyzing the occupant compartment intrusion. These simulations included the 48 kmph full frontal rigid wall tests at 0, 15, 30 degrees, the 48 kmph full frontal fixed deformable barrier, and the vehicle-to-vehicle collisions. The intrusion estimates were based on the motions of the A-pillar, the left lower instrument panel and the toe board/floorboard. For the toe board/floorboard intrusion, six points in two horizontal rows were defined. The toeboard longitudinal, rearward intrusion was estimated at both upper row and lower row levels as shown in Figure B-20.

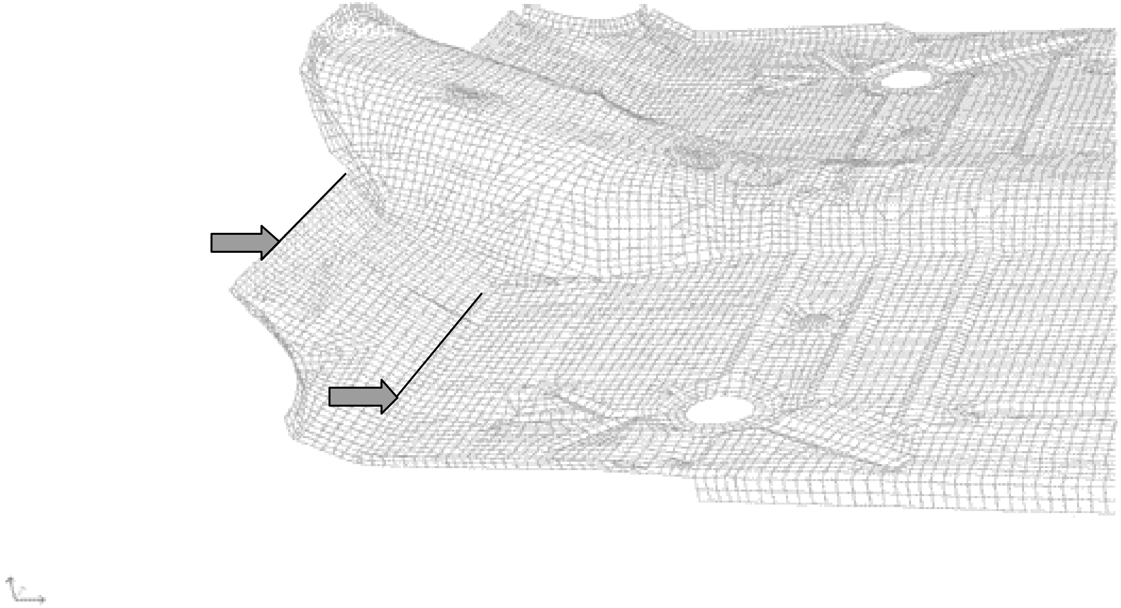


Figure B-20: 208 Simulation, Toeboard/Floorboard Configuration

For each of the points selected as the toe board intrusion measurement locations, displacement measurements were taken for both the X and Y axes. In order to separate the vehicle motion from the intrusion, a node corresponding to the center of the rear bumper was selected as a reference point. The maximum difference between the displacement of the reference node and the six selected nodes respectively determined the toe board intrusion. Figure B-21 shows the toeboard / floorboard final configuration for the FMVSS No. 208 at 150 milliseconds.

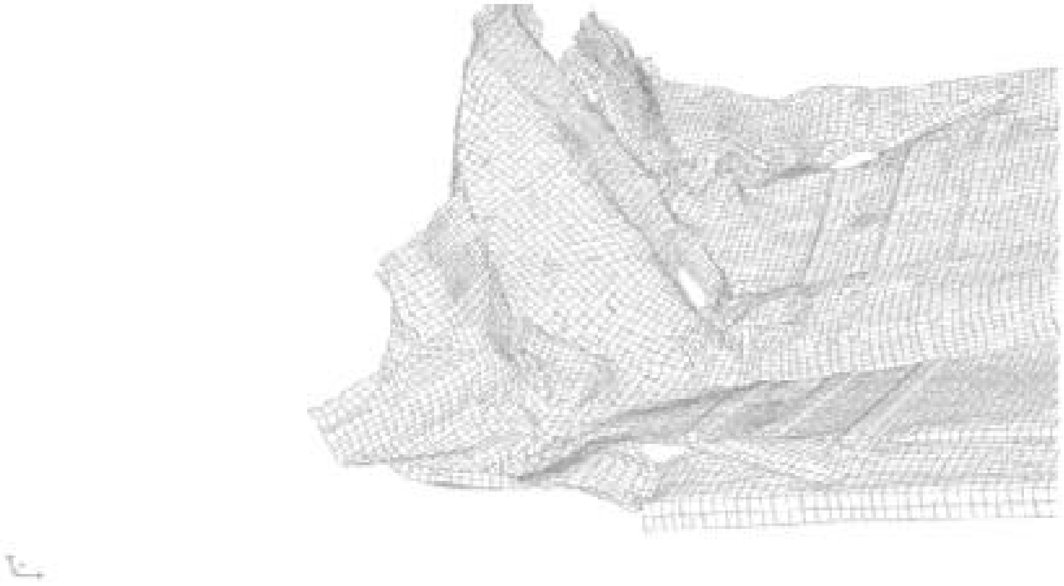


Figure B-21: 208 Simulation, Toeboard/Floorboard Configuration, 150 ms

Figure B-22 shows the final configuration of the toeboard/floorboard of the Neon for the 30 degree, 49 kmph rigid barrier impact simulation.

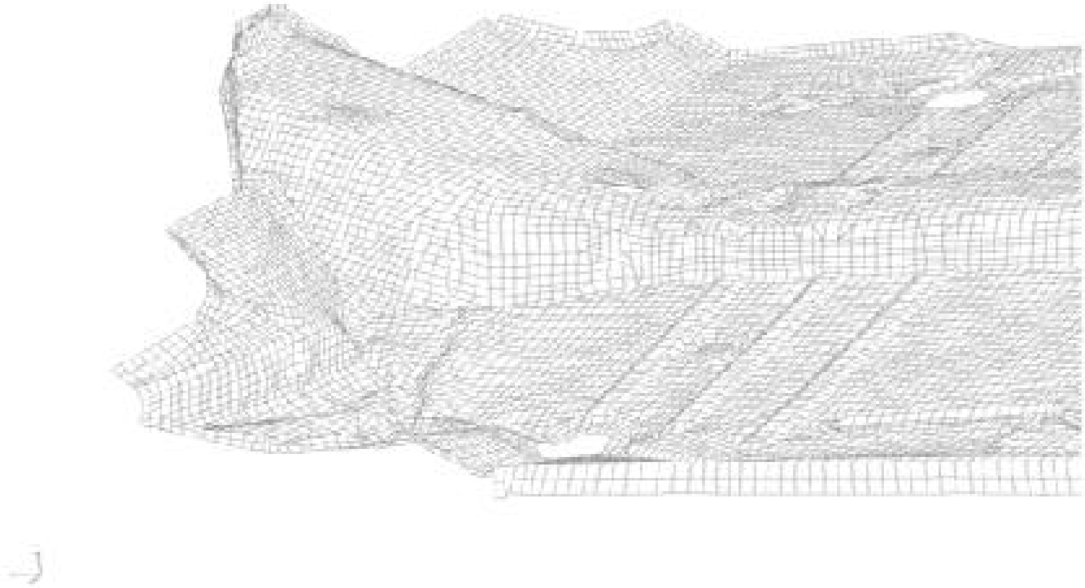


Figure B-22: 30 Degree, 48 kmph Floorboard/Toeboard Configuration, 150 ms

Figure B-23 shows the final toe board/floorboard configuration for the inline vehicle-to-vehicle simulation of the Neon into a Chevrolet CK 2500 pickup truck

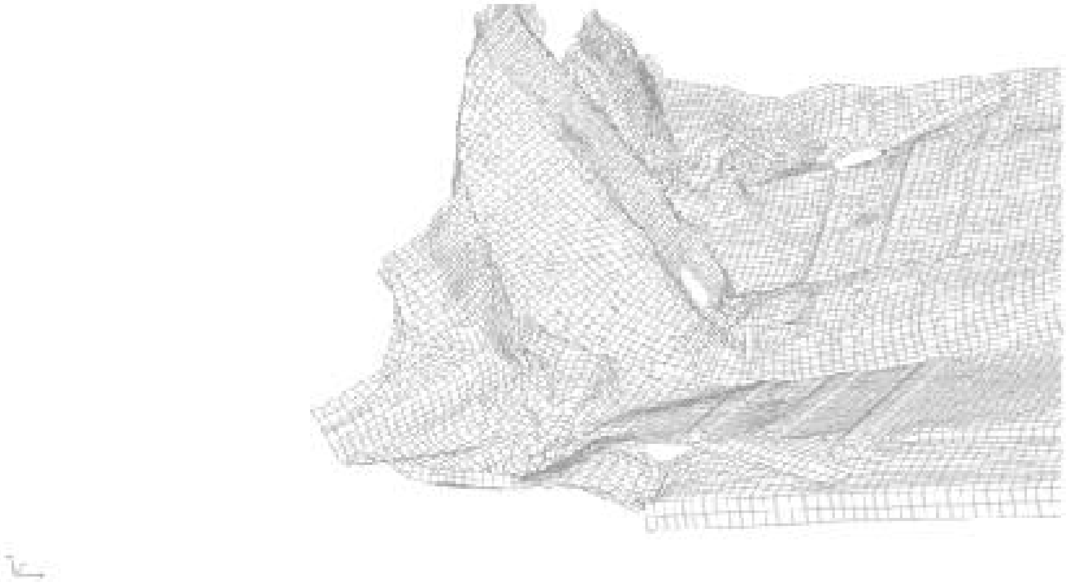


Figure B-23: Neon - CK, Toeboard/Floorboard Configuration, 150 ms

Figure B-24 shows the final toe board/floorboard configurations for the oblique offset impact simulation of the CK pickup truck into the Neon with an angle of 30 degrees between the line of travel of the two vehicles.

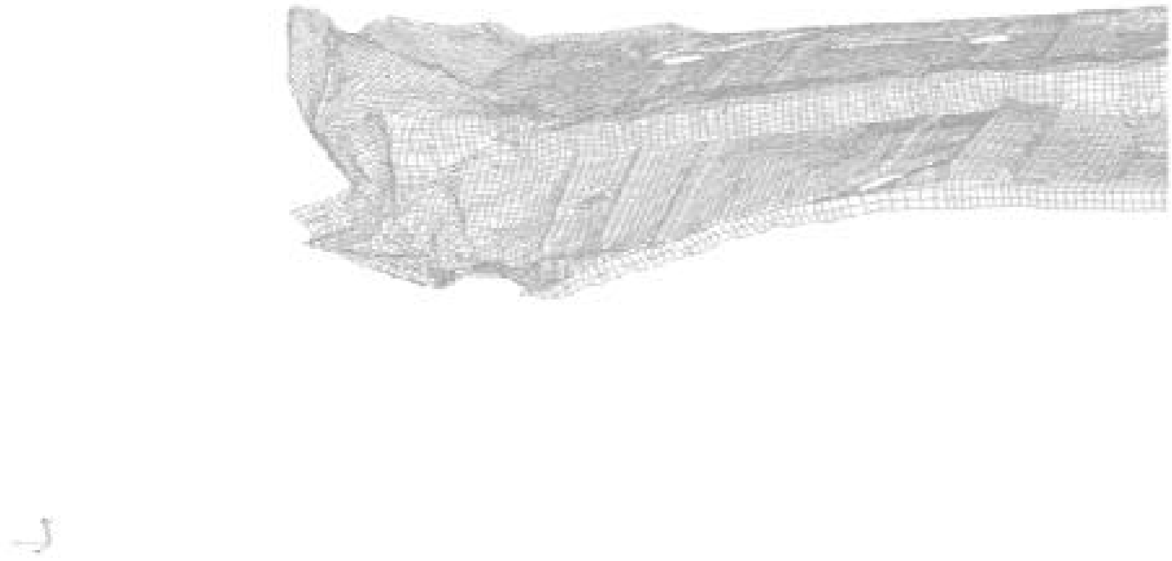


Figure B-24: Neon - CK 30 Degree 50% Offset, Toeboard/Floorboard Configuration, 150ms

The same methodology was developed for the intrusion evaluation of the other two selected interior components, respectively the A-pillar and the lower instrument panel. For each of the latter cases, seven points were selected and the displacements were computed relative to the same reference position on the rear bumper. The intrusion of selected interior components are summarized in Table B-2.

Table B-2: Intrusion of Selected Interior Components

Vehicle	**Intruding Component (mm)**		
	A	**B**	**C**
Neon 208 Barrier	25	145	25
Neon Full Frontal Deformable Barrier	25	50	25
CK into Neon 30 Degree Oblique	250	380	250
Neon 30 mph 30 Degree Rigid Barrier	320	370	370
Neon 25 ph 30 Degree Rigid Barrier	225	350	275

Vehicle	Intruding Component (mm)		
Neon 30 mph 15 Degree Rigid Barrier	280	330	325
Neon 25 mph 15 Degree Rigid Barrier	220	270	260
CK-Neon 30 mph Inline Frontal	60	280	90

A = A-pillar at door junction
B = Toeboard/Floorboard -driver's side
C = Lower Left Instrument Panel

B.3 MADYMO Simulations

The MADYMO articulated mass simulations were conducted by starting with an occupant model for a 1991 Ford Taurus. The interior geometry was adjusted to match the interior of the Neon. The original Taurus air bag was used without alteration and with the initiation time held constant for all of the simulations, 15 ms. The measured injury criteria for the 208 simulation are significantly higher than was measured in the test data. Most of the high injury criteria occurred during contact with the air bag. The model could be significantly improved by using a more representative air bag. The measured injury criteria are shown in Table B-3 below. In Table B-3, The Nij injury parameters are listd as Ntf for tension-flexion, Nte for tension-extension, Ncf for compression-flexion, and Nce for compression-extension.

Table B-3: Injury Criteria from the MADYMO simulations

INJURY PARAMETERS- UNBELTED DUMMY

Test	HIC	3 MS (G's)	Chest Deflection (mm)	Ntf	Nte	Ncf	Nce
Neon 208	856.1 (72-99 ms)	74	49.61	1.17 (79 ms)	1.04 (79 ms)	0.34 (155 ms)	0.11 (33 ms)
Neon - CK	1768.3 (72-105 ms)	105.24	77	1.31 (78 ms)	1.22 (87 ms)	0.73 (161 ms)	0.47 (161 ms)
FFFDB	684.4 (108-136)	68.08	51	1.06 (121 ms)	0.91 (122 ms)	0.20 (117 ms)	0.07 (73 ms)
Generic Sled Pulse	408.3 (77-112 ms)	48.14	37.75	0.73 (100 ms)	0.61 (100 ms)	0.13 (113 ms)	0.10 (64 ms)
Neon - CK Offset Oblique	686.8 (84-120 ms)	47.34	39.22	0.58 (101 ms)	0.82 (93 ms)	0.28 (141 ms)	0.33 (90 ms)
15 Degree Barrier 40 kmph	377.2 (85-119 ms)	49.46	41.74	0.78 (91 ms)	0.66 (97 ms)	0.14 (94 ms)	0.15 (67 ms)
15 Degree Barrier 48 kmph	666.7 (80-110 ms)	66.5	54.91	1.05 (89 ms)	0.96 (89 ms)	0.12 (84 ms)	0.16 (147 ms)
30 Degree Barrier 40 kmph	389.4 (91-126 ms)	37.3	26	0.64 (109 ms)	0.60 (109 ms)	0.12 (150 ms)	0.10 (69 ms)
30 Degree Barrier 48 kmph	577.3 (83-115 ms)	47.11	35.81	0.65 (98 ms)	0.95 (98 ms)	0.19 (148 ms)	0.32 (96 ms)

APPENDIX C

Table C-1. Maximum Crush Displacements and Linear Stiffness Values Derived from New Car Assessment Program Tests

Test Number	Model Year	Vehicle Make	Vehicle Model	Test Weight (kg)	Impact Speed (kmph)	Maximum Disp. (m)	Linear Stiffness (kN/m)
5	80	CHEVROLET	CITATION	1465	56.3	0.785	581.5
7	79	VOLKSWAGEN	RABBIT	1179	56.0	0.719	551.9
25	79	OLDSMOBILE	CUTLASS	1733	56.5	.	
27	79	TOYOTA	CELICA	1372	56.0	0.767	564.3
30	79	VOLVO	244DL	1530	56.3	.	
33	79	PLYMOUTH	CHAMP	1051	56.8	0.818	391.0
35	79	NISSAN	210	1100	56.6	0.765	464.6
51	79	MERCURY	MARQUIS	1916	57.0	0.912	577.5
52	79	BUICK	RIVIERA	2014	56.8	0.876	653.4
53	79	PLYMOUTH	HORIZON	1207	56.2	0.810	448.3
63	79	PLYMOUTH	VOLARE	1733	56.3	0.768	718.6
64	79	CHEVROLET	MONZA	1470	56.5	0.759	628.5
65	79	FORD	LTD	1982	57.0	0.884	635.8
66	79	FORD	GRANADA	1792	55.7	0.782	701.5
71	79	DODGE	MAGNUM	2014	56.8	0.841	708.9
73	79	CHEVROLET	CHEVETTE	1232	56.0	0.632	746.4
92	79	FORD	FAIRMONT	1497	57.0	0.790	601.3
94	79	HONDA	CIVIC	989	56.0	0.630	603.0
99	79	TOYOTA	COROLLA	1202	56.2	.	
102	80	AUDI	4000	1286	56.8	0.696	660.9
118	80	MAZDA	626	1391	56.6	0.726	652.4
119	80	NISSAN	310GX	1090	55.8	0.615	692.4
122	80	TOYOTA	TERCEL	1050	56.8	0.546	876.8
133	80	SUBARU	GLF	1177	56.3	0.625	736.9
136	80	OLDSMOBILE	CUTLASS	1730	57.0	.	
137	80	MERCEDES	240	1685	56.3	0.660	946.1
156	79	MERCURY	BOBCAT	1360	56.5	0.742	608.5
157	79	MERCURY	CAPRI	1391	56.3	0.904	416.3
182	79	DODGE	ST.REGIS	2022	55.2	.	
183	79	OLDSMOBILE	98	2136	56.2	0.820	774.2
186	80	NISSAN	200SX	1378	54.9	0.757	559.2
194	80	FIAT	STRADA	1228	56.0	0.955	325.8
199	79	OLDSMOBILE	CUTLASS	1723	56.0	0.851	575.7
202	79	PONTIAC	FIREBIRD	1773	56.8	0.851	609.5
203	79	FORD	LTD II	2184	56.2	0.892	669.0
204	79	LINCOLN	CONTINENTAL	2432	56.5	0.876	780.6
206	81	FORD	ESCORT	1175	56.5	0.785	469.7
207	81	PLYMOUTH	RELIANT	1356	56.2	0.744	597.0
216	80	HONDA	PRELUDE	1154	56.2	0.752	497.3
217	80	HONDA	CIVIC	1042	55.8	0.620	651.3
218	80	RENAULT	LECAR	996	55.5	0.452	1158.7
219	79	PEUGEOT	504	1599	56.8	.	

220	80	DODGE	MIRADA	1876	57.1	0.790	756.2
263	79	FORD	FIESTA	991	56.2	.	
271	80	FORD	THUNDERBIRD	1716	56.8	0.564	1342.9
272	80	AMERICAN	CONCORD	1678	55.8	0.584	1182.0
273	81	HONDA	CIVIC	1114	56.3	0.709	542.0
333	81	TOYOTA	STARLET	1004	56.5	0.643	598.1
334	81	TOYOTA	CRESSIDA	1550	56.5	0.658	881.8
335	81	CHRYSLER	IMPERIAL	2069	56.3	1.008	498.0
356	81	HONDA	CIVIC	980	56.5	0.660	554.2
357	81	AUDI	5000	1525	55.8	0.787	591.5
360	81	FORD	EXP	1154	56.3	0.792	450.0
363	81	RENAULT	18i	1247	56.6	0.726	584.8
364	81	AMERICAN	SPIRIT	1442	56.3	0.612	941.6
365	81	VOLKSWAGEN	JETTA	1202	56.2	0.683	628.0
376	79	CHRYSLER	LEBARON	1887	56.3	0.765	788.6
386	81	AMERICAN	CONCORD	1783	55.5	0.699	867.3
418	82	VOLVO	DL	1521	56.2	0.798	582.1
423	79	CHEVROLET	IMPALA	1896	56.6	0.671	1040.9
425	80	CADILLAC	SEVILLE	2093	55.8	0.803	779.8
426	80	CHEVROLET	CHEVETTE	1198	56.6	0.757	516.8
427	80	CHRYSLER	LEBARON	1760	56.5	0.818	647.9
428	80	VOLKSWAGEN	RABBIT	1255	56.2	0.724	583.5
444	82	DODGE	OMNI	1211	56.6	0.785	485.8
445	82	VOLKSWAGEN	SCIROCCO	1216	56.5	0.726	568.3
446	82	SAAB	900	1461	56.8	0.759	631.3
450	82	CHEVROLET	CAMARO	1555	57.0	.	
451	82	CHEVROLET	CELEBRITY	1485	56.3	0.919	430.0
452	82	FORD	ESCORT	1172	55.5	.	
453	82	DODGE	400	1381	56.3	.	
454	82	TOYOTA	CELICA	1388	55.8	0.747	597.6
455	82	HONDA	ACCORD	1195	56.0	0.848	402.1
462	82	NISSAN	STANZA	1218	55.7	.	
463	82	RENAULT	FUEGO	1316	56.3	0.732	600.7
464	82	NISSAN	SENTRA	1114	56.6	.	
465	82	VOLKSWAGEN	QUANTUM	1340	55.7	0.787	517.9
466	82	CHEVROLET	IMPALA	1864	56.8	0.843	653.0
468	82	FORD	LTD	1873	57.0	0.836	671.9
470	82	MAZDA	626	1315	56.6	0.688	686.7
471	82	FORD	GRANADA	1556	55.7	.	
496	82	TOYOTA	CORONA	1379	56.0	0.790	534.7
514	83	DODGE	600	1411	56.6	0.912	419.3
515	83	CHEVROLET	CAPRICE	1869	56.8	0.838	662.5
523	82	CHEVROLET	CAVALIER	1284	56.3	0.686	667.3
525	82	CHEVROLET	CHEVETTE	1282	56.2	0.726	592.8
526	82	DODGE	COLT	1129	56.2	.	
528	82	LINCOLN	CONTINENTAL	1886	55.8	0.879	586.5
550	82	CHRYSLER	LEBARON	1361	56.8	0.815	510.1
563	83	TOYOTA	COROLLA	1252	56.6	0.678	673.2
569	83	FORD	EXP	1175	56.6	0.732	542.1
573	83	VOLVO	760GLE	1615	56.6	0.660	916.5
574	83	PONTIAC	FIREBIRD	1510	56.6	0.965	400.8

575	83	FORD	THUNDERBIRD	1624	56.8	0.912	486.1
579	83	MITSUBISHI	PICKUP	1403	56.6	0.559	1109.8
580	83	FORD	BRONCO II	1744	57.0	.	
583	83	MITSUBISHI	MONTERO	1757	56.2	0.617	1124.8
588	83	PEUGEOT	505	1641	56.5	.	
590	83	TOYOTA	TERCEL	1282	56.6	0.706	635.8
593	83	PLYMOUTH	RELIANT	1320	56.5	0.856	443.7
594	83	TOYOTA	CAMRY	1352	56.2	0.696	680.2
598	83	NISSAN	PULSAR	1116	56.8	0.719	537.4
599	83	MAZDA	626	1315	56.8	0.820	486.8
600	83	FORD	LTD	1616	56.6	.	
612	84	MERCURY	COUGAR	1615	56.2	0.866	524.8
613	84	CHEVROLET	CORVETTE	1669	55.8	0.922	471.7
624	84	OLDSMOBILE	CUTLASS	1678	56.0	0.909	491.4
625	84	PONTIAC	PARISENNE	1878	56.2	0.785	742.7
632	84	RENAULT	ENCORE	1179	56.2	0.630	723.9
633	84	JEEP	CJ	1442	56.5	.	
644	84	FORD	LTD	1669	55.7	0.818	597.1
661	84	CHEVROLET	CAVALIER	1411	56.3	0.729	649.4
665	84	PLYMOUTH	COLT VISTA	1352	57.0	0.724	646.6
667	84	PONTIAC	FIERO	1361	56.5	0.770	565.4
668	84	PLYMOUTH	CONQUEST	1438	56.8	0.754	629.7
669	84	HONDA	CIVIC CRX	1048	56.5	0.681	556.6
674	84	DODGE	DAYTONA	1361	57.0	0.879	441.6
681	84	FORD	TEMPO	1397	56.3	0.655	796.4
682	84	TOYOTA	COROLLA	1216	56.3	0.645	714.9
685	84	TOYOTA	COROLLA	1184	56.2	0.635	715.6
686	84	NISSAN	300ZX	1529	56.3	0.828	545.5
688	84	CHEVROLET	CELEBRITY	1628	56.3	0.914	476.6
689	84	PONTIAC	T1000	1246	56.8	0.617	814.8
693	84	NISSAN	STANZA	1276	56.6	0.696	651.1
694	84	HONDA	CIVIC	1139	56.2	0.729	522.3
696	84	CHEVROLET	C10	2191	56.6	0.749	965.4
697	84	FORD	F150	1849	56.6	.	
703	84	DODGE	CARAVAN	1720	56.5	0.653	993.6
705	84	HONDA	CIVIC	1048	57.0	0.620	683.5
706	84	MERCURY	MARQUIS	1956	57.0	0.980	510.6
707	84	JEEP	CHEROKEE	1653	56.8	0.665	930.5
711	84	RENAULT	SPORTWAGON	1407	56.5	0.688	732.2
720	84	TOYOTA	VAN	1640	57.0	0.480	1784.5
721	84	MERCEDES	300SD	1946	55.8	.	
722	84	NISSAN	200SX	1306	55.8	0.709	624.2
738	85	BUICK	ELECTRA	1746	56.2	0.879	550.7
739	84	FORD	MUSTANG	1615	56.0	0.846	546.0
743	84	ISUZU	IMPULSE	1465	55.7	0.699	717.8
745	84	HONDA	PRELUDE	1261	55.8	0.770	511.0
746	84	MITSUBISHI	TREDIA	1243	55.8	0.721	574.5
747	84	TOYOTA	TERCEL	1107	56.3	0.653	634.9
756	84	RENAULT	ALLIANCE	1116	56.0	0.632	676.1
788	85	BUICK	SOMERSET	1456	55.5	0.803	536.7

789	85	SUBARU	DL	1224	56.5	0.719	583.2
790	85	MAZDA	RX-7	1303	56.8	0.780	533.2
791	85	DODGE	COLT	1186	56.0	0.721	552.1
792	85	DODGE	LANCER	1474	55.8	0.838	504.3
793	85	PLYMOUTH	CARAVELLE	1438	56.5	0.894	443.2
794	85	PLYMOUTH	RELIANT	1388	56.3	0.787	548.1
797	85	VOLKSWAGEN	JETTA	1290	56.0	0.676	683.1
798	85	MITSUBISHI	GALANT	1524	56.3	0.688	787.4
799	85	RENAULT	ALLIANCE	1275	56.2	.	
800	85	CHEVROLET	ASTRO	1855	56.0	0.617	1179.1
801	85	CHEVROLET	BLAZER	1769	56.3	0.572	1322.4
802	85	CHEVROLET	SPECTRUM	1064	56.0	0.716	502.2
807	85	VOLVO	DL	1628	55.7	0.815	586.7
808	85	VOLVO	DL	1542	55.8	0.805	571.7
809	85	NISSAN	MAXIMA	1706	56.2	0.676	909.8
813	85	AUDI	5000	1541	56.3	0.892	473.7
814	85	TOYOTA	CRESSIDA	1674	55.7	0.660	920.0
817	85	VOLKSWAGEN	VANAGON	1715	56.2	0.488	1755.1
818	85	FORD	TEMPO	1356	56.0	0.610	881.8
821	85	FORD	MERKUR	1566	56.2	0.759	662.5
823	85	TOYOTA	MR2	1324	56.8	.	
826	85	TOYOTA	4RUNNER	1768	57.1	0.569	1373.8
827	86	MAZDA	B2000	1397	56.3	0.572	1044.3
828	85	ISUZU	I-MARK	1293	56.0	0.660	718.3
839	85	BMW	318	1335	56.3	0.744	589.9
840	85	ISUZU	TROOPER II	1636	56.5	0.437	2110.2
841	85	CHEVROLET	SPRINT	926	56.5	0.665	515.8
842	85	FORD	TEMPO	1359	56.5	0.693	697.0
843	85	FORD	CLUBWAGON	2375	56.2	0.566	1806.8
889	86	BUICK	CENTURY	1524	56.5	0.823	554.2
890	86	BUICK	CENTURY	1474	56.6	0.851	503.1
894	86	MAZDA	323	1139	56.6	0.678	612.5
896	86	YUGO	GV	1052	56.5	0.610	696.4
897	86	HONDA	ACCORD	1389	56.3	0.823	501.6
901	86	PLYMOUTH	COLT VISTA	1352	55.8	0.706	651.7
902	86	ISUZU	I-MARK	1080	56.2	0.681	567.5
904	86	JEEP	COMANCHE	1613	56.6	.	
905	86	BUICK	LESABRE	1656	57.1	0.917	495.4
906	86	OLDSMOBILE	DELTA 88	1683	57.0	0.937	480.6
921	86	VOLKSWAGEN	SCIROCCO	1538	56.3	.	
936	86	SAAB	9000	1538	56.2	0.671	832.5
937	86	CHEVROLET	NOVA	1170	56.6	0.683	620.0
938	86	TOYOTA	CELICA	1338	56.2	0.744	589.1
942	86	BUICK	SKYLARK	1429	55.7	0.792	545.4
943	86	OLDSMOBILE	TORONADO	1674	56.8	0.892	523.7
944	86	FORD	TAURUS	1569	56.3	0.699	785.4
945	86	VOLKSWAGEN	GOLF	1188	56.2	0.655	674.8
946	86	SUZUKI	SAMURAI	1209	56.5	0.541	1017.5
947	86	DODGE	SPORTSMAN	2057	56.3	0.549	1669.2
948	86	MITSUBISHI	CORDIA	1282	56.3	0.770	528.8
949	86	MERCURY	SABLE	1619	56.5	0.683	854.9

950	86	HYUNDAI	EXCEL	1247	56.0	0.711	596.9
951	86	CHEVROLET	CAVALIER	1360	56.6	0.699	688.0
952	86	SUBARU	GL	1230	56.5	0.691	634.5
953	86	SUBARU	XT	1251	56.5	0.782	503.9
977	87	FORD	AEROSTAR	1641	56.5	0.658	933.6
978	87	CHEVROLET	SPORTVAN	2475	56.3	0.653	1419.6
979	87	ISUZU	SPACECAB	1519	56.6	0.485	1596.3
989	87	PONTIAC	SUNBIRD	1343	56.3	0.846	458.9
994	87	CHEVROLET	CAMARO	1598	56.6	0.902	485.5
995	87	FORD	MUSTANG	1516	56.6	0.884	479.5
996	87	HYUNDAI	EXCEL	1184	56.6	0.704	590.5
997	87	FORD	ESCORT	1243	55.8	0.635	740.6
998	87	MERCURY	TOPAZ	1442	56.2	0.658	811.7
999	87	YUGO	GV	1052	56.2	0.607	695.8
1000	87	JEEP	COMANCHE	1612	56.6	0.655	928.8
1010	87	DODGE	DAKOTA	1651	56.3	0.696	833.6
1011	87	PLYMOUTH	VOYAGER	1660	56.3	0.655	946.3
1012	87	JEEP	WRANGLER	1642	56.0	0.597	1114.8
1013	87	TOYOTA	CAMRY	1474	56.2	0.594	1018.1
1014	87	MITSUBISHI	STARION	1565	56.3	0.716	746.6
1015	87	MAZDA	626	1379	56.3	0.841	476.9
1016	87	DODGE	SHADOW	1361	55.8	0.853	449.4
1039	87	PLYMOUTH	SUNDANCE	1383	55.7	0.861	446.6
1040	87	SAAB	9000	1597	55.7	0.742	694.4
1041	87	SUBARU	JUSTY	957	55.8	0.635	570.2
1042	87	ISUZU	I-MARK	1166	56.2	0.676	621.8
1043	87	CHRYSLER	LEBARON	1506	56.0	0.945	408.1
1044	87	ACURA	INTEGRA	1261	55.5	0.681	646.3
1045	87	HONDA	ACCORD	1324	56.3	0.747	580.3
1048	87	HYUNDAI	EXCEL	1207	57.0	0.742	549.6
1049	87	OLDSMOBILE	CALAIS	1415	55.7	0.759	588.0
1052	87	VOLKSWAGEN	FOX	1184	56.8	0.622	761.8
1057	87	PONTIAC	GRAND AM	1356	56.6	0.744	605.5
1058	87	PEUGEOT	505	1524	56.3	0.742	677.0
1059	87	TOYOTA	PICKUP	1461	55.8	0.533	1235.6
1062	87	FORD	RANGER	1525	56.3	0.544	1260.3
1063	87	CHEVROLET	S10	1464	56.5	0.650	853.5
1065	87	CHEVROLET	SUBURBAN	2771	57.0	0.775	1156.6
1066	87	SUBARU	GL	1243	56.6	0.650	727.2
1067	87	NISSAN	PICKUP	1524	56.5	0.513	1426.4
1070	87	NISSAN	200SX	1460	55.8	0.653	822.6
1071	87	NISSAN	SENTRA	1225	56.3	0.711	592.7
1103	88	FORD	TAURUS	1660	56.5	0.696	844.1
1104	88	MERCURY	SABLE	1687	56.5	0.663	945.3
1117	88	VOLKSWAGEN	FOX	1225	56.5	0.597	846.6
1128	88	VOLKSWAGEN	VANAGON	1869	56.2	0.500	1822.0
1129	88	TOYOTA	TERCEL	1120	56.3	0.635	679.3
1130	88	TOYOTA	COROLLA	1247	55.7	0.673	659.1
1131	88	PEUGEOT	505	1588	56.0	0.665	868.9
1132	88	PONTIAC	LEMANS	1206	56.3	0.683	632.3
1133	88	NISSAN	MAXIMA	1673	55.5	0.638	976.9

1142	88	CHEVROLET	SPORTVAN	2210	57.0	0.531	1964.9
1143	88	CHEVROLET	ASTRO	2003	56.8	0.635	1236.6
1144	88	CHEVROLET	C1500	1954	56.8	0.775	809.9
1147	88	FORD	F150	1989	57.0	0.787	805.1
1148	88	NISSAN	PULSAR	1288	55.8	0.739	566.6
1149	88	NISSAN	VAN	1901	56.2	0.480	2010.8
1150	88	DODGE	D150	1895	56.6	0.907	569.4
1151	88	DODGE	COLT	1294	56.6	0.803	496.1
1152	88	HONDA	CIVIC	1153	56.3	0.688	595.8
1153	88	NISSAN	PICKUP	1478	56.5	0.508	1410.7
1154	88	MITSUBISHI	MONTERO	1781	56.3	0.511	1668.2
1157	88	NISSAN	SENTRA	1213	56.6	0.693	624.3
1159	88	ACURA	LEGEND	1683	56.3	0.681	887.6
1160	88	DAIHATSU	CHARADE	1006	56.6	0.706	498.9
1166	88	VOLVO	740GLE	1610	56.0	0.635	966.2
1167	88	CHEVROLET	CORSICA	1465	56.6	0.770	610.8
1173	88	CHEVROLET	BERETTA	1520	55.7	0.808	557.4
1174	88	OLDSMOBILE	DELTA 88	1792	56.3	0.904	536.3
1175	88	MAZDA	RX-7	1506	56.0	0.785	591.4
1176	88	MAZDA	929	1778	57.1	0.653	1049.0
1178	88	SAAB	900S	1515	56.8	0.681	813.2
1179	88	ISUZU	SPACECAB	1700	56.6	0.655	979.5
1186	88	FORD	TEMPO	1397	56.0	0.668	757.6
1187	88	FORD	FESTIVA	993	56.0	0.579	716.7
1188	88	BUICK	REGAL	1683	56.5	0.744	748.9
1189	88	CHRYSLER	NEW YORKER	1656	56.0	0.859	543.1
1190	88	RENAULT	MEDALLION	1406	56.6	0.734	645.1
1191	88	BUICK	ELECTRA	1749	56.2	0.856	581.7
1214	89	EAGLE	MEDALLION	1433	56.3	0.719	678.0
1223	89	MITSUBISHI	MIRAGE	1302	56.3	0.706	638.9
1234	89	MITSUBISHI	GALANT	1479	57.0	0.709	737.6
1273	89	DODGE	DAYTONA	1506	55.8	0.904	442.7
1282	89	FORD	THUNDERBIRD	1864	55.8	0.780	736.1
1287	89	DODGE	SPIRIT	1492	56.5	0.800	574.2
1288	89	HONDA	CIVIC CRX	1045	55.7	.	
1290	89	CHEVROLET	CAPRICE	1914	56.6	0.874	619.4
1294	89	EAGLE	PREMIER	1615	55.8	0.709	771.9
1295	89	CHRYSLER	FIFTH AVE	1969	55.8	0.780	777.5
1296	89	MERCURY	TRACER	1220	56.5	0.693	625.7
1297	89	CHEVROLET	BLAZER	1858	56.6	.	
1298	89	CHEVROLET	ASTRO	2145	56.3	.	
1299	89	PLYMOUTH	ACCLAIM	1483	55.8	0.803	552.6
1308	89	FORD	PROBE	1388	55.5	0.714	647.1
1309	89	LINCOLN	CONTINENTAL	1923	56.0	0.810	709.2
1311	89	FORD	BRONCO II	1818	56.6	.	
1312	89	TOYOTA	COROLLA	1275	56.3	0.721	599.9
1313	89	TOYOTA	CRESSIDA	1787	55.8	0.693	894.0
1314	89	TOYOTA	VAN	1726	56.0	.	
1315	89	TOYOTA	PICKUP	1438	56.8	.	
1316	89	HYUNDAI	SONATA	1510	55.8	0.706	727.8
1318	89	MITSUBISHI	VAN	1844	56.3	.	

1320	89	JEEP	CHEROKEE	1774	56.3	0.645	1042.9
1321	89	AUDI	80	1506	56.0	0.767	619.5
1322	89	VOLKSWAGEN	FOX	1197	56.0	0.617	760.8
1327	89	PEUGEOT	505	1592	56.0	0.660	884.4
1328	89	ISUZU	TROOPER II	1955	56.5	.	
1329	89	SUZUKI	SIDEKICK	1329	56.3	.	
1330	89	GEO	METRO	934	56.8	0.668	521.1
1332	89	GEO	METRO	957	56.0	0.655	539.8
1353	89	NISSAN	MAXIMA	1656	55.5	0.688	831.5
1361	89	NISSAN	PICKUP	1510	56.3	0.579	1101.6
1363	89	NISSAN	240SX	1415	56.0	0.790	548.6
1364	89	AUDI	100	1719	56.3	0.820	625.3
1365	90	ACURA	INTEGRA	1322	55.8	0.658	733.6
1367	90	MITSUBISHI	ECLIPSE	1350	56.5	0.762	572.7
1368	90	CHEVROLET	LUMINA	1647	56.0	0.820	592.7
1377	90	MAZDA	MIATA	1166	56.6	0.671	640.2
1379	90	NISSAN	STANZA	1483	56.3	0.678	789.0
1380	90	TOYOTA	4RUNNER	2055	56.2	0.561	1591.3
1381	90	LEXUS	ES250	1710	56.5	0.643	1018.8
1383	90	HYUNDAI	EXCEL	1207	56.3	0.704	595.6
1385	90	FORD	TAURUS	1642	56.2	0.714	785.0
1397	90	GEO	PRIZM	1266	56.5	0.696	643.7
1398	90	NISSAN	AXXESS	1557	56.8	0.709	771.1
1399	90	TOYOTA	CELICA	1352	55.8	0.699	664.8
1419	90	CHRYSLER	LEBARON	1588	55.7	0.930	439.5
1435	90	CHEVROLET	BLAZER	2028	56.3	0.643	1199.7
1436	90	CHEVROLET	S10	1842	56.3	0.582	1330.0
1437	90	DODGE	DAKOTA	2000	56.0	0.602	1335.4
1438	90	CADILLAC	DEVILLE	1814	56.2	0.891	556.9
1439	90	PONTIAC	TRANS SPORT	2005	56.5	0.988	505.9
1440	90	CHEVROLET	CAVALIER	1388	56.3	0.836	485.7
1441	90	SUBARU	LEGACY	1397	56.5	0.660	790.0
1442	90	FORD	RANGER	1874	56.8	0.630	1175.4
1448	90	INFINITI	M30	1742	56.3	.	
1449	90	LINCOLN	TOWN CAR	2091	55.8	0.907	610.7
1450	90	FORD	MUSTANG	1753	56.2	0.780	702.2
1451	90	ISUZU	AMIGO	1606	56.3	0.424	2184.9
1453	90	BMW	325i	1541	56.0	0.559	1193.3
1454	90	HONDA	PRELUDE	1389	56.2	0.681	729.9
1455	90	ISUZU	TROOPER II	1951	56.5	0.462	2251.5
1456	90	VOLKSWAGEN	PASSAT	1551	56.0	0.612	1002.0
1457	90	FORD	CLUBWAGON	2590	56.6	0.610	1720.6
1459	90	MERCEDES	190	1584	56.0	.	
1461	90	BUICK	LESABRE	1701	56.2	0.909	501.7
1470	90	CHRYSLER	IMPERIAL	1864	56.3	0.919	539.8
1496	90	JEEP	CHEROKEE	1769	56.3	0.625	1107.6
1519	91	TOYOTA	PREVIA	1894	55.7	0.517	1696.3
1523	91	FORD	ESCORT	1254	56.2	0.694	634.5
1533	91	CHEVROLET	CAPRICE	2050	56.8	0.828	744.4
1536	91	FORD	EXPLORER	2157	56.2	0.595	1484.9
1537	91	DODGE	SHADOW	1433	56.6	0.846	494.9

1538	91	NISSAN	SENTRA	1284	56.6	0.668	711.3
1539	91	CHEVROLET	BLAZER	2018	56.3	0.619	1288.1
1541	91	HONDA	ACCORD	1483	55.7	0.630	894.5
1543	91	CHEVROLET	BERETTA	1419	56.3	0.867	461.7
1545	91	BUICK	CENTURY	1576	56.5	0.789	623.6
1548	91	MITSUBISHI	GALANT	1468	56.3	0.728	677.5
1558	91	CHEVROLET	CAMARO	1638	56.3	0.874	524.5
1559	91	TOYOTA	COROLLA	1284	56.3	0.679	681.1
1560	91	MAZDA	PROTEGE	1286	57.1	0.653	758.7
1561	91	HONDA	CIVIC	1244	56.3	0.632	761.7
1565	91	TOYOTA	PICKUP	1771	56.3	0.534	1519.0
1568	91	ISUZU	STYLUS	1249	56.3	0.573	930.4
1569	91	SATURN	SL2	1316	56.3	0.773	538.7
1570	91	FORD	PROBE	1456	56.3	0.735	659.2
1585	91	CHEVROLET	CORSICA	1497	56.0	0.756	633.8
1586	91	ISUZU	RODEO	1851	56.3	0.444	2296.4
1589	91	SUZUKI	SIDEKICK	1477	56.3	0.571	1108.0
1590	91	CHRYSLER	NEW YORKER	1742	56.3	0.868	565.5
1591	91	NISSAN	300ZX	1693	56.3	0.716	807.7
1592	91	NISSAN	STANZA	1456	56.5	0.724	684.2
1593	91	TOYOTA	TERCEL	1120	56.8	0.634	693.6
1595	91	GEO	STORM	1197	56.3	0.692	611.4
1597	91	HONDA	ACCORD	1669	56.3	0.679	885.4
1600	91	FORD	TAURUS	1774	56.3	0.699	888.0
1604	91	MAZDA	MPV	1973	56.0	0.613	1270.5
1606	91	HYUNDAI	SCOUPE	1192	56.8	0.692	619.7
1607	91	PLYMOUTH	ACCLAIM	1497	56.3	0.818	547.2
1628	92	OLDSMOBILE	88 ROYALE	1723	56.6	0.938	484.1
1629	92	TOYOTA	PASEO	1133	56.6	0.696	578.2
1631	92	MITSUBISHI	DIAMANTE	1741	56.7	0.661	988.5
1656	92	ACURA	VIGOR	1628	56.8	0.664	919.2
1659	92	BMW	325i	1623	56.7	0.676	881.0
1667	92	CHEVROLET	S10	1653	56.3	0.613	1075.9
1669	92	DODGE	CARAVAN	1841	56.3	0.763	773.4
1670	92	FORD	F150	2091	56.0	0.674	1113.8
1671	92	CHEVROLET	SPORTVAN	2468	55.8	0.642	1438.6
1673	92	GEO	METRO	920	56.3	0.730	422.2
1675	92	DODGE	DAKOTA	1615	56.3	0.689	832.0
1677	92	CHEVROLET	ASTRO	2084	56.3	0.556	1648.8
1679	92	ISUZU	PICKUP	1569	56.3	0.489	1604.8
1684	92	NISSAN	MAXIMA	1656	56.7	0.680	888.4
1689	92	VOLVO	240	1590	56.7	0.774	658.4
1690	92	TOYOTA	CAMRY	1632	56.0	0.710	783.4
1691	92	HONDA	ACCORD	1437	56.2	0.682	752.9
1695	92	FORD	CLUBWAGON	2624	56.7	0.572	1989.5
1697	92	FORD	AEROSTAR	1941	56.2	0.576	1425.8
1700	92	MITSUBISHI	MIGHTY MAX	1518	56.7	0.429	2046.1
1701	92	DODGE	RAM WAGON	2501	56.3	0.489	2558.0
1705	92	CADILLAC	SEVILLE	1870	56.7	0.935	530.6
1706	92	OLDSMOBILE	ACHIEVA	1493	56.7	0.829	538.9
1708	92	SATURN	SL2	1325	56.3	0.770	546.6

1709	92	ISUZU	TROOPER II	2227	56.7	0.489	2310.3
1717	92	FORD	RANGER	1688	56.7	0.647	1000.3
1718	91	NISSAN	PATHFINDER	2066	56.3	0.509	1950.3
1722	92	HYUNDAI	EXCEL	1225	55.7	0.692	612.4
1723	92	PLYMOUTH	COLT VISTA	1510	56.5	0.727	703.7
1724	92	MAZDA	B2200	1566	56.7	0.551	1279.5
1726	92	HYUNDAI	ELANTRA	1339	55.8	0.643	778.1
1727	92	HONDA	PRELUDE	1471	55.8	0.666	796.8
1729	92	FORD	FESTIVA	1034	56.2	0.606	686.2
1730	92	FORD	CROWN VICTR	2036	56.3	0.821	738.8
1731	92	MAZDA	MX3	1384	56.7	0.678	746.9
1733	92	ACURA	LEGEND	1787	56.2	0.714	854.3
1741	92	CHEVROLET	C1500	2023	55.8	0.679	1054.2
1742	93	MAZDA	626	1441	56.3	0.660	809.1
1743	93	JEEP	CHEROKEE	1982	56.3	0.673	1070.3
1746	92	PONTIAC	BONNEVILLE	1842	56.6	0.928	528.7
1765	93	PONTIAC	GRAND AM	1488	56.0	0.843	506.7
1771	93	TOYOTA	COROLLA	1229	56.3	0.658	694.2
1774	93	DODGE	DYNASTY	1674	56.3	0.851	565.3
1776	93	BUICK	CENTURY	1601	56.2	0.807	599.1
1778	93	DODGE	INTREPID	1679	56.2	0.783	667.4
1792	93	NISSAN	ALTIMA	1515	56.3	0.672	820.5
1793	93	NISSAN	QUEST	2059	56.7	0.688	1079.1
1797	93	NISSAN	PICKUP	1551	56.3	0.497	1535.7
1798	93	CHEVROLET	BLAZER	2051	56.2	0.582	1475.7
1800	93	MITSUBISHI	MIRAGE	1147	55.6	0.692	571.3
1801	93	HONDA	CIVIC	1256	56.8	0.673	690.3
1813	93	FORD	RANGER	1677	56.6	0.695	858.2
1815	93	TOYOTA	PICKUP	1445	56.1	0.493	1443.8
1816	93	TOYOTA	T100	1825	56.2	0.604	1219.2
1817	93	TOYOTA	4RUNNER	2145	56.6	0.502	2104.0
1818	93	DODGE	STEALTH	1654	56.2	0.712	795.1
1820	93	FORD	EXPLORER	2178	56.6	0.560	1716.8
1853	93	TOYOTA	PREVIA	1902	56.5	0.529	1674.1
1856	93	DODGE	RAM 150	2027	56.6	0.899	620.0
1857	93	VOLKSWAGEN	EUROVAN	2026	56.2	0.567	1535.8
1858	93	FORD	TEMPO	1404	56.3	0.663	781.2
1874	93	CHEVROLET	SUBURBAN	2849	56.3	0.786	1127.9
1875	93	HONDA	ACCORD	1579	56.0	0.663	869.2
1877	93	FORD	BRONCO	2501	56.5	0.692	1286.5
1878	93	FORD	PROBE	1404	56.3	0.641	835.7
1879	93	MITSUBISHI	MONTERO	2204	56.3	0.585	1575.1
1884	93	SAAB	9000	1707	56.3	0.793	663.9
1885	93	SUBARU	LEGACY	1433	56.0	0.692	724.1
1886	93	TOYOTA	TERCEL	1123	56.7	0.613	741.3
1888	93	NISSAN	SENTRA	1263	56.3	0.640	754.2
1890	93	FORD	TAURUS	1711	56.3	0.674	921.2
1891	93	ISUZU	RODEO	2105	56.9	0.478	2301.5
1892	93	HONDA	CIVIC	1324	56.3	0.623	834.3
1928	94	CHRYSLER	NEW YORKER	1831	55.7	0.755	769.0
1975	94	MITSUBISHI	GALANT	1467	56.0	0.719	686.7

1977	93	CHEVROLET	CAMARO	1738	57.0	0.874	570.4
1979	93	CHEVROLET	ASTRO	2132	56.2	0.640	1268.5
1983	94	DODGE	CARAVAN	1739	56.5	0.741	780.1
1990	94	PONTIAC	TRANS SPORT	1962	56.5	0.861	651.9
1993	94	DODGE	SPIRIT	1494	56.3	0.788	588.5
1996	93	LEXUS	GS300	1925	56.3	0.677	1027.2
1998	94	MAZDA	626	1447	56.7	0.667	806.8
2002	93	INFINITI	J30	1864	56.3	0.724	869.7
2004	94	FORD	BRONCO	2447	56.2	0.622	1541.4
2017	94	TOYOTA	T100	1815	56.0	0.566	1370.9
2021	94	DODGE	RAM 1500	2305	56.5	0.753	1001.3
2024	94	CADILLAC	DEVILLE	1937	56.2	0.915	563.8
2030	94	CHEVROLET	CORSICA	1456	56.3	0.795	563.4
2033	94	PONTIAC	GRAND PRIX	1677	56.2	0.713	803.9
2034	94	TOYOTA	COROLLA	1344	56.2	0.621	849.3
2035	94	OLDSMOBILE	ACHIEVA	1483	56.3	0.814	547.4
2038	94	TOYOTA	CAMRY	1639	56.3	0.681	864.4
2044	94	FORD	THUNDERBIRD	1780	56.3	0.720	839.8
2048	94	HONDA	ACCORD	1509	56.6	0.663	848.6
2049	94	BUICK	REGAL	1694	56.5	0.751	739.8
2052	94	MERCEDES	C220	1650	56.5	0.645	976.9
2053	94	VOLVO	850	1700	56.3	0.581	1231.7
2054	94	CHEVROLET	S10	1811	56.4	0.765	759.5
2055	94	FORD	F150	2296	55.9	0.757	966.1
2056	94	DODGE	DAKOTA	2057	56.2	0.738	920.4
2057	94	JEEP	WRANGLER	1553	56.8	0.615	1022.2
2058	94	TOYOTA	PREVIA	1865	56.8	0.533	1634.2
2059	94	NISSAN	ALTIMA	1495	56.3	0.656	849.7
2061	94	CHEVROLET	SPORTVAN	2559	56.4	0.650	1486.6
2062	94	FORD	ESCORT	1369	56.3	0.632	838.3
2063	94	FORD	MUSTANG	1605	56.3	0.753	692.3
2064	94	FORD	PROBE	1441	56.0	0.626	889.8
2066	94	HONDA	CIVIC	1249	56.5	0.605	840.5
2067	94	NISSAN	QUEST	1999	56.3	0.684	1045.0
2068	94	HYUNDAI	ELANTRA	1379	56.3	0.605	921.4
2072	94	CHEVROLET	CAPRICE	2133	56.5	0.768	890.8
2126	95	NISSAN	MAXIMA	1561	56.6	0.679	836.9
2127	95	PLYMOUTH	NEON	1288	56.3	0.683	675.3
2129	95	FORD	ASPIRE	1124	56.8	0.655	652.2
2130	95	FORD	WINDSTAR	2005	56.1	0.755	854.2
2131	95	MAZDA	MILLENIA	1620	56.3	0.610	1064.8
2139	94	VOLKSWAGEN	JETTA	1467	56.2	0.612	954.5
2140	95	NISSAN	240SX	1440	56.5	0.726	673.0
2142	95	DODGE	RAM WAGON	2162	56.6	0.518	1991.7
2149	95	FORD	CROWN VICTR	1985	56.3	0.804	751.0
2154	95	FORD	CONTOUR	1581	56.2	0.584	1129.7
2157	95	HYUNDAI	SONATA	1449	56.2	0.678	768.2
2158	95	SUBARU	LEGACY	1394	56.6	0.731	644.9
2159	95	CHEVROLET	MONTE CARLO	1705	56.2	0.833	598.8
2160	95	SATURN	SL2	1256	56.3	0.797	483.6

2161	95	MAZDA	PROTEGE	1282	56.6	0.647	757.0
2193	95	OLDSMOBILE	AURORA	2041	55.8	0.562	1552.5
2195	95	CHEVROLET	BLAZER	2165	56.2	0.717	1026.3
2197	95	TOYOTA	TERCEL	1183	56.3	0.664	656.2
2198	95	SAAB	900	1601	56.5	0.733	734.0
2200	95	JEEP	CHEROKEE	1637	56.3	0.627	1018.4
2203	95	MAZDA	MPV	2003	56.3	0.509	1890.9
2207	95	FORD	RANGER	1755	56.0	0.575	1284.4
2208	95	VOLKSWAGEN	PASSAT	1650	56.3	0.636	997.7
2209	95	AUDI	A6	1833	56.4	0.788	724.5
2211	95	FORD	EXPLORER	2206	56.2	0.592	1534.0
2212	95	ACURA	INTEGRA	1420	56.6	0.688	741.6
2221	95	DODGE	AVENGER	1516	56.2	0.622	955.0
2222	95	CHEVROLET	LUMINA	1741	56.2	0.833	611.5
2223	95	CHEVROLET	S10	1687	56.8	0.664	952.5
2231	95	MITSUBISHI	MONTERO	2252	56.5	0.523	2028.0
2232	95	MITSUBISHI	ECLIPSE	1490	56.5	0.607	996.1
2239	95	GEO	METRO	1125	56.6	0.711	550.1
2240	95	CHEVROLET	C1500	2072	57.0	0.752	918.5
2250	95	BMW	325i	1717	56.5	0.638	1039.0
2252	95	DODGE	STRATUS	1626	57.0	0.663	927.3
2253	95	CHEVROLET	CAVALIER	1433	56.5	0.705	710.2
2254	95	SUZUKI	SIDEKICK	1471	56.3	0.556	1163.8
2257	95	KIA	SEPHIA	1290	56.5	0.682	683.1
2262	95	ISUZU	TROOPER II	2232	56.3	0.508	2115.3
2263	95	HONDA	ODYSSEY	1830	56.2	0.680	964.5
2264	95	FORD	ESCORT	1325	56.4	0.674	715.9
2280	95	TOYOTA	CAMRY	1576	56.6	0.713	766.3
2282	95	TOYOTA	AVALON	1714	56.5	0.698	866.6
2296	95	TOYOTA	TACOMA	1447	56.6	0.468	1633.1
2297	95	NISSAN	ALTIMA	1549	56.4	0.689	800.9
2298	95	NISSAN	SENTRA	1293	56.3	0.666	713.0
2299	95	HYUNDAI	ACCENT	1213	56.0	0.614	778.6
2311	95	CHEVROLET	TAHOE	2678	56.6	0.730	1242.2
2312	96	FORD	TAURUS	1764	56.5	0.700	886.7
2313	95	ISUZU	RODEO	2075	56.4	0.493	2095.5
2319	96	AUDI	A4	1763	56.5	0.693	904.2
2320	96	DODGE	NEON	1354	56.5	0.686	708.7
2335	96	DODGE	CARAVAN	2003	56.2	0.757	851.8
2336	96	DODGE	RAM	2119	55.7	0.567	1577.9
2341	96	PONTIAC	GRAND AM	1560	57.0	.	
2342	96	LEXUS	ES300	1759	56.5	0.715	847.5
2343	96	LANDROVER	DISCOVERY	2315	56.3	0.605	1546.9
2359	96	CADILLAC	DEVILLE	2024	56.5	0.866	664.8
2360	96	FORD	MUSTANG	1700	56.3	0.779	685.2
2367	96	MERCURY	VILLAGER	2009	56.0	0.659	1119.4
2368	96	FORD	CROWN VICTR	1985	56.2	0.786	783.0
2370	96	MAZDA	MIATA	1227	56.5	0.638	742.5
2371	96	HONDA	CIVIC	1250	56.3	0.686	649.6
2372	96	MITSUBISHI	MIRAGE	1185	56.5	0.660	670.1
2373	96	SUBARU	IMPREZA	1435	56.3	0.650	830.7

2376	96	GEO	TRACKER	1347	56.6	0.502	1321.3
2398	96	HYUNDAI	ELANTRA	1422	56.3	0.641	846.4
2404	96	CHEVROLET	ASTRO	2278	56.6	0.605	1538.4
2405	96	ACURA	TL	1678	56.6	0.651	978.7
2407	96	CHEVROLET	C1500	2163	56.3	0.758	920.7
2409	96	TOYOTA	4RUNNER	2076	55.7	0.557	1601.9
2413	96	ISUZU	TROOPER	2227	56.7	0.540	1894.5
2414	96	NISSAN	PICKUP	1566	57.0	0.482	1689.8
2427	96	MAZDA	MPV	2013	56.5	0.659	1141.7
2428	96	HONDA	CIVIC	1245	56.6	0.688	650.2
2429	96	LINCOLN	TOWN CAR	2072	56.6	0.919	606.4
2430	96	JEEP	CHEROKEE	1998	56.3	0.653	1146.0
2452	97	FORD	F150	2056	55.7	0.648	1172.1
2453	96	DODGE	CARAVAN	1934	56.2	0.784	766.8
2454	97	PONTIAC	GRAND PRIX	1763	56.2	0.772	720.9
2455	97	JEEP	WRANGLER	1732	56.0	0.689	882.8
2456	96	NISSAN	PATHFINDER	2089	57.0	0.604	1435.5
2457	96	FORD	RANGER	1709	56.5	0.550	1391.6
2458	96	CHRYSLER	SEBRING	1716	56.6	0.759	736.3
2459	96	TOYOTA	PASEO	1126	57.0	0.696	582.7
2460	97	PONTIAC	GRAND AM	1542	56.6	0.789	612.3
2461	97	MITSUBISHI	GALANT	1487	57.0	0.705	750.0
2464	97	FORD	ESCORT	1347	56.5	0.657	768.7
2465	97	CADILLAC	DEVILLE	2055	56.3	0.835	720.9
2466	97	CHEVROLET	S10	1883	56.5	0.637	1143.1
2475	97	HONDA	ACCORD	1497	56.4	0.667	825.9
2476	97	FORD	CLUBWAGON	2595	56.2	0.606	1722.1
2478	97	CHEVROLET	BLAZER	2107	56.3	0.659	1186.6
2487	97	VOLVO	960	1814	56.2	0.581	1309.6
2488	97	FORD	EXPEDITION	2778	56.3	0.766	1157.9
2492	97	PONTIAC	GRAND AM	1569	56.4	0.778	636.2
2496	97	TOYOTA	RAV4	1642	56.2	0.551	1318.1
2527	97	HYUNDAI	ACCENT	1220	56.2	0.609	801.7
2528	97	CHEVROLET	CAVALIER	1414	56.3	0.674	761.3
2529	97	CHEVROLET	MALIBU	1617	56.2	0.730	739.5
2530	97	DODGE	RAM	2422	56.5	0.684	1275.1
2531	97	TOYOTA	CAMRY	1622	56.2	0.671	878.0
2540	97	CHEVROLET	TAHOE	2732	55.5	0.713	1277.3
2542	97	TOYOTA	TACOMA	1575	56.3	0.401	2395.5
2550	97	DODGE	DAKOTA	2015	56.6	0.602	1374.4
2551	97	BUICK	LESABRE	1788	56.5	0.866	587.3
2552	97	CHEVROLET	VENTURE	1946	56.8	0.760	838.7
2556	97	JEEP	CHEROKEE	1839	56.2	0.632	1122.1