# RESEARCH TESTS TO DEVELOP IMPROVED FMVSS 301 REAR IMPACT TEST PROCEDURE

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## ABSTRACT

A test series was conducted with a moving deformable barrier similar to the FMVSS 214 (Federal Motor Vehicle Safety Standard 214) barrier impacting the rear of the subject vehicle in a partial overlap configuration to evaluate fuel system integrity. The tests were conducted in two phases. The first phase examined rear impact test configuration differences such as overlap, speed and alignment; the second phase examined the performance of various vehicles using a consistent test protocol based on the first phase of testing and crash data analysis. This paper presents the results of these fuel system integrity tests.

## INTRODUCTION

A rear impact crash test program was conducted with a moving deformable barrier to simulate real world crash conditions which produced loss of fuel system integrity. The impactor was chosen on the basis of the aluminum honeycomb impactor face and barrier cart used in FMVSS 214 (Federal Motor Vehicle Safety Standard 214), dynamic side impact standard. The moving deformable impactor (MDB) represents a medium weight vehicle of moderately high stiffness. The rear impact configuration used in this test series is shown in Figure 1, where the overlap is on the side of the filler neck.

The tests were conducted in two phases. The first phase examined rear impact test configuration differences such as overlap, speed and alignment; the second phase examined the performance of various vehicles using a consistent test protocol, judged to be survivable yet severe enough to distinguish levels of fuel system integrity performance. Table 1 shows the complete test matrix and test conditions, including overlap percentages and overlapped side, impact speeds, weights and vertical bumper alignment.

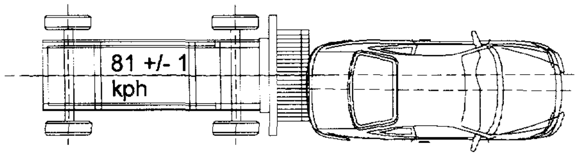
## PHASE 1 - BASELINE TESTING

In the first phase of testing, 1993 Ford Mustangs were chosen as the subject vehicles. This vehicle model was chosen based on its compact size and its placement of the fuel tank between the bumper

**Table 1.**
**Test Matrix of Moving Barrier Deformable Rear Impact Crash Tests**

| FMVSS 301 Rear Impact Test Procedure Development - Test Matrix | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Vehicle | | | | Test | | | |
| Test Number | Make | Model | Yr. | No. | Speed, kph | Weight, kg | Overlap Percent | Impactor Height |
| *Baseline:* | | | | | | | | |
| B1 | NHTSA | MDB | | | 84.0 | 1329 | | FMVSS |
| | Ford | Mustang | '93 | | 0.0 | 1520 | 80% | 214 |
| B2 | NHTSA | MDB | | 1 | 80.3 | 1349 | | FMVSS |
| | Ford | Mustang | '93 | 2 | 0 | 1565.0 | 88% | 214 |
| B3 | NHTSA | MDB | | 1 | 79.7 | 1349 | | FMVSS |
| | Ford | Mustang | '93 | 2 | 0.0 | 1525 | 80% | 214 |
| B4 | NHTSA | MDB | | 1 | 80.1 | 1333 | | |
| | Ford | Mustang | '93 | 2 | 0.0 | 1554 | 50% | raised 2" |
| *Comparison:* | | | | | | | | |
| 1 | NHTSA | MDB | | 1 | 80.3 | 1344 | | lowered 2" |
| | Ford | Mustang | '96 | 2 | 0.0 | 1628 | 70% | |
| 2 | NHTSA | MDB | | 1 | 81.5 | 1342 | | lowered 2" |
| | Plymouth | Voyager | '96 | 2 | 0.0 | 1946 | 70% | |
| 3 | NHTSA | MDB | | 1 | 81.6 | 1344 | | lowered 2" |
| | Suzuki | Sidekick | '96 | 2 | 0.0 | 1370 | 70% | |
| 4 | NHTSA | MDB | | 1 | 81.8 | 1343 | | lowered 2" |
| | Chev | Blazer | '96 | 2 | 0.0 | 1906 | 70% | |
| 5 | NHTSA | MDB | | 1 | 82.1 | 1344 | | lowered 2" |
| | Dodge | Neon | '96 | 2 | 0.0 | 1360 | 70% | |
| 6 | NHTSA | MDB | | 1 | 81.9 | 1337 | | lowered 2" |
| | Geo | Prizm | '96 | 2 | 0.0 | 1326 | 70% | |

and the rear axle. This fuel tank location is known to present difficult design challenges in terms of fuel system integrity. Four 1993 Mustangs were subjected to different test conditions as shown for test numbers B1-B4 in Table 1. In the B1 test as described in the FMVSS 301 advanced notice of proposed rulemaking (docket number 92-066N3), the fuel tank ruptured and spilled an excessive quantity of Stoddard solvent which was used to replace the gasoline in the tank. This test was conducted using a standard FMVSS 214 moving




Moving Deformable Barrier

**Figure 1**. Moving Deformable Barrier rear impact partial overlap test setup.

deformable barrier (MDB) impacting the rear of the Ford Mustang on the filler neck (right) side with an 80% overlap at 84 kph (52 mph).

In the B2 Mustang test, the overlap was increased to 88% (also right side) and the speed reduced slightly to approximately 80 kmph. The vehicle leaked Stoddard only during post test rollover. Since this test condition caused both frame rails to be engaged, it was concluded that 88% overlap produced insufficient loading of the tank. Therefore this test speed of 80 kmph was repeated for the B3 Mustang test, but the overlap was adjusted back to 80% as in the B1 test. In the B3 test some Stoddard spillage was recorded but the leakage was within the spillage requirements of FMVSS 301. This result was unexpected since the difference in impact speed was small. It was also observed that the damage pattern was inconsistent with the B1 test, indicating differences in crash forces. Further investigation from film analysis revealed that the vertical bumper alignment was different between the two tests which resulted in more tank penetration and more tank damage in the B1 test. It was noted that the ride height of the Mustang was lower in test B3 by approximately 2 inches. This resulted in the moving deformable barrier overriding the rear bumper of the Mustang in test B3, thus indirectly loading the fuel tank. The difference in ride height could not be explained by vehicle loading and weight distribution differences because they were nearly identical. Since the vehicle was previously used before being purchased for test B3, the springs were believed to be sagging from normal wear of the vehicle. The B2 test vehicle on the other hand was new when purchased and was not subject to this potential problem. In the B4 test, to be sure that override did not occur, and to assure maximum fuel tank penetration, it was decided to test with the Mustang rear-end raised by two inches as measured at the rear bumper. Coincidentally, it was decided that bumper mismatch made sense for rear impacts after determining that the average pitch from panic braking caused approximately 2" dip at the front bumper and a 2" rise at the rear bumper. Therefore, this condition simulates either braking of the striking car or braking of the struck car prior to impact. Thus, the B4 Mustang was tested with the Mustang rear springs raised by spacers to accomplish a 2" height rise at the rear bumper. The speed was held to 80 kmph as in prior tests, but the overlap was reduced to 50% which was believed to produce more penetration into the tank. This test did produce spillage of Stoddard solvent (in excess of FMVSS 301 requirements) upon impact, but leakage was at a somewhat slower rate. The B4 test produced less penetration into the tank than the B1 test and it was concluded that a smaller overlap, such as 50%, actually produces less penetration into the fuel tank because the fuel tank is not full engaged.

**Table 2.**
**Stoddard Fuel Leakage Measurements for Rear Impact Crash Tests with MDB**

FMVSS 301 Rear Impact Test Procedure Development - Fuel Leakage

| Test Number | Model | Impact 28g | 5 min 140g | 25 min 28g/ min. | Rollover 142g/ 5 min. |
|---|---|---|---|---|---|
| *Baseline:* | | | | | |
| B1 | Mustang | failed | Fail 2 gal | NA | NA |
| B2 | Mustang | Pass | Pass | Pass | Fail 472g |
| B3 | Mustang | Trace | Pass 46 g | Pass 0 g | Pass 59 g |
| B4 | Mustang | Trace | Fail 971 g | NA | NA |
| *Comparison:* | | | | | |
| 1 | Mustang | Trace | Pass | Pass | Pass |
| 2 | Voyager | Pass | Pass | Pass | Pass |
| 3 | Sidekick | Fail (not meas.) | Fail 2674 g | Fail 7349 g | Na |
| 4 | Blazer | Trace (carbon cannister line) | Pass | Pass | Pass |
| 5 | Neon | Fail (not meas.) | Fail 2200 g | Fail 8706 g | NA |
| 6 | Prizm | Trace | Pass | Pass | Fail 281g |

## PHASE 2 - COMPARISON TESTING

In the second phase of testing, also shown in Table 1, six vehicles were selected representing a cross section of vehicle types (minivan, sport utilities and passenger cars). The 1996 Ford Mustang was also tested since it was believed to have been improved over the 1993 version in terms of fuel system integrity. To accomplish full engagement of fuel tanks while avoiding engagement of opposite side frame rails required approximately 70% overlap. Coincidentally, fatal crash cases (1) were reviewed for rear impact fatalities which were survivable in the absence of fires. From these cases 70% overlap was the approximate average observed from the rear impact fatal fires. Therefore the test condition chosen for phase two testing was at 70% overlap, 81 +/- 1 kph, and the bumper alignment adjusted by lowering the barrier face height by 2 inches.

Table 2 shows the test results for fuel system leakage. Two of the six vehicles exceeded the FMVSS 301 leakage requirements directly following impact and one vehicle leaked in excess of FMVSS 301 requirements only in the rollover phase of the FMVSS 301 procedure. It is interesting to note that three of the six vehicles had tanks located aft of the rear axle, but only one of these vehicles exceeded the leakage requirements in FMVSS 301. It is also quite significant to note that one of the vehicles, a 1996 Ford Mustang, passed the test with much less crush, better tank protection, and better occupant protection (discussed later) than previously seen with the earlier 1993 Mustang. Ford has informed NHTSA that the Mustang was redesigned in 1994. The new version was based on the old chassis with extensive modifications, but the tank location was maintained. Therefore it may be concluded that regardless of tank location, it is possible and practical to design a fuel tank system which offers reasonable protection from rear impact fires at this severity level.

## ANTHROPOMORPHIC TEST DEVICE RESPONSES

Table 3 shows the responses of both driver and passenger Hybrid III anthropomorphic test devices (ATDs) used in phase one and phase two testing. Head and chest measurements are shown in the table. Neck measurements were taken, but due to lack of widely accepted injury criteria for rear impacts, data are not presented. It should be noted that the injury assessment reference values and the Hybrid III ATD were developed for frontal impacts. Therefore, injury measurements recorded during these rear impact tests are presented for relative comparisons and with less confidence in predicting injury risk than in frontal impacts. FMVSS 208 limit is 1000 for HIC (Head Injury Criteria) and 60 g's for 3 milliseconds of chest acceleration in frontal impacts. In the baseline Mustang tests, both head and chest injury indicators exceeded 208 criteria, with one HIC at 1332 and one chest reading as high as 108.8 g's. In the six phase two tests, four of the twelve ATDs exceeded the value of 1000 for HIC, with values ranging from 389 to 2552. Three of these four HICs exceeding 1000 occur

**Table 3.**
**Results of Hybrid III Dummy response in MDB crash tests based on FMVSS 208 criteria**

FMVSS 301 Rear Impact Test Procedure Development - Dummy Response

| Test Number | Vehicle Model | Dummy Position | Head HIC | Chest 3 ms clip | Contact surface |
|---|---|---|---|---|---|
| *Baseline :* | | | | | |
| B1 | Mustang | driver | 1109 | 97.6 | Rear seat back |
| | | passenger | 1238 | 108.8 | Rear seat back |
| B2 | Mustang | driver | 198 | 22.8 | |
| | | passenger | 913 | 53.9 | |
| B3 | Mustang | driver | 892 | 38.0 | |
| | | passenger | 1191 | 60.4 | Rear seat back |
| B4 | Mustang | driver | 721 | 44.9 | |
| | | passenger | 1332 | 66.4 | Rear seat back |
| *Comparison:* | | | | | |
| 1 | Mustang | driver | 1586 | 41.8 | Rear seat back |
| | | passenger | 583 | 53.6 | |
| 2 | Voyager | driver | 690 | 15.8 | |
| | | passenger | 1578 | 15.5 | Rear seat bottom |
| 3 | Sidekick | driver | 389 | 39.5 | |
| | | passenger | 569 | 39.7 | |
| 4 | Blazer | driver | 783 | 22.6 | |
| | | passenger | 2552 | 18.9 | Floorpan |
| 5 | Neon | driver | 739 | 22.2 | |
| | | passenger | 1423 | 43.0 | Rear seat back, rear door panel |
| 6 | Prizm | driver | 829 | 37.2 | |
| | | passenger | 604 | 19.6 | |

in vehicles which "passed" the fuel leakage requirements. High HICs in rear impact testing may be significant since HIC was developed as an indicator of skull fracture which is related to serious head injury. This may be particularly relevant in the event of a post-crash rear impact fire, in which rapid evacuation is critical for survival. This research suggests that more attention to head protection may need to be directed for rear impact occupant protection with and without fires.

The B1 '93 Mustang test and the '96 Mustang test (test number 1) are used to compare ATD and vehicle structural response under similar crash test conditions. In comparing these Mustang tests, it may appear at first glance that the '96 Mustang with a driver HIC of 1586 is worse than the '93 Mustang with a driver HIC of 1109, but further examination is necessary to understand conflicting data. First, the driver ATD in the '96 Mustang had chest resultant acceleration of only 41.8 g's as compared to 97.6 g's for the driver ATD in the '93 Mustang. Secondly, the passenger ATD in the '96 Mustang "passed" 208 injury criteria, whereas the passenger in the '93 Mustang "failed" head and chest criteria (1238 HIC and 108.8 chest resultant acceleration). These phenomena can best be explained by film analysis. From the film analysis it is observed that in the B1 '93 Mustang test, the rear seat was pushed forward into the backs of the front seats before significant ATD motion occurred, thus thrusting the dummies forward by loading the chest. Also the dummies' heads were carried forward by the chest, reducing the contact velocity of the head with the rear seat back. In the '96 Mustang, the passenger compartment remained relatively intact, particularly on the driver side, allowing the seat backs to deform. This deformation of the seat allowed the driver's head to move rearward and strike the seat back with sufficient force to create the high HIC. Some intrusion on the passenger side helped to restrain the dummy without excessive force as seen in the baseline test. Though intrusion in this case may have helped lower the HIC, prudence for protection of rear seat occupants would favor a seat back stiffening and intrusion reduction countermeasures to achieve the same result. Thus, the '96 Mustang performed better than the '93 in terms of vehicle structural performance and ATD response. This difference in performance appeared to be due to design changes made on the 1996 Mustang in improving structural integrity. It is particularly noteworthy that the '96 Mustang rear seat area did not completely collapse as in the test of the '93 Mustang providing space for survivability of rear seated occupants.

For the other five vehicles and 10 ATDs, three ATDs exceeded a HIC frontal criterion of 1000. One vehicle, the Chevrolet Blazer, had a particularly high HIC for the right front passenger of 2552. This high HIC occurred due to the lack of a rear passenger seat and the seat back failure which allowed the right front ATD's head to strike the rear floor surface.

## CONCLUSIONS

From the test series we may conclude that the moving deformable barrier impact used in phase two of the test series distinguished between vehicles with marginal performance and improved performance. For example, the '96 Mustang with a rear-mounted tank (improved over the 1993 Mustang), did not leak Stoddard, and a '96 Geo Prizm with a tank forward of the axle did leak excessive Stoddard. With minor improvements it appeared the Geo Prizm could prevent fuel leakage in the proposed test. Another vehicle, the Dodge Neon, with a tank forward of the axle leaked excessive Stoddard. This vehicle leaked due to a particularly vulnerable location for the sender unit. Therefore, more difficult design changes may be needed for this vehicle.

Since all of the vehicles that leaked excessive Stoddard were small ($\leq$ 1370 kg), the one question after completing these tests was whether any small car could pass the test procedure. To answer this question, GM conducted five rear impact tests of small cars under the GM/NHTSA settlement agreement (docket number 92-066N3). GM and NHTSA selected five small 1998 vehicles based on production volumes from Asian, American and European manufacturers. These vehicles were Nissan Sentra, Honda Civic, Ford Escort, Chevrolet Cavalier and Volkswagen Jetta. The Civic and the Sentra passed the leakage requirements of FMVSS 301, but all cars showed potential to prevent fuel spillage with minor modifications. Most important, the test produced damage to the vehicles that was similar to that observed in case studies of fatal crashes which would have been survivable in the absence of fire.

## REFERENCES

1. Ragland, C.L. and Hsia, H. " A Case Study of 214 Fatal Crashes Involving Fire", paper number 98-S4-O-08, 16th International Safety Conference on the Enhanced Safety of Vehicles, Windsor, Canada, June 1998.