Attenuating Head Impact with Vehicular (Including Heavy Truck) Interiors

S E Meyer*, B Herbst**, A O Nelson*, S Forrest*

*Safety Analysis & Forensic Engineering (S.A.F.E.), 6775 Hollister Ave, Ste 100, Goleta, CA 93117, USA
**SAFE Laboratories, 6775 Hollister Ave, Ste 100, Goleta, CA 93117, USA

Abstract - Automotive interiors have long been a potentially injurious impact area to occupants during accidents, especially in the absence of adequate padding. The U.S. Federal Motor Vehicle Safety Standard (FMVSS) 201, Occupant Protection in Interior Impact, outlines test procedures and performance criteria in order to mitigate potentially injurious head impacts to interior surfaces. FMVSS 201 specifies a finite set of impact locations and applies to passenger vehicles of a specified year range and with a gross vehicle weight rating less than 10,000 lb. In this paper, two head impact test methodologies are presented, a pendulum-test device and a Free Motion Headform (FMH) launching device, which allows for dynamic, repeatable impact evaluation of various vehicle interior surfaces and their impact attenuation abilities.

The presented testing includes multiple series that evaluate the effect of differing vehicle upper interior padding on occupant head injury. One study in particular, analyzes a head impact to the side header of a heavy truck (not included in FMVSS 201) during a 90 degree rollover. Additionally, two other series of tests are presented which assess the injury reduction effect of side airbags to near side as well as far side occupants in a side impact scenario. Lastly, a forensic analysis is presented which evaluates two possible head impact locations experienced in a real world accident by analysis of the resulting interior compartment damage utilizing the FMH launching device test method. The data collected and presented includes accelerometer instrumentation and high speed video analysis. These studies demonstrate that adequate padding and airbags are very effective at mitigating head injury potential at impact speeds of 12-25 mph (19-40 kph).

INTRODUCTION

Traumatic head injuries to automobile occupants have been shown to be a major cause of death and permanent brain injury within the U.S. and internationally. Further, padding materials have long been recognized, and therefore frequently incorporated into automotive interiors, to reduce the potential for head injury. The interior of motor vehicles has been identified for literally decades as an area where injury can occur in the absence of padding and/or friendly contact surfaces. Such surfaces include the instrument panel, steering wheel, roof pillars, roof rails, the roof panel, and any foreseeable area(s) with which a vehicle occupant's head might make contact during a collision. Impacts with interior vehicle structures have been studied extensively by various researchers, including the U.S. federal government [1-4].

To address injury risks to motor vehicle occupants associated with impact to upper interior surfaces, the U.S. National Highway Traffic Safety Administration (NHTSA), within the U.S. Federal Motor Vehicle Safety Standard (FMVSS) 571.201, requires foreseeable interior impact surfaces to be padded in order to reduce head injury risk [5]. Testing conducted pursuant to FMVSS 201 is carried out using anthropometric test dummies (ATDs) and/ or head forms instrumented to capture data regarding peak accelerations throughout the duration of the test. These recorded accelerations are used to calculate Head Injury Criterion (HIC), which is a measure of the potential of head injury arising from an impact. The government requires that the HIC(d) shall not exceed 1000 when calculated in accordance with the following formula:

$$HIC = \left[\frac{1}{(t_2-t_1)}\int_{t_1}^{t_2} a\,dt\right]^{2.5}(t_2-t_1) \qquad \& \qquad HIC\,(d) = 0.75446(HIC) + 166.4 \qquad [6]$$

Where a is the resultant head acceleration expressed as a multiple of the acceleration of gravity (g) and t_1 and t_2 are any two points in time during the impact which are separated by not more than a 36 millisecond time interval .

Head impact research conducted throughout the early 1990's provides a basis for this FMVSS 201 requirement and established that the addition of 1 inch of rigid padding to the upper interior surfaces was found to decrease the Head Injury Criteria (HIC) values obtained in head form impact tests by approximately 40%. For a 15 mph (24 kph) head form impact test, estimates were made of the proportion of the total U.S. passenger car fleet that would pass a HIC < 1000 test both with and without 1 inch (2.5 cm) of padding being added to upper interior structures [7-9] (Table 1).

Table 1: Percentages of the Total US Fleet Passing a HIC 1000 Test With and Without Padding

Structure	% of Fleet Passing HIC 1000 Test	
	Without Padding	With 1" Padding
A-pillar	32	98
Front Header	71	100
Side rail	44	99
B-pillar	29	93

Accident statistics have long shown that heavy truck rollovers are an extremely dangerous accident mode for truck drivers and their passengers. In 1986, NHTSA published a study indicating that approximately 1,000 heavy truck occupants are killed in crashes every year and identifying rollovers as one of the key factors that play a contributing role in causing those fatalities [10]. Researchers from the University of Michigan Transportation Research Institute (UMTRI), reported in 1991 that approximately 60% of all heavy truck driver fatalities were associated with rollover accidents [11]. They further concluded that truck drivers had a 50% chance of being injured in a rollover even if they were restrained. If the truck did not rollover, the risk of injury drops by a factor of 10. By many estimates, rollover accidents involving heavy trucks account for more than 50% (as much as 58%) of accidents in which the truck driver sustained fatal injuries. The most common rollover accident mode for these heavy trucks involves only ¼ turn, or merely a 90 degree tip-over onto the side of the truck. Studies of actual truck rollover accidents have shown that a significant source of truck driver injuries was contact of the head and neck to portions of the vehicle upper interior.

More recently, research regarding occupant kinematics and restraint effectiveness during a quarter-turn rollover in heavy trucks, published by the Society of Automotive Engineers, points out that a belted occupant's motion will be mostly lateral in these tip-over type crashes and, that although the lap belt may be effective at keeping the driver's pelvis in the seat, research demonstrates that drivers will face a risk of head strikes with upper interior surfaces [12]. These statistics make clear that heavy trucks have high propensity for occupant contact injury with upper interior surfaces in rollover and therefore, interior padding and their energy absorbing characteristics must be taken into considerations. Presented testing evaluates the original equipment manufacture (OEM) characteristics of a heavy truck cab upper interior side header structure along with its padding or energy absorbing characteristics.

Field evidence evaluation in real-world vehicle crashes wherein injurious contact with interior surfaces are suspected often includes consideration of the occupant's motions/kinematics through the crash sequence and inspection of the headliner/ interior vehicle trim components in an effort to evaluate the contacted surface including potential identification of occupant witness marks. This information can then be considered along with specific injuries to determine the (approximate) orientation of the head at the time the injury was received. Once the orientation of the head and the injurious contact surface has been established, one can evaluate the adequacy of the energy absorbing characteristics of the relevant portion of the interior design. This paper presents head impact testing of head impact surfaces with head impact orientations similar to what was identified in specific real-world crashes. This testing was conducted to evaluate the padding characteristics and injury potential associated with the OEM surface and then compared to that same surface with additional padding.

HEAVY TRUCK PENDULUM TESTING

Series 1 - Test Setup

Test Series 1 utilizes the pendulum impact methodology. This methodology has been shown to be extremely reliable and repeatable. The pendulum has a long history of application in automotive safety testing and has been used in the development of injury thresholds through cadaver testing as well as test dummy development and calibration. The pendulum methodology is the methodology called for to apply specific and repeatable loads currently required to demonstrate compliance with a variety of Federal Government Safety Standards both in the United States and abroad [13-17] (Figure 1).

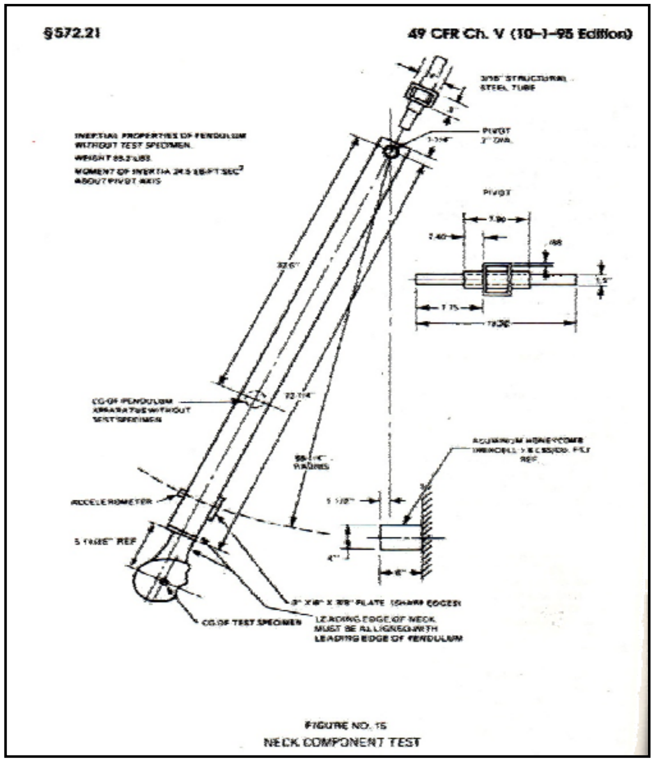

Figure 1. United States Federal Government Pendulum Test Figure

Series 1 testing utilized a Hybrid III ATD head and neck mounted to a pendulum arm such that it is free to pivot down into impact with the desired test specimen (Figure 2). The test specimen was an OEM side header structure from a popular heavy truck cab. The portion of side header structure used is located just outboard of the driver's seating position and, in a driver's side rollover, a likely area of head contact. The head form was instrumented with a triaxial accelerometer array, located at the center of gravity of the Hybrid III head. Head acceleration data was collected as a function of time at a rate of 10,000Hz in accordance with SAE Recommended Practice J211. Each test was documented utilizing a real-time camera and two high-speed cameras recording at 300 fps each.

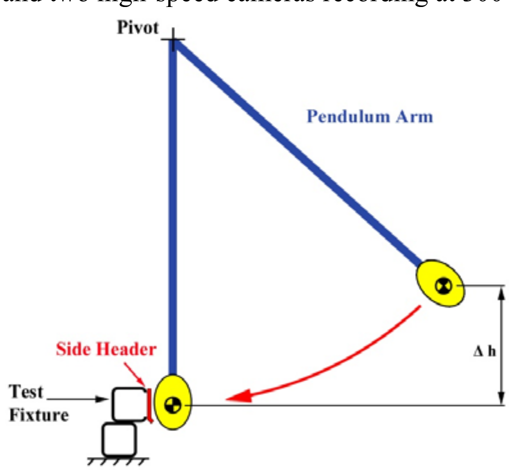

Figure 2. Pendulum Methodology Test Fixture

The exemplar interior side header structure of a 2007 Mack heavy truck cab was obtained from a local dealer and was evaluated in its OEM installed condition, as well as with the addition of alternative padding materials. The pendulum methodology was selected not only for its repeatability, but also for its ability to provide similarity to the occupant kinematics experienced in the heavy truck tip over, or quarter roll rollover, accident. A 50th percentile Hybrid III head and neck were attached to a light weight 11.85 foot (3.6 m) length pivoting pendulum. The head form was aligned to the test fixture such that the side of the head would strike the inboard face of the OEM side header (See Figure 3).

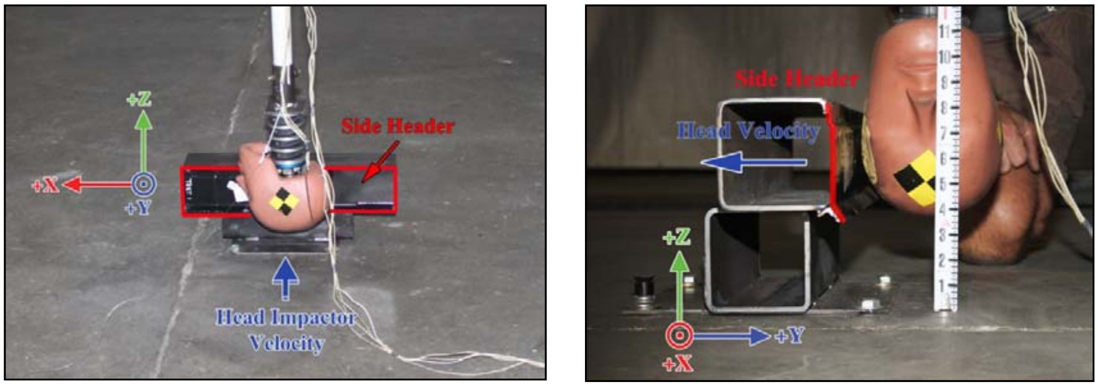

Figure 3. Series 1 Test Setup

The pendulum swing arc was perpendicular to the face of the side header. In each test, the head was pulled rearward until a change in height (Δh) of 6.5 feet (2 m) was achieved at the forehead target on the head which resulted in an impact speed of 14 mph (22.5 kph).

Series 1 – Test Results

The testing included a baseline test wherein the Hybrid III ATD head and neck complex impacted the bare Mack sheet metal side header at an impact speed of approximately 14 mph (22.5 kph). This produced a resulting HIC of approximately 1135. A second test was then conducted including the addition of the approximately ¼ inch (6.4 mm) thick OEM headliner material that covered the side header sheet metal in the production vehicle. The resulting HIC with the headliner present was still recorded at approximately 1110, indicating that the headliner provides little or no padding benefit or head impact protection as compared to the metal structure itself. Two additional tests were then conducted wherein a sample of OEM foam padding found on the side header of a production 2003 Jeep Grand Cherokee (FMVSS 201 compliant) was positioned over the OEM Mack side header structure. With and without the addition of OEM padding and the same head impact speed of approximately 14 mph (22.5 kph), the recorded HICs were found to be reduced to well below 1000, averaging approximately 565. Test data is summarized in Table 2 below.

Table 2. Series 1 Testing Summary Table

Test	Description	HIC36	T1 (ms)	T2 (ms)	Peak Resultant Acceleration (g)
1a	Mack Side Header	1133.9	0.8	8.0	283.11
1b	Mack Side Header with Mack Headliner	1109.5	1.2	8.5	214.41
1c	Mack Side Header with Jeep Padding	523.5	2.2	12.3	98.55
1d	Mack Side Header with Jeep Padding & Mack Headliner	604.8	1.8	10.6	106.74

FREE MOTION HEAD FORM (FMH) TESTING

FMH Testing Setup

In the free motion head form (FMH) testing, a Hybrid III ATD FMH is propelled by a pneumatic launching ram through a given free flight distance until impact with the desired test location (Figure 4). The FMH is a 50^{th} percentile Hybrid III head, weighing 10 lbs (4.5 kg), modified according to FMVSS 201 for use as a free-motion head form impactor. The pneumatic launching ram was mounted into vehicle occupant compartments at various orientations so that the padding properties of different potential occupant contact locations could be evaluated. NHTSA selected this test methodology for its ability to evaluate many areas of the interior that the head contacts during real-world crashes instead of being limited to those contacted by a dummy in frontal or side impact tests. The FMVSS 201 describes a FMH speed of 15 mph (24 kph) with no airbag or 12 mph (19 kph) in the presence of a dynamically deploying occupant protection system (airbag) [15]. The following presented testing analyzes the injury mitigating potential of various padded surfaces for FMH impact speeds ranging from 12-25 mph (19-40 kph).

Two series of the FMH testing were conducted with and without deployed side airbags to quantify the airbag's effectiveness in injury reduction potential. The head form was instrumented with a triaxial accelerometer array located at its center of gravity and each test was documented with real-time camera and high-speed cameras. Head form velocity was calculated by integrating the longitudinal (X) head acceleration data as described in FMVSS 201 [16].

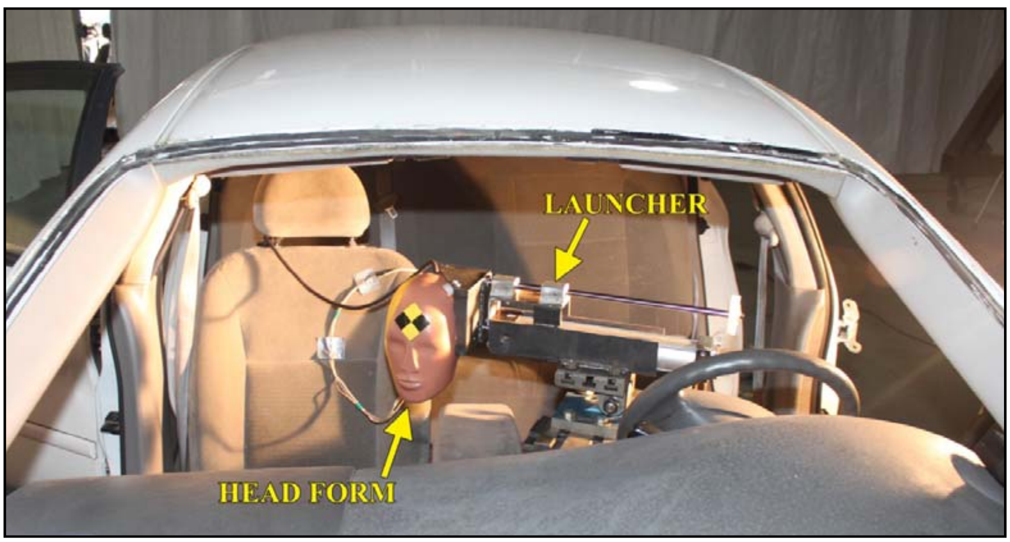

Figure 4. Head Form on Launch Fixture

Series 2 – FMH into B-pillar with Various Trim and Padding

A 1999 Subaru Legacy Outback Wagon test vehicle, or buck, was utilized for Series 2 testing. The front seating was removed from the vehicle in order to allow for the free motion head form (FMH) test equipment. The head form was propelled by a pneumatic ram through a stroke distance of approximately 12 inches (30.5 cm) and a free flight distance of approximately 1.5 inches (3.8 cm) for each test. The head form and ram were oriented such that the head form struck the OEM B-pillar near the D-ring with a vertical approach angle of -9 degrees from horizontal (downward from level) and a horizontal approach angle of 39 degrees from the driver side rocker panel (Figure 5).

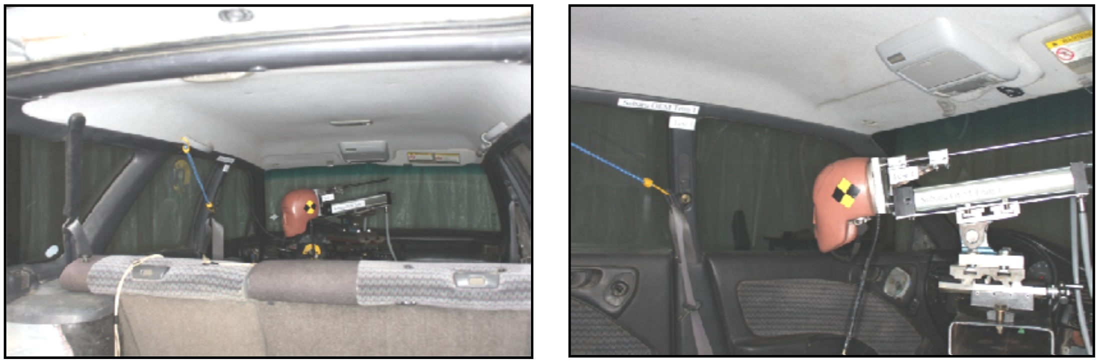

Figure 5. Series 2 Test Setup

Five tests were conducted in Series 2: test 2a utilized a new OEM replacement B-pillar trim piece purchased from a local Subaru dealership for the 1999 Subaru Legacy Outback; 2b & 2e utilized OEM padding from the next generation 2000 Subaru Legacy Outback padding which complied with updated FMVSS 201U upper interior padding requirement; 2c and 2d utilized metal air gap (MAG) padding constructed out of standard sheet steel with a thickness for the thicker and thinner padding of 0.035" (0.89 mm) and 0.022" (0.56 mm) respectively, and was positioned in place of the OEM trim. Due to the curved geometry of the B-pillar, the MAG padding resulted in approximately 1 to 2 inches (2.5-5 cm) of air gap. In all tests except 2e, the OEM restraint system that came with the test buck was in its stowed position on the impacted B-pillar. For test 2e, the 2000 Legacy Outback OEM restraint was also utilized along with the 2000's FMVSS 201U complaint trim. Test data is summarized in Table 3 below.

Table 3. Series 2 Testing Summary Table

Test #	Description	Impact Speed	FMH HIC36	HIC(d)	T1	T2	Peak Resultant Acceleration
2a	OEM Trim	15 mph (24 kph)	1972	1654	0.3552	0.3579	288.28
2b	201U Trim	15 mph (24 kph)	1353	1187	0.3470	0.3504	217.88
2c	Thinner Metal (0.022in/0.56 mm) MAG Padding	15 mph (24 kph)	489	535	0.4518	0.4567	124.64
2d	Thicker Metal (0.035in/0.89 mm) MAG Padding	15 mph (24 kph)	162	289	0.4787	0.4974	79.44
2e	201U Trim and Restraint	15 mph (24 kph)	794	765	0.3734	0.3797	240.95*

* After B-pillar impact, registered on rebound

Series 3 – FMH With and Without Side Airbags, Far Side Impact

Series 3 testing utilized a partial 2001 Ford Taurus occupant compartment, or vehicle buck. The FMH pneumatic ram launcher was positioned in the occupant compartment such that its vertical approach angle was 0 degrees from horizontal (or level) and its horizontal approach angle was 108 degrees from the vehicle's longitudinal (forward) axis. The FMH was propelled by the pneumatic ram through a stroke distance of approximately 12 inches (30.5 cm) at which point it had a free flight distance of approximately 10 inches (25.4 cm) before striking the passenger B-pillar with the right side of the head (Figure 6).

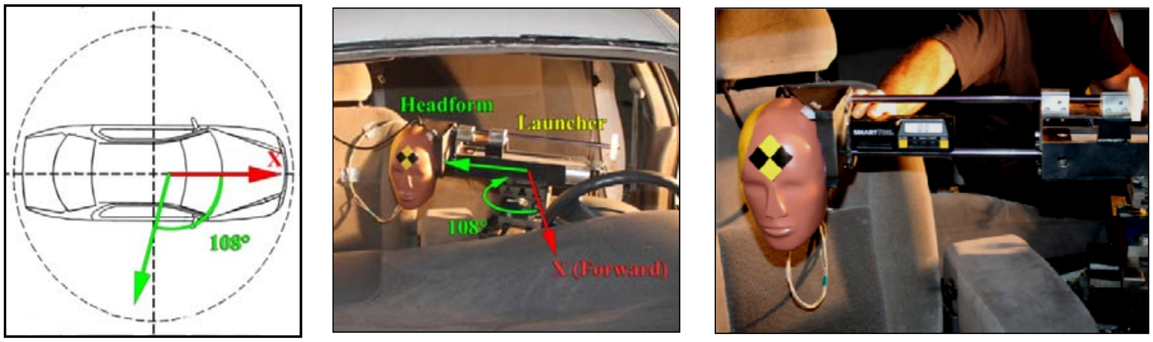

Figure 6. Series 3 Test Setup

The FMH was aligned to strike the B-pillar upper/lower trim interface near the window opening line. The upper and lower trim pieces were replaced for each test with OEM trim pieces. An OEM right front seat equipped with a seat integrated side impact airbag was placed in the full rear position with seatback recline angle of 23 degrees from vertical. The complete seat and airbag was replaced after each test in which the seat mounted side airbag was deployed.

Five tests were conducted in Series 3: two without airbag deployment and three with the airbags deployed. For test 3a, the FMH struck the B-pillar at 15.3 mph (24.6 kph) resulting in a HIC(d) of 916.4 and resulting peak head accelerations 196.4 g. When the seat-mounted side airbag was deployed at comparable speeds in tests 3d and 3e, the HIC(d) was reduced by 37-65% to 324.9 and 577.7 and the peak head accelerations were reduced by 62-64% to 71.4 and 73.9 g.

For test 3b, the FMH struck the B-pillar at 20.8 mph (33.5 kph) resulting in a HIC(d) of 1,875.1 and resulting peak head acceleration 285.6 g. When the airbag was deployed at a comparable speed in test 3c, HIC(d) was reduced by 49% to 957.0 and the peak head acceleration was reduced by 44% to 159.7 g. The B-pillar trim was removed after each test and no significant visible damage to the underlying sheet metal was noted subsequent to any of the testing.

Table 4. Series 3 Testing Summary Table

Test	Impact Surface	Speed	FMH HIC36	HIC(d)	Peak Resultant Acceleration	Airbag Contact Time
3a	B-pillar	15.3 mph (24.6 kph)	994.1	916.4	196.4 g	N/A
3b	B-pillar	20.8 mph (33.5 kph)	2,264.7	1,875.1	285.6 g	N/A
3c	B-pillar & Airbag	20.5 mph (33.0 kph)	1,047.9	957.0	159.7 g	111 ms
3d	B-pillar & Airbag	15.3 mph (24.6 kph)	210.1	324.9	71.4 g	98 ms
3e	B-pillar & Airbag	16.7 mph (26.9 kph)	545.2	577.7	73.9 g	111 ms

Series 4 – FMH With and Without Side Airbags, Near Side Impact

A 2004 Hyundai Elantra vehicle clip, or partial occupant compartment, was used for test Series 4. The FMH pneumatic ram launcher was positioned in the occupant compartment such that its vertical approach angle was 0 degrees from horizontal (or level) and its horizontal approach angle was -90 degrees from the vehicle's longitudinal (forward) axis. The FMH was propelled by the pneumatic ram through a stroke distance of approximately 18 inches (45.7 cm) at which point it had a free flight distance of approximately 8 inches (20.3 cm) before striking the driver's side B-pillar mounted D-ring with the left side of the head (Figure 7).

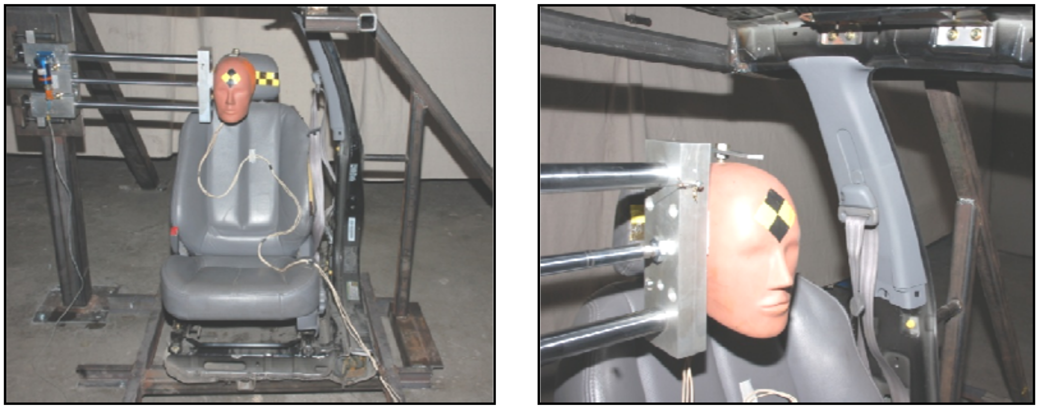

Figure 7. Series 4 Test Setup

The FMH was aligned to strike the driver's D-ring, in its full down position, mounted to the B-pillar. An OEM left front seat was utilized with its associated seat mounted side airbag for the testing. The side airbag was manually and continually inflated with a residual pressure of approximately 0.3 psi (2,068 Pa) as measured by a digital manometer.

Two tests were conducted in Series 4: one without the deployed, seat mounted side airbag and one with the side airbag in its deployed position. For test 4a, the FMH struck the B-pillar mounted D-ring at 18.2 mph (29.3 kph) resulting in a HIC(d) of 925.5 and peak head acceleration of 158.3 g. When the seat-mounted side airbag was deployed a comparable speed for test 4b, the HIC(d) was reduced by approximately 62% to 354.9 and the peak head acceleration was reduced by approximately 68% to 50.0 g.

Table 5. Series 4 Testing Summary Table

Test	Impact Surface	Speed	FMH HIC36	HIC(d)	Peak Resultant Acceleration
4a	D-ring	18.2 mph (29.3 kph)	1006.2	925.5	158.3 g
4b	D-ring & Airbag	17.3 mph (27.8 kph)	249.8	354.9	50.0 g

Series 5 – FMH Forensic Evidence Study

A 2003 Ford F250 Superduty Supercab test vehicle/buck was utilized to analyze two proposed witness marks and occupant injurious impact locations identified during a real-world rollover accident. The FMH launcher was oriented in the vehicle at two different locations in order to evaluate the resulting vehicle damage and injury measurements for each location. The FMH was propelled by a pneumatic launcher ram through a stroke distance of approximately 8 inches (20.3 cm) and a free flight distance of approximately 1.5 inches (3.8 cm) for each test. The head form and ram were oriented such that the head form was accelerated along its vertical (-Z) axis striking the intended impact location with the vertex of the head.

The test setup for the four tests conducted is summarized in Table 6, below. Tests 5a and 5c were conducted with the head form impacting the radio, located in the center of the dash. The radio was replaced between the tests to allow for analysis of the radio post-test deformation. The impact location on the radio was centered between the second and third station preset buttons (Figure 8). For tests 5b and 5d, the head form was launched vertically into the roof panel above the front center occupant seating location. For test 5d, the impact point was moved towards the passenger side of the vehicle by 5 inches (12.7 cm) and rearward by 1.5 inches (3.8 cm). The roof panel impact locations were varied to allow for separate examination of the impact damage to the roof panel from each tests (Figure 9).

Table 6. Series 5 Test Setup

Test #	Impact Target	Launch / Approach Orientation	Impact Speed
5a	Radio In Dash	Horizontal	10 mph (16 kph)
5b	Roof Panel	Vertical	10 mph (16 kph)
5c	Radio In Dash	Horizontal	15 mph (24 kph)
5d	Roof Panel	Vertical	15 mph (24 kph)

Figure 8. Series 5 Test Setup For Horizontal Impact Into Dash Radio

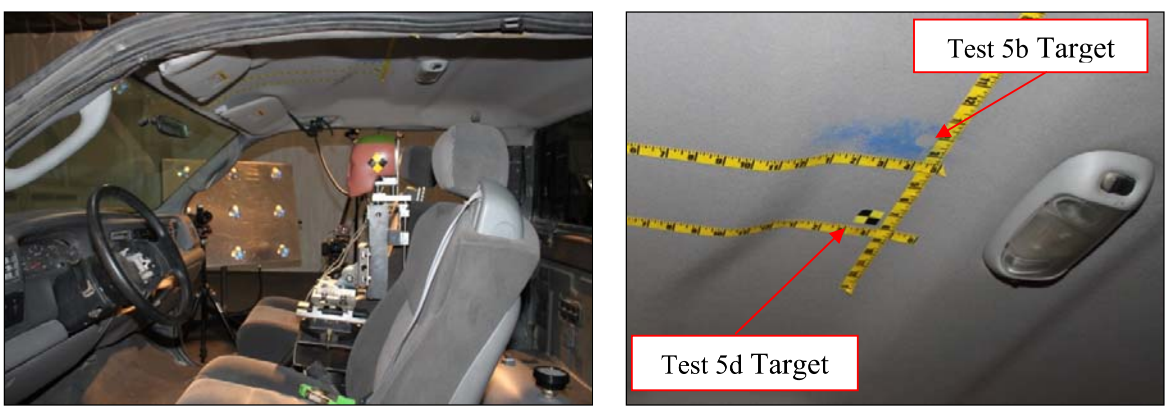

Figure 9. Series 5 Test Setup For Vertical Impact Into Roof Panel

The testing results are reported in Table 7, below. In test 5a, the head form impacted the radio at 10.5 mph (16.9 kph) and indented the second and third radio buttons (Figure 10). Test 5c, which also impacted the dash/radio, at 15.0 mph (24.1 kph), resulted in more deformation to the radio buttons and a larger contact area than that observed in test 5a. Additionally, in test 5c, the impact caused a dislocation of the surrounding dash panel (Figure 11). Test 5b was conducted with the head form striking the roof panel at 10.6 mph (17.1 kph) and resulted in a small but visible outward dent in the roof exterior sheet metal (Figure 12). Test 5d, also into the roof at 15.2 mph (24.5 kph), resulted in a much larger exterior roof panel dent, measuring approximately 3 inches (7.6 cm) in diameter and a maximum depth of approximately one tenth of an inch (2.5 cm) (Figure 13).

Table 7. Series 5 Test Results

Test #	Description	Impact Speed	FMH HIC36	HIC(d)	Peak Resultant Acceleration	Impact Force[1]
5a	Head Into Dash/Radio	10.5 mph (16.9 kph)	106	247	88 g	880 lb. (3,914 N)
5b	Head Into Roof Panel	10.6 mph (17.1 kph)	420	483	111 g	1110 lb. (4,937 N)
5c	Head Into Dash/Radio	15.0 mph (24.1 kph)	322	409	139 g	1390 lb. (6,182 N)
5d	Head Into Roof Panel	15.2 mph (24.5 kph)	1064	969	178 g	1780 lb. (7,917 N)

[1] Estimated using Force = Mass * Acceleration or Force = 10 lb. (4.5 kg) * Acceleration

Figure 10. Post Test Damage, Test 5a – Dash Impact

Figure 11. Post Test Damage, Test 5c – Dash Impact

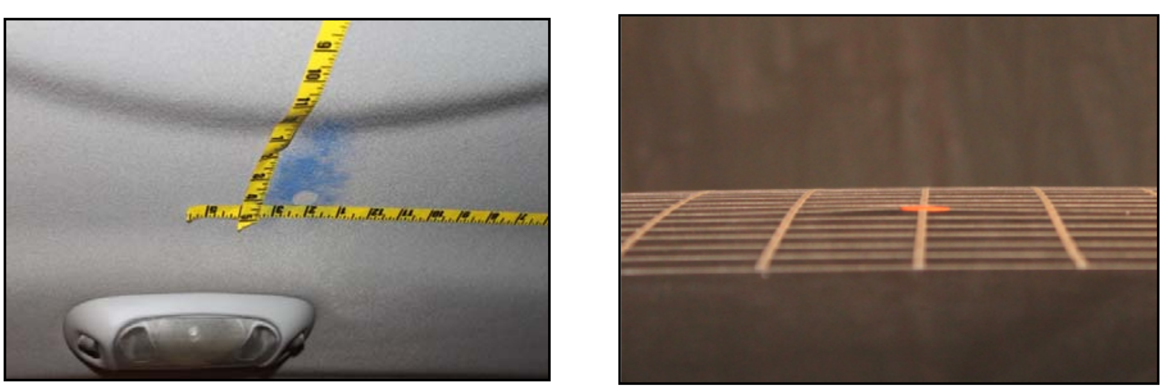

Figure 12. Post Test Damage, Test 5b – Roof Panel Impact

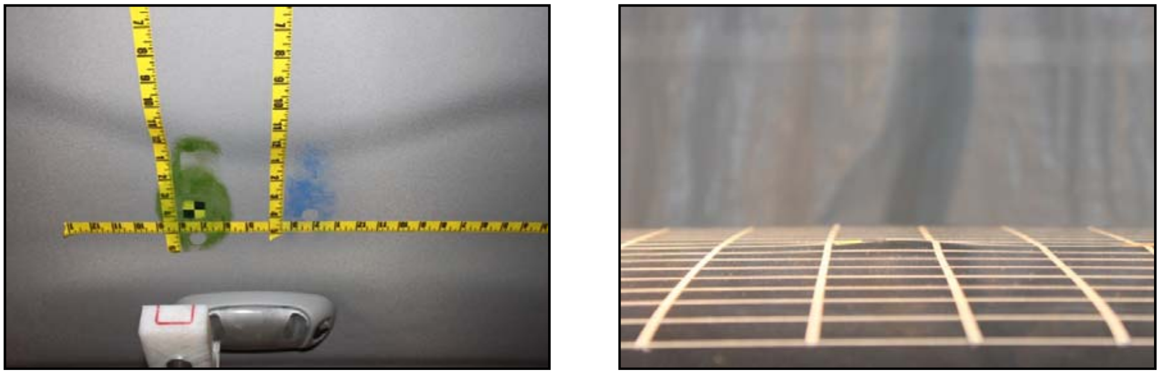

Figure 13. Post Test Damage, Test 5d – Roof Panel Impact

An impact to the roof panel with sufficient force to cause the neck fracture observed in the subject accident would have left observable residual sheet metal deformation that was not seen in the accident vehicle. Considering the results of this testing, compared to the damage documentation on the subject accident vehicle made clear that there was no coordinating deformation on the roof structure of the accident vehicle to indicate the occupant had made such contact with the surface of the roof; however, the radio/dash area was found to exhibit similar deformation to that seen in the presented testing. As such, the FMH launcher testing was able to rule out one proposed impact location (the roof) and confirm the deformation seen to the other (the dash).

CONCLUSIONS

The presented test series have been performed on various upper interior automotive vehicle compartments with their various padding characteristics. Their performance, along with modified padding, including airbags, has been evaluated. As pointed out above, there are numerous foreseeable occupant interior impact locations associated with real world impacts, including rollovers. These studies indicate that effective padding, whether via increased thickness, improved energy absorption characteristics, or inclusion of airbags, was found to significantly reduce potential occupant injury measures to foreseeable impact surfaces in automotive interiors.

Specifically, in test Series 1 conducted on the upper interior padding surfaces of a heavy truck compartment, a reduction in HIC of 54% was observed between the baseline Mack truck side header versus the side header equipped with the FMVSS 201 compliant padding at impact speeds of approximately 14 mph (22.5 kph). This confirms that the inclusion of upper interior padding in heavy trucks would result in similar injury risk reduction to truck occupants to that seen for passenger vehicle occupants in vehicles complying with FMVSS 201.

Side airbags were shown to be effective at reducing injury measurements for both near and far side occupants in side impacts. With FMH impact velocities ranging from approximately 15 to 20 mph (24-32 kph), an average HIC reduction of approximately 53 percent was observed.

Review of the Series 5, Ford F250 testing, demonstrates the usefulness of both test methodologies for evaluating the damage patterns that can be produced within an occupant compartment for a given crash circumstance. Injury levels can also be quantified and compared to damage observed on the energy absorbing material, whether plastic radio/dash trim, headliner scuffs/abrasions, etc, to help establish the feasibility of a possible impact or injurious location.

REFERENCES

1 Fan, W., NHTSA, “Head Impacts with Roof-Pillar Support Structures – Problem Identification,” SAE 831620, 1983.

2 Monk, M., Sullivan, L., National Highway Traffic Safety Administration (NHTSA)/Vehicle Research and Test Center (VRTC), "Energy Absorption Material Selection Methodology for Head/A-Pillar," SAE 861887, 1986.
3 Partyka, S., National Highway Traffic Safety Administration (NHTSA) Office of Vehicle Safety Standards Rulemaking, "Serious Head Injury in Light Passenger Vehicles from Rail, Header, and Pillar Contact," June 27, 1991.
4 National Highway Traffic Safety Administration (NHTSA), U.S. Department of Transportation, "Preliminary Regulatory Impact Analysis, Upper Interior Head Protection FMVSS No. 201," December 1992.
5 National Highway Traffic Safety Administration (NHTSA), U.S. Department of Transportation, "Federal Motor Vehicle Safety Standards; Standard No. 201; Occupant protection in interior impact," 571.201.
6 National Highway Traffic Safety Administration (NHTSA), U.S. Department of Transportation, "Federal Motor Vehicle Safety Standards; Standard No. 201; Occupant protection in interior impact," 571.201.
7 Willke, D., National Highway Traffic Safety Administration (NHTSA),"Upper Interior Head Protection, Volume I: The Development of a Research Test Procedure," DOT HS 807-865, November 1991.
8 Willke, D., National Highway Traffic Safety Administration (NHTSA), "Upper Interior Head Protection, Volume II, Fleet Characterization and Countermeasure Evaluation," DOT HS 807-866, November 1991.
9 McClean, A., Fildes, B., Kloeden, C., Digges, K., Anderson, R., Moore, V., Simpson, D., Monash University Accident Research Centre, "Prevention of Head Injuries to Car Occupants: An Investigation of Interior Padding Options," Report No. CR 160 770X, August 1997.
10 Clarke, R., Leasure, W., National Highway Traffic Safety Administration (NHTSA), U.S. Department of Transportation, "Truck Occupant Protection," NHTSA Technical Report DOT HS 807 081, December 1986.
11 Campbell, K., Sullivan, K., University of Michigan Transportation Research Institute, "Heavy Truck Cab Safety Study," SAE 912903, 1991.
12 Kress, T., Rink, R., Sewell, P., "Occupant Kinematics and Restraint Effectiveness during a Quarter-Turn Rollover in a Heavy Truck," SAE 2004-01-0327, March 8-11, 2004.
13 National Highway Traffic Safety Administration (NHTSA), U.S. Department of Transportation, "Federal Regulations 49 Part 572, "Anthropomorphic Test Devices."
14 National Highway Traffic Safety Administration (NHTSA), U.S. Department of Transportation, "Federal Regulations 49 Part 581, "Bumper Standard - Passenger Motor Vehicles other than Multipurpose Passenger Vehicles."
15 United Nations Economic Commission for Europe (UNECE) Vehicle Regulations, Regulation No. 17, "Uniform Provisions Concerning the Approval of Vehicles with Regard to the Seats, Their Anchorages and Any Head Restraints."
16 United Nations Economic Commission for Europe (UNECE) Vehicle Regulations, Regulation No. 21, "Uniform Provisions Concerning the Approval of Vehicles with Regard to Their Interior Fittings."
17 United Nations Economic Commission for Europe (UNECE) Vehicle Regulations, Regulation No. 42, "Uniform Provisions Concerning the Approval of Vehicles with Regard to their Front and Rear Protective Devices."