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Upper Interior Head Impacts: The Safety Performance of Passenger Vehicles

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Abstract
Each year in the U.S., it is estimated that 4000 persons are killed and another 9300 sustain serious head injury due to impacts with vehicle upper interior structures. The safety performance of passenger vehicles in occupant head impacts with the upper interior is examined in this paper. The upper interior is defined as the A/B/C-pillars, the side roof rails, the front header rail, and the rear header rail. The results of a recent NHTSA fleet characterization effort involving over 220 free motion headform (FMH) impact tests on fourteen passenger cars, light trucks, and minivans are presented in this paper. The effects of variations in impact angle, impact location, and contact velocity on FMH responses are explored in this test series. Localized hard spots and protrusions (e.g. motorized seat belt tracks) were identified and tested to determine design-specific head impact hazards. The conclusions are that head impact injury potential is a strong function of vehicle design, and that upper interior head impact protection varies widely from vehicle to vehicle.

Background
In the United States in 1989, estimates are that 4000 occupants of passenger cars, light trucks, and vans died as a result of head to upper interior impact [1]. Another 9300 occupants survived these impacts, but were left with a serious head injury. Survival of a head to upper interior impact is frequently debilitating: the National Highway Traffic Safety Administration (NHTSA) disability studies show that approximately 50% of the medium term cognitive impairment in frontal crashes are due to contact with the A-pillar and roof rails [2].

As a result of increasing restraint usage, increasing numbers of restrained occupants are exposed to the national traffic accident environment each year. As shown in Figures 1-2, the number of fatally injured belted occupants who suffered at least one serious head injury from head to upper interior impact has grown over
the last 10 years. Belted occupants are not injured as a result of wearing their safety belts, but rather are injured despite wearing their safety belts. In fact, safety belts provide some degree of protection against injuries from head impact with the upper interior.

![Figure 1. Upper Interior Head Impacts—Car Fatals with Serious Head Injury](image1)

![Figure 2. Upper Interior Head Impacts—LTV Fatals with Serious Head Injury](image2)

The distribution of serious injuries among the primary upper interior components is shown in Figure 3 [1]. Note that for belted occupants serious injury from impacts with the front header and the A-pillar are greatly reduced. However, as would be expected, belts apparently have little effect on injuries from head impacts with the side components including the side roof rail, B-pillar, or side window frame.

![Figure 3. Upper Interior Head Impacts Serious Head Injury by Component](image3)

frontal accidents, but data on airbag deployments are still too sketchy for the national accident statistics to allow an estimate of airbag effectiveness at preventing head to upper interior contact. While airbags may reduce head injuries in frontal accidents, airbags are not expected to prevent head to upper interior impacts in side and rear impacts or rollovers. In fact, even in frontal impacts, airbags are not guaranteed to prevent head contact with the upper interior. A preliminary investigation of the NHTSA Special Study of Airbag Deployments has shown a number of head to upper interior contacts of moderate severity, for occupants restrained by airbag.

To alleviate the head to upper interior impact problem, NHTSA research efforts have focused on the evaluation of promising upper interior paddings as a countermeasure for all occupants—regardless of restraint type, lack of restraint, or accident mode. Earlier NHTSA studies [3] have shown that in sled tests using full vehicle bodies, the application of 1" of padding to upper interior surfaces can reduce HIC by as much as half. Note that NHTSA countermeasure tests are conducted using add-on pads. Integral design of the padding and underlying structure could improve the effectiveness in a production upper interior design.

The upper interior, as defined in this paper, includes all components of the roof support structure. This grouping includes the A-pillar, the B-pillar, the C-pillar, the front header rail, the side roof rails, the rear header rail, and the side door window frames. For this paper, passenger vehicles refers to both passenger cars, light trucks, vans, and utility vehicles under 10,000 pounds. When the paper refers to head hereafter, this term will refer to both the head and the face.

**Objective**

The primary objective of this paper is to present the results of an investigation of head impact injury potential as a function of vehicle upper interior designs currently in the U.S. passenger vehicle fleet. The second goal is to present an evaluation of the effectiveness of padding as a countermeasure for reducing head injury potential.

**Approach**

In Reference 3, an initial research test procedure for upper interior testing was presented, along with the results of tests conducted on twelve baseline passenger cars. Nearly all the HIC responses from these tests were below 1000, seeming to indicate that head to upper interior impacts are not likely to produce serious head injuries. In fact, according to accident statistics [1], many people are seriously injured and killed from these types of impacts. Therefore, the test procedure used in those tests did not result in impacts that were of the severity representative of those that produce serious head injuries in real accidents.

An investigation was then initiated to explore appropriate test procedure modifications. There were two main
goals for this revision of the procedure. The first was to
develop a research test procedure that results in labora-
tory impact severities that are more representative of real
world severities. This would be done largely through the
adjustment of approach angles and/or impact speed. The
second goal was to develop a research test procedure that
allowed for a thorough evaluation of the injury causing
potential of a vehicle's upper interior structures. This
would be done by defining ranges for impact locations
and approach angles, rather than defining specific values
for these parameters, as in the initial research procedure.

The following is a summary of the revised research
test procedure used in the testing presented later in this
paper. A more detailed description of the investigation
that lead to the revisions is in Reference 4.

Headform. A free-motion headform (FMH) was select-
ed for use in this program. A series of twenty-two sled
tests was conducted in which the head of a full Hybrid-
III dummy impacted lengths of rectangular tubing, simu-
lating upper interior structures. Both 15 and 20 mph tests
were performed on unpaded and padded simulated
structures, in which the tubing stiffness and impact angle
were varied. An identical series of tests was also con-
ducted using the FMH, rather than the full dummy. A
linear regression between the HIC responses of the two
surrogates was performed, and a strong correlation was
found. The regression produced a coefficient of deter-
mination, $r^2$, of 0.969.

There are two distinct advantages of the FMH over the
more traditional guided impactor. First, and most im-
portantly, the FMH can simulate the more realistic
glancing impacts, while guided headform tests are con-
ducted normal to the structure. Since the two approaches
may lead to the selection of different countermeasures, it
is important to conform to reality as much as is practi-
cal to increase the chances that the most beneficial
countermeasures are used. Second, since the FMH is free
to rotate after impact, head rotational motion can be
measured. Therefore, the FMH may be a viable headform
when rotational head injury criteria are developed, allow-
ing a more complete evaluation of the head injury caus-
ing potential of upper interior structures.

Impact Zone on the FMH. Since the FMH is essen-
tially a Hybrid-III head, it was developed for use in fore-
head impacts. The biofidelity of the Hybrid-III head in
impacts to the lower face and jaw areas has not been
established. Therefore in this procedure, the first contact
between the FMH and the structure must occur within a
specified impact zone on the FMH. This zone consists of
the area within a 5° wide strip, centered on the head's
midsagittal plane, extending from the top most point of
the head, down to the bridge of the nose (note that the
nose is removed for FMH testing).

Impact Zones on the Structures. Since accidents of all
modes (front, side, oblique, rollover, etc.) occur on the
roadways, occupants can strike their heads on essentially
any exposed interior structure or surface. This is
especially true for the upper interior structures. Since all
these structures are candidate for head impacts, all must
provide protection.

The impact location on each structure must fall within
the structure impact zones as described below. Impact
location is defined as the location of first contact be-
tween the structure and the FMH. All zones include only
those interior surfaces which can be contacted by the
FMH.

- Roof rails (front and rear headers, side rails)—The
  impact zones on these structures consist of the areas
  along the entire length of the roof rails, from the
  lowest portion of the rails, up six inches into the
  roof, along the contour of the roof.
- A-pillar—The impact zone on this structure consists
  of the area along the length of the structure, from
  the instrument panel to the roof rail juncture.
- B, C and D-pillars—The impact zones on these
  structures consist of the areas along the length of the
  structures, from the side door window level to the
  roof rail junctures.

Approach Angles—Horizontal Plane. Similar to the
concept used to define impact zones on the structures, an
occupant's head can strike the upper interior structures
from nearly any angle interior to the vehicle. Although
the most severe cases should usually occur from nearly
perpendicular angles, certain designs could produce
severe impacts from other angles. Following this philo-
sophy, approach angles in the horizontal plane were select-
ed to encompass all interior angles. They are as follows
(0° is forward and positive angles are clockwise):

- Front header: -90° to 90°
- Side rails: left: -180° to 0°, right: 0° to 180°
- Rear header: 90° to -90°
- A-pillar: left: -90° to 0°, right: 0° to 90°
- B-pillar: left: -180° to 0°, right: 0° to 180° (unless
  rearmost pillar)
- C-pillar: left: -180° to 0°, right: 0° to 180° (unless
  rearmost pillar)
- D-pillar (or rearmost pillar): left: -180° to -90°,
  right: 90° to 180°

Note: For any particular structure, it may not be
possible to test throughout the entire range of listed
approach angles and also achieve impact within the
specified impact zones on the structure and FMH.

Approach Angles—Vertical Plane. The limits for the
ranges of approach angles in the vertical plane were
selected based on a survey of 5th percentile female
seated positions and FMH test results [4]. The female
dummy was used to find head-to-structure angles for a
variety of vehicles, since it represents the "worst case"
adult position for these angles. Means and standard
deviations were found for each measurement, weighted
to represent the 1989 sales fleet.

To represent a large percentage of small adult females,
the upper limits (positive angles) were chosen as the
The top 46 selling body types were then listed, in order of sales, for each weight category. From these lists, the appropriate number of body types from each category was selected for testing, based on their availability to the VRTC. The 8 passenger car models tested are listed in Table 1.

For the LTV's, a small and a full sized pickup were selected, as well as a van and an all purpose vehicle. The models chosen were as follows:

- **Chevrolet S-10 Pickup**
- **Ford F-150 Pickup**
- **Chevrolet Astro Mini-van**
- **Ford Bronco II**

**15 mph testing.** The 15 mph tests were conducted after the 20 mph tests, so some of the vehicles listed above were not re-usable, due to damage. Therefore, only five passenger cars were tested, one from each of the five weight categories. The models were as follows:

- **Ford Escort**
- **Volkswagen Golf**
- **Toyota Camry**
- **Ford Taurus**
- **Mercury Grand Marquis**

Three of the LTV’s were re-usable, and two additional models were also tested. These were as follows:

- **Chevrolet S-10 Pickup**
- **Chevrolet Astro Mini-van**
- **Ford Bronco II**
- **Dodge Caravan**
- **Dodge B-150 Van**

**Test Procedure**

As described above, this project tested vehicle upper interiors at two distinct impact velocities, 15 mph and 20 mph, in order to bracket the range of median impact speeds. Not all vehicles were tested at both speeds. Each vehicle in our fleet sample was subjected to FMH tests of the four primary components—(1) A-pillar, (2) B-pillar, (3) side roof rail, and (4) the front header. As an aside to the main program, some vehicles were subjected to additional testing of the C-pillar, rear header, and roof. The results of these auxiliary tests are not presented in this paper.

Two FMH tests were conducted for each of the four major upper interior components. In the 20 mph series, the first tests were conducted at "standard" impact locations and approach angles. The locations were chosen based on the position of a normally seated 50th percentile male Hybrid III dummy. For the front header, this location was centered vertically on the header directly forward of the dummy head c.g., the approach angle in the horizontal plane was 0°, and the approach angle in the vertical plane was 50°. For the side roof rail, the location was centered vertically on the rail directly lateral to the dummy head c.g., and approach
angles in the horizontal and vertical planes were 90° (or -90°) and 20°, respectively. On the A-pillar, the location was at the same height as the dummy head c.g., with horizontal and vertical approach angles of 35° (or -35°) and 20°, respectively. Finally, for the B-pillar, the location was centered longitudinally on the pillar at the same height as the dummy head c.g., with horizontal and vertical approach angles of 90° (or -90°) and 5°, respectively. Also in the 20 mph series, the second tests were conducted at alternate locations and approach angles. In these tests, the impact locations were subjectively chosen at hard spots (e.g. weld overlaps or stiffeners), when present, and a variety of approach angles were used. In some cases, the standard location was a hard spot, so the alternate location was selected at a second hard spot, if present.

The standard and alternate impact locations for the 15 mph series were chosen in the same manner as for the 20 mph series. "Standard" approach angles were not used in this series, though. Instead, each test was conducted at the most severe approach angle allowed by the research test procedure outlined in the APPROACH section of this paper.

The nominal test matrix for a single vehicle is shown in Table 2.

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**Measure of Safety Performance**

The central goal of this study was to determine the safety performance of current passenger vehicles in head impacts with the upper interior. This evaluation was performed in tests of the upper interiors of production vehicles. This baseline evaluation was then followed up with an evaluation of the safety performance of upper interiors with add-on pads.

To evaluate vehicle upper interiors, this study used two measures of safety performance—both related to the potential for head injury. The first was the Head Injury Criterion (HIC) used by the NHTSA to assess the safety of vehicles in frontal-barrier impacts. The second was the Head Injury Risk function developed by GM and others [7,8]. This risk function curve is an example of many such injury probability curves which can be derived from existing biomechanical data by various analytical methods.

The Head Injury Risk Function has been proposed as a relationship between HIC and Probability of AIS 4+ Brain Injury [7]. The function may not directly apply to other types of head injury, e.g. functional impairment, which may also be present with brain tissue injury at a given HIC level. In addition, the risk function is strictly applicable only to frontal head impacts. The function may not apply, for example, to HICs measured when the side of the head impacts a component. The reader should keep these restrictions in mind when reading this paper. When the paper refers to "probability of AIS 4+ head injury" and "head injury risk," these terms will refer to the probability of AIS 4+ brain injury in impacts between the forehead of the headform and the component of interest.

The head injury risk can be computed from the Logistic probability function shown below, and is shown in Figure 4.

\[
p(x) = \frac{1}{1 + e^{c + \beta HIC}}
\]

where \( \alpha = 5.02 \) and \( \beta = 0.0351 \)

**Figure 4. Injury Risk Function Based on HIC and Serious Head Injury**

**Fleet Characterization Results**

The primary goal of this study was to assess the safety performance of a sample of the current passenger vehicle fleet in head to upper interior impacts. The results of the baseline fleet characterization are tabulated in Table 3. The HIC responses resulting from the 15 mph tests are presented in Figures 5-8. The Probability of AIS 4+ head injury for the 15 mph tests are presented in Figures 9-12. The HIC responses resulting from the 20 mph head impact tests are presented in Figures 13-16. The Probability of AIS 4+ head injury for the 20 mph tests are presented in Figures 17-20.

In the discussion below, \( p(4+) \) refers to the probability of AIS 4+ injury. Also, the term "worst HIC" refers to the highest HIC response measured for a structure of a particular vehicle, between the standard and alternate impact locations. Also, the probability of injury, padding effectiveness, and reductions in HIC are based on FMH HIC responses. If these responses are transformed to full dummy HIC responses, these probability of injury, HIC
Table 3. Results of Baseline Characterization

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<td>1910</td>
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<td>1465</td>
<td>Canopy</td>
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<td>Astro Van</td>
<td>2181</td>
<td>2387</td>
<td>Astro Van</td>
<td>2249</td>
<td>F-150 Pickup</td>
<td>1465</td>
<td>Canopy</td>
<td>2178</td>
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<td>Astro Van</td>
<td>2398</td>
<td>Elantra</td>
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<td>VW Golf</td>
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<td>Elantra</td>
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<td>VW Golf</td>
<td>2460</td>
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</tbody>
</table>

A-pillar

![A-pillar Diagram](image1)

Side Rail

![Side Rail Diagram](image2)

Front Header

![Front Header Diagram](image3)

B-pillar

![B-pillar Diagram](image4)
reductions, and padding effectiveness values may change.

In 15 mph head impacts with the A-pillar, HIC in impacts at the standard location varied from a minimum of 524 for the Ford Escort to 2586 for the Dodge Caravan. This corresponds to a Head Injury Risk ranging from p(4%)=4% to p(4%)=98%. In 20 mph head to A-pillar impacts, HIC at the standard location ranged from a low of 1220 for the VW Golf to an unsurvivable 4908 for the Chevrolet Astro, or a Head Injury Risk ranging from p(4%)=32% to p(4%)=100%. The maximum worst HIC in 15 mph impacts was recorded for the Dodge B-150 Van (HIC=2752); the highest worst HIC in 20 mph impacts was recorded for the Chevrolet Astro (HIC=4996).

In head impacts with the front header, all 15 mph HIC responses measured at the standard impact locations were under 1000 and showed little variation from vehicle to vehicle. The maximum worst HIC was recorded when an overlap in the Dodge B-150 Van front header was impacted, resulting in a HIC of 2077. An impact to an overlap on the Chevrolet Astro front header was the only other 15 mph front header impact to result in a HIC over 1000 (HIC=1311). At 20 mph, all HIC responses measured at the standard locations were very near to or above 1000. The maximum worst HIC of 2980 was measured in the Buick Electra, once again at a header overlap.

Side roof rail 15 mph impact tests at the standard locations showed HIC varying from 439 for the Ford Escort all the way to 1434 for the Toyota Camry. The largest worst HIC recorded at 15 mph was on the Dodge Caravan (HIC=2304), a nearly 50% jump from its standard location 15 mph HIC of 1207. The Mercury Grand Marquis also displayed a very severe worst HIC (HIC=2182). In 20 mph impacts to the standard locations, HIC ranged from 833 for the Honda Civic to 3075 for the Ford F-150 Pickup. The highest worst HIC at 20 mph was again on the Mercury Grand Marquis, with a HIC of 3968.

B-pillar 15 mph impact tests to the standard locations showed HIC varying from 744 for the Ford Bronco II to 1867 for the Chevrolet S-10 Pickup. The HIC at the standard location for the Chevrolet S-10 pickup was also the maximum worst HIC recorded. In the 20 mph standard location impacts, HIC ranged from 1198 for the Ford Bronco II to 3113 for the Chevrolet S-10 Pickup. The highest worst HIC at 20 mph was recorded on the VW Golf, with a HIC of 3460.

Discussion
The fleet characterization tests show a wide vehicle to vehicle variation in HIC for each upper interior component. With the exception of the B-pillar, there was a slight trend toward lighter vehicles producing lower HIC responses, although the correlations were not strong. If such a relationship does exist, it may result from the need to provide adequate roof support in the event of a rollover. Presumably, heavier vehicles would require a stronger, possibly stiffer, roof support structure to meet FMVSS No. 216 and to prevent roof collapse in rollovers.

One surprising finding was the severity of HIC responses recorded in tests on minivans and vans. In 15 mph head impacts with the A-pillar, the three vans in this study, a Dodge Caravan, a Chevrolet Astro mini-van, and a Dodge B-150 full-sized van, resulted in HIC responses higher than any other vehicle tested. In 20 mph head impacts with the A-pillar, the Chevrolet Astro resulted in HIC=4908 (standard location) and HIC=4996 (worst HIC), which were the highest HIC responses recorded in this test series. The reasons for HIC responses are unclear, but may indicate that upper interior designs in vans and minivans are unlike those found in either passenger cars or light trucks.

It was also interesting to note the effect that the presence of tracks for motorized passive shoulder belts had on the resulting HIC responses. Two of the vehicles tested had such passive belts, the Toyota Camry and the Ford Escort. The HIC responses from all the tests conducted on the Ford Escort seat belt track are listed in Table 3 and are as follows:

- 15 mph
  A-pillar/standard: HIC=524
  B-pillar/standard: HIC=925
  B-pillar/worst: HIC=1029

- 20 mph
  A-pillar/standard/worst: HIC=1564
  Side roof rail/standard: HIC=1286
  Side roof rail/worst: HIC=1447
  B-pillar/standard/worst: HIC=2383

The HIC responses from all but two of the tests conducted on the Toyota Camry seat belt track are also listed in Table 3, and are as follows:

- 15 mph
  A-pillar/not listed: HIC=881
  Side roof rail/not listed: HIC=1398
  B-pillar/standard/worst: HIC=1068

- 20 mph
  A-pillar/worst: HIC=1595
  Side roof rail/worst: HIC=2887
  B-pillar/worst: HIC=1642
  B-pillar/worst: HIC=2014

A comparison of these HIC responses to those from impacts on structures without seat belt tracks indicate that the presence of the track did not generally seem to cause unusually high HIC responses. In fact, the HIC responses from the seat belt track tests were in the upper half of all worst HIC responses (for a structure) in only the 20 mph Toyota Camry side roof rail and the Ford Escort B-pillar tests. In some cases, the HIC from the impact on the track was lower than the HIC response from the non-track impact (eg. 15 mph Ford Escort A-pillar).
The Effectiveness of Padding

A major goal of this study was to determine the effectiveness of padding as a countermeasure for reducing head injury potential in our fleet sample. Earlier NHTSA full dummy tests have shown that 1 inch of properly chosen padding can reduce HIC by as much as half. To evaluate this head injury countermeasure in the fleet sample, a subset of the vehicles was chosen for additional tests with padding. To evaluate the padding under severe conditions, the padding was usually applied to that spot on each component identified as the “worst HIC” impact location. Note that the “padded” tests were conducted using add-on pads in order to evaluate feasibility. Integral design of the padding and underlying structure could improve the effectiveness in a production upper interior design.

The objective in this study was to simply determine the feasibility of lowering HIC in our fleet sample. Hence, the padded tests varied both padding material and their thickness in order to achieve HIC < 1000 where possible. In the tables below, the computation of padding effectiveness is based on a comparison of the baseline vehicle and that particular padding design which met the design goal of minimum HIC. That is, it is 100% minus the probability of receiving an AIS 4+ head injury in the padded test, given a head injury would have occurred in the baseline test.

To limit the effect on driver field of vision, the design target was to limit A-pillar and frontal header paddings to 1 inch of thickness. For the B-pillar and side rail, two components outside of the driver’s forward field of vision, the design target was to limit padding thickness to 1.5" inches. In some instances where these padding thicknesses were not sufficient to reduce HIC responses below 1000, additional tests were conducted with thicker paddings. The results of the padding effectiveness tests are presented for 15 mph impacts in Table 4 and for 20 mph impacts in Table 5.

As shown in Table 4, a 1" thickness of Dytherm padding (manufactured by the ARCO Chemical Company) was sufficient to reduce HIC responses below 1000 in all but one of the 15 mph impacts. The single exception was the Dodge Caravan A-pillar, which required 1.25" of padding to achieve this reduction. In these tests, padding was found to reduce HIC by 17% to 73%. Effectiveness of padding was a dramatic 42% to 94%.

At the much more severe impact speed of 20 mph, the target thicknesses of padding were generally not sufficient to reduce HIC responses below 1000, although several just slightly exceed this criterion (note that a test with 1" of padding was not conducted on the VW Golf front header). Even with an additional 0.25" to 0.5" of padding, some of HIC responses were still above 1000. These tests did show nearly the same impressive percent reductions in HIC observed at 15 mph. Added padding reduced the HIC responses by 32% to 59%, and the effectiveness of padding was 36% to 85%.

Table 4. Effectiveness of Padding in 15 mph Head to Upper Interior Impacts

<table>
<thead>
<tr>
<th>Upper Interior Components</th>
<th>Vehicle</th>
<th>Padding</th>
<th>HIC No Pad</th>
<th>Pad</th>
<th>% Diff</th>
<th>Probability of AIS 4+ Injury (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-Pillar</td>
<td>Gde. Marquis</td>
<td>1° Dytherm-3</td>
<td>1080 617</td>
<td>41.9%</td>
<td>23  6</td>
<td>75.1%</td>
</tr>
<tr>
<td></td>
<td>Golf</td>
<td>1° Dytherm-3</td>
<td>985 682</td>
<td>30.8%</td>
<td>17  7</td>
<td>61.1%</td>
</tr>
<tr>
<td></td>
<td>S-10 Podep</td>
<td>1° Dytherm-4</td>
<td>1749 884</td>
<td>49.2%</td>
<td>75 13</td>
<td>83.0%</td>
</tr>
<tr>
<td></td>
<td>Brzno II</td>
<td>1° Dytherm-4</td>
<td>2373 780</td>
<td>67.1%</td>
<td>96 9</td>
<td>90.4%</td>
</tr>
<tr>
<td></td>
<td>Avo Vnas</td>
<td>1° Dytherm-4</td>
<td>2257 611</td>
<td>68.2%</td>
<td>98 10</td>
<td>89.0%</td>
</tr>
<tr>
<td></td>
<td>Carrey</td>
<td>1° Dytherm-4</td>
<td>1225 866</td>
<td>39.2%</td>
<td>33 12</td>
<td>63.2%</td>
</tr>
<tr>
<td></td>
<td>Caravan</td>
<td>1.25° Dytherm-2</td>
<td>2606 1196</td>
<td>56.0%</td>
<td>98 24</td>
<td>75.5%</td>
</tr>
<tr>
<td></td>
<td>B-150 Vnas</td>
<td>1° Dytherm-3</td>
<td>2712 89</td>
<td>67.0%</td>
<td>99 13</td>
<td>86.0%</td>
</tr>
<tr>
<td></td>
<td>Carrey</td>
<td>1° Dytherm-4</td>
<td>801 340</td>
<td>51.3%</td>
<td>30 3</td>
<td>78.4%</td>
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<tr>
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<td>Gde. Marquis</td>
<td>1° Dytherm-3</td>
<td>925 627</td>
<td>31.1%</td>
<td>15 5</td>
<td>59.9%</td>
</tr>
<tr>
<td></td>
<td>Avo Vnas</td>
<td>1° Dytherm-4</td>
<td>1211 767</td>
<td>46.3%</td>
<td>40 7</td>
<td>81.6%</td>
</tr>
<tr>
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<td>Carrey</td>
<td>1° Dytherm-4</td>
<td>954 719</td>
<td>29.0%</td>
<td>15 8</td>
<td>48.9%</td>
</tr>
<tr>
<td></td>
<td>B-150 Vnas</td>
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<td>2077 876</td>
<td>58.0%</td>
<td>91 13</td>
<td>86.2%</td>
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<tr>
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<td>Gde. Marquis</td>
<td>1° Dytherm-3</td>
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<td>93 6</td>
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<td></td>
<td>Carrey</td>
<td>1° Dytherm-4</td>
<td>2306 628</td>
<td>72.8%</td>
<td>94 6</td>
<td>94.1%</td>
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<td></td>
<td>Avo Vnas</td>
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<td>Carrey</td>
<td>1° Dytherm-4</td>
<td>1434 711</td>
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<td>50 7</td>
<td>85.5%</td>
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<td></td>
<td>Carrey</td>
<td>1° Dytherm-3</td>
<td>1068 612</td>
<td>42.7%</td>
<td>22 5</td>
<td>75.5%</td>
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<td>Gde. Marquis</td>
<td>1° Dytherm-3</td>
<td>3180 981</td>
<td>16.9%</td>
<td>29 17</td>
<td>41.7%</td>
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<tr>
<td></td>
<td>Avo Vnas</td>
<td>1° Dytherm-3</td>
<td>1008 704</td>
<td>30.2%</td>
<td>19 7</td>
<td>60.8%</td>
</tr>
<tr>
<td></td>
<td>Tauros</td>
<td>1° Dytherm-2</td>
<td>1642 944</td>
<td>42.5%</td>
<td>68 15</td>
<td>77.3%</td>
</tr>
<tr>
<td></td>
<td>Golf</td>
<td>1° Dytherm-3</td>
<td>1362 823</td>
<td>39.6%</td>
<td>11 7</td>
<td>75.6%</td>
</tr>
<tr>
<td></td>
<td>Caravan</td>
<td>1° Dytherm-3</td>
<td>1511 980</td>
<td>35.1%</td>
<td>57 17</td>
<td>70.1%</td>
</tr>
<tr>
<td></td>
<td>B-150 Vnas</td>
<td>1° Dytherm-2</td>
<td>1237 600</td>
<td>40.6%</td>
<td>34 6</td>
<td>81.4%</td>
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</table>

Table 5. Effectiveness of Padding in 20 mph Head to Upper Interior Impacts

<table>
<thead>
<tr>
<th>Upper Interior Components</th>
<th>Vehicle</th>
<th>Padding</th>
<th>HIC No Pad</th>
<th>Pad</th>
<th>% Diff</th>
<th>Prob. of AIS 4+ Head Injury</th>
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</thead>
<tbody>
<tr>
<td>A-Pillar</td>
<td>VW Golf</td>
<td>1° Dytherm-4</td>
<td>1529 1005</td>
<td>52.0%</td>
<td>59 20</td>
<td>65.5%</td>
</tr>
<tr>
<td></td>
<td>Civic</td>
<td>1.25° Dytherm-2</td>
<td>2314 906</td>
<td>39.9%</td>
<td>44 14</td>
<td>65.4%</td>
</tr>
<tr>
<td></td>
<td>Tauros</td>
<td>1° Dytherm-2</td>
<td>1298 1504</td>
<td>54.4%</td>
<td>66 56</td>
<td>45.5%</td>
</tr>
<tr>
<td></td>
<td>VW Golf</td>
<td>1.25° Dytherm-2</td>
<td>1910 1280</td>
<td>33.0%</td>
<td>54 37</td>
<td>56.0%</td>
</tr>
<tr>
<td></td>
<td>Civic</td>
<td>1° Dytherm-3</td>
<td>2015 1055</td>
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<td>89 30</td>
<td>77.4%</td>
</tr>
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<td></td>
<td>VW Golf</td>
<td>1.25° Dytherm-2</td>
<td>2147 1156</td>
<td>45.9%</td>
<td>93 28</td>
<td>70.1%</td>
</tr>
<tr>
<td></td>
<td>Tauros</td>
<td>1.25° Dytherm-2</td>
<td>2282 1048</td>
<td>54.1%</td>
<td>95 21</td>
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<tr>
<td></td>
<td>Civic</td>
<td>1.25° Dytherm-2</td>
<td>1698 1181</td>
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<td>72 23</td>
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<td>3460 1592</td>
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<td>100 64</td>
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<td>1.25° Dytherm-2</td>
<td>2912 1546</td>
<td>56.9%</td>
<td>99 60</td>
<td>39.0%</td>
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</table>

Tables 4 and 5 above report the results of padded tests using three types of Dytherm foam—Dytherm-2, Dytherm-3, and Dytherm-4. The numeric designation after the Dytherm trade name refers to the foam density. Dytherm-2, for example, refers to a Dytherm foam of density 2 pounds / cubic foot. The denser foams, e.g., Dytherm-4, tend to be stiffer than the less dense foams, e.g. Dytherm-2.

These tests suggest that padding the upper interior is a feasible and extremely effective method of reducing head injury potential. These padding tests should not be
viewed an upper bound on improvements that can be made to the upper interior. The countermeasure tests only explored the use of padding: even higher countermeasure effectiveness may be possible by softening or otherwise redesigning the underlying metal pillars and rails.

Conclusions
This paper has presented the research test procedure and the results from a recent NHTSA fleet characterization effort to examine the safety performance of fourteen passenger cars, light trucks, and minivans in head to upper interior impacts. The test series explored the effect of variations in impact angle, impact location, and contact velocity on FMH responses. A test series was also conducted in which the upper interiors of a subset of the baseline vehicles were padded, and then subjected to FMH tests. The conclusions from this study are as follows:

- Head impact injury potential is a strong function of vehicle design, and upper interior head impact protection varies widely from vehicle to vehicle. In 15 mph FMH impacts to baseline structures, HIC responses varied from 439 to 2752, while those from 20 mph impacts varied from 833 to 4996.

- The minivans and vans tested in this program appear to have upper interior designs which yield severe HIC responses. In 15 mph FMH impacts with the A-pillar, the three vans in this study resulted in HIC responses higher than any of the other vehicles tested. The highest HIC response recorded in this test series were measured in 20 mph FMH impacts with a mini-van A-pillar.

- Padding the upper interior is a feasible and exceptionally effective method of reducing head injury potential. Padding effectiveness was dramatic (varying from 36% to a high of 94%), and regularly exceeded 50% (i.e., in 35 of 41 tests). Note that the NHTSA padded tests were conducted using add-on pads. Integral design of the padding and underlying structure could improve the effectiveness in a production upper interior design. [Note: Padding effectiveness is defined here as 100% minus the probability of receiving an AIS 4+ head injury in the padded test, given a head injury would have occurred in the baseline test.]

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References

A Study of the Safety Performance of Production Vehicles Equipped with Driver Air Bags in the NHTSA Test Programs

William T. Hollowell, Fabienne J. Frey
National Highway Traffic Safety Administration

Abstract
In issuing Federal Motor Vehicle Safety Standard (FMVSS) No. 208, "Occupant Crash Protection," the