# INJURY RISKS FROM ADVANCED AIR BAGS IN FRONTAL STATIC OUT-OF-POSITION TESTS

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Paper No. 427

## ABSTRACT

In March of 1997, the National Highway Traffic Safety Administration (NHTSA) published a final rule amending the Federal Motor Vehicle Safety Standard No. 208 (FMVSS 208) Occupant Protection requirements to allow manufacturers to de-power their air bags. The agency subsequently issued a notice of proposed rulemaking (NPRM) on advanced air bags in September 1998 and a supplemental NPRM (SNPRM) in November 1999. The final rule was issued in May 2000 amending the occupant protection standard to have the manufacturers design the air bags to protect small stature adults and young children in frontal crashes and to reduce the risk of serious air bag induced injury, particularly for small women and children. In June of 2001, the NHTSA published in the Federal Register a request for comments on a plan to monitor the performance of advanced air bags and to develop data for potential future air bag rulemaking. An ongoing research program was created to look at the air bags by following the new procedures in FMVSS No. 208. This paper looks at the findings of the out-of-position (OOP) air bag testing involving the 6-year old and 5$^{th}$ percentile female dummies for the model year 2001 vehicles.

## BACKGROUND

FMVSS 208 (49 CFR Part 571.208) is the occupant protection regulation in the United States. In May 2000 and December 2001, the final rule amended the occupant crash protection standard to require future air bags to be less aggressive to small stature adults and young children, but still provide protection for all occupants. To achieve these goals, the rule added many new requirements, test procedures, injury criteria and new dummies to FMVSS 208. It also replaced the existing sled test with a rigid barrier crash test with unbelted dummies.

The new rule improves protection and minimizes risk by requiring new tests and injury criteria for the entire family (12 month, 3, 6 year old, 50$^{th}$ percentile male and female) of test dummies. The rule will be phased in during two stages. The first phase-in will include an unbelted rigid barrier test (32-40 kph) with the 50$^{th}$ percentile male dummy and the 5$^{th}$ percentile female dummy. It also minimizes the risks to OOP young children and small adults (12 month CRABI, 3YO, 6YO, 5$^{th}$ percentile female dummies). The second phase-in covers the belted rigid barrier test (56 kph) with the 50$^{th}$ percentile male dummy.

Automobile manufacturers must meet one of the following minimum requirements designed to minimize air bag risks: Option 1 – Automatic Suppression feature, Option 2 – Dynamic Automatic Suppression system that suppresses the air bag when an occupant is out of position, or Option 3 – Low Risk Deployment (LRD) or (OOP testing). This paper looks at Option 3- OOP testing on selected model year (MY) 2001 vehicles. Recent studies of prototype dual stage air bags indicate that their performance has improved over single stage bags in providing protection to occupants in high speed crashes while reducing aggressivity to OOP occupants [3].

## TEST MATRIX

To fully evaluate the new model air bags, they need to be tested under several different conditions. The new air bags must be able to protect adults in high-speed impacts, while protecting OOP small adults and young children at low speeds. Vehicles were chosen for this study depending on what advanced safety features they had. A wide variety of vehicles: passenger cars, light trucks and vans were included in this selection. Several vehicles make/models had dual stage air bags and advanced seat belts. Table 1 shows the vehicles selected and their safety features.

It should be noted that all the vehicles selected in this study were certified to a previous version of FMVSS 208, which required performance in a sled test or crash test. Therefore, these vehicles were not required to meet the OOP injury criteria listed in Table 3. These results setup a baseline to which future air bag designs that comply with the new FMVSS No. 208 can be compared.

**OOP Testing**

The out-of-position testing was performed on all six vehicles at the Vehicle Research and Test Center (VRTC), in East Liberty, Ohio. The OOP testing was done with the Hybrid III 6-year-old (6YO) dummy on the passenger side and the Hybrid III 5$^{th}$ percentile female dummy on the driver's side. The vehicles with the dual stage air bags were tested in the low mode first. If the dummy readings passed the injury assessment reference values (IARV) in the low mode, then the high mode was tested. Table 2 shows the different fire times used during testing.

**Test Positions**

The dummy positions selected examine the head, neck and chest interaction with the deploying air bag. The test positions used for the OOP testing were the positions in the December 2001 version of the FMVSS No. 208 final rule. However, the descriptions and pictures in this paper should not be considered surrogates for the test procedures for the FMVSS No. 208 final rule.

**Table 1. Vehicle Selection**

| Vehicle | Dual Stage Air bags | Force Limited Seatbelts | Pre-tensioners in the Seatbelts |
|---|---|---|---|
| 2001 Honda Accord | X | X | X |
| 2001 Chevy Impala | X | X | |
| 2001 Dodge Caravan | X | X | X |
| 2001 Toyota Echo | | X | X |
| 2001 Ford Escape | | X | X |
| 2001 Ford F150 | | X | X |

**Table 2. Air bag Fire Times**

| MY2001 Vehicles | Time gap between stages, msec | | | | Pass. Bag Loc |
|---|---|---|---|---|---|
| | Driver | | Passenger | | |
| | Low | High | Low | High | |
| 2001 Honda Accord | 20 | 0 | 30 | 0 | Top |
| 2001 Chevy Impala | Primary Only | 4 | Primary Only | 4 | Mid |
| 2001 Dodge Caravan | Primary Only | 0 | Primary Only | 0 | Mid |
| 2001 Toyota Echo | N/A | N/A | N/A | N/A | Top |
| 2001 Ford Escape | N/A | N/A | N/A | N/A | Front |
| 2001 Ford F150 | N/A | N/A | N/A | N/A | Mid |

**6-Year Old**

The 6-year old dummy was placed in the right front passenger's seat and positioned according to the December 2001 FMVSS No. 208 final rule [1]. There are two positions for the 6-year old in the low risk deployment test procedure; Position 1, Chest on Instrument Panel and Position 2, Head on Instrument Panel. Position 1 aligns the chest with the air bag opening. Position 2 allows the dummy to sit with its head and neck close to the air bag. Both positions look at the head, neck and chest interaction with the deploying air bag.

**Figure 1** Position 1 Position 2

**Position 1:** In order to get the dummy in the required position, wooden spacer blocks or foam blocks were placed on the seat and were used to prop the dummy up to the opening from which the air bag deploys. A string was used to support the dummy from falling back into the seat. For the first couple of

tests, the seatback was at the nominal seatback angle, but for the majority of the tests, it was adjusted to the most reclined position. This was done to avoid damage to the seats.

**Position 2:** For this position, in most of the vehicles, the dummy had to be pushed forward to make contact with the instrument panel. In some of the vehicles the dummy needed a string to help hold it in position. For the first couple of tests, the seatback was at the nominal seatback angle, but for the majority of the tests, it was adjusted to the most reclined angle. This was done to avoid damage to the seats.

**5th Female**

The test positions that were used for the Hybrid III 5th percentile female dummy were positions 1 and 2 from the FMVSS No. 208 final rule [1]. The 5th female was tested on the driver's side of the vehicle. The two positions that were used were Position 1: Chin on Air bag Module and Position 2: Chin on Steering Wheel Rim.

**Figure 2**. Position 1 Position 2

**Position 1:** This position aligns the chin with the air bag opening. This position is sometimes unattainable, because the position is low on the steering wheel. In most of the vehicles tested in this study, this was unattainable. The dummy was adjusted to be at the closest point to the opening as possible. The seatback was adjusted to the nominal position and also was braced to avoid damage to the seat.

**Position 2:** This position places the chin on the upper edge of the steering wheel rim and the chest close to the air bag. This was obtained by placing foam blocks under the dummy to get the correct angle and to raise it higher in the seat so the correct alignment could be achieved. In some vehicles, the windshield interfered with this position, and the steering wheel had to be moved slightly lower than the mid position to get the correct positioning.

## INSTRUMENTATION OF THE DUMMIES

The dummies were instrumented with the following:

6YO:

- 3-axis head CG accelerometers
- 6-axis upper and lower neck load cells
- 3-axis chest accelerometers
- 1-axis chest deflection
- Upper and lower sternum accelerometers
- Lower thorax insert accelerometer
- Upper spine box accelerometer
- 3-axis pelvis accelerometer
- Right and left ASIS upper and lower load cells

5th Female:

- 3-axis head CG accelerometers
- 9-array head accelerometers
- 6-axis upper and lower neck load cells
- 3-axis chest accelerometers
- 1-axis chest deflection
- Upper, middle and lower sternum accelerometers
- 6-axis lumbar load cells

The femur load cells were not used for this testing.

The data channels were digitally sampled at 20,000 samples per second and processed per SAE J211 March 1995. The tests were filmed using two high-speed digital video cameras at 1000 frames per second.

## INJURY CRITERIA

The testing results were analyzed using the FMVSS No. 208 injury criteria for out-of-position occupants for the Hybrid III 6 year old (6YO) and 5th percentile female dummies. The peak values for tension and compression are also lower. The injury assessment reference values (IARV) used for this study are listed in Table 3.

**Table 3. Injury Assessment Reference Values**

| OOP Injury Criteria | Threshold Values | |
|---|---|---|
| | 5th % Female | 6YO Child |
| **15ms HIC** | 700 | 700 |
| **3ms Clip (g)** | 60 | 60 |
| **Chest Deflection (mm)** | 52 | 40 |
| **Femur Loads (kN)** | 6.8 | N/A |
| **OOP Neck Injury Critical Values** | | |
| **Nij** | 1.0 | 1.0 |
| **Tension (N)** | 3880 | 2800 |
| **Compression (N)** | 3880 | 2800 |
| **Flexion (Nm)** | 155 | 93 |
| **Extension (Nm)** | 61 | 37 |
| **Peak Tension (N)** | 2070 | 1490 |
| **Peak Compression (N)** | 2520 | 1820 |

## 6YO RESULTS

The dummy injury measurements were normalized to the IARV and are shown in Table 4. The **green** cells have injury values less than 80% of IARV, the **yellow** cells have injury values between 80% and 100% (inclusive) of IARV, and the **red** cells have injury values that exceeded the IARV.

None of the vehicle passed all injury values for each position. The Ford Escape and the Toyota Echo passed all the IARV for position 1, however the Toyota Echo exceeded Nij for position 2. The Ford Escape exceeded Nij and neck tension for position 2. The Honda Accord passed all the IARV for position 2, but exceeded Nij and neck tension for position 1. The Nij IARV was exceeded for all the other vehicles, in both positions. Similarly, the neck tension IARV was exceeded for all the other vehicles, in both positions, except for the Toyota Echo. Those values were below 0.80 for both positions.

There were three vehicles that had dual stage air bags, but only the Dodge Caravan was tested in the high mode with the 6YO dummy. The information on firing time was not made available to NHTSA for these tests. NHTSA assumed that for the low mode, the primary stage inflator alone would be fired, and for the high mode both stages would be fired simultaneously. When tested in the low mode with the 6YO, the Caravan exceeded Nij and neck tension in position 1, and it exceeded Nij, neck tension, and 15ms HIC for position 2. For the high mode, the injury values exceeded these same IARV for both positions, although the 3 ms clip and chest deflection increased into the 80-100% IARV range.

## 5TH FEMALE RESULTS

The Toyota Echo and the Chevrolet Impala (two of the six vehicles) passed all the injury values for both positions for the 5th female tests. The Chevrolet Impala was equipped with dual stage air bags, in which both modes were tested and both modes passed without exceeding the IARV's. The Honda Accord was equipped with dual stage air bags, but wasn't tested in the high mode since it exceeded the IARV for Nij in position 2.

There were three vehicles that exceeded the IARV for Nij for position 1: the Dodge Caravan (high mode), the Ford Escape, and the Ford F-150. The Caravan (high mode) also exceeded the IARV for neck tension.

The Ford F-150 passed all the injury values with position 2, but exceeded the Nij in position 1. The Honda Accord passed all of the injury values with position 1, but exceeded the Nij in position 2. Position 2 also produced some high chest deflections, exceeding the IARV for the Dodge Caravan (low and high modes).

## OBSERVATIONS

None of the vehicles passed all tests for both the 6-year old and the 5th percentile female adult dummies. At least one position for each vehicle exceeded the injury criteria limits. None of the vehicles passed all the injury measures for both positions tested with the 6YO. Only the Ford Escape and the Toyota Echo passed all the IARV for position 1, and only the Honda Accord (low mode) passed all the injury measures for position 2. Two vehicles passed all injury measures for both positions tested with the 5th percentile female. These were the Toyota Echo and the Chevrolet Impala (low and high modes). The Honda Accord (low mode) and the Dodge Caravan (low mode) passed all the IARV for position 1, and the Ford F-150 passed all the injury measures for position 2.

For testing with the 6YO, the failures were primarily due to high Nij and neck tension values. Only the Ford Escape and Toyota Echo passed the Nij IARV for position 1, and only the Honda Accord passed that measure for position 2. Similarly, only the Toyota Echo and Ford Escape passed the neck tension IARV for position 1, and only the Toyota Echo and Honda Accord passed that measure for position 2.

For testing with the 5th percentile female dummy, the failures for position 1 were due to high Nij values, although the Dodge Caravan (high mode) also produced high neck tension. For position 2, the failures were primarily due to high chest deflections, although the Honda Accord failed due to a high Nij response.

Three of the vehicles tested had dual-stage air bags. When tested in the low mode, none of these were able to pass all injury measures for the 6YO in both positions, although the Honda Accord passed all the IARV for position 2. Only the Chevrolet Impala passed all the injury measures for the 5th female in both positions, although the Honda Accord and Dodge Caravan passed all the IARV for the 5th female in position 1. The Chevrolet Impala also passed all injury measures for the 5th female in both positions, when tested in the high mode.

## CONCLUSIONS

- The first stages of the dual stage inflator air bags were powerful enough to prevent the 6YO from meeting the OOP requirements.

- The predominant failure mode for the 6YO was Neck Injuries:
  - 11/14 (79%) tests exceeded Nij
  - 10/14 (71%) tests exceeded Neck Tension

- The predominant failure for the 5th percentile female was Neck Injury (Nij) and Chest Deflection
  - 4/16 (25%) tests exceeded Nij
  - 3/16 (19%) tests exceeded chest deflection

- There are vehicles whose air bags are not certified but can meet the requirements of the advanced air bag for the 5th percentile female OOP testing.

- None of the vehicles chosen could pass both the 5th female and the 6YO OOP performance requirements.

## REFERENCES

1. Federal Register, 49 CFR parts 571 Federal Motor Vehicle Safety Standards: Occupant Crash Protection Rules: Vol. 66, No. 243, December 18, 2001.

2. Federal Register, 49 CFR parts 571 Federal Motor Vehicle Safety Standards: Occupant Crash Protection Rules: Vol. 66, No. 122, June 25, 2001.

3. Performance Evaluation of Dual Stage Passenger Air Bag Systems, William T. Hollowell, Lori K. Summers, Aloke Prasad: NHTSA, Gopal Narwani: ASL, Tadayuki Ato: Takata Corporation, 17th ESV, Amsterdam, The Netherlands 2001.

## Table 4 Test Results

**Hybrid III 6YO Position 1**

| Vehicle | 15ms HIC | 3ms Clip (g's) | Chest Def. (mm) | NIJ | Neck Tension (N) | Neck Comp. (N) |
|---|---|---|---|---|---|---|
| 2001 Toyota Echo | 0.001 | 0.548 | 0.720 | .998 | 0.783 | 0.078 |
| 2001 Ford Escape | 0.420 | 0.477 | 0.788 | 0.659 | 0.895 | 0.300 |
| 2001 Ford F150 | 0.097 | 0.625 | 1.303 | 1.415 | 1.714 | 0.004 |
| 2001 Honda Accord (low) | 0.054 | 0.238 | 0.461 | 1.378 | 1.061 | 0.010 |
| 2001 Dodge Caravan (low) | 0.243 | 0.506 | 0.623 | 1.996 | 2.264 | 0.005 |
| 2001 Dodge Caravan (high) | 0.217 | 0.571 | 0.713 | 1.979 | 1.865 | 0.004 |
| 2001 Chevrolet Impala (low) | 0.043 | 0.371 | 0.718 | 1.095 | 1.094 | 0.004 |

**Hybrid III 6YO Position 2**

| 15ms HIC | 3ms Clip (g's) | Chest Def. (mm) | NIJ | Neck Tension (N) | Neck Comp. (N) |
|---|---|---|---|---|---|
| 0.059 | 0.221 | 0.060 | 1.128 | 0.383 | 0.783 |
| 0.506 | 0.595 | 0.630 | 2.494 | 2.745 | 0.519 |
| 0.329 | 0.577 | 1.105 | 1.681 | 2.019 | 0.015 |
| 0.273 | 0.247 | 0.028 | 0.695 | 0.557 | 0.724 |
| 1.620 | 0.768 | 0.209 | 1.593 | 1.993 | 0.179 |
| 1.930 | 0.872 | 0.892 | 2.224 | 2.267 | 0.016 |
| 0.586 | 0.266 | 0.028 | 1.016 | 1.004 | 0.004 |

**Hybrid III 5th Percentile Female Position 1**

| Vehicle | 15ms HIC | 3ms Clip (g's) | Chest Def. (mm) | NIJ | Neck Tension (N) | Neck Comp. (N) |
|---|---|---|---|---|---|---|
| 2001 Toyota Echo | 0.071 | 0.247 | 0.247 | 0.728 | 0.678 | 0.004 |
| 2001 Ford Escape | 0.039 | 0.281 | 0.451 | 1.493 | 0.600 | 0.009 |
| 2001 Ford F150 | 0.030 | 0.260 | 0.428 | 1.386 | 0.841 | 0.157 |
| 2001 Honda Accord (low) | 0.039 | 0.243 | 0.203 | 0.310 | 0.455 | 0.044 |
| 2001 Dodge Caravan (low) | 0.023 | 0.418 | 0.718 | 0.736 | 0.905 | 0.092 |
| 2001 Dodge Caravan (high) | 0.061 | 0.483 | 0.815 | 1.870 | 1.113 | 0.041 |
| 2001 Chevrolet Impala (low) | 0.007 | 0.314 | 0.483 | 0.229 | 0.322 | 0.048 |
| 2001 Chevrolet Impala (high) | 0.044 | 0.263 | 0.258 | 0.411 | 0.320 | 0.040 |

**Hybrid III 5th Percentile Female Position 2**

| 15ms HIC | 3ms Clip (g's) | Chest Def. (mm) | NIJ | Neck Tension (N) | Neck Comp. (N) |
|---|---|---|---|---|---|
| 0.023 | 0.480 | 0.553 | 0.670 | 0.394 | 0.010 |
| 0.036 | 0.664 | 1.003 | 0.590 | 0.384 | 0.018 |
| 0.027 | 0.621 | 0.931 | 0.582 | 0.479 | 0.020 |
| 0.061 | 0.422 | 0.607 | 1.015 | 0.520 | 0.065 |
| 0.040 | 0.586 | 1.217 | 0.670 | 0.828 | 0.129 |
| 0.060 | 0.667 | 1.241 | 0.845 | 0.741 | 0.027 |
| 0.010 | 0.264 | 0.540 | 0.273 | 0.181 | 0.054 |
| 0.027 | 0.278 | 0.756 | 0.493 | 0.285 | 0.041 |