# DESCRIPTION AND PERFORMANCE OF THE HYBRID III THREE YEAR OLD, SIX-YEAR-OLD AND SMALL FEMALE TEST DUMMIES IN RESTRAINT SYSTEM AND OUT-OF-POSITION AIR BAG ENVIRONMENTS

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## INTRODUCTION

With the introduction of air bags coming into the market at a brisk pace, and foreseeing the need for assessing the safety benefits of the air bag for all sizes of vehicle occupants, the Center for Disease Control (CDC) awarded in 1987 a contract to the Ohio State University under the title "Development for Multisized Hybrid III-Based Dummy Family." At the time the funding covered only the development of a small female and a large male dummies. Recognizing the need for dummies with improved biofidelity and extended measuring capability and capacity to evaluate the safety of children, CDC provided additional funding in 1989 to develop a design foundation for the Hybrid III-type child size dummies. To support this work, the Ohio State University asked the Society of Automotive Engineers (SAE) to form an appropriate working group that would provide advice and guidance from the automotive perspective. The SAE, through its Hybrid III Dummy Family Task Group and later, also through the Dummy Testing Equipment Subcommittee, has continued the development work since then, resulting in the construction of prototype Hybrid III-type 5th percentile female, 95th percentile male, six-year-old, three-year-old, and CRABI 12-month-old dummies.

In 1997, NHTSA, in cooperation with the appropriate technical committess of SAE, initiated an evaluation program for the prototype Hybrid III dummies prior to proposing them for incorporation into Part 572 as regulated test devices. This paper provides highlights of the Agency program which was used to evaluate the Hybrid III three-year-old and six-year-old child dummies and the 5th percentile female dummy for their sufficiency as measurement devices. It includes detailed anthropometry, biofidelity responses, and performance data for out-of-position static air bag tests and dynamic sled tests. Similar evaluations for the 95th percentile male and the CRABI 12-month-old are forthcoming.

Table 1 summarizes the overall weight and key dimensions for a number of current dummies including the three dummies described in this paper. The three dummies along with the 50th male are shown in the photograph of Figure 1.

Figure 2 illustrates a key feature that has been added to the thorax of each of these three dummies. Accelerometers have been added to the sternum and spine box to allow the determination of the viscous criteria (v*c). Two or three pairs of accelerometers (one accelerometer on the sternum and one on the spine box constitute a pair) are used to determine the velocity of the sternum relative to the spine.

To assess biofidelity, component tests were conducted with the head, neck, and thorax of each dummy. The component test responses were then compared to the appropriate biofidelity corridors which represent estimated typical human responses to similar test conditions. Given the absence of sufficient data for the three- and six-year-old children, and the $5^{th}$ percentile female, the biofidelity corridors were developed by applying the appropriate mass distribution and geometric scaling factors to the H-III 50M corridors.

When evaluating biofidelity, one must consider the limitations imposed by the mechanical nature of the dummy. For example, the biofidelity requirements must be balanced with the equally important qualifications that the dummy be durable and that its responses are repeatable. These requirements make it necessary to construct the dummy from

**Table 1**
**Comparison of Weight, Sitting Height, and Stature for Hybrid III Family**

| | | 12 month CRABI | 3 YO Child | 6 YO Child | 5th %ile Female | 50th %ile Male | 95th %ile Male |
|---|---|---|---|---|---|---|---|
| Weight | lbs | 22.0 | 34.5 | 46.00 | 108.7 | 171.3 | 223 |
| Stature | in | 29.4 | 37.2 | 47.30* | 59.0* | 68.7* | 73.4* |
| Sitting Height | in | 18.9 | 21.50 | 25.00 | 31.1 | 34.80 | 36.8 |
| *Estimated | | | | | | | |

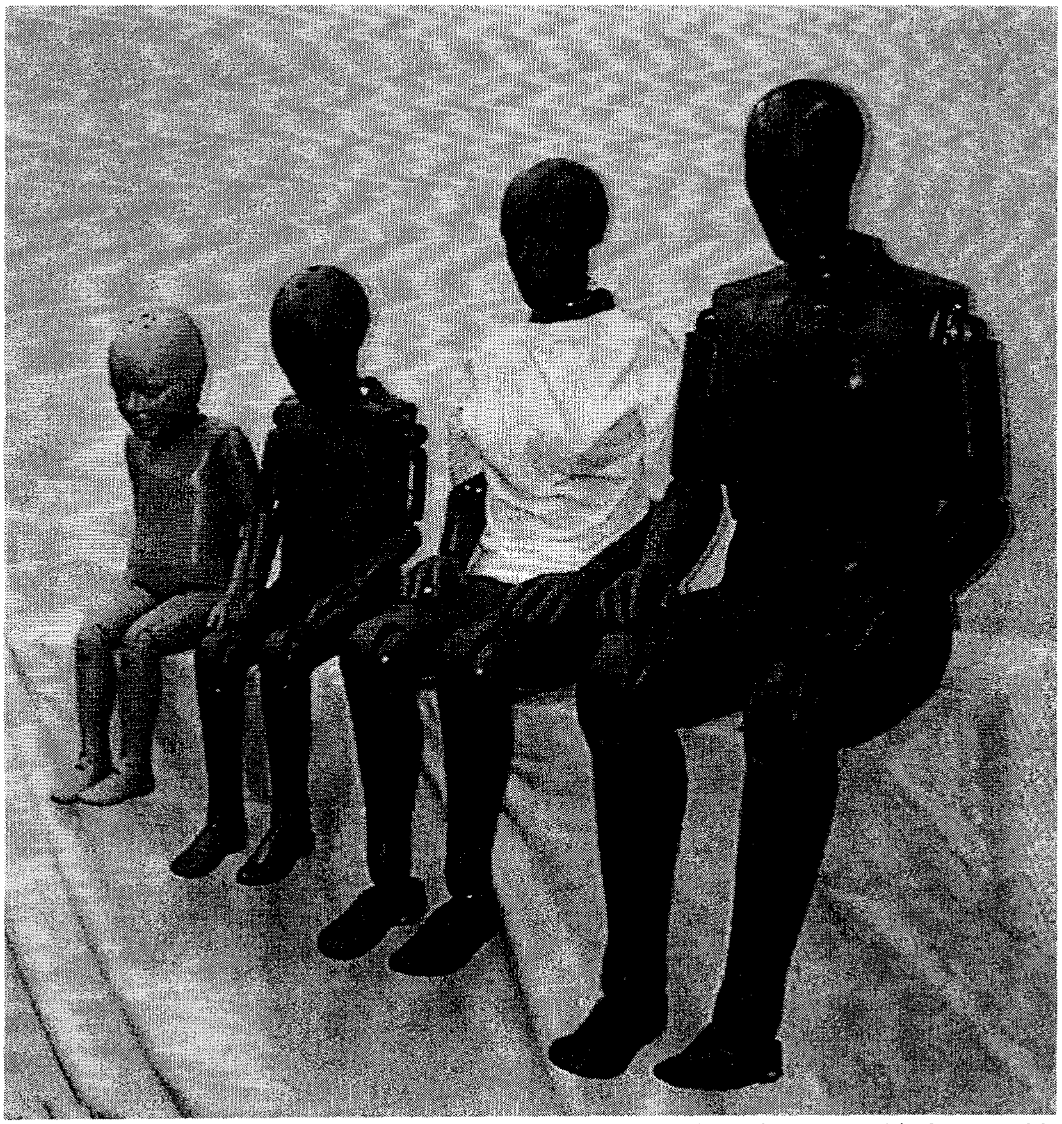

Figure 1. Photograph of the Hybrid III Dummy Family: (left to right) three-year-old, six-year-old small female and mid-size male.

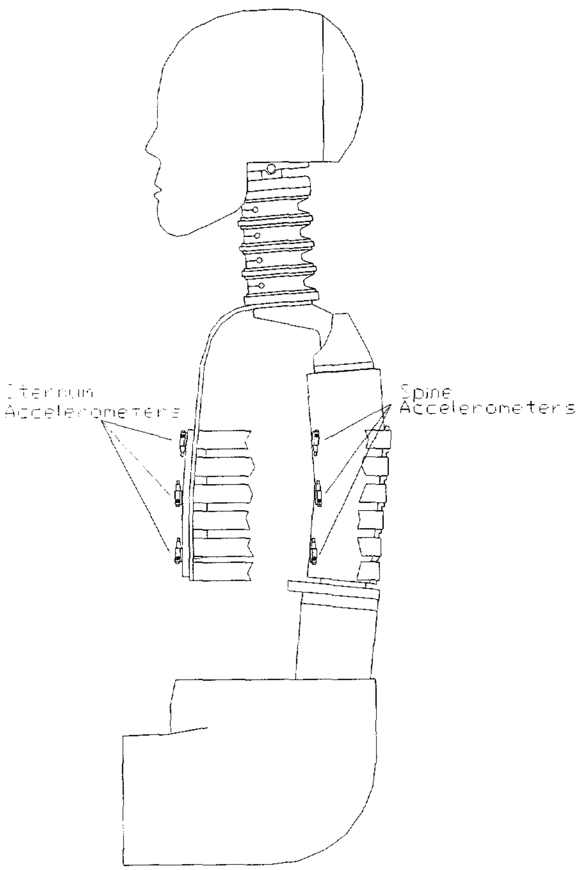


Figure 2. Accelerometer pairs in the thorax of the small female. (Middle ribs removed for clarity.)

engineering materials which can withstand repeated impacts of high energy, whereas the human body, consisting of frangible bones and soft tissue, cannot endure frequent exposures of this destructive nature. Given these limitations, it is not reasonable to expect that the dummies' responses can be tuned to fit perfectly within the biofidelity corridors. For the purposes of this evaluation, biofidelity has been deemed acceptable when the following subjective criteria have been met: (1) the area under the curve of the dummy's response is reasonably similar to that of the biofidelity corridor; (2) the hysteresis properties of the dummy's response are reasonably similar to those of the biofidelity corridor; (3) the maximum points of interest (force, deflection, rotation, etc.) are within the biofidelity corridor.

Each section to follow describes the features of the dummy, the instrumentation capability, the biofidelity responses of the major components, and key results of out-of-position and sled tests. All data presented in this paper conforms to SAE J-211 requirements for both filtering and sign convention.

## HYBRID III THREE-YEAR-OLD DUMMY

### Description of Dummy Features

The Hybrid III Three-year-old child (H-III3C) dummy was designed to be used in testing child restraints and assessing the injury risks associated with air bag interactions. The dummy's final design was based on a combination of designs from the Three-year-old "Air Bag" dummy, scaled-down versions of the Hybrid III 50th percentile male, and scaled-up versions of the Child Restraint Air Bag Interaction (CRABI) dummy. The dummy's current design includes some changes made by General Motors, First Technology Safety Systems and the Vehicle Research and Test Center (VRTC) to maximize permissable chest deflection and protect instrumentation, and further changes made by the SAE as a result of this evaluation. Some of the distinguishing characteristics of the H-III3C design are a segmented neck with a steel cable to limit elongation, a set of ribs and rib stiffeners made of 1095 steel for increased durability, upper and lower rib guides to deter vertical movement of the ribs for improved accuracy of chest deflection measurement and sternum-to-spine bumpers to prevent instrumentation destruction caused by metal-to-metal contact in the event of extreme chest deflection. As the dummy was intended to be used while properly restrained in child restraint systems as well as out-of-position with air bags, the dummy's pelvis allows sitting, standing and kneeling postures.

### Anthropometry

Tables A1 and A2 in Appendix A show the measured segment weights and external dimensions of a Hybrid III Three-year-old dummy and provide a comparison to the published SAE guidelines (Draft Hybrid III Three-Year-Old Dummy User Manual dated May 13, 1997). The measurement data shows that the segment weights of the dummy measured at VRTC are all within the SAE specifications, with the exception of the head and torso with jacket, which are both only 0.03 lb. over the specified weight. All but two of the measured external dimensions made at VRTC fall within the specified range. The outstanding measurements were not significant enough to prevent testing.

## Instrumentation

This dummy has numerous instrumentation capabilities including 19 accelerometers, 10 load cells and a rotary potentiometer in the chest, totalling 50 data channels. Unique instrumentation capabilities of this dummy include a pair of uniaxial accelerometers in the skull to calculate angular acceleration and rotation of the head, two sternal uniaxial accelerometer pairs for use in calculating the viscous criterion (VC), two triaxial configurations of accelerometers on the spine to allow calculation of angular acceleration and rotation of the thoracic spine, upper and lower neck and left and right iliac, acetabulum and shoulder load cells. The dummy also has the capacity to mount a pubic load cell to measure loads associated with child restraint systems. A table of instrumentation is included in Table 2.

## Biofidelity

The Agency has conducted several tests with this dummy including component, static out-of-position (OOP) air bag and dynamic sled tests. Repeated component tests on the head, neck and thorax were conducted before, after, and throughout a series of OOP and sled tests to assess the dummy's biofidelity, repeatability, reproducibility and durability. Figures 3-6 show typical plots of component test data for the head drop, neck extension, neck flexion and thorax impact, respectively, with their biofidelity corridors as defined by Mertz[1].

Only a limited number of tests have been performed thus far on the latest versions of the head skin and neck as they have recently been modified to

**Table 2**
**H-III3C Dummy Instrumentation Capabilities**

| Dummy | Type | Location | Measurements | # Channels |
|---|---|---|---|---|
| H-III3C | Accelerometers | Head | Ax, Ay, Az1, Az2 | 4 |
| | | Upper Thoracic Spine | Ax, Ay, Az | 3 |
| | | Middle Thoracic Spine | Ax, Ay, Az | 3 |
| | | Lower Thoracic Spine | Ax, Ay, Az | 3 |
| | | Upper Sternum | Ax | 1 |
| | | Lower Sternum | Ax | 1 |
| | | Lower Spine Box | Ax | 1 |
| | 19 max. | Pelvis | Ax, Ay, Az | 3 |
| | Rotary Potentiometer | Thorax | Dx | 1 |
| | Load Cells | Upper Neck | Fx, Fy, Fz, Mx, My, Mz | 6 |
| | | Lower Neck | Fx, Fy, Fz, Mx, My, Mz | 6 |
| | | Lumbar | Fx, Fy, Fz, Mx, My, Mz | 6 |
| | | Anterior Superior Iliac Spine x 2 | Fx upper, Fx lower | 4 |
| | | Acetabulum x 2 | Fy | 2 |
| | | Pubic | Fx, Fz | 2 |
| 50 max. | *30 max.* | Shoulder x 2 | Fx, Fz | 4 |

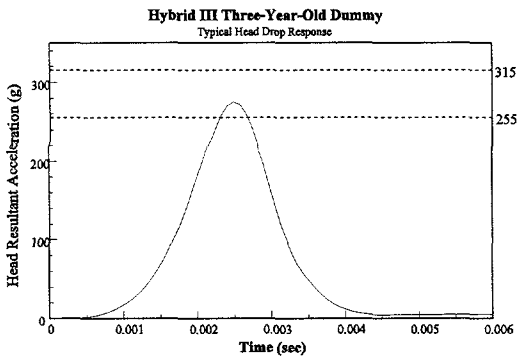


Figure 3. Typical head drop response with biofidelity corridor.

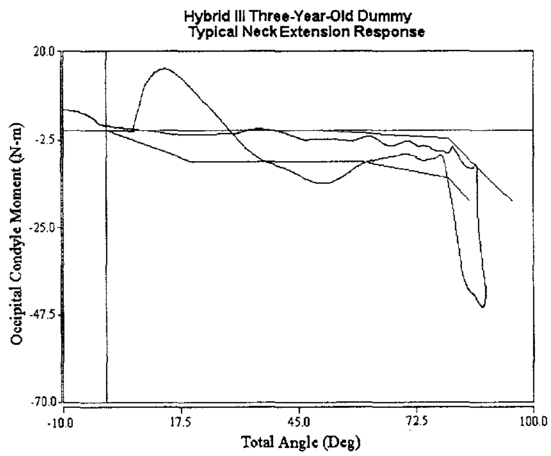


Figure 4. Typical neck pendulum response in extension with biofidelity corridor.

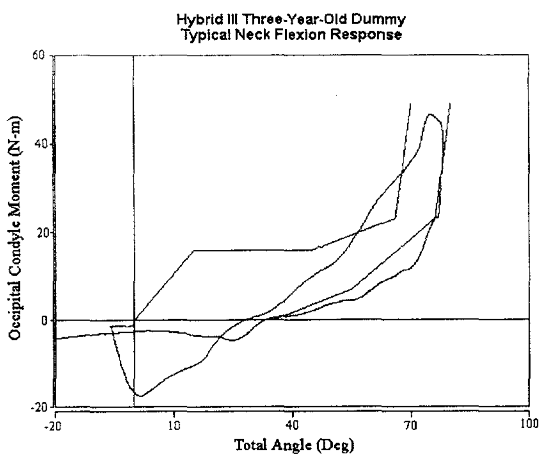


Figure 5. Typical neck pendulum response in flexion with biofidelity corridor.

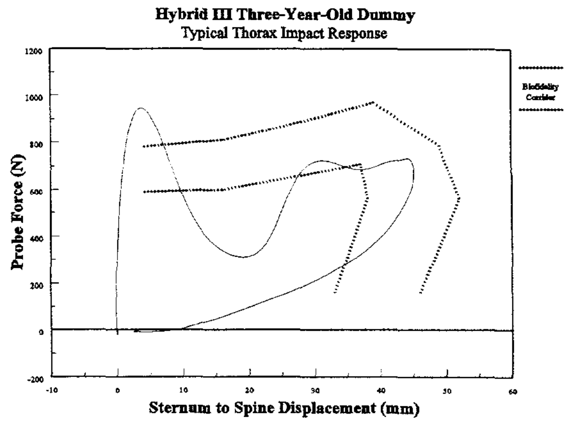


Figure 6. Typical thorax impact response with biofidelity corridor.

incorporate improvements. Insufficient component test data with the final dummy configuration prevents discussion of repeatability, reproducibility and durability of the head and neck. Note that the steep rise in moment during neck extension is caused by the segments of the neck contacting each other, resisting further rotation, producing a dramatic increase in the moment. This is a mechanical limit of the engineering materials and the geometry of the dummy neck. Both the neck flexion and extension responses show an inertial moment opposite to the direction of the primary response. For example, in the neck extension response, an initial flexion moment occurs. This response is observed in adult cadaver data and is due to the inertial response of the head during impact, but the biofidelity corridors do not include this inertial response.

Also note that the initial rise in force during thorax impact is due to the dummy skin slapping the ribs, is not an indicator of the response of the ribs, and is therefore disregarded when assessing the dummy's thorax biofidelity. This also is a mechanical limitation of the engineering materials, but one which is not seen in adult cadaver data. The thorax appears to show excellent repeatability and reproducibility and is reasonably durable.

### Static Out-of-Position Air Bag Testing

The OOP and sled tests were performed to assess the dummy's durability and system performance. The OOP tests were conducted in several different vehicle configurations in ISO positions 1 and 2 to simulate pre-impact braking positions where severe interactions would occur with a deploying passenger air bag. The procedure for seating the dummy in the ISO positions is described in Appendix B. The air bag systems were selected based on the current trend toward depowered systems, in order to represent supplemental restraint systems which will be incorporated into vehicles in the future. The systems chosen were mildly aggressive and aggressive full-powered air bags which would subject the dummy to appropriate loads in order to evaluate its durability and system performance. It should be noted that the OOP and sled tests were conducted with a preliminary version of the dummy as some minor improvements were made to the dummy after the testing was completed. Additional tests with the latest dummy revisions are underway.

The tests were conducted in a generic setup, using actual vehicle seats, dash panels and passenger air bag modules to simulate front passenger environments. The orientation of each vehicle setup was representative of the actual vehicle including seat pan and seat back angles, windshield angle, air bag center height from the floor of the vehicle, and the relationship among these parts. Table 3 shows maximum responses from the primary channels during OOP tests.

**Table 3.**
**H-III3C Out-of -Position Maximum Responses**

| Measurement/Calculation | Units | Peak Values |
|---|---|---|
| HIC | | 848 |
| Head Resultant Acceleration | g | 99 |
| Upper Neck Force-X | N | -1771 |
| Upper Neck Force-Z | N | 2244 |
| Upper Neck Moment-Y | N-m | -56 |
| Chest Deflection | mm | -30 |
| Resultant Chest Acceleration | g | 53 |

**Sled Testing**

The dynamic simulation vehicle setup was the same as the OOP setup except two passenger seats were positioned next to each other, one on the driver side of the dash panel with the seat in the rearwardmost track position to keep the dummy from contacting the dash, and the other dummy on the passenger side of the dash panel with the seat in its forwardmost track position to ensure dummy contact with the air bag when deployed. The steering column was removed from the instrument panel for a more passenger-like setting, allowing more room for excursion. Again, it should be noted that the sled tests were also conducted with a preliminary version of the dummy. Additional tests with the latest dummy are being conducted.

The sled test set-ups included several different vehicle configurations with various child restraints, vehicle restraints and sled pulses. Three types of sled pulses were employed: (1) the FMVSS 213 pulse (approximately 47 kph, 23 g), (2) 208-type crash pulses (approximately 50-54 kph, 34-35 g), and (3) a 208 AAMA sled pulse (approximately 47 kph, 17.5 g). The dummy was typically properly restrained and seated in a child restraint system, except for some partially and completely unrestrained tests. The vehicle configurations were chosen to represent a range of aggressive environments in order to evaluate the durability of the dummy. The sled test matrix (Table C1, Appendix C) was designed to represent several sled pulses, two different vehicles, and a variety of restraint systems. Post-test dummy inspections were conducted to identify problems and/or ensure structural integrity before proceeding to the next test. In this way, dummy durability could be followed closely.

Table 4 shows the maximum responses from the primary channels during sled tests.

The loading of the OOP and sled tests was significant as demonstrated by the magnitude of the peak values in Tables 3 and 4. Overall peak chest deflection achieved 80% *(38/47 mm at the time; available space now is 41 mm, so overall peak deflection was 93%)* of the available clearance between the sternum and spine bumpers, illustrating that the test matrix provided chest loadings which were not inconsequential. The measured responses from the various conditions on the sled prove the dummy is able to provide useful and reasonable measurements using the different sled pulses, restraint conditions and vehicle setups as a basis for comparison. The dummy did not sustain significant damage throughout the test series, suggesting that the dummy is quite robust.

However, there were minor problems identified during the static and dynamic test series that have since been addressed by SAE and are in the process of being validated. For instance, the head skin began coming loose and shifting during both OOP and sled testing, which could potentially have affected head acceleration measurements and head injury criterion (HIC) calculations. Several modifications were made to the head skin and skull which resulted in a more secure attachment and better fit, as well as slightly

**Table 4.**
**H-III3C Sled Test Maximum Responses**

| Criteria/Measurement | Maximum Response | | | | | | |
|---|---|---|---|---|---|---|---|
| Sled Pulse<br>Air bag deployed?<br>Child Restraint Used? | 213<br>W/AB*<br>W/CRS$ | 208<br>W/O AB<br>W/CRS | 208<br>W/AB<br>W/CRS | 208 Sled<br>W/O AB<br>W/CRS | 208 Sled<br>W/AB<br>W/CRS | 208<br>W/O AB<br>W/O<br>CRS# | 208<br>W/AB<br>W/O<br>CRS |
| HIC | 757 | 1828 | 1003 | 444 | 218 | 3032 | 666 |
| Neck Flexion Moment (N-m) | 31 | 57 | 37 | 34 | 13 | 214 | 27 |
| Neck Extension Moment (N-m) | -22 | -25 | -27 | -13 | -8 | 0 | -59 |
| Neck Shear Force (N) | 933 | 837 | 726 | -702 | 373 | 4078 | 813 |
| Neck Axial Force (N) | -1735 | 2235 | -1396 | 1178 | -467 | 1564 | 1868 |
| Chest Resultant Acceleration (g) | 67 | 64 | 76 | 32 | 44 | 119 | 72 |
| Chest Deflection (mm) | -13 | -22 | -13 | -14 | -13 | -38 | -13 |

*AB=Air Bag
$CRS=Child Restraint System
#W/O CRS=The dummy was not in a child seat and was not belted

improved biofidelity. In addition, the shoulder belts of the child restraint systems became lodged between the dummy's neck and shoulder, causing unrealistic loading. The shoulder load cell cover and structural replacement were modified with the addition of a belt guide to prevent such occurrences. The neck segments were shaved down to provide additional rotation as the neck response was short of the biofidelity rotation corridors in both flexion and extension. Concerns from members of the SAE Hybrid III Dummy Family Task Group prompted an increase in the depth of the sternum-to-spine bumpers from 4 mm to 10 mm as instrumentation had been destroyed using the thinner bumpers. It was thought that thicker bumpers would prevent such damage to instrumentation and a depth of 10 mm was chosen because it was the thickest depth which could be used without affecting thorax calibration deflection results.

## HYBRID III SIX-YEAR-OLD DUMMY

### Description of Dummy Features

The Hybrid-III6C dummy was designed for use in frontal impact testing and scaled from the Hybrid III 50th shape and biofidelity response. SAE and industry were further refining and revising the dummy in 1996 when NHTSA decided to use the dummy in research testing to evaluate the injury risks which full-powered passenger air bag systems posed for out-of-position children. In late 1997 NHTSA evaluated the suitability of the H-III6C dummy to be proposed for incorporation into the Part 572 standard. The dummy as received from the manufacturer was modified to include patches of skin under the chin and at the occipital condyles of the dummy head and around the shoulder to decrease the possibility of air bag punctures during testing. The dummy design included a neck and lumbar which were equipped with nylon inserts to prevent signal noise. The dummy's thorax was equipped with both a chest potentiometer and accelerometers and also has several structural enhancements to optimize it for use in the air bag environment. These enhancements included strong steel ribs and rib stiffeners, rubber sternum stops like the kind used on the HIII 50th percentile dummy, additional clearance in the thoracic cavity for travel of the chest deflection transducer arm, upper and lower rib stops to prevent vertical motion of the ribs and a metal strip with recesses to hold each rib from pivoting about the sternum area. A modified abdomen provided additional clearance for travel of the chest deflection transducer arm while maintaining posture.

## Anthropometry

The dummy's design is based on established scaling procedures from the Part 572 Subpart E 50th percentile male Hybrid III crash test dummy matching anthropometry, mass distribution, sitting heights, and motion ranges of the average six year old[2,3,4]. Examination of the dummies' anthropometry and mass distribution and the SAE Task Group specified targets (Task Group minutes of May 10, 1991) are shown in Appendix A, Tables A.3 and A.4. A few of the components varied from the SAE specifications but were not considered sufficiently critical to preclude testing.

## Instrumentation

The dummy's instrumentation capabilities shown below in Table 5 are particularly suited for assessing air bag induced injuries.

## Biofidelity

Component tests[5] were performed throughout the test program to evaluate critical components, compare their response to the specified biofidelity corridors and determine repeatability after continuous testing of the dummy. The component tests were the head drop test, neck pendulum test, and thorax impactor test.

Typical responses of these three components overlayed onto their appropriate biofidelity corridors are shown in Figure 7 for the head, Figures 8 and 9 for the neck in flexion and extension, and in Figure 10 for the thorax.

The responses of the two dummies used in the test program were found to be excellent for both repeatability and reproducibility. None of the responses showed any tendency to drift in any specific direction.

**Table 5.**
**H-III6C Instrumentation**

| Dummy | Type | Location | Measurements | Channels |
|---|---|---|---|---|
| H-III6C | Accelerometers | Head | Ax, Ay, Az | 3 |
| | | Upper Thoracic Spine | Ax, Ay, Az | 3 |
| | | Middle Thoracic Spine | Ax, Ay, Az | 3 |
| | | Upper Sternum | Ax | 1 |
| | | Lower Sternum | Ax | 1 |
| | | Upper Spine Box | Ax | 1 |
| | | Lower Spine Box | Ax | 1 |
| | | Pelvis | Ax, Ay, Az | 3 |
| | Rotary Potentiometer | Thorax | Dx | 1 |
| | Load Cells | Upper Neck | Fx, Fy, Fz, Mx, My, Mz | 6 |
| | | Lower Neck | Fx, Fy, Fz, Mx, My, Mz | 6 |
| | | Lumbar | Fx, Fy, Fz, Mx, My, Mz | 6 |
| | | Anterior Superior Iliac Spine | Fx upper, Fx lower | 4 |
| 51 max. | | Femur x 2 | Fz<br>Fx, Fy, Fz, Mx, My, Mz | 2<br>12 |

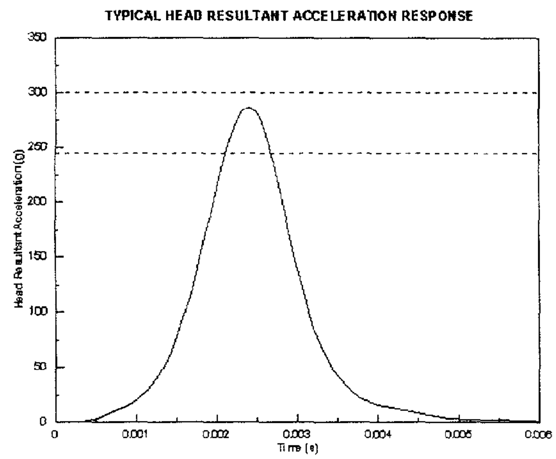


Figure 7. Typical H-III6C Head Response

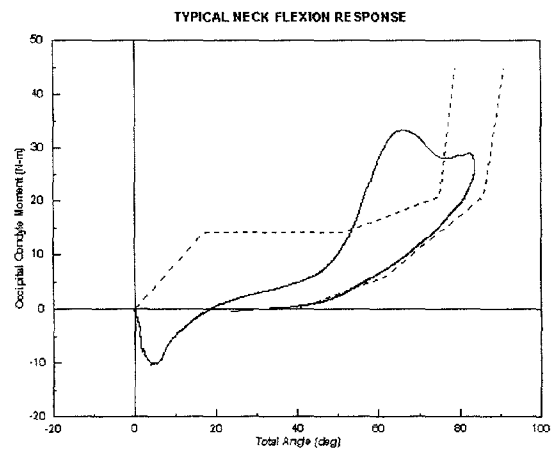


Figure 8. Typical H-III6C Neck Flexion Response

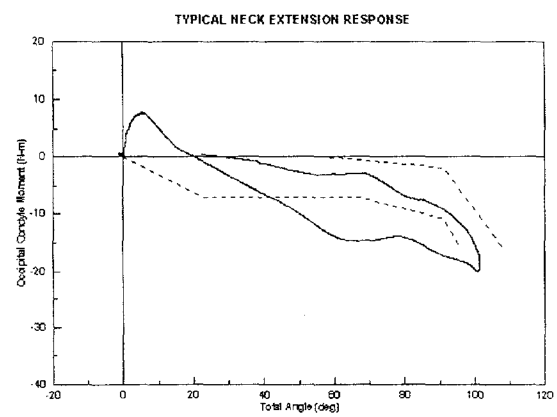


Figure 9. Typical H-III6C Neck Extension Response

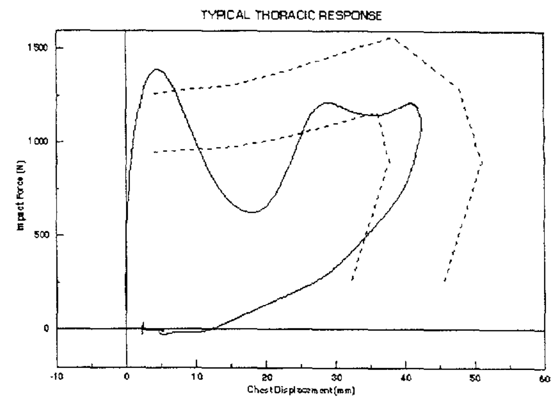


Figure 10. Typical H-III6C Thoracic Response

## Static Out-of-Position Air Bag Testing

While the aim of the component level testing was primarily to determine the dummy's repeatability, the aim of the OOP test program was to determine the dummy's ability to provide useful and practicable measurements and to establish its structural integrity in a relatively severe air bag deployment environment.

Front passenger compartments of two popular compact vehicles were selected for OOP Tests. These systems were chosen as representative compact vehicles with top-mounted passenger-side air bag systems. The dummy set-up procedures for OOP tests are based on ISO child positions 1 and 2 modified to facilitate the placement of dummies within the vehicle as described in Appendix B. Sixteen tests were conducted and maximum primary dummy responses are shown in Table 6.

The OOP test program showed the dummy has the ability to provide useful and practicable measurements. The OOP test program tried the structural integrity of the dummy at the outset of the test program, requiring a modification to the metal strip in the front of the ribs. With this modification, the durability of the dummy in the relatively severe air bag environment was established.

## Sled Testing

The purpose of the sled tests was to determine if the dummy (1) was capable of useful, consistent and repeatable measurements; (2) could distinguish among different crash pulses, seating configurations and restraint systems; and (3) had adequate durability.

**Table 6.**
**H-III6C OOP Test Maximum Responses**

| CRITERIA/RESPONSE | VALUE |
|---|---|
| HIC | 1085 |
| Neck Flexion Moment (N-m) | 62 |
| Neck Extension Moment (N-m) | -94 |
| Neck Shear Force (N) | 2541 |
| Neck Axial Force (N) | -3492 |
| Resultant Chest Acceleration (g) | 90 |
| Chest Deflection (mm) | -34 |

The same vehicle configurations used in the OOP tests were used in HYGE sled tests. The dummy was positioned with various restraint conditions including booster seats, 3-point belts and air bags. The dummy was also tested unbelted and completely unrestrained. See Table C2 in Appendix C. Three types of sled pulses were employed: (1) the FMVSS 213 pulse (approximately 47 kph, 23 g), (2) 208-type crash pulses (approximately 50-54 kph, 33 g), and (3) a 208 AAMA sled pulse (approximately 48 kph, 17 g). Twelve sled tests were performed with two dummies. In two tests only one dummy was used, for a total of twenty-six dummy tests. Table 7 summarizes the maximum responses recorded for the various testing configurations.

The measured response values in the sled tests varied from very low to extremely high sensor outputs. Under extremely severe loading conditions, none of the measurements showed traces of contamination by unusual signals or distortions that would be a cause for questioning the response validity of the measurements. The patterns of measurements obtained from dummy-based sensors appeared to provide correct trends of comparative responses based on pulse aggressivity, seat locations and restraint conditions.

## HYBRID III FIFTH PERCENTILE FEMALE

### Description of Dummy Features

The H-III5F dummy is essentially a scaled-down version of the Hybrid III 50th (H-III50M) percentile dummy with several updated components to provide more human-like range of motion and improve performance and durability in the air bag

**Table 7.**
**H-III6C Sled Test Maximum Responses**

| CRITERIA/RESPONSE | VALUE | | | | |
|---|---|---|---|---|---|
| | **213 W/O AB*** | **213 W/AB** | **208 W/O AB** | **208 W/AB** | **208 SLED W & W/O AB** |
| HIC | 694 | 906 | 1476 | 1119 | 313 |
| Neck Flexion Moment (N-m) | 31 | 21 | 28 | 34 | 24 |
| Neck Extension Moment (N-m) | -42 | -60 | -46 | -47 | -15 |
| Neck Shear Force (N) | -770 | -940 | -1439 | -1172 | -493 |
| Neck Axial Force (N) | 2544 | -3016 | 3953 | -2096 | 1806 |
| Resultant Chest Acceleration (g) | 55 | 58 | 85 | 70 | 40 |
| Chest Deflection (mm) | -38 | -33 | -55 | -38 | -39 |
| Excursion (mm) | 624 | | | | |
| *AB = Air Bag | | | | | |

environment. The thorax contains several significant modifications including rib guides which limit upward and downward movement of the ribs, similar to those found in the H-III3C and H-III6C. The pelvis contains features which reduce the likelihood of submarining when tested in a 3-point belt environment. Mounted on each upper femur is a hard plastic bumper which limits the amount of hyperflexion of the femur and prevents metal-to-metal contact in extreme conditions. A rubber bumper mounted on the ankle limits the range of motion of the foot and prevents metal-to-metal contact between the foot and ankle. Also incorporated into the heel of the foot is an Ensolite pad which provides a degree of heel compliance.

**Anthropometry**

The external dimensions and segment weights of an H-III5F dummy were measured and compared to design guidelines published by SAE. The results of these measurements appear in Tables A.5 and A.6 in Appendix A. The external dimensions meet the SAE guidelines and the segment weights meet all of the requirements except for one. The total dummy weight was well within the published guidelines.

**Instrumentation**

The dummy contains provisions for mounting a wide variety of electronic instrumentation. Similar to the H-III3C and H-III6C, the H-III5F has capacity for mounting three accelerometer pairs to the sternum and spine for computing the viscous criterion (V*C). Another unique feature is the anterior-superior iliac spine (ASIS) load cell which provides useful information relative to belt loading. Table 8 summarizes the available instrumentation for the H-III5F.

**Biofidelity**

The H-III5F biomechanical impact response requirements for the head, neck, and chest were

**Table 8.**
**Available Instrumentation for H-III5F**

| Type | Location | Measurements | # Channels |
|---|---|---|---|
| Accelerometers | Head CG | Ax, Ay, Az | 3 |
| | Thorax | Ax, Ay, Az | 3 |
| | Pelvis | Ax, Ay, Az | 3 |
| | Sternum - Upper, Middle, Lower | Ax | 3 |
| | Spine - Upper, Lower, Middle | Ax | 3 |
| Rotary Potentiometer | Thorax (Chest Deflection) | Dx | 1 |
| Linear Potentiometer | Knee Slider* | Dx | 1 |
| Load Cells | Upper Neck | Fx, Fy, Fz, Mx, My, Mz | 6 |
| | Lower Neck | Fx, Fy, Fz, Mx, My | 5 |
| | Lumbar Spine | Fx, Fy, Fz, Mx, My | 5 |
| | Thoracic Spine | Fx, Fy, Fz, Mx, My | 5 |
| | ASIS* | Fx, My | 2 |
| | Femur - 1 channel*# | Fz | 1 |
| | Femur - 6 channel*# | Fx, Fy, Fz, Mx, My, Mz | 6 |
| | Upper Tibia Load Cell* | Fx, Fz, Mx, My | 4 |
| *71 max.* | Lower Tibia Load Cell* | Fx, Fz, Mx, My | 4 |

** indicates that right and left load cells are required*
*# The two femur load cells are mutually exclusive; if one is used, the other is excluded.*

obtained by applying the appropriate mass and geometric scale factors to the response requirements for the H-III50M[6]. Multiple head, neck, and thorax component tests were conducted to assess biofidelty and also to establish the repeatability and reproducibility of the responses. Tests were conducted throughout the duration of the evaluation to ensure the long term durability of the biofidelity responses.

The biomechanical head impact response requirements state that the peak resultant acceleration of the head c.g. for a 376 mm drop of the head onto a flat, rigid impact surface shall be between 240 and 295 g. Figure 11 shows a typical head drop response in comparison to the biomechanical response requirement.

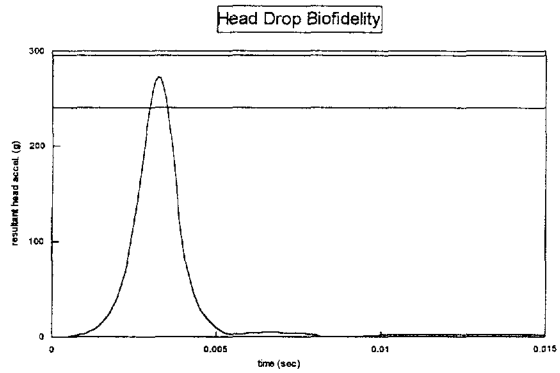


Figure 11. Typical H-III5F Head Impact Response

The biomechanical neck bending requirements are defined by the head and neck's response to a prescribed deceleration pulse resulting from a rigid pendulum drop into an energy absorbing material. A typical response for neck flexion and neck extension tests compared against their respective biomechanical corridors can be found in Figures 12 and 13, respectively.

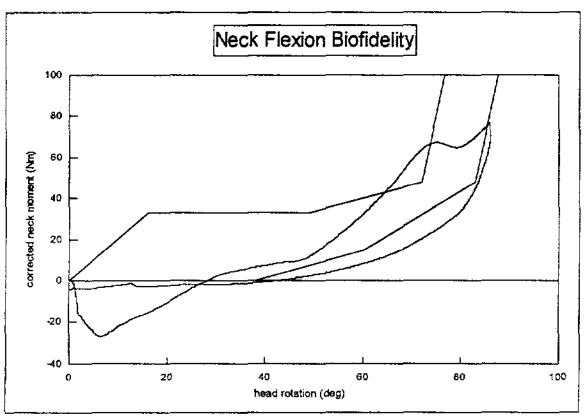


Figure 12. Typical H-III5F Neck Flexion Response

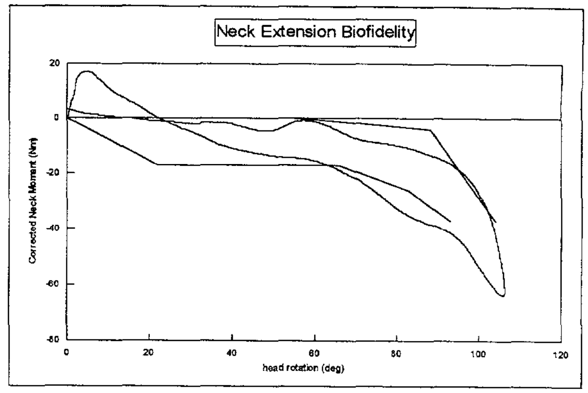


Figure 13. Typical H-III5F Neck Extension Response

The biomechanical requirements for the chest specify the force-deflection characteristics of the thorax in response to a mid-sternal impact of a 14 kg pendulum at 6.71 m/s. A typical response to a thoracic impact test compared against the biomechanical corridor can be found in Figure 14.

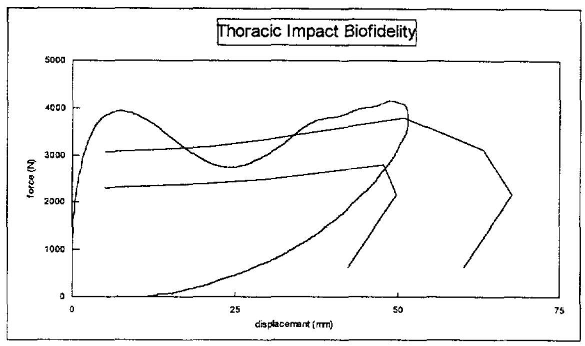


Figure 14. Typical H-III5F Thorax Impact Response

**Static Out-of Position Air Bag Testing**

Driver and passenger static out-of-position tests were conducted in several different vehicle systems. The OOP tests were primarily intended as an evaluation of the dummies' durability and the integrity of the instrumented measurements. Tests involving the driver systems were carried out in an actual vehicle using standard seats, dash panels, and air bags; for the passenger tests, however, the seats were removed to achieve proper dummy positioning. Tests involving the passenger systems were conducted in a generic setup. The driver test environment was made up of a flat, steel seat pan with a padded seat back, standard air bags and steering wheels, and a reusable steering column. The passenger tests utilized a standard dash panel and air bag. For all passenger OOP tests, the lower legs were removed to achieve proper dummy positioning.

For driver OOP tests, the International Standards Organization (ISO) seating procedures were followed. The procedures are contained in Appendix B. For the passenger tests, however, the ISO has not yet developed a standard positioning procedure for the H-III5F. Therefore, the dummy was positioned in what was considered to be a reasonable OOP testing configuration in close proximity to the air bag. An attempt was made to follow the driver positioning format, in that passenger position 1 is intended to maximize head and neck loading while passenger position 2 is intended to maximize chest loading.

A total of 16 driver and 6 passenger OOP tests were conducted and the dummies were thoroughly inspected after each test. The maximum driver and passenger OOP responses for all of the tests, including both ISO 1 and 2, are listed in Table 9. Table 9 indicates that the dummy can sustain significant loading to the head, neck, and chest without experiencing significant structural damage.

**Table 9.**
**OOP Test Maximum Responses for H-III5F**

| Criteria | Units | Driver OOP | Pass. OOP |
|---|---|---|---|
| HIC | | 281 | 3319 |
| Neck Force-X | N | -2739 | -9918 |
| Neck Force-Z | N | 3324 | 9884 |
| Neck Moment | N-m | -117 | -152 |
| Chest Displacement | mm | -62.4 | -59.5 |
| Chest Resultant | g | 170 | 358 |
| V*C | m/s | 4.13 | 4.02 |

## Sled Testing

Following OOP testing, 30 dynamic sled tests were conducted, 28 of which utilized two dummies simultaneously. Two different vehicle systems were employed in these tests: a compact car and a mid-size car. The tests were conducted in actual vehicle bodies using standard seats, instrument panels, steering wheels and columns, air bags, and 3-point belt restraints.

The test matrix was developed to evaluate the dummy's responses to several different restraint systems. Emphasis was placed on 3-point belt restraint tests because such an environment was considered to be the best condition for evaluating the repeatability of the dummies' response. See Table C3 in Appendix C.

Analysis of the dummy-based test measurements indicate reasonably consistent responses without any apparent tendencies to drift as a function of time or frequency to impact exposure. Post-test inspections of the dummy hardware did not reveal any damage, visual indications of wear or tendencies of the hardware to take on permanent deformation.

A repeatability and reproducibility analysis was completed for the dummies' responses in the sled environment. In order to make a reasonable comparison of responses, it was desired to analyze the results of those tests in which the dummy was subjected to repeatable test conditions. The most repeatable test condition was when the dummy was seated in the passenger seat of the mid-size vehicle and the 3-point belt system was the only restraint. The pulse of the mid-size car had a peak acceleraiton of approximately 25 g's. The peak velocity was approximately 49 kph. Table 10 contains a summary of the repeatability and reproducibility analysis for two different H-III5F dummies.

As Table 10 indicates, the measured responses exhibit good repeatability and reproducibility.

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1. Mertz, H.J. and Irwin, A.L., "Biomechanical Bases for the CRABI and Hybrid III Child Dummies," Proceedings of the 41st Stapp Car Crash Conference, SAE 973317, November, 1997.

2. Minutes of the SAE H-III Dummy Family Task Group of May 10, 1990.

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5. Society of Automotive Engineers Dummy Testing Equipment Subcommittee Draft Calibration Procedures for the Hybrid III Six-Year-Old Child, August 1996.

6. Mertz, H.J., et. al., "Size, Weight, and Biomechanical Impact Response Requirements for Adult Size Small Female and Large Male Dummies," Society of Automotive Engineers # 890756, March, 1989.

**Table 10.**
**H-III5F Repeatability/Reproducibility Analysis for 3-Point Belt Sled Tests in Mid-size Buck**

| | | Dummy A - Repeatability | | | Dummy B - Repeatability | | | Dummies A & B - Reproducibility | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Avg. | Std. Dev. | %CV | Avg. | Std. Dev. | %CV | Avg. | Std. Dev. | %CV |
| HIC | | 881.3 | 60.5 | 6.9 | 832.2 | 57.6 | 6.9 | 854.0 | 60.8 | 7.1 |
| Neck Fx | N | -1574.0 | 24.5 | 1.6 | -1648.6 | 81.6 | 5.0 | -1615.4 | 71.4 | 4.4 |
| Neck Fz | N | 2416.3 | 142.2 | 5.9 | 2278.4 | 86.0 | 3.8 | 2339.7 | 128.7 | 5.5 |
| Neck Moc | N-m | 70.8 | 3.3 | 4.2 | 70.6 | 2.4 | 3.5 | 70.7 | 2.6 | 3.6 |
| Neck Moc- | N-m | -26.3 | 1.3 | 4.7 | -24.4 | 1.9 | 7.2 | -25.2 | 1.9 | 7.1 |
| Chest Res. | g | 53.8 | 1.0 | 1.8 | 53.6 | 1.7 | 3.4 | 53.7 | 1.3 | 2.6 |
| Chest X | mm | -35.7 | 1.2 | 3.5 | -33.2 | 2.4 | 7.4 | -34.3 | 2.3 | 6.7 |
| Pelvis Res. | g | 55.3 | 4.0 | 6.5 | 53.4 | 3.4 | 6.3 | 54.2 | 3.6 | 6.2 |

## ACKNOWLEDGMENT

The efforts reported in this paper were conducted by the Vehicle Research and Test Center of the National Highway Traffic Safety Administration and by the Transportation Research Center. We are indebted to the staff at these facilities for their support.

## APPENDIX A

**Table A1.**
**Segment Weights of H-III3C Dummy**

| Dummy Body Segment | Specification (lbs.) | Tolerance (lbs.) | Actual Measurement (lbs.) |
|---|---|---|---|
| Head | 6.02 | 0.15 | **6.20*** |
| Neck | 1.65 | 0.05 | 1.65 |
| Torso w/jacket | 14.32 | 0.50 | **14.85*** |
| Right Upper Arm | 0.93 | 0.10 | 0.940 |
| Left Upper Arm | 0.93 | 0.10 | 0.940 |
| Right Lower Arm | 1.05 | 0.10 | 1.053 |
| Left Lower Arm | 1.05 | 0.10 | 1.004 |
| Right Upper Leg | 2.13 | 0.20 | 2.136 |
| Left Upper Leg | 2.13 | 0.20 | 2.222 |
| Right Lower Leg | 1.34 | 0.10 | 1.360 |
| Left Lower Leg | 1.34 | 0.10 | 1.346 |
| Right Foot | 0.60 | 0.10 | 0.670 |
| Left Foot | 0.60 | 0.10 | 0.646 |
| Total Weight | 33.83 | 1.20 | **35.75*** |

*Not within specified tolerance

**Table A2.**
**External Dimensions of H-III3C Dummy**

| Description | Specification (in.) | Tolerance (in.) | Actual Measurement (in) |
|---|---|---|---|
| Head Depth (length) | 6.89 | 0.30 | 6.81 |
| Head Width (breadth) | 5.35 | 0.30 | 5.44 |
| Head Height | 6.89 | 0.30 | 6.94 |
| Lateral Neck Breadth (width) | 2.76 | 0.10 | 2.69 |
| Chest Breadth at Axilla | 6.77 | 0.30 | 6.56 |
| Chest Depth w/o jacket | 4.60 | 0.30 | 4.63 |
| Waist Breadth (width) | 6.93 | 0.30 | 6.83 |
| Sitting Height | 21.50 | 0.30 | 21.50 |
| Shoulder Width (breadth) | 9.61 | 0.30 | 9.50 |
| Shoulder Pivot Height | 13.15 | 0.30 | **12.60*** |
| Shoulder to Elbow Length | 7.60 | 0.30 | **8.38*** |
| Back of Elbow to Fingertip | 10.04 | 0.30 | 10.13 |
| Buttock to Knee Length | 11.61 | 0.30 | 11.50 |
| Max. Hip Breadth (seated) | 7.68 | 0.30 | 7.83 |
| Thigh Depth (seated) | 3.39 | 0.20 | 3.20 |
| Standing Height | 37.20 | 0.50 | 37.25 |

*Not within specified tolerance

**Table A3.**
**H-III6C External Dimensions**

| Feature | SAE Specification (in.) | Measured (in.) |
|---|---|---|
| Head Circumference | 20.6 | 20.6 |
| Head Width | 5.6 | 5.6 |
| Head Length | 7.1 | 7.1 |
| Erect Sitting Height | 25 | 25 |
| Shoulder/Elbow | 9.2 | 8.13 |
| Elbow/Fingertip | 12.2 | 11.31 |
| Buttock/Knee | 15 | 15.5 |
| Knee/Floor | 14.1 | 12.44 |
| Stature-erect standing (estimated) | 47.3 | 44.9 |

**Table A4.**
**H-III6C Segment and Assembly Weight**

| Feature | Specification (lbs) | Measured (lbs) |
|---|---|---|
| Head | 7.66 | 7.65 |
| Neck | 0.91 | 1.27 |
| Upper Torso | 10.12 | 11.9 |
| Lower Torso | 13.56 | 13.2 |
| Upper Arms (both) | 2.21 | 2.1 |
| Lower Arms and Hands (both) | 2.15 | 2.6 |
| Upper Legs (both) | 4.35 | 6.6 |
| Lower Legs and Feet (both) | 5.04 | 5.4 |
| Total | 46 | 50.7 |

**Table A5.**
**H-III5F External Dimensions**

| Description | Feb. '98 SAE Targets (inches) | Actual |
|---|---|---|
| Total Sitting Height | 31.00 +/- 0.50 | 30.63 |
| Shoulder to Elbow Length - right | 11.30 +/- 0.40 | 11.3 |
| Shoulder to Elbow Length - left | 11.30 +/- 0.40 | 11.3 |
| Buttock to Knee Length - right | 21.00 +/- 0.50 | 21.4 |
| Buttock to Knee Length - left | 21.00 +/- 0.50 | 21.25 |
| Head Breadth | 5.60 +/- 0.20 | 5.6 |
| Head Depth | 7.20 +/- 0.20 | 7.2 |
| Head Circumference | 21.20 +/- 0.40 | 21.25 |
| Knee Pivot Height - right | 16.00 +/- 0.50 | 15.7 |
| Knee Pivot Height - left | 16.00 +/- 0.50 | 15.7 |
| Stature | 56.40 +/- 1.70 | 56.43 |

**Table A6.**
**H-III5F Segment Weights**

| Segment | Feb. '98 SAE Target (lbs) | Actual Weight (lbs) |
|---|---|---|
| Head Assembly | 8.10 +/- 0.10 | 8.13 |
| Neck Assembly | 2.00 +/- 0.20 | 2.09 |
| Upper Torso Assembly with Torso Jacket | 26.44 +/- 0.30 | 26.30 |
| Lower Torso Assembly | 30.40 +/- 0.30 | 28.88 |
| Total Dummy Weight | 108.74 +/- 2.00 | 107.63 |

## APPENDIX B

### SEATING POSITIONS - THREE- AND SIX-YEAR-OLD CHILD

Position 1 is designed primarily to evaluate contact forces of the deploying air bag on the chest. However, head accelerations and neck loading will typically be significant factors in this test position. The positioning is intended to represent a standardized worst case condition in which the child has been thrown against the frontal structures of the vehicle's interior due to pre-impact braking and/or vehicle impact. While possible, it is not assumed that the child will be seated, or resting on the seat, at the initiation of air bag deployment.

Position 2 is designed to primarily address the contact forces and loading forces of the deploying air bag on the head and loading forces on the neck. The Child Position Number 2 is intended to represent a standardized worse case scenario in which the child slides forward or is sitting forward on the seat while the upper torso jack-knifes downward into the dashboard. The final positioning may not necessarily place the head into direct contact with the air bag's cover but does reflect a reasonable positioning based on estimated body kinematics resulting from pre-impact braking. See Figures B1 and B2.

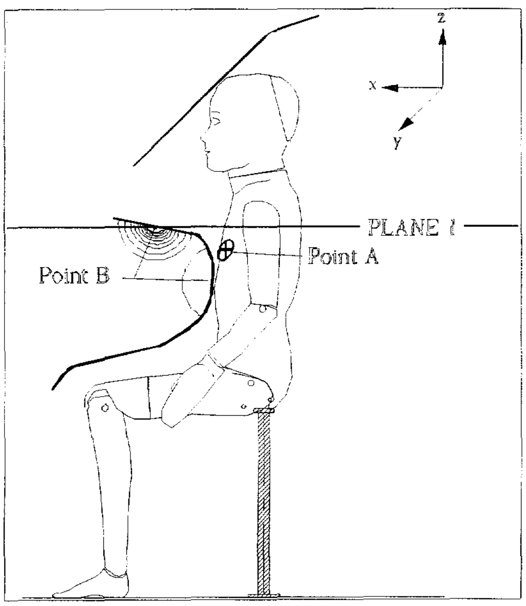

Figure B1. Position 1.

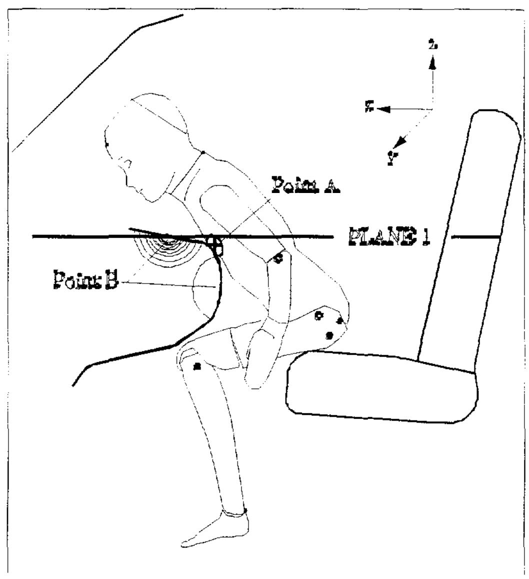

Figure B2. Position 2.

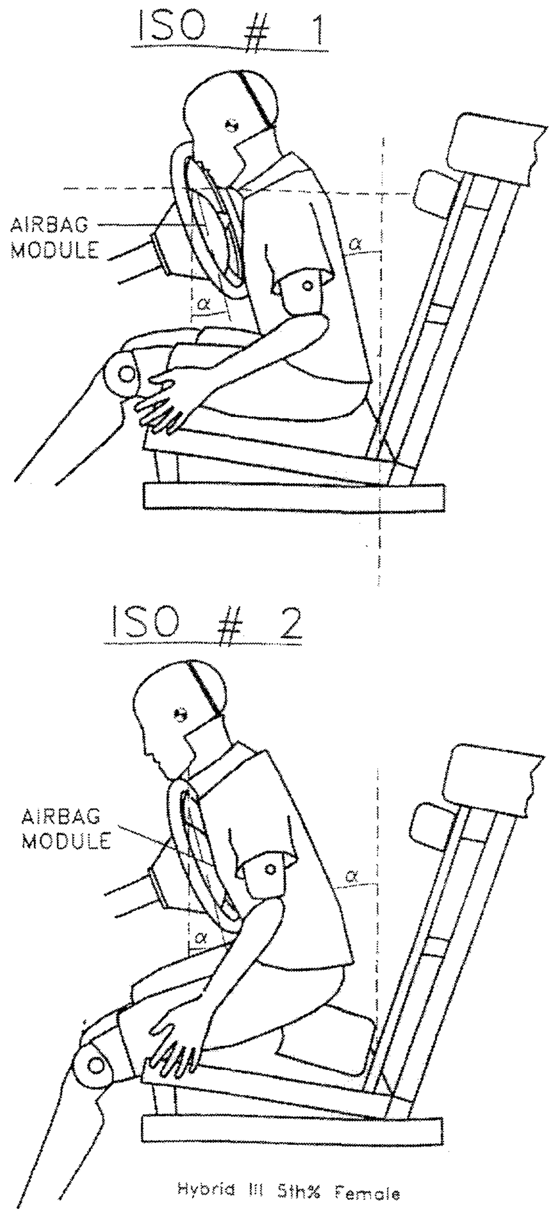


Figure B3. Hybrid III 5th percentile female.

## HYBRID III 5th PERCENTILE FEMALE POSITIONS FOR OOP TESTING

The dummy positioning procedure used for the driver side air bag tests is based on the positioning procedure adopted by ISO.

**Position 1**

Position 1 is intended to position the dummy to maximize head and neck loading. For this seating procedure, the driver's seat is moved to the full forward position. The dummy is placed on the seat and the torso arranged so that the spine is parallel to the plane defined by the rim of the steering wheel.

**Position 2**

Position 2 is intended to position the dummy to maximize chest loading. This in turn will create significant neck and head loadings. The driver's seat track position is not specified and may be positioned to best facilitate the positioning of the dummy. The dummy is placed on the seat and the torso is arranged so that the spine is parallel to the plane of the steering wheel. The dummy is positioned so that the center of the chin is in contact with the uppermost portion of the rim of the steering wheel. Note: The chin is not hooked over the top of the rim of the steering wheel. It is positioned to rest on the upper edge of the rim. See Figure B3.

## APPENDIX C

**Table C1.**
**H-III3C Sled Test Matrix**

| Sled Pulse | Simulated Vehicle | CRS Belted No AB Dummy # 20 | CRS Belted No AB Dummy # 18 | CRS Belted AB Dummy # 18 | No CRS Unbelted No AB Dummy # 18 | No CRS Unbelted AB Dummy # 18 |
|---|---|---|---|---|---|---|
| 213 | D-96 w/ 213 seat | 1 | | 1 | | |
| | | 1 | | 1 | | |
| | D-96 w/ D-96 seat | 1 | | 1 | | |
| 208 crash | D-96 | 1 | 1 | 1 | 1 | 1 |
| | | 1 | | | | |
| | | 1 | | | | |
| | I-96 | 1 | 1 | | | |
| | | 1 | 1 | | | |
| | | 1 | | 1 | | |
| 208 sled | I-96 | 1 | | 1 | | |

CRS=Child Restraint System
AB=Air bag

**Table C2.**
**H-III6C Sled Test Matrix**

| | Occupant/Vehicle Restraint | | | | | | Velocity |
|---|---|---|---|---|---|---|---|
| **Test/seat** | **B[a]** | **3PT[b]** | **B/AB[c]** | **3PT/AB** | **None** | **AB** | **(KPH)** |
| **213** | 4[d] | 2[d] | 1 | 1 | | | 47 |
| **213/Veh. 1** | 1 | 1 | 1 | 1 | | | 47 |
| **208 sled Veh. 2** | 1 | | 1 | | | | 48 |
| **208 crash/Veh. 2** | 1 | 1 | 1 | 1 | | | 50 |
| **208 crash/Veh. 1** | 2 | 2 | 1 | 1 | 1 | 1 | 54 |

**a - B indicates Booster Seat restrained by 3 point belt system**
**b - 3PT indicates 3 point belt restraint**
**c - AB indicates Air Bag**
**d- Number of tests evenly split between two dummies**

**Table C3.**
**H-III5F Dynamic Sled Test Matrix**

| | Mid-size Buck | | Compact Buck | |
|---|---|---|---|---|
| **Condition** | **Driver** | **Passenger** | **Driver** | **Passenger** |
| 3 pt. belt | 20 | 20 | 4 | 4 |
| 3 pt. belt + air bag | | 1 | | |
| air bag | 1 | 2 | 1 | 1 |
| unrestrained | 1 | 1 | 1 | 1 |