

**Small Overlap Frontal Crashworthiness
Evaluation Crash Test Protocol (Version II)**

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**INSURANCE INSTITUTE
FOR HIGHWAY SAFETY**

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SMALL OVERLAP FRONTAL CRASHWORTHINESS EVALUATION CRASH TEST PROTOCOL (VERSION II)

Supporting documents for the Insurance Institute for Highway Safety (IIHS) small overlap frontal crash test program are available from the technical protocols section of the IIHS website (<http://www.iihs.org/ratings/protocols>).

DOCUMENT REVISION HISTORY

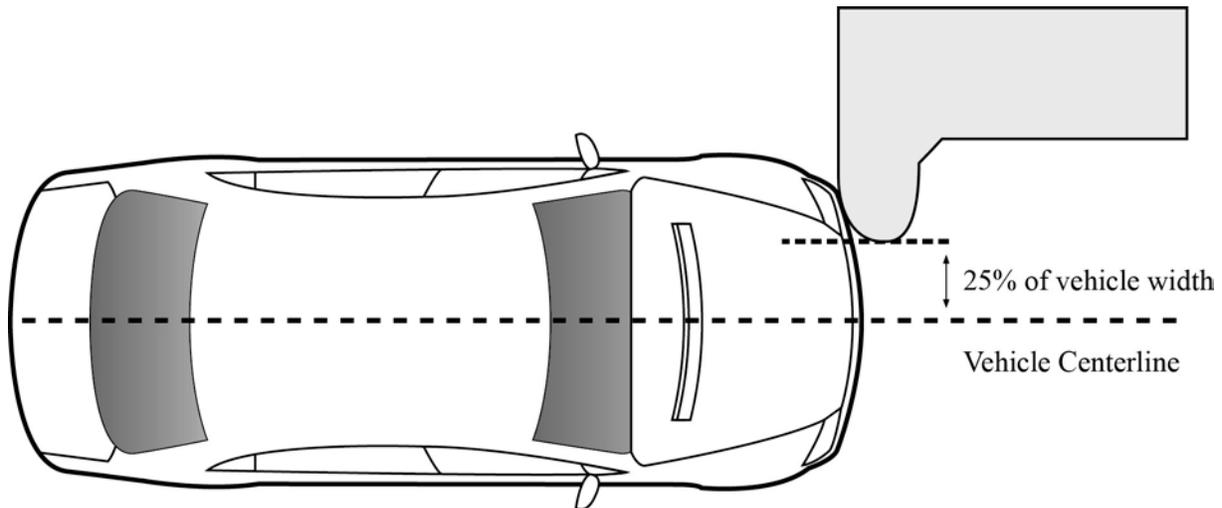
A document revision history is provided in Appendix E.

TEST CONDITIONS

Impact Speed and Overlap

Small overlap barrier crash tests are conducted at 64.4 ± 1 km/h (40 ± 0.6 mi/h) and 25 ± 1 percent overlap. The test vehicle is aligned with the rigid barrier such that the right edge of the barrier face is offset to the left of the vehicle centerline by 25 ± 1 percent of the vehicle width (Figure 1). The vehicle width is defined and measured as indicated in Society of Automotive Engineers (SAE) J1100 – Motor Vehicle Dimensions, which states, “The maximum dimension measured between the widest part on the vehicle, excluding exterior mirrors, flexible mud flaps, and marker lamps, but including bumpers, moldings, sheet metal protrusions, or dual wheels, if standard equipment.”

Figure 1
Vehicle Overlap with Flat 150 Small Overlap Barrier



The vehicle is accelerated by the propulsion system at an average of 0.3 g until it reaches the test speed and then is released from the propulsion system approximately 25 cm before the barrier. The onboard braking system, which applies the vehicle's service brakes on the rear wheels, is activated 1.5 seconds after the vehicle is released from the propulsion system.

Barrier Design

The rigid barrier is composed of a vertical steel plate, with a radius on the right edge (Figures 2 and 3). The front plate has a thickness of 38.1 mm, and is 1000 mm wide to the point at which the 150 mm radius begins. This radius continues over a 115 degree arc. The side of the barrier is set back from the radius to prevent secondary contacts with the vehicle. The barrier rests on the floor and has a height of 1524 mm.

Because this front plate is the only surface of the barrier that should contact the vehicle, details on the support structure are not included below, but a drawing package of the complete barrier design is available on the IIHS website.

Figure 2
Flat 150 Barrier, Top and Isometric Views

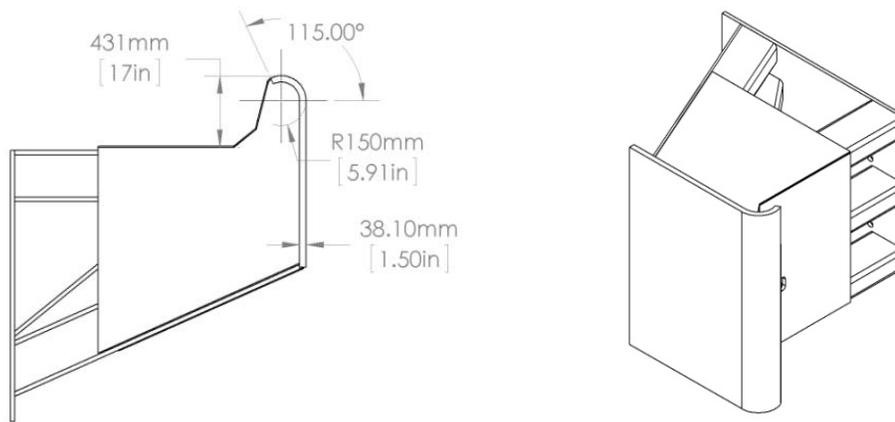
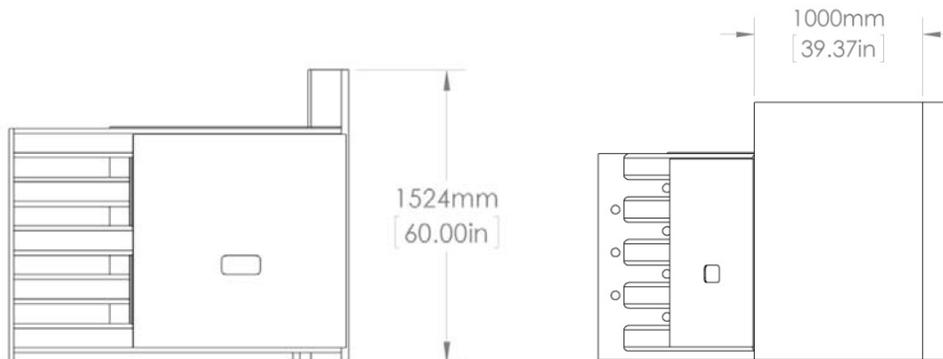


Figure 3
Flat 150 Barrier, Side and Front Views



Test Vehicle Preparation

Each vehicle is inspected upon arrival at the research center. Vehicles are checked for evidence of prior collision damage or repair. Each vehicle is further examined to verify that it is in satisfactory operating condition and to note defects such as missing parts, maladjustments, or fluid leaks. If directly relevant to testing, such deficiencies are corrected or a replacement vehicle is procured.

All engine and transmission fluids are drained from the vehicle prior to the test. The gasoline is removed from the fuel tank, and fuel lines are replaced with Stoddard solvent to 90-95 percent of useable capacity. The engine is started for a short period to ensure the Stoddard solvent has filled the fuel lines. The electrolyte is drained from the battery. The air conditioning system refrigerant is recovered by a means that complies with applicable environmental regulations. The left front axle boots and grease are removed.

High-voltage batteries in vehicles with hybrid electric and full electric drivetrains are tested in a charged state as per Federal Motor Vehicle Safety Standard (FMVSS) 305, which specifies a maximum state of charge recommended by the manufacturer. If no recommendation is made, the battery is tested at a state

of charge of not less than 95 percent of maximum capacity. Maintenance fuses are not removed, but additional precrash and postcrash precautions specified by the vehicle manufacturer are followed. Equipment will be added to the high-voltage system in accordance with manufacturer recommended procedures for monitoring electrical isolation as per FMVSS 305.

Multiple onboard video cameras are placed in the vehicle. Typically, one is attached to the right front passenger door, just aft of the A-pillar, and two others are attached to the roof in the rear seating area. Lights for these cameras also are attached to the vehicle. The total weight of the three digital cameras and lights are 18 kg.

The front of the vehicle is attached to the propulsion system via chains attached to steel hooks, which are welded to the left and right sides of the subframe or engine cradle (not to suspension components). The rear of the vehicle is attached to the propulsion system with a nylon strap and ratchet strap assembly. The front and rear attachment hardware weighs 10.0 kg.

An aluminum instrumentation rack, which supports the test equipment, is installed in the cargo area of the vehicle with four bolts through the floor of the cargo area. The carpeting in this area is removed to allow access to the floor. If necessary, the spare tire and accessory jack may be removed to permit installation of the instrumentation rack. The following test equipment is installed on the instrumentation rack located in the cargo area:

Onboard emergency braking system: When activated, this system applies pressurized nitrogen gas against the brake fluid in the lines to the rear wheels. The remaining brake fluid in the master cylinder is removed. Flexible hoses connect the emergency braking system to the brake lines in the engine compartment. The onboard braking system weighs 10.6 kg.

12-volt battery and monitoring system: This system supplies electrical power for the vehicle, emergency braking system, the Diversified Technical Systems (DTS) data acquisition system (DAS), and a wireless bridge for DAS communication. The system weighs 36.0 kg. The wireless device for DAS-to-network communication is mounted to the outside of the vehicle and weighs 1.5 kg.

High-speed camera power supply: This system supplies electrical power to the onboard high-speed video cameras. The total weight of the system is 8.8 kg.

Onboard lighting power supply: This system provides lighting for onboard high-speed cameras. The total weight of the lighting system is 21 kg.

The test weight of the vehicle is 125-175 kg greater than the measured curb weight of the vehicle (weight of the vehicle as delivered from the dealer with full fluid levels). If the vehicle test weight needs to be increased to fall within the range, steel plates are added to the instrumentation rack. If the vehicle test weight needs to be decreased, nonessential, nonstructural items are removed from the rear of the vehicle (e.g., muffler, tailpipe).

A steel plate is welded to the floor of the rear seating area along the centerline of the vehicle for mounting accelerometers. The carpeting in this area is removed to allow access to the floor. If floor mats are standard or offered as an option through the manufacturer or dealership, a floor mat is installed only in the driver footwell.

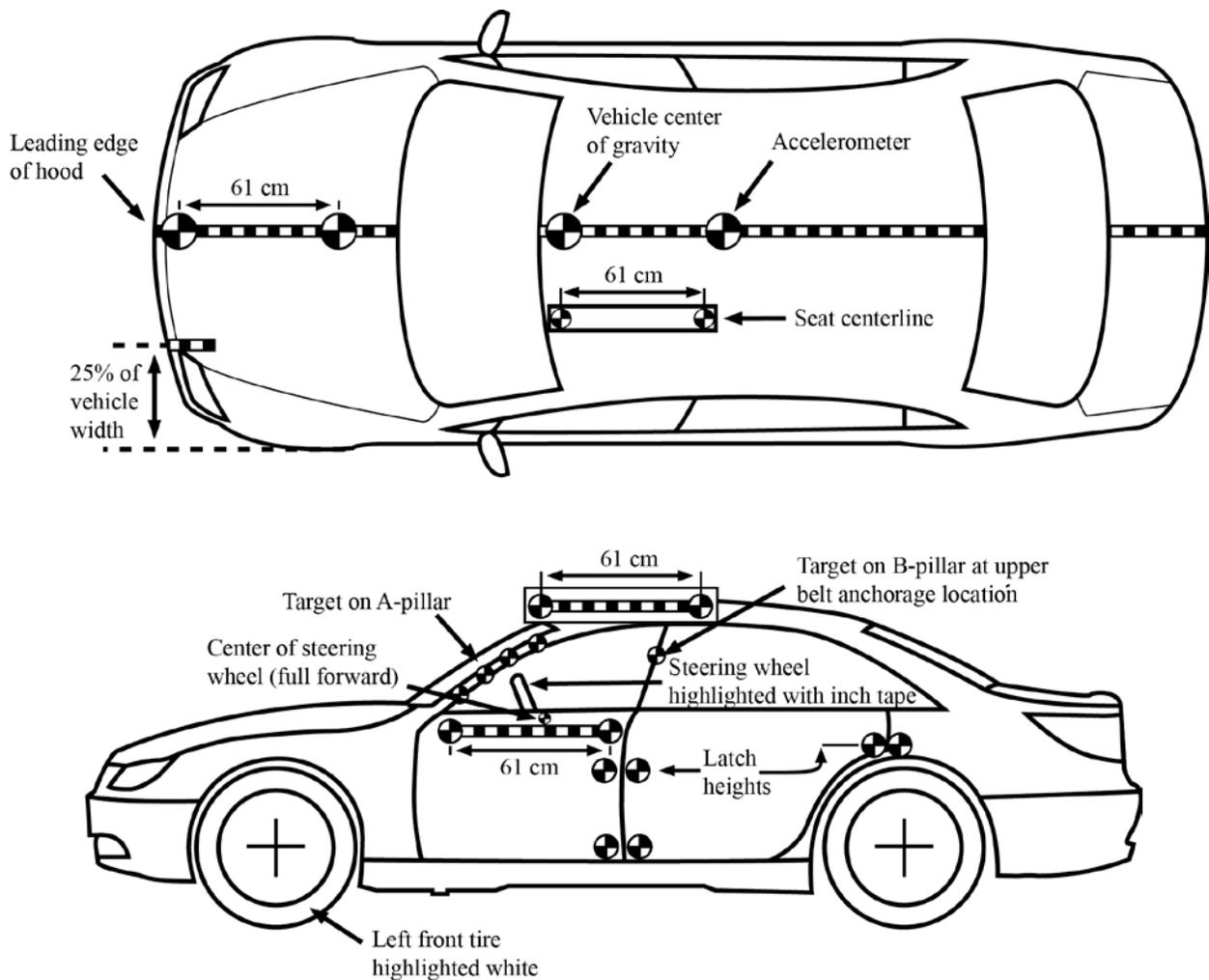
The daytime running lights (if equipped) are disabled by means of removing fuses or relays to these devices to reduce the electrical power required for the test.

A plastic block containing an array of high-intensity LEDs is attached to the hood of the vehicle with sheet metal screws. The LEDs are illuminated when the vehicle first contacts the barrier.

Two pressure-sensitive tape switches are applied to the vehicle such that they make first contact with the barrier during the crash. Pressure applied to these switches completes an electrical circuit that illuminates the LEDs mounted on the hood and signals the start of the crash (time-zero) for the data acquisition system and onboard digital cameras.

The exterior surfaces of the vehicle are trimmed with inch tape and photographic targets to facilitate analysis of the high-speed camera footage (Figure 4). The scheme consists of five 61-cm length gages in four separate reference planes: the surface of the roof, the surface of the hood, the surface of the front left and right side doors, and a vertical plane passing through the centerline of the driver seat. The location of the vehicle accelerometers and the location of the vehicle precrash center of gravity are marked with photographic targets applied to the appropriate top surfaces of the vehicle. The locations of the front and rear door latch locations (left and right sides of vehicle) and driver shoulder belt upper anchorage are marked on the side surfaces with photographic targets. Targets are applied along the A-pillar, beginning at the base, every 10 cm in the longitudinal direction. To determine the side head protection airbag forward coverage, a target is placed on the driver door to designate the forwardmost position of the steering wheel center in the longitudinal direction. The steering wheel and the leading edge of the dash are highlighted with inch tape, and the left front tire is highlighted with white paint.

Figure 4
Exterior Surface Marking



The head restraints are removed from the front seats, and the front right passenger frontal and side curtain airbags are deactivated (if necessary) to prevent these components from obstructing camera views. The airbags are deactivated by inserting an appropriately sized resistor in place of the connection to each airbag.

The driver seat manually adjustable inboard armrest (if equipped) is adjusted to its lowered position. For vehicles equipped with multiple locking armrest positions, the position that results in the top surface of the armrest being closest to parallel with the ground is chosen.

All doors are fully latched but not locked. However, if the vehicle is equipped with automatically locking doors that cannot be set to remain unlocked when the vehicle is in forward motion, the door locks are kept in their automatic state. All side windows are lowered to their lowest position, the ignition is turned to its on position, and the transmission is shifted into its neutral position prior to the test.

Crash Dummy Preparation and Setup

A 50th percentile male Hybrid III dummy (49 *CFR* 572 (E)) with instrumented lower legs is positioned in the driver seat according to the *Guidelines for Using the UMTRI ATD Positioning Procedure for ATD and Seat Positioning (Version V)* (IIHS, 2004).

The dummy is equipped with feet and ankles described in the final rule incorporating Hybrid III dummy modifications (Docket 74-14 Notice 104; *FR* vol. 61, no. 249, pp. 67953-67962). The feet have been further modified to include two accelerometers, and the ankles have been modified to prevent metal-to-metal contact that results from bottoming of the ankle bumper (Humanetics Innovative Solutions, Inc., part numbers 78051-653-FT and 78051-654-FT)

The dummy's knees are equipped with ball-bearing sliders, and the neck is fitted with a neck shield. In addition, the dummy's thoracic spine has been modified to accommodate an onboard data acquisition system (DTS TDAS G5). The mass and moments of inertia of the modified thoracic spine are similar to those of the standard dummy.

The dummies used in these tests are calibrated according to 49 *CFR* 572 (E) after being subjected to no more than five crash tests. Additionally, individual parts are recalibrated if levels recorded during a test exceed the higher of published injury reference values or the values achieved in dummy certification tests, or if postcrash inspection reveals damage. All visible damage is repaired before the dummy is used again.

The dummy and vehicle are kept in a temperature controlled area where the temperature is maintained at 20.0-22.2 degrees Celsius and the relative humidity at 10-70 percent for at least 16 hours prior to the test. The driver seat belt is fastened around the dummy. For vehicles with continuous-loop lap/shoulder seat belts, the slack from the lap portion of the driver seat belt is removed and the webbing is pulled fully out of the retractor and allowed to retract under tension a total of four times. The lap belt slack is then removed again with a small pulling force. For vehicles with separate lap and shoulder seat belt retractors, the webbing from each is pulled fully out of the retractor and allowed to retract under tension a total of four times. The dummy's head, knees, and shins are colored with grease paint to facilitate postcrash identification of impacts with the vehicle interior. Photographic targets are placed on both sides of the head to mark the location of its center of gravity.

Photography

Still Photography

The precrash and postcrash conditions of each test vehicle are photographed. Two precrash and two postcrash views show the side and left front quarter of the test vehicle.

Additional photographs document the precrash position of the driver dummy, including close-up views of the dummy's legs.

Three standard views of the vehicle in its postcrash position in front of the barrier are recorded. Additional photographs document the postcrash position of the driver dummy.

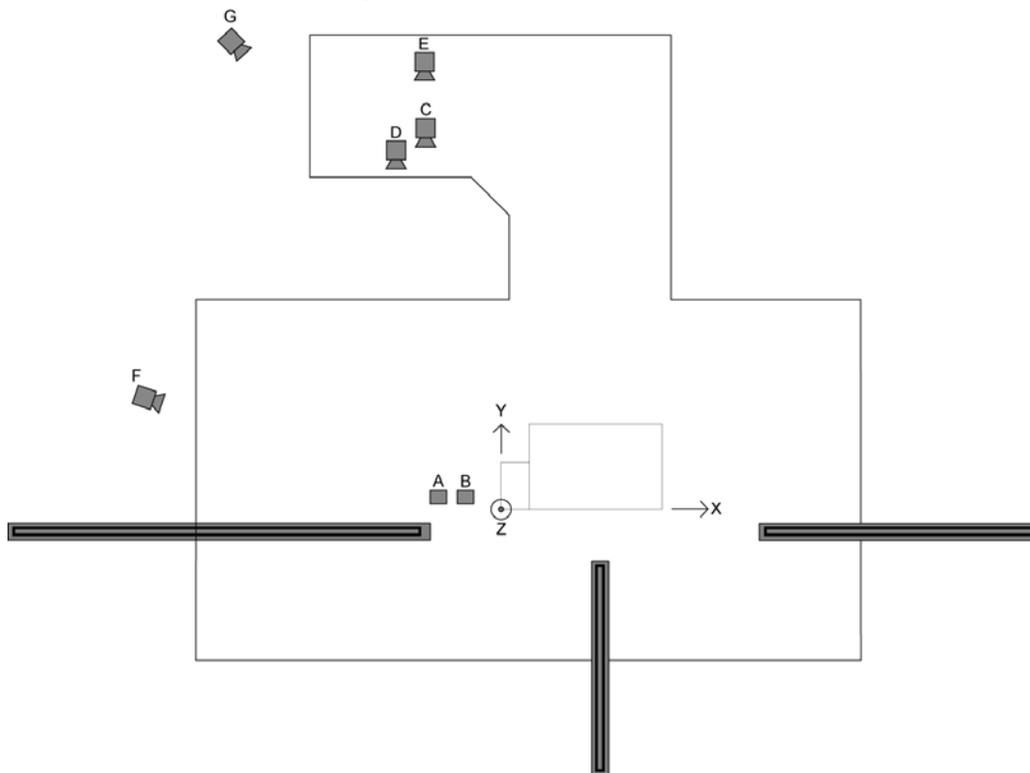
High-Speed Motion Picture Photography

Motion picture photography is made of the test with eight 16 mm film cameras, four high-speed digital imagers (one offboard and three onboard). The lens focal length and frame rate of each camera are listed in Table 1. Frame rates for the 16 mm cameras are accurate to ± 1 percent of the set frame rate. The positions of all cameras are shown in Figure 5.

**Table 1
High-Speed Camera Coordinates and Settings**

	A	B	C	D	E	F	G
Camera Position	Wide Overhead	Tight Overhead (Digital)	Wide Left	Medium Left	Tight Left	Down Left Side	Real-Time Left Pan
Coordinate X (cm)	-61	0	-97	-132	-97	-2,020	-825
Coordinate Y (cm)	0	0	1,420	1,367	1,597	521	1,806
Coordinate Z (cm)	894	894	121	95	139	95	203
Focal length (mm)	16	50	25	50	85	100	8.5-127 zoom
Film speed (frames/sec)	500	500	500	500	500	500	30

**Figure 5
High-Speed Camera Positions**



MEASUREMENTS AND OBSERVATIONS

Test Weight

The test weight of the vehicle is measured at each of the four wheels. The vehicle is weighed with all test equipment installed including the driver dummy. The front and rear axle weights are used to determine the longitudinal position of the center of gravity for the test vehicle.

Impact Speed

The impact speed is determined by averaging two speed trap measurements. Both speed traps measure the average velocity of the vehicle at 1-1.5 m before impact with the barrier. The propulsion system also has an optical speed measuring device that serves as a backup to the two speed traps. This device measures the speed of the hardware attaching the vehicle to the propulsion system immediately prior to the vehicle's release from the propulsion system before impact. The speed is clocked over a 1 m length of vehicle travel ending 0.5 m before the vehicle's release from the propulsion system.

Overlap

The actual overlap is determined from the video taken by the high-speed digital imager tight overhead view (position B in Figure 5). The lateral distance between the line representing the outer 25 percent of the vehicle width and the right edge of the deformable barrier is determined by proportionally scaling a frame from the digital imager. Photographic targets applied to the barrier at the point of impact are used for the image scaling.

Vehicle Accelerations

The linear accelerations in three orthogonal directions (longitudinal, lateral, and vertical) of the vehicle occupant compartment are measured by accelerometer arrays (three Endevco 7264A-2000 or 7264B-2000 accelerometers) and recorded by the TDAS G5 system. A DTS SLICE MICRO DAS with a triaxial accelerometer array (Accel SLICE) also may be used to measure vehicle acceleration. Positive vehicle accelerations are forward along the longitudinal axis, rightward along the lateral axis, and downward along the vertical axis. The data are presented filtered according to the channel frequency class (CFC) 60 as defined in SAE J211 – Instrumentation for Impact Tests (SAE, 1998).

Fuel System Integrity

Observations about fuel system integrity are recorded for each test. Any Stoddard fluid leaked from the fuel system within 1 minute after the impact is collected as the first sample. This typically is done by soaking up the fluid with an absorbent pad of known mass. The second sample of leaked Stoddard fluid is collected during the 5 minutes immediately following the collection of the first sample. This sample typically is collected in pans placed under the sources of identified leaks. The third sample is collected during the 25 minutes immediately following the collection of the second. The pans used to collect the second sample are replaced with clean empty pans. The volume of each sample is determined by dividing the weight of the sample by the density of Stoddard fluid (790 g/l). The elapsed time is determined using a stopwatch. The entire process is recorded with a video camera equipped with an internal timer, which displays the time in each frame.

High-Voltage System Integrity

Vehicles with a hybrid or full-electric drivetrain are monitored to ensure the high-voltage electrical system has not been compromised. Postcrash observations include a measure of electrolyte spillage (if any), battery retention, and electrical isolation of the high-voltage system as per FMVSS 305.

Additionally, the battery temperature will be monitored to detect a rapid increase in temperature that may indicate a thermal runaway condition. Following the crash, power will be drained from high-voltage systems in a manner specified by the manufacturer.

Intrusion Measurements

A total of 18 locations are marked on the driver side interior and exterior of the vehicle, and their longitudinal, lateral, and vertical coordinates are recorded using a coordinate measurement machine (CMM – Romer Absolute Arm). These same marks are measured after the crash using the same reference coordinate system.

Coordinate System Definition

A right-handed, three-axis orthogonal coordinate system is used for these measures: longitudinal (front to rear is positive), lateral (left to right is positive), and vertical (bottom to top is positive). The precrash coordinate system is defined with the vehicle unloaded (no occupants) on a level floor. The plane of the ground is used to define the X-Y plane, and the two end points on the centerline of the roof are used to define the X axis (Figure 4).

Coordinates of three marked reference points inside the vehicle compartment are recorded precrash to establish the postcrash coordinate system. For most vehicles, the reference points will be taken on the vehicle structure on the nonstruck (right side) rear door frame.

Measurement Point Locations

The following are the locations for measuring vehicle intrusion (Figure 6):

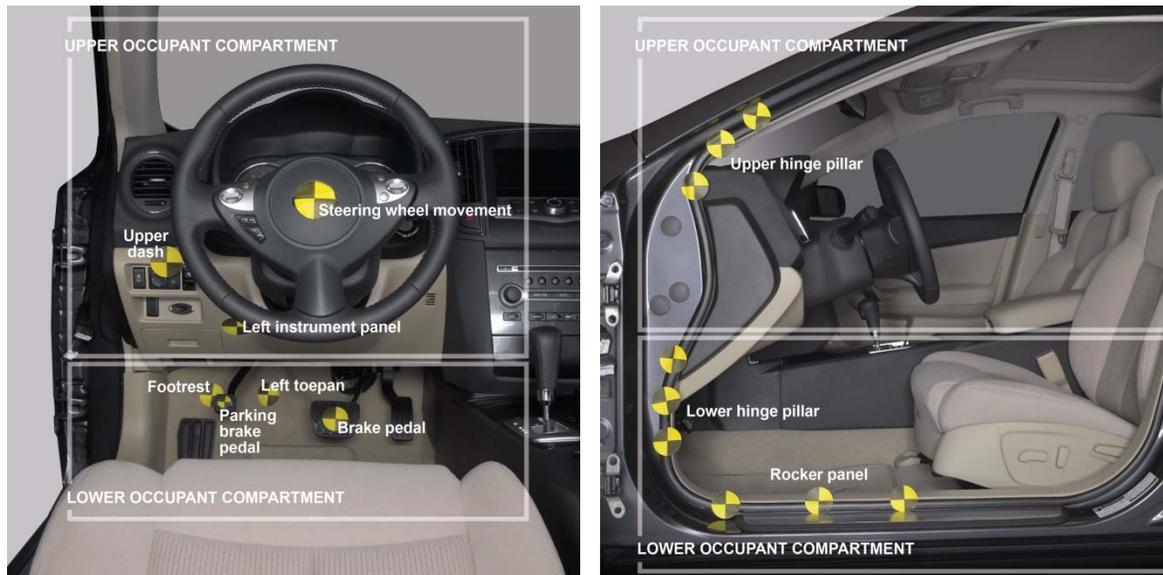
Steering column (one point): The marked reference is the geometric center of the steering wheel, typically on the airbag door. After the crash, this point is measured by folding the airbag doors back into their undeployed position. In most cases, this measurement is probably less than the maximum intrusion into the compartment. However, if the steering column completely separates from the instrument panel (due to shear module separation, for example) during the crash, the steering column postcrash measurement is taken by placing and holding the wheel and column in its approximate maximum dynamic position as recorded on the high-speed video. The video footage may not always show clearly where the column was during the crash, and in such cases other clues would be needed to reposition the column for measurement. In rare instances, it may not be possible to obtain any meaningful postcrash measurement.

Left lower instrument panel (one point): The left lower instrument panel (knee bolster) lateral coordinates are defined by subtracting 15 cm from the steering column reference lateral coordinate, respectively. The vertical coordinate is defined as 45 cm above the height of the floor (without floor mats). If the panel or knee bolster loosens or breaks away in the crash, the postcrash measurements are taken by pressing and holding the panel against the underlying structure.

Brake pedal (one point): The marked reference is the geometric center of the brake pedal pad (top surface). If the brake pedal is constructed so that it dangles loosely after the crash, the brake pedal is pushed straight forward against the toepan/floorpan and held there to take the postcrash measurement. If the pedal drops away entirely, no postcrash measurement is taken.

Parking brake pedal (one point): The marked reference is the geometric center of the parking brake pedal (top surface). If the parking brake is a hand brake or button located on the instrument panel or center console, no measurement is taken.

Figure 6
Locations for Measuring Vehicle Intrusion



Left footrest (one point): The vertical coordinate for the footrest measurement location is the vertical coordinate of the brake pedal reference. The lateral coordinate of the footrest is obtained by subtracting 25 cm from the brake pedal reference lateral coordinate. The same procedure described above for cutting the carpet is used to mark and measure the underlying structure. In cases where there is a specific footrest construct at the footrest measurement location, the construct is removed and the underlying structure is marked and measured. The construct is reinstalled prior to the crash.

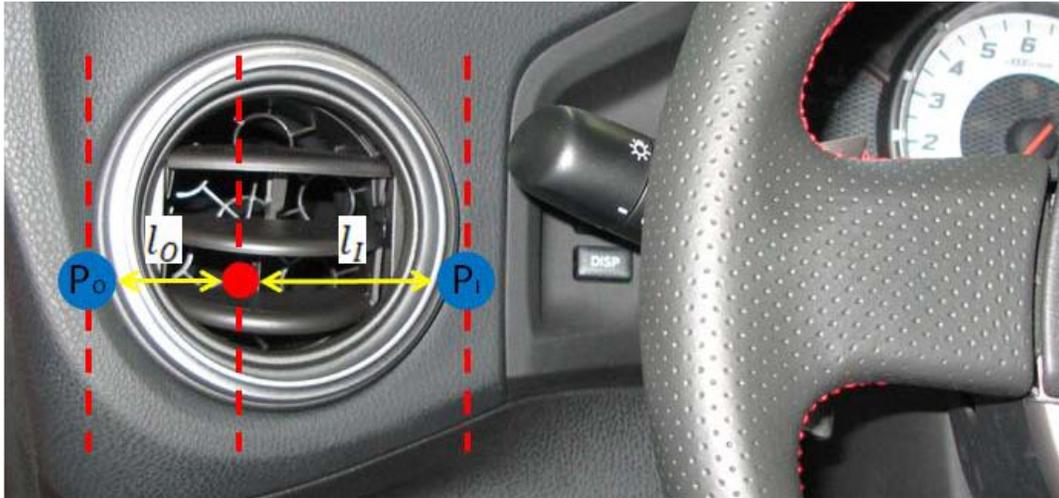
Seat bolts (two points): The marked reference is the two rear bolts that anchor the driver seat to the floor of the vehicle.

Left toe pan (one point): The vertical coordinate for the left toe pan measurement location is the vertical coordinate of the brake pedal reference. The lateral coordinate of the left toe pan locations is obtained by subtracting 15 cm from the brake pedal reference lateral coordinate. The longitudinal coordinate is measured, and a mark is temporarily placed at the locations on the toe pan. A utility knife is used to cut a small “v” in the carpet and underlying padding on the toe pan. The point of the “v” is peeled back, and the exposed floor is marked and measured. The carpet and padding are then refitted prior to the crash.

Upper dash (one point): The upper dash point is obtained by subtracting 25 cm from the lateral coordinate of the steering column reference lateral coordinate. This defines a line of points on the edge of the upper dash. The upper dash point is located on the rearward most (toward the rear of the vehicle) point on this line. This point must be located at least 30 cm above the brake pedal reference point to ensure a vertical location high enough to represent a location that could be contacted by the driver’s upper body or head. If the rearward most point is less than 30 cm above the brake pedal reference point, the upper dash point is located at this 30 cm reference location.

There may be instances when the upper dash point is located on a “soft component” such as an air vent or control knob (Figure 7). To measure a more robust structure, the upper dash point is replaced with two additional points, and the weighted average of their coordinates is used to represent the deformation of a point at the original location (Equation 1). Each new point is determined by moving inboard/outboard to a location that is just off of the soft component.

Figure 7
Equation for Measuring Soft Component Upper Dash Point



$$\text{Simulated upper dash point location} = \frac{l_1}{l_0+l_1} \times [x_{P_0}, y_{P_0}, z_{P_0}] + \frac{l_0}{l_0+l_1} \times [x_{P_1}, y_{P_1}, z_{P_1}] \quad (1)$$

Lower (three points) and upper (three points) hinge pillar: The hinge pillar is measured at the inner most surface of the door opening, typically on the pinch weld. The vertical coordinates for the three lower points are obtained by adding 0 cm (lower hinge pillar point 1), 7.5 cm (lower hinge pillar point 2), and 15 cm (lower hinge pillar point 3) to the brake pedal reference point. The upper points are obtained by adding 45 cm (upper hinge pillar point 1), 52.5 cm (upper hinge pillar point 2), and 60 cm (upper hinge pillar point 3)

Rocker panel (three points): The rocker panel also is measured at the inner most surface of the door opening, typically on the pinch weld. The longitudinal coordinates are obtained by adding 20 cm (rocker panel point 1), 35 cm (rocker panel point 2), and 50 cm (rocker panel point 3) to the brake pedal reference point

If the 20 cm point is forward of the actual door frame, this point is located 5 cm rearward of the lower hinge pillar point.

Dummy Kinematics and Contact Locations

Dummy kinematics are studied by reviewing the high-speed video. Contact of the dummy's head or knees with the vehicle interior is recorded on the basis of postcrash grease paint deposits.

The dummy is inspected in its undisturbed postcrash position. Any damage to the dummy or unusual dummy resting position information is noted. The locations of paint transferred from the dummy to the vehicle interior are noted.

The high-speed video is used to estimate the time after the start of the crash that various events occur. For each event, the camera that provides the clearest view of the event is used. The start of the crash is considered to be the first frame from each camera in which the LEDs mounted on the hood of the vehicle are illuminated. The time recorded for each event is based on the number of frames elapsed from the start of the crash and the nominal operating speed of the camera. For the cameras operating at 500 frames per second, the estimate of the crash start time can be up to 2 ms late, and the event's time, as determined

from the video, can be early or late by 2 ms. The time of the driver airbag deployment, full inflation, and first dummy contact are recorded as well as any other notable events.

Dummy Responses

Each Hybrid III dummy is equipped with instrumentation for measuring the following:

Head

- Triaxial accelerations (three Endevco 7264A-2000 (or 7264B-2000) accelerometers)
- Triaxial angular rate sensors (three DTS ARS Pro – 18k)

Neck

- A-P shear force
- L-M shear force
- Axial force
- A-P moments (Humanetics Innovative Solutions, Inc. Model 2564 or 1716A upper neck load cell)

Chest

- Triaxial accelerations (three Endevco 7264A-2000 (or 7264B-2000) accelerometers)
- Rib compression

Lower Extremities

- Femur axial forces (Humanetics Innovative Solutions, Inc. Model 2121A load cell)
- Tibia-femur displacements
- Upper tibia A-P moments
- Upper tibia L-M moments (Humanetics Innovative Solutions, Inc. Model 1583 load cell)
- Lower tibia A-P moments
- Lower tibia L-M moments
- Lower tibia axial forces (custom Humanetics Innovative Solutions, Inc. Model 3093 load cell)
- Biaxial foot accelerations (A-P and I-S) (two Endevco 7264A-2000 (or 7264B-2000) accelerometers)

All instruments are regularly calibrated to a known standard. Accelerometers, load cells, and angular rate sensors are calibrated every 12 months. All measurements recorded from these instruments comply with the recommendations of SAE Information Report J1733 – Sign Convention for Vehicle Crash Testing DEC94 (SAE, 1998).

The DTS TDAS G5 data acquisition system is installed in the thorax of the Hybrid III dummy and used for dummy and vehicle data acquisition. A TDAS G5 iPort or DTS SLICE MICRO may be used for additional dummy or vehicle data acquisition. During the crash, all measurements are recorded in the system's random access memory with 16-bit resolution at a sample rate of 10 kHz. Signals in all channels convert simultaneously, so the time reference for different channels is not skewed. To ensure digital fidelity, all signals are filtered by an analog low-pass prefilter with a 3 kHz cutoff frequency.

After the data have been downloaded, any initial offset from zero is removed from each channel by computing the mean value for 100 data points preceding the crash event (from 50 to 40 ms before impact) for each channel and subtracting each mean from the respective data channel. The data are digitally filtered using the frequency response classes recommended in SAE Recommended Practice J211/1 – Instrumentation for Impact Test – Part 1, Electronic Instrumentation MAR95. Foot accelerations are filtered to SAE CFC 180. All filtering and subsequent calculations are executed using DIAdem (National Instruments Corporation, 2010).

Modifications to Hybrid III Lower Leg A-P (M_Y) Moments

The Hybrid III lower leg geometry allows pure compressive loads on the tibia to result in the tibia bowing forward (negative Y moment per SAE J1733 sign convention). This forward upper tibia bending in many cases can be shown to be only the product of the axial force acting on the moment arm between the upper tibia load cell and the line of force through the ankle and knee pivots, and not due to external forces bending the tibia. The upper tibia A-P moment (and to a much lesser extent, the lower tibia A-P moment) are modified mathematically to correct the problem. The mathematical adjustment is based on the tibia axial force, the known moment arms between the tibia load cells and the line of force through the ankle and knee pivots, and the known angle between the tibia shaft and the actual line of force. The adjusted upper tibia moment is calculated using Equation 2, and the adjusted lower tibia moment is calculated using Equation 3. Note that these equations are based on the SAE J1733 sign convention, with moments in Newton-meters (Nm) and axial force in Newtons (N). The lower tibia moments change very little because the line of force between the ankle and knee is very close to the center of the lower tibia load cell (Wellbourne and Shewchenko, 1998; Zuby et al., 2001).

$$M_{Y \text{ adjusted}} = M_{Y \text{ measured}} - F_{Z \text{ measured}} (0.02832) \quad (2)$$

$$M_{Y \text{ adjusted}} = M_{Y \text{ measured}} + F_{Z \text{ measured}} (0.006398) \quad (3)$$

In addition to summary metrics for each of the recorded data channels, the following calculations are made: vector resultant of the head acceleration, 3 ms clip of the vector resultant head acceleration, head injury criterion (HIC),* neck N_{ij} (calculated using formulas presented in 65 FR 30680), vector resultant of the spine accelerations, 3 ms clip of the vector resultant thoracic spine acceleration, viscous criterion, sternum deflection rate; vector resultant of the tibia bending moments (using the adjusted tibia A-P moments), tibia index (using the adjusted tibia A-P moments), and vector resultant of the foot accelerations. All calculations comply with the recommendations of SAE Information Report J1727 – Injury Calculation Guidelines AUG96 (SAE, 1998). The sternum deflection rate is calculated from the sternum deflection filtered to CFC 60.

Seat Belt Movement

The dynamic movement of the seat belt is measured by an optical belt movement sensor (IES-2098) mounted along the B-pillar near the retractor end of the belt. Positive belt spool out occurs when the belt is pulled off of the retractor. The data are filtered to SAE CFC 600.

Occupant Excursion

Occupant excursion is calculated by combining measures of the dummy's movement away from the seat back with measures of seat back deflection. Peak dummy movement away from the seat back is measured by pull-strings or fiberglass measuring tapes tied to a bracket at the top of the dummy's torso and threaded through the seat back material. Dynamic seat back deflection is recorded using two cable potentiometers (Celesco MT2A) mounted to a fixed point behind the driver seat. The seat back deflection data are filtered to SAE CFC 60. A detailed procedure is provided in Appendix A.

* HIC is calculated two ways: the first limits the maximum HIC interval to 36 ms (HIC-36), and the second limits the maximum HIC interval to 15 ms (HIC-15).

Side Head Protection Airbag Forward Coverage

High-speed video camera views are used to determine if the side head protection airbag has air chambers that extend forward to at least the orthogonal vertical plane intersecting the center of the steering wheel in its forwardmost telescoping position (if adjustable). The measurement is made in a zone from 12-22 cm above the center of the steering wheel. A detailed procedure is provided in Appendix B.

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- Zuby, D.S.; Nolan, J.M.; and Sherwood, C.P. 2001. Effect of Hybrid III leg geometry on upper tibia bending moments. SAE Technical Paper Series 2001-01-0169. *Biomechanics Research and Development* (SP-1577) Warrendale, PA: Society of Automotive Engineers.

APPENDIX A

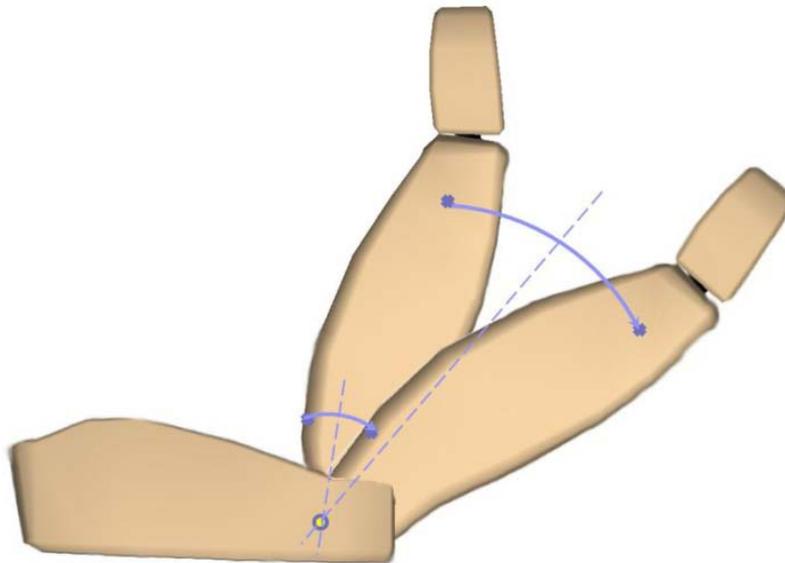
Occupant Excursion

The following procedure is used to measure the dummy's forward excursion during the test.

1. With the seat in its test position, calculate the seat back "hinge" point location. This is done using the locations of two points on the seat back (recorded with a CMM) with the seat upright and reclined (Figure A-1).
2. Two cable potentiometers are mounted to rigid points behind the driver seat. The cable ends are attached to the rear of the driver seat back near the top, with one near the centerline of the seat and the other near the inboard edge. Access holes may be cut through the seat back fabric but the seat frame is not modified in any way. Plastic cable ties are used to attach the potentiometers to the seat back frame.
3. The dummy's movement away from the seat is measured using two pull strings or fiberglass measuring tapes (McMaster-Carr part# 3519A32, cut into 4mm wide strips).
 - 3.1. The string or tapes are tied to an aluminum bracket secured to the top of the dummy's neck adjusting bracket flange. The right (inboard) rear bolt that holds the neck adjusting bracket to the top of the thoracic spine assembly is used as the attachment point for the bracket. To provide clearance above the chest jacket, the bracket extends upward 10 cm above the neck adjusting bracket flange.
 - 3.2. The other ends of the strings or tapes are threaded through holes cut in the seat back material. One hole is located directly rearward from the dummy attachment bracket and the other is angled toward the inboard edge of the seat. The vertical locations of the holes should be close to each other. The strings or tapes are pulled tight between the dummy and seat, with the loose ends allowed to hang freely (Figure A-2).
 - 3.3. If pull strings are used, they are marked where they first meet the seat back fabric. If fiberglass measuring tapes are used, the reading is recorded at the point where they meet the seat back. The CMM is used to record the locations of both ends of both potentiometers, the locations on the seat back where the string/tapes pass through, and the location of the dummy attachment bracket.
4. After the test, the amount of string/tape pulled through the seat back is recorded.
5. Using footage from the onboard digital imagers, the time when the strings/tapes are at the maximum pullout is determined. At this time, the seat back deflection angles are found at the locations where the potentiometers attach to the rear of the seat back. These angles are extrapolated to the locations of the pull strings/tapes on the front of the seat back.
6. The overall resultant excursion is calculated by finding the difference between the position of the dummy attachment bracket pre-test and the intersection point of the circles described by the two pull strings/tapes, after adjusting the seat points for the seat back deflection at the time determined in step 5 (Figure A-3). The resultant excursion is resolved into its longitudinal and lateral components. The file *small overlap excursion template.xlsx* is used to perform all calculations and determine the overall dummy excursion value.

7. In calculating the overall excursion, the following assumptions are made:
 - 7.1. The seat back rotates about the “hinge” point and the seat pan does not move.
 - 7.2. The lateral component of the seat back movement/deflection is negligible (though the longitudinal component of any twisting about the vertical axis of the seat is captured).
 - 7.3. The vertical component of the dummy’s movement from the seat is negligible.

**Figure A-1
Finding Seat Back Hinge Point**



**Figure A-2
Fiberglass Tapes Between Dummy and Seat Back**

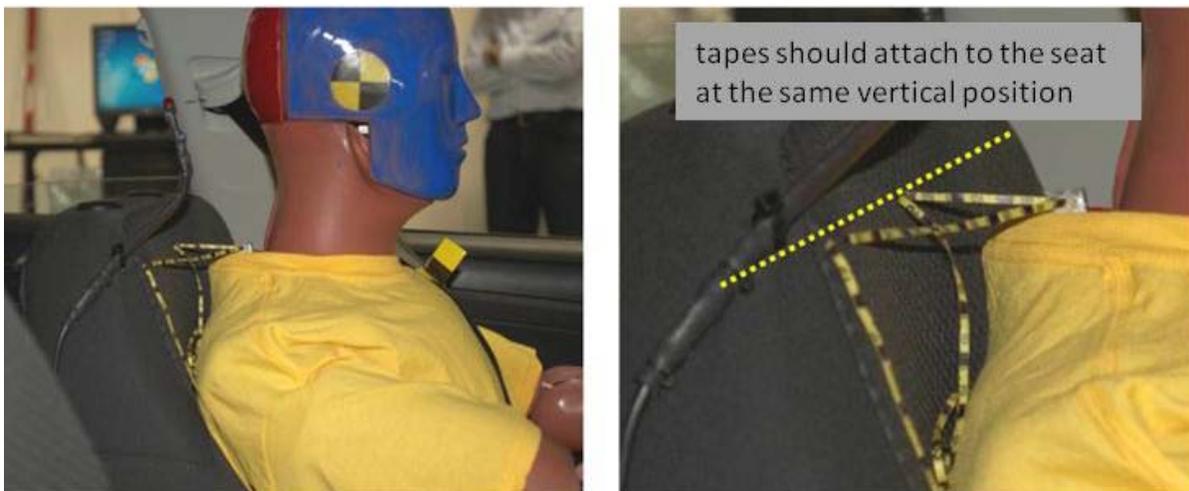
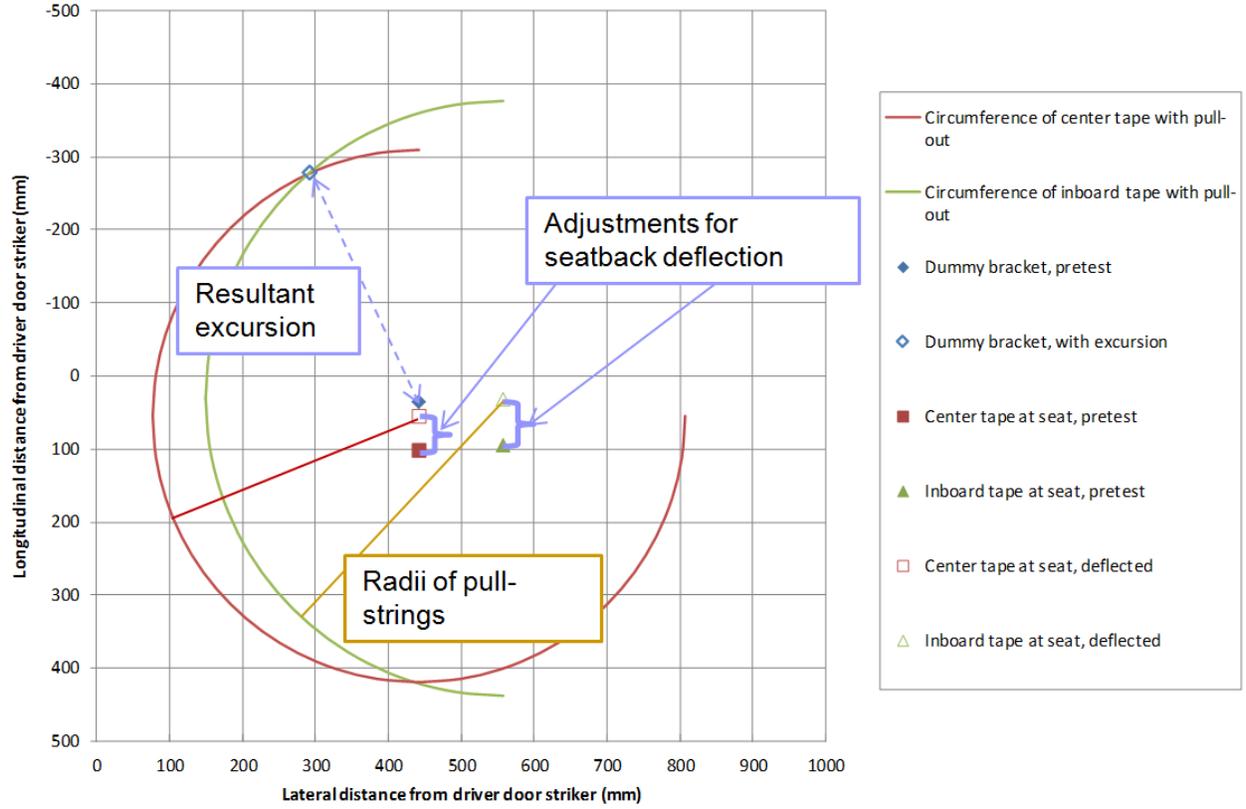


Figure A-3
Calculating Overall Dummy Excursion



APPENDIX B

Video Analysis Procedure for Measuring Side Head Protection Airbag Coverage

The following procedure should be used when measuring the forward coverage of the side curtain airbag during small overlap frontal crash tests. All video screen grabs should be saved from the same camera angle (driver side, wide view) at the same size. The forwardmost edge of the side head protection airbag is measured a) in the longitudinal direction at the center of the steering wheel in its forwardmost position, and b) in the vertical direction in a zone from 12-22 cm above the center of the steering wheel.

1. Select Video Frames

- 1.1. Save a screen grab from the driver side camera view (wide) when the steering wheel is approximately in the center of the frame.
- 1.2. Save a screen grab when the side curtain airbag becomes fully inflated, and then save the next 9 frames in sequence. Multiple frames are measured to ensure that measurements are taken during the frame when the airbag has the greatest forward coverage.

2. Measuring Steering Wheel Location on Door

- 2.1. Using photo editing software (e.g., Photoshop), open the first screen grab and rotate the image so that the horizontal targets on the top of the door are parallel with the x axis. Next, record the coordinates of the steering wheel center target on the driver door, using the rear door latch target as the origin (Figure B-1). The steering wheel door target is located on the outer edge of the door with the same X and Z coordinates as the steering wheel when positioned in the forwardmost (telescoping) position and at the mid-tilt angle. In this example, X = 462 pixels and Z = 13 pixels.
- 2.2. Record the distance, in pixels, between the horizontal targets on the top of the door. This measurement will be used later for scaling purposes (Figure B-2). In this example, the distance is 168 pixels. The actual distance between the targets is 61 cm (61 cm = 168 pixels).

3. Mark Steering Wheel Center on Door

- 3.1. Open the second screen grab (side curtain fully deployed) and apply the rotation found in step 2.1. Using the measuring tool in the photo editing software, locate the X and Z steering wheel center coordinates recorded in step 2.1, again using the rear door latch target as the origin. Mark this location with a small dot (Figure B-3).
- 3.2. Repeat step 3.1 for the remaining 9 screen grabs. If the airbag is clearly never near the reference point throughout the crash (forward or rearward), measurements are only taken for this first screen grab, for reference purposes.

4. Determining Forward Edge of Side Curtain Airbag

- 4.1. With a known number of pixels equaling 61 cm (distance between the horizontal door target), determine the number of pixels that equal 12 and 22 cm (33 and 61 pixels, respectively, in the example)
- 4.2. Open the second screen grab (side curtain fully deployed). Using the measuring tool in the photo editing software, and starting at the steering wheel 'dot' placed on the door in step 3.2, measure upward (vehicle Z axis) the number of pixels found to equal 12 and 22 cm. In this zone move either forward or backward (vehicle X axis) until the pointer contacts the leading edge of the

inflated side curtain airbag chamber (Figure B-4). Record the number of pixels in the X axis (negative if rearward of the steering wheel, positive if forward), then convert to centimeters. In the example, the leading edge of the airbag chamber is 2 pixels forward of the steering wheel center; this equates to 0.7 cm.

4.3. Repeat step 4.2 for the remaining 9 screen grabs.

5. Final Measure

5.1. From the 10 photos analyzed, choose the largest value (most forward location). This number will be considered the leading edge of the side curtain airbag.

Figure B-1
Rear Door Latch Target to Steering Wheel Center Target Measure



Figure B-2
Distance Between Horizontal Door Targets (61 cm), All Vehicles

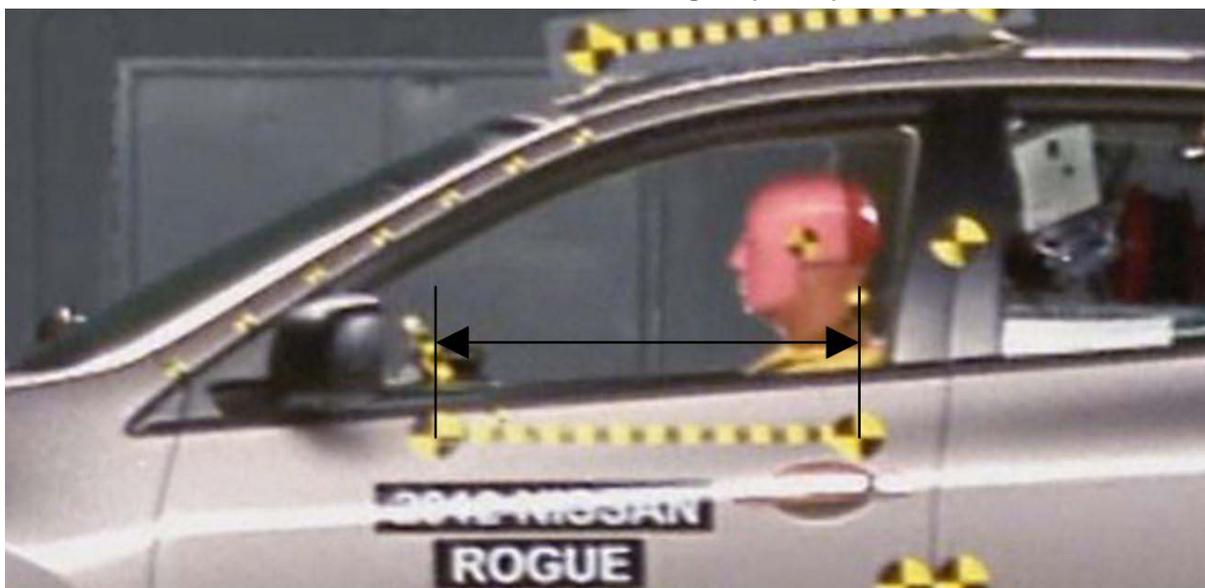


Figure B-3
Marking Steering Wheel Center on Door, Mid-Crash



Figure B-4
Steering Wheel Center to Front of Side Curtain Airbag Chamber Measure



APPENDIX C

Test Vehicle Selection

For each vehicle model used in the small overlap frontal test, the specific trim level selected is the one that most closely meets the IIHS definition of a “typical” vehicle of that class. This definition is made for each class by listing the presence or absence of certain features in a prioritized order. As an example, the following were the requirements for midsize luxury/near luxury 4-door sedans in 2012:

1. 2-wheel drive
2. Automatic transmission or CVT
3. 3.0- to 4.0-liter 6-cylinder engine
4. Air conditioning
5. Sunroof
6. Power windows/locks/mirrors
7. Alloy wheels
8. Power adjustable driver seat
9. Leather seats

When a given model is available in more than one body type (e.g., hatchback and sedan), the most popular version is tested. Counts of insurance policies from the Highway Loss Data Institute serve as the main source for determining the most popular body type. The small overlap frontal rating is applied only to the tested body type, except that sedans and hatchbacks as a general rule share the rating. Sedan/hatchback ratings may be assigned to station wagons (and vice versa) if the manufacturer provides engineering drawings showing that front end structure and occupant restraint systems are comparable. Corporate twins of the same body type and with identical structure and restraints are assigned the same rating based on the one test.

Definitions of Typically Equipped Vehicles by Class

Microcars and Minicars

1. 2-wheel drive
2. Four-door
3. Automatic transmission or CVT
4. Smallest engine (4 cylinders or fewer)
5. Air conditioning
6. No sunroof
7. Manual windows/locks/mirrors
8. Standard wheels with above options
9. Manually adjustable seats
10. Cloth or leatherette seats

Small Four-Door Cars

1. 2-wheel drive
2. Automatic transmission or CVT
3. Smallest 4-cylinder engine
4. Air conditioning
5. No sunroof
6. Power windows/locks/mirrors
7. Standard wheels with above options
8. Manually adjustable seats
9. Cloth or leatherette seats

Midsize Moderately Priced Two-Door Cars

1. 2-wheel drive
2. Automatic transmission or CVT
3. Base engine
4. Air conditioning
5. No sunroof
6. Power windows/locks/mirrors
7. Standard wheels with above options
8. Power adjustable driver seat
9. Cloth or leatherette seats

Midsize Moderately Priced Four-Door Cars

1. 2-wheel drive
2. Automatic transmission or CVT
3. Base engine
4. Air conditioning
5. No sunroof
6. Power windows/locks/mirrors
7. Standard wheels with above options
8. Power adjustable driver seat
9. Cloth or leatherette seats

Midsize Luxury Four-Door Cars

1. 2-wheel drive
2. Automatic transmission or CVT
3. 3.0- to 4.0-liter 6-cylinder engine
4. Air conditioning
5. Sunroof
6. Power windows/locks/mirrors
7. Alloy wheels
8. Power adjustable driver seat
9. Leather seats

Large Family Four-Door Cars

1. 2-wheel drive
2. Automatic transmission or CVT
3. 3.0- to 4.0-liter 6-cylinder engine
4. Air conditioning
5. No sunroof
6. Power windows/locks/mirrors
7. Alloy wheels
8. Power adjustable driver seat
9. Leather seats

Large Luxury Four-Door Cars

1. 2-wheel drive
2. Automatic transmission or CVT
3. 3.0- to 4.0-liter 6-cylinder engine
4. Air conditioning
5. Sunroof
6. Power windows/locks/mirrors
7. Alloy wheels
8. Power adjustable driver seat
9. Leather seats

Small SUVs

1. 4-wheel drive
2. Automatic transmission
3. 4-cylinder engine
4. Air conditioning
5. No sunroof
6. Two rows of seats
7. Power windows/locks
8. Standard wheels with above options
9. No longitudinal roof racks
10. Manually adjustable front seats
11. Cloth or leatherette seats

Midsize SUVs

1. 4-wheel drive
2. Automatic transmission
3. Larger 6-cylinder engine (if two are offered)
4. Air conditioning
5. No sunroof
6. Third row seat
7. Power windows/locks/mirrors
8. Standard wheels with above options
9. Longitudinal roof racks

10. Power adjustable driver seat
11. Cloth or leatherette seats

Midsize Luxury SUVs

1. 4-wheel drive
2. Automatic transmission
3. Larger 6-cylinder engine (if two are offered)
4. Air conditioning
5. Sunroof
6. Two rows of seats
7. Power windows/locks/mirrors
8. Alloy wheels
9. Longitudinal roof racks
10. Power adjustable front seats
11. Leather seats

Large SUVs

1. 4-wheel drive
2. Automatic transmission
3. Standard engine (6 or 8 cylinder)
4. Air conditioning
5. Sunroof
6. Third row seat
7. Power windows/locks/mirrors
8. Alloy wheels
9. Longitudinal roof racks
10. Power adjustable front seats
11. Leather seats

Minivans

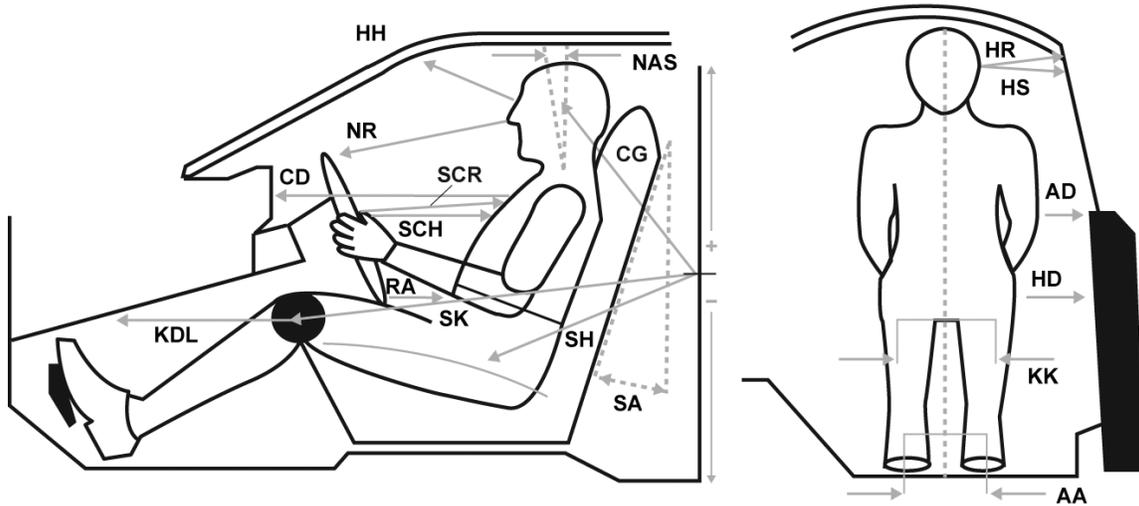
1. 2-wheel drive
2. Automatic transmission or CVT
3. 3.5- to 4.0-liter 6-cylinder engine
4. Air conditioning
5. No sunroof
6. Power windows/locks/mirrors
7. Power sliding doors (both sides)
8. Power tailgate
9. Alloy wheels
10. Power adjustable driver seat
11. Cloth seats

Small and Large Pickups

1. 2-wheel drive
2. Crew cab
3. Short bed (nominal 6 foot)
4. Automatic transmission
5. 3.5- to 4.0-liter V6 (small trucks) or 4.5- to 5.3-liter V8 (large trucks)
6. Air conditioning
7. No sunroof
8. Power windows/locks/mirrors
9. Standard wheels with above options
10. Manually adjustable seats
11. Cloth seats

APPENDIX D

Driver Dummy Clearance Measurement Definitions



Location	Code	Definition of Measurement
Ankle to ankle	AA	Taken between the center points of both ankles, after the feet are placed per IIHS protocol.
Arm to door	AD	Horizontal measurement taken from the center point of the elbow to the first contact point of the door panel.
Chest to dash	CD	Taken from the clavicle adjustment holes in the chest to the point on the dash at level of chest landmark.
Head to A-pillar	HA	Horizontal measurement taken from the center of the head outboard center of gravity target to the A-pillar (not shown in figure).
Hub to chest, minimum	HCM	Minimum horizontal distance measured from the hub to the dummy chest (not shown in figure).
H-point to door	HD	Horizontal measurement taken from the H-point hole to the first contact point of the door panel.
Head to header	HH	Taken from the center point between the eyes to the header directly in front of dummy.
Head to roof	HR	Taken from the center of the outboard target to the roof edge (not the upper edge of the vehicle door), perpendicular to the longitudinal axis of the vehicle. If a tape measure is held from the target and extends below the roof, the point to measure is at the low edge of the roof line, which will make contact with the tape measure.
Head to side window	HS	Taken from the center of the outboard target to the side window, measured horizontally and perpendicular to the longitudinal axis of the vehicle. In cases where the window is not fully up, a flat bar should be placed across the window opening to simulate the position of the window.

continued

Location	Code	Definition of Measurement
Knee to dash, left	KDL	Taken from the knee pivot point to the point on the dash that is directly level with the center of the knee.
Knee to dash, right	KDR	Taken from the knee pivot point to the point on the dash that is directly level with the center of the knee.
Knee to knee	KK	With the legs in a vertical plane after the feet are placed per IIHS protocol, the measurement is taken from the outside flange to the outside flange of the knees. The minimum distance is 270 mm (10.6 inches).
Neck angle, seated	NAS	Taken from the neck when the dummy is seated across two of the “vertebral disks” of the neck.
Nose to rim	NR	Taken from the tip of the nose to the steering wheel rim at the 12 o’clock position.
Pelvis angle	PA	Taken from the instrumented pelvis sensor (if available) or by placing an inclinometer on the H-point bar, which is used to align the H-point with previous measurements.
Rim to abdomen	RA	Taken from the point where the bottom of the chest jacket and the abdominal insert meet to the steering wheel rim at the 6 o’clock position.
Seat back angle	SA	Taken on the head restraint posts of the driver seat back unless otherwise directed by the manufacturer at which time it will be properly noted along with the measurement.
Steering wheel to chest, horizontal	SCH	Horizontal measurement taken from the center of the steering wheel to the dummy chest.
Steering wheel to chest, reference	SCR	Taken from the center of the steering wheel to the center of the clavicle adjustment holes (on the Hybrid III dummies).
Striker to head center of gravity, horizontal	CGH	Horizontal measurement taken from the head center of gravity to the driver door striker. Value is negative if the head center of gravity is forward of the striker.
Striker to head center of gravity, lateral	CGL	Lateral measurement taken from the head center of gravity to the driver door striker.
Striker to head center of gravity, vertical	CGV	Vertical measurement taken from the head center of gravity to the driver door striker. Value is negative if the head center of gravity is below the striker.
Striker to H-point, horizontal	SHH	Horizontal measurement taken from the H-point to the driver door striker. Value is negative if the H-point is forward of the striker.
Striker to H-point, vertical	SHV	Vertical measurement taken from the H-point to the driver door striker. Value is negative if the H-point is below the striker.
Striker to knee	SK	Taken from the center point of the knee to the striker.
Striker to knee angle	SKA	Taken from the center point of the knee to the striker.
Torso recline angle	TRA	Taken from the H-point to the head’s center of gravity

APPENDIX E

Document Revision History

Revisions to Version II, December 2012 of the protocol compared with Version I, October 2012:

- Addition of a marker on the outside of the driver door locating the center of the steering wheel.
- The standard location for postcrash recovery points was moved to the non-struck (right) side rear door frame.
- The method for measuring occupant excursion changed from using seat belt spool out data to a direct measurement of occupant excursion (also Appendix A).
- The location for measuring forward coverage of the side head protection airbag changed from a specific vertical location to a zone of measurement (also Appendix B with updated photographs).

Revisions to Version I, October 2012 of the protocol compared with Version I, August 2012:

- Intrusion measurement point locations on the lower and upper hinge pillar have been named (points 1, 2, and 3) to correspond with their vertical coordinates.
- Intrusion measurement point locations on the rocker panel have been named (points 1, 2, and 3) to correspond with their longitudinal coordinates.
- Corrected inconsistencies in the video analysis procedure in determining the forward edge of the side curtain airbag compared with the Excel spreadsheet.
- In step 5 of Appendix A, the leading edge of the side curtain airbag is considered to be the largest value (most forward location), not the smallest value.