

Moderate Overlap Frontal Crashworthiness Evaluation Crash Test Protocol

Version XIX

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DOCUMENT REVISION HISTORY

Revisions to Version XIX of the protocol compared with Version XVIII:

- In the Test Vehicle Preparation section, the following updates were made:
 - Purple dye is added to the Stoddart solvent.
 - The description of attaching the vehicle the propulsion system was updated.
 - The crash avoidance features are deactivated before the test.
 - The mass of the onboard test equipment was updated (onboard emergency breaking system, to 11 kg from 10.6 kg; 12-volt battery and monitoring system, to 25 kg from 35.2 kg; onboard lighting system, to 26 kg from 28 kg).
 - The hoses connecting the onboard emergency breaking system to the brake lines can be placed beneath the vehicle.
 - The steel plate for mounting the accelerometers is attached to (instead of welded to) the floor of the rear-seating area.
 - Lengths of the segmented tape were updated to two 50-cm and two 75-cm-length gages; Figure 4 was also updated with these gage lengths.
- In the Crash Dummy Preparation and Setup section, clarified the position of the shoulder belt upper anchorage point.
- In the Measurement Point Locations section, the following updates were made:
 - For vehicles with manual transmissions, both the clutch and brake pedals are measured pre and postcrash, with the higher resultant of the two used for the rating.
 - The measuring point locations for the A-pillar and B-pillar were clarified.

Revisions to Version XVIII of the protocol compared with Version XVII:

- Hybrid vehicle high-voltage batteries to be charged to manufacturer recommendations.

Revisions to Version XVII of the protocol compared with Version XVI:

- The high-voltage battery state of charge (SoC) for hybrid and full-electric vehicles was reduced from 95 to 12.5% prior to conducting a crash test.

Revisions to Version XVI of the protocol compared with Version XV:

- New vehicle offset tape scheme illustration, and a description for determining vehicle overlap was added.
- Onboard brake activation time changed from 1.5 to 1.0 second from skate release.

Revisions to Version XV of the protocol compared with Version XIV:

- The weight of the onboard test equipment was updated.
- The Photography section indicates that high-speed digital imagers now are used instead of high-speed film cameras. Crash hall positions of the cameras also have been updated.

Revisions to Version XIV of the protocol compared with Version XIII:

- Stoddard may now be added to the fuel system at any point in the vehicle preparation process. Previously, Stoddard could only be added to the vehicle up to 48 hours before the test.
- High-voltage systems found in vehicles with electric drivetrains are discussed in the Test Conditions and Measurements and Observations sections
- Onboard lighting system specifications have been added to the Test Vehicle Preparation section.
- The allowable vehicle test weight range increased from 100–140 kg greater than the measured curb weight to 100–175 kg. The increase range was required to accommodate an onboard lighting system.
- Data processing is now performed with the DIAdem software program.
- The title of the protocol was changed to *Moderate Overlap Frontal Crashworthiness Evaluation Crash Test Protocol*.

Revisions to Version XIII of the protocol compared with Version XII:

- Impact speed and offset tolerances of ± 1 km/h and $\pm 1\%$ have been added.
- Prior to the offset barrier test, some vehicles are used in the IIHS bumper test program.
- Several dummy clearance measures have been eliminated: head-to-windshield, neck angle (torso 90), and steering wheel-to-chest perpendicular. Striker-to-head center of gravity (horizontal, lateral, and vertical) and torso recline angle measures have been added.

Revisions to Version XII of the protocol compared with Version XI:

- Test vehicles are no longer used in the Institute's low-speed crash test program prior to being crashed. Descriptions of the low-speed tests and the vehicle repair process have been removed from the Test Vehicle Preparation section.
- In the Test Vehicle Preparation section, the weights for the front and rear attachment hardware and the 12-volt battery and monitoring system have been updated. The attachment hardware is 1 kg lighter and the battery and monitoring system is 4 kg heavier than those used in the previous protocol version. In addition, a 1.5 kg wireless device has been added to the vehicle.
- A heat-shrink material is being placed over the dummy ankle shafts to reduce the likelihood of leg sensor noise due to metal-to-metal contact that occurs when the foot reaches a mechanical stop. Specifications for the heat-shrink material are provided in the Crash Dummy Preparation and Setup section of this protocol.
- The in-dummy data acquisition system has been changed from a Denton IDDAS to a DTS TDAS G5 system.

Revisions to Version XI of the protocol compared with Version X:

- The reference list reflects recent updates to the Guidelines for Using the UMTRI ATD Positioning Procedure for ATD and Seat Positioning (Version V).
- The "reference medium left" high-speed film camera view has been eliminated.
- Precrash and postcrash bumper crush profiles have been eliminated.
- The seat pan points have been eliminated from precrash and postcrash intrusion measures.
- The coordinate measurement machine used for intrusion measures has changed from FARO Technologies Inc. Bronze Series FARO ARM to Romer CimCore Inc. 3000i Series Arm.
- The method of defining the coordinate system for intrusion measures with a coordinate measurement machine has changed.
- Seat belt retractor spool-out and crash tensioner spool-in measures have been eliminated.

Revisions to Version X of the protocol compared with Version IX:

- The driver dummy seat positioning follows the *Guidelines for Using the UMTRI ATD Positioning Procedure for ATD and Seat Positioning (Version IV)* instead of placing the driver seat in the midtrack full-down position.

Revisions to Version IX of the protocol compared with Version VIII:

- Underbody photography, underbody deformation measurements, and rotating the test vehicle onto its passenger side to check for postcrash fuel spillage and to photograph the overhead view all were eliminated.
- Prior to the offset barrier crash test, test vehicles are subject to a frontal impact at 5 mi/h (8 km/h) into either a flat barrier or an angle barrier (formerly angle barrier only).

OVERVIEW

This document describes the Insurance Institute for Highway Safety's (IIHS's) protocol for its moderate overlap frontal crash test. Rating protocols for this test and supporting documents for the IIHS's frontal offset crash test program are available from the Technical Protocols section of the IIHS website.

Test Vehicle Selection

For information on how we select vehicles for our crash test programs, see *Test Vehicle Selection* (IIHS, 2021).

TEST CONDITIONS

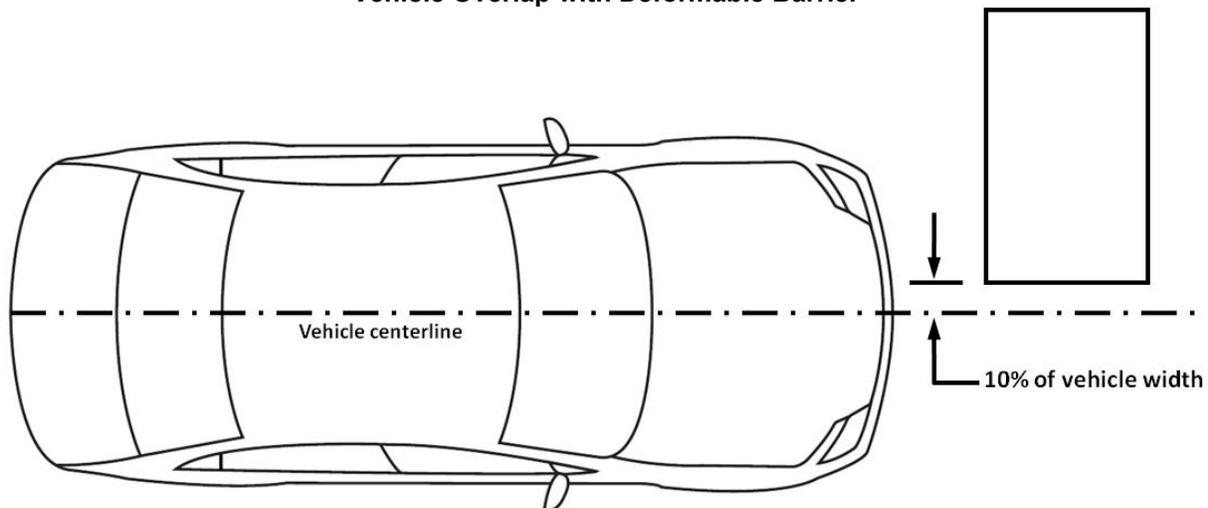
Impact Speed and Overlap

Offset barrier crash tests are conducted at 64.4 ± 1 km/h (40 ± 0.6 mi/h) and $40 \pm 1\%$ overlap. For verification test results submitted by auto manufacturers, the impact speed can exceed the 1 km/h tolerance.

The test vehicle is aligned with the deformable barrier such that the right edge of the barrier face is offset to the left of the vehicle centerline by $10 \pm 1\%$ of the vehicle's width (Figure 1).

The vehicle width is defined and measured as indicated in the Society of Automotive Engineers (SAE) Surface Vehicle Recommended Practice J1100 (2009), 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 Deformable 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 25 cm before the barrier. The onboard braking system, which applies the vehicle's service brakes on all four wheels, is activated 1.0 second after the vehicle is released from the propulsion system.

Barrier Composition and Preparation

The barrier is composed of three elements: base unit, extension, and deformable face (Figure 2).

The base unit is 184 cm high, 366 cm wide, and 542 cm deep. It is composed of laminated steel and reinforced concrete with a total mass of 145,150 kg.

The extension is 91 cm high, 183 cm wide, and 125 cm deep. It is made of structural steel and has a 1.9-cm thick piece of plywood attached to the 4.5-cm thick face plate.

The deformable face is 1 m wide and consists of a bumper element of 1.723 MPa honeycomb material attached to a base of 0.345 MPa honeycomb material. The face is attached to the extension at a height of 20 cm from the ground. The profile (height and depth) of the deformable face is shown in Figure 3.

Figure 2
Deformable Barrier Elements

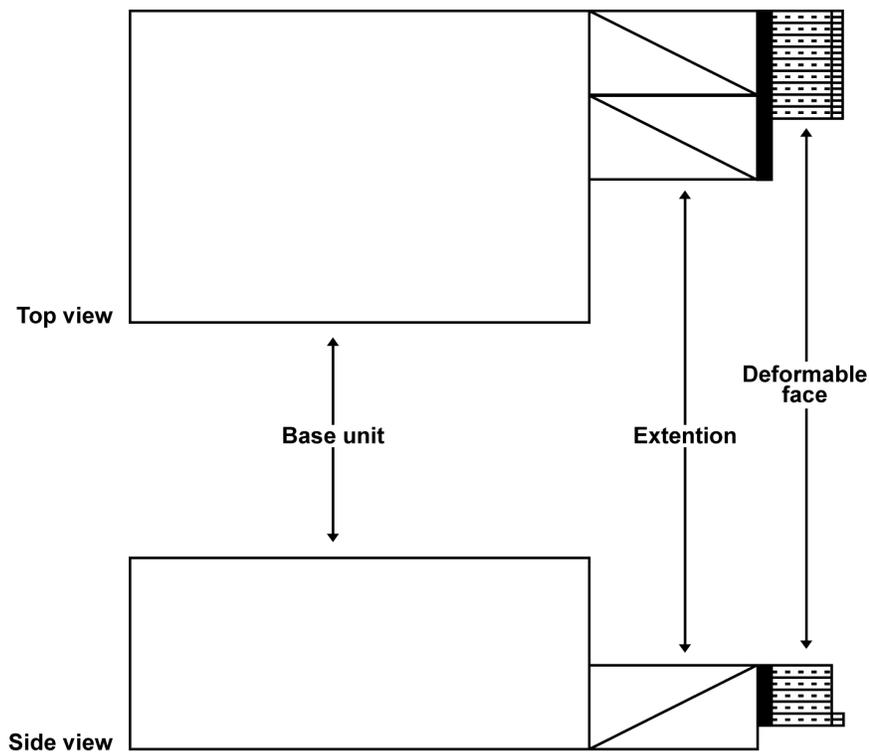
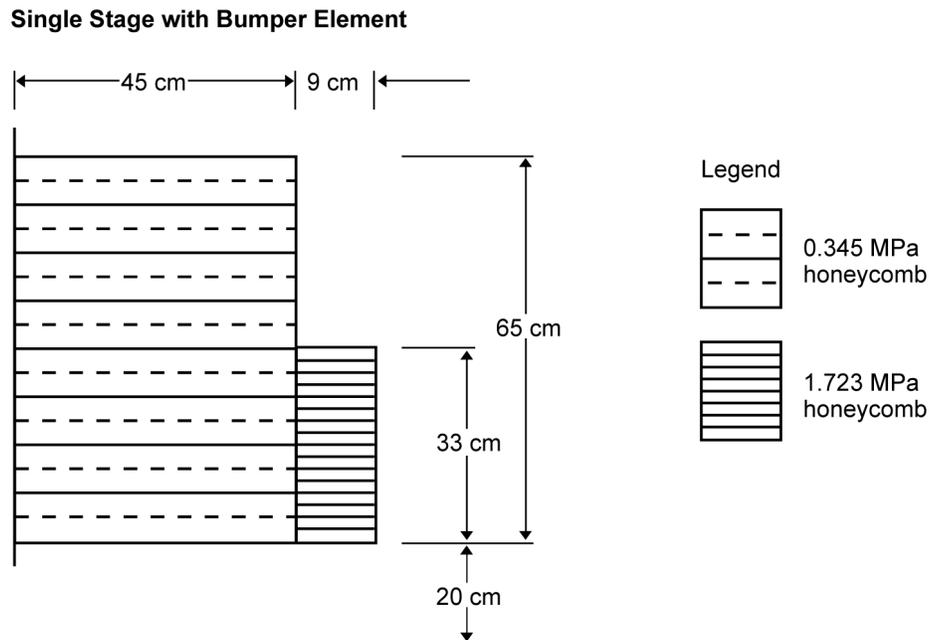


Figure 3
Deformable Barrier Face Profile and Dimensions



Segmented tape (is applied to the right and leading edges of the top surface of both the bumper element and base to highlight them for the overhead camera views. In addition, both barrier surfaces are marked with a 50-cm length gage consisting of two circular photographic targets (yellow and black reference points).

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, maladjustment, 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 and replaced with Stoddard solvent to 90–95 % of useable capacity. Purple dye has been added to the Stoddard to better identify leaks postcrash. 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’s refrigerant is recovered by a means that complies with applicable environmental regulations.

High-voltage batteries in vehicles with full-electric drivetrains are tested at a state of charge (SoC) of 12.5% ($\pm 2.5\%$), with a minimum of 25 miles of travel capacity on the battery. To avoid the possibility of the hybrid system attempting to begin a charge cycle, (i.e., engine start), the high-voltage batteries in hybrid vehicles are tested at the minimum SoC recommended by the manufacturer. Maintenance fuses are not removed, but additional precrash and postcrash precautions specified by the vehicle manufacturer are followed. Equipment is added to the high-voltage system in accordance with manufacturer-recommended procedures for monitoring electrical isolation as per U.S. Federal Motor Vehicle Safety Standard (FMVSS) 305. Thermocouple(s) also are attached to the high-voltage battery to detect temperature increases that may indicate a thermal runaway condition.

The front of the vehicle is attached to the propulsion system via two separate straps, chains, or cables that are wrapped around the left and right sides of the suspension, subframe, or engine cradle. These separate straps, chains, or cables allow components to break away from the vehicle if designed to do so. 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 kg.

Vehicle crash avoidance features are deactivated, by using the onboard vehicle settings **and/or** by physically disconnecting the sensors (cameras, radars, etc.).

An aluminum instrumentation rack, which supports the test equipment, is installed in the cargo area of the vehicle. 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 or beneath the vehicle. The onboard braking system weighs approximately 11 kg.

12-volt battery and monitoring system: This system supplies electrical power for the vehicle, emergency braking system, Diversified Technical Systems (DTS) data acquisition system (DAS), and wireless bridge for DAS communication. The system weighs approximately 25 kg. The wireless device for DAS-to-network communication is mounted to the outside of the vehicle and weighs 2 kg.

Onboard lighting system: This system includes an array of onboard lights and its electrical power supply. The system provides additional lighting for offboard high-speed cameras shooting from angles that are not sufficiently illuminated by the crash hall lighting system. The lighting system weighs 26 kg.

The test weight of the vehicle is 100–175 kg greater than the measured curb weight (weight of the vehicle as delivered from the dealer with full fluid and fuel levels) of the vehicle. 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.

A steel plate is attached to the floor of the rear-seating area along the centerline of the vehicle for mounting the 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.

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

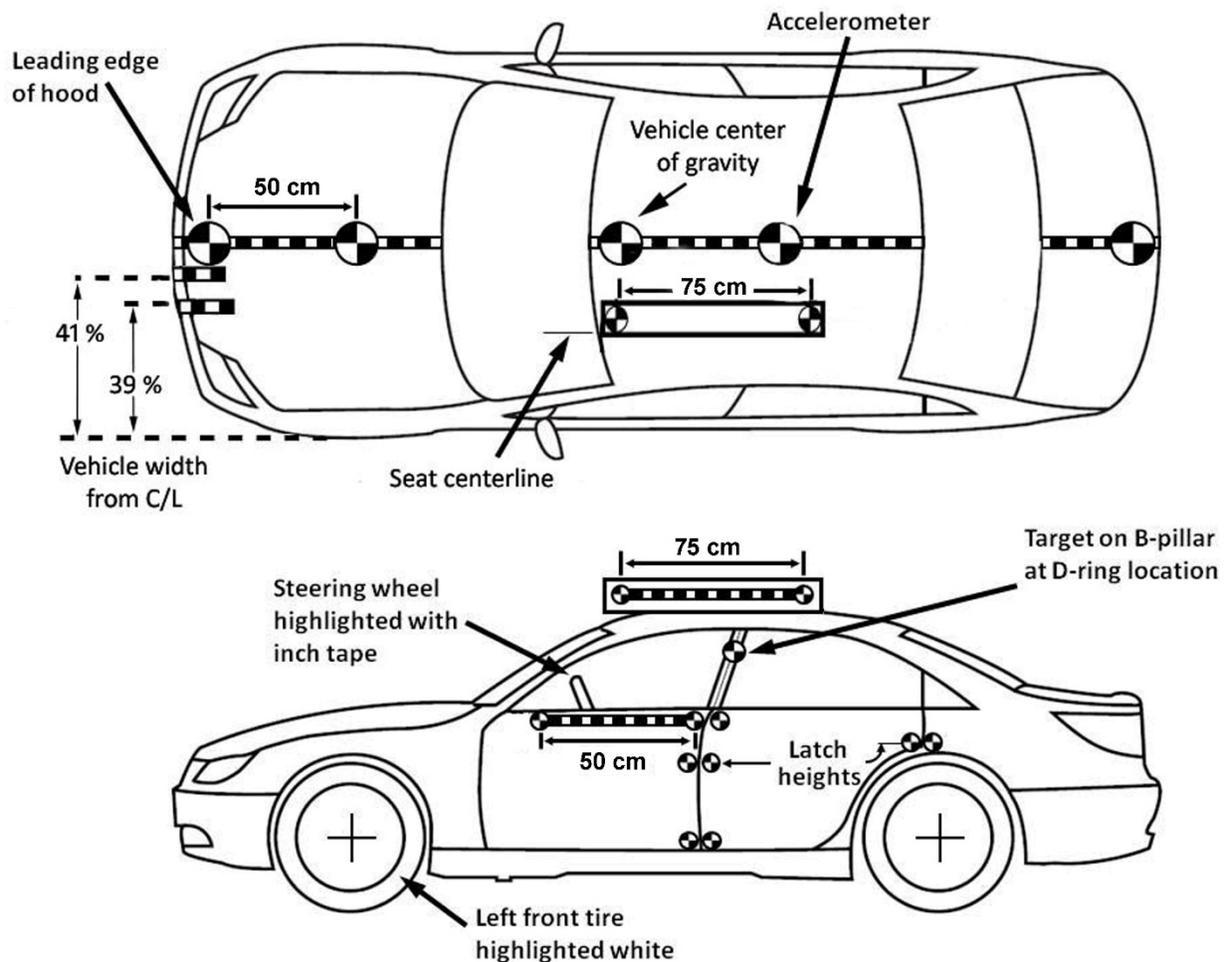
A plastic block containing an array of high-intensity light-emitting diodes (LED) is attached to the hood of the vehicle with sheet metal screws. The LEDs are illuminated when the vehicle first contacts the barrier.

A pressure-sensitive tape switch is applied to the vehicle such that it makes first contact with the barrier during the crash. Pressure applied to this tape completes an electrical circuit that signals the start of the crash (time-zero) for the data acquisition system and illuminates the LEDs mounted on the hood.

The exterior surfaces of the vehicle are trimmed with segmented tape and photographic targets to facilitate analysis of the high-speed camera footage (Figure 4). The scheme consists of four gages in separate reference planes: two 50-cm-length gages, one each on the surface of the hood and on the surface of the driver door; and two 75-cm-length gages, one each on the surface of the roof and in a vertical plane passing through the centerline of the driver seat. The location of the vehicle accelerometers and the location of the vehicle's precrash center of gravity are marked with photographic targets applied to the appropriate top surfaces of the vehicle. An additional target also is placed at the rear of the vehicle on the centerline.

The locations of the driver door latch, the left rear door latch, and the driver shoulder belt upper anchorage D-ring are marked on the side surfaces with photographic targets. The steering wheel is highlighted with tape, and the left front tire is highlighted with white paint. To determine vehicle alignment with the barrier at impact, tape is placed at 39 and 41% of the vehicle width.

Figure 4
Exterior Surface Marking



The driver's head restraint (if adjustable) is adjusted upward until the top of the head restraint is level with the top of the dummy's head. If the head restraint lacks sufficient height adjustment to reach the top of the dummy's head, the test is conducted with the head restraint set at its highest setting. The locking

mechanism for adjusting the head restraint height (if equipped) is examined to ensure the mechanism has engaged. All manually adjustable, head-restraint-tilting mechanisms are adjusted to their full-rearward position.

The manually adjustable inboard armrest for the driver seat (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 automatic-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 C.F.R. 572 [E], 1986) 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 (61 Fed. Reg. 67953, 1996). 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-H and 78051-654-H).

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 C.F.R. 572 (E) (1986) 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% for at least 16 hours prior to the test. The dummy's head, knees, and shins are colored with grease paint to identify its impacts with the vehicle interior postcrash. Photographic targets are placed on both sides of the head to mark the location of its center of gravity.

Seat Belt Placement

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 shoulder belt upper anchorage point should be set to the topmost position, if adjustable, or positioned according to the manufacturer's recommendation.

Photography

Still Photography

The precrash and postcrash conditions of each test vehicle are photographed. Two precrash views 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.

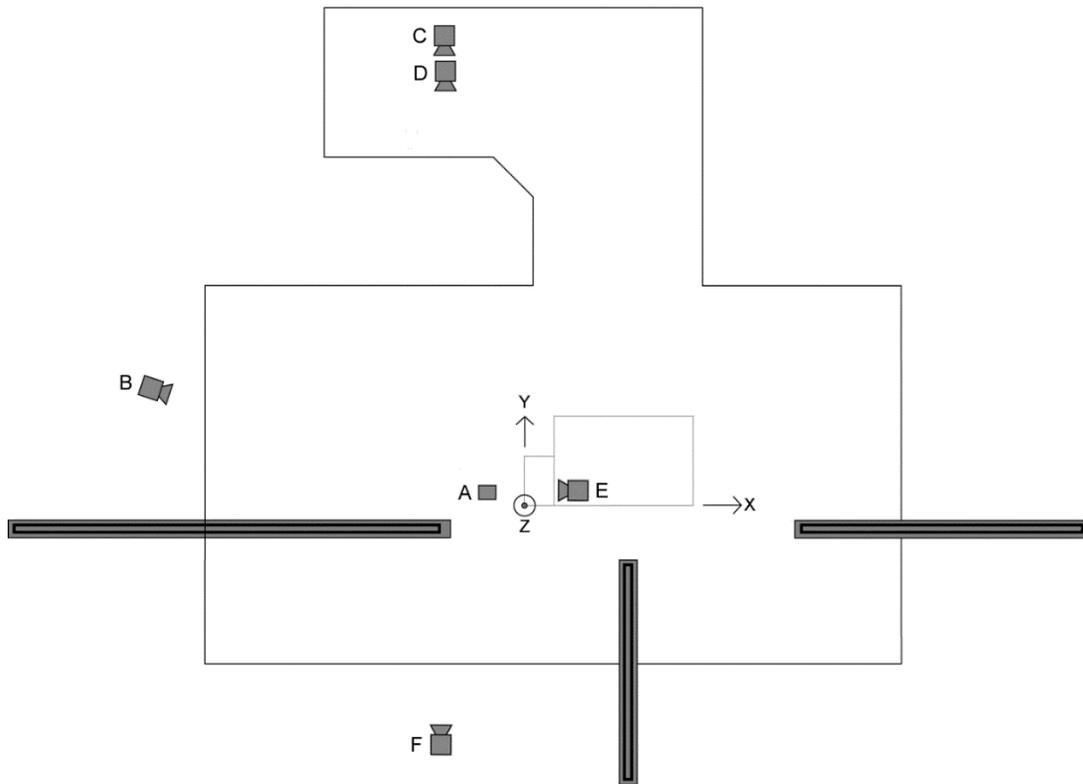
High-Speed Video

Six high-speed digital imagers along with real-time cameras record video for the test. The coordinates and lens focal length of each high-speed camera are described in Table 1. All high-speed imagers record at 500 frames per second. The positions of all cameras are shown in Figure 5.

Table 1
Crash Hall High-Speed Cameras — Coordinates, Focal Points, and Settings

	A	B	C	D	E	F
Camera Position	Overhead	Rear Oblique	Wide Left	Medium Left	Barrier	Passenger Tight
Coordinate X (cm)	-33	-2,031	-159	1,980	189	-70
Coordinate Y (cm)	10	517	1,410	-1,055	-70	-1,643
Coordinate Z (cm)	910	152	150	130	285	135
Focal length (mm)	35	200	50	100	25	95

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 the measurements of two speed-measurement devices. Both devices measure the average velocity of the vehicle at 1–1.5 m before impact with the barrier.

Overlap

The test overlap is verified from the video taken by the high-speed digital imager overhead view (position A in Figure 5). At the time of impact, the outboard edge of the deformable barrier (Figure 6) should fall within the 39 and 41% vehicle width tape on the front bumper of the vehicle. If the target falls outside of this area, additional analysis is conducted to determine the actual offset.

Figure 6
Determining Vehicle Overlap — Video Screen Shot



Vehicle Accelerations

The linear accelerations in three orthogonal directions (longitudinal, lateral, and vertical) of the vehicle's occupant compartment are measured by accelerometer arrays (three Endevco 7264A-2000 or 7264B-2000 accelerometers) and recorded by the TDAS G5 system. Positive vehicle accelerations are forward along the longitudinal axis, to the right 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 Surface Vehicle Recommended Practice J211/1* (2014).

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.

Intrusion Measurements

A total of 14 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). These same marks are measured after the crash using the same reference coordinate system. Intrusion of the steering wheel, instrument panel, and footwell relative to the driver is calculated by subtracting the average component displacements (difference between precrash and postcrash coordinates) of the four seat-attachment bolts, which also were measured relative to the primary coordinate system, from the respective components of displacement for each of the target locations.

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.

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 right rear passenger-side door, or the vehicle structure below the rear-passenger seatpan cushion.

Measurement Point Locations

The following are the locations for measuring vehicle intrusion:

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 has loosened (from release of adjustment lever), or 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, upward and forward. High-speed video may be used to determine the approximate steering column position; however, 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.

Lower instrument panel (two points): The left and right lower instrument panel (knee bolster) lateral coordinates are defined by adding 15 cm to and subtracting 15 cm from the steering column reference lateral coordinate, respectively. The vertical coordinate is the same for both left and right references and 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 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.

For vehicles with a manual transmission, the clutch pedal is also measured, and the pedal with the most resultant intrusion postcrash is used for the final rating.

Toepan (three points): The vertical coordinate for all toepan measurement locations is the vertical coordinate of the brake pedal reference. The lateral coordinates of the left, center, and right toepan locations are obtained by adding 15 cm to, adding 0 cm to, and subtracting 15 cm from the brake pedal reference lateral coordinate, respectively. The longitudinal coordinate is measured, and a mark is temporarily placed at the locations on the toepan. A utility knife is used to cut a small "v" in the carpet and underlying padding at each point on the toepan. 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.

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 adding 25 cm to 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 (typically, four points): Each of the four (or fewer) bolts that anchor the driver seat to the floor of the vehicle.

A-pillar (one point): The A-pillar is marked on the inside of the door opening of the vehicle, at the vertical coordinate of the base of the left front window.

B-pillar (one point): The B-pillar is marked on the inside of the door opening of the vehicle, at the longitudinal center of the pillar at the same vertical coordinate as the A-pillar mark.

Dummy Kinematics and Contact Locations

Dummy kinematics are studied by reviewing the high-speed film using a film analyzer. 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 film record 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 in the film 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/second, the estimate of the crash's start time can be up to 2 ms late, and the event's time, as determined from the film, 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

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 Surface Vehicle Information Report J1733* (2018).

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 from the TDAS G5, 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 Surface Vehicle Recommended Practice J211/1* (2014). Foot accelerations are filtered to SAE CFC 180. All filtering and subsequent calculations are executed using DIAdem (National Instruments Corporation).

Note: This test protocol documents the sensors and data acquisition systems that IIHS uses. Other crash test laboratories, at their discretion, may use sensors and data acquisition systems that are different than those that we use.

Additional Calculations

In addition to summary metrics for each of the recorded data channels, the following calculations are made:

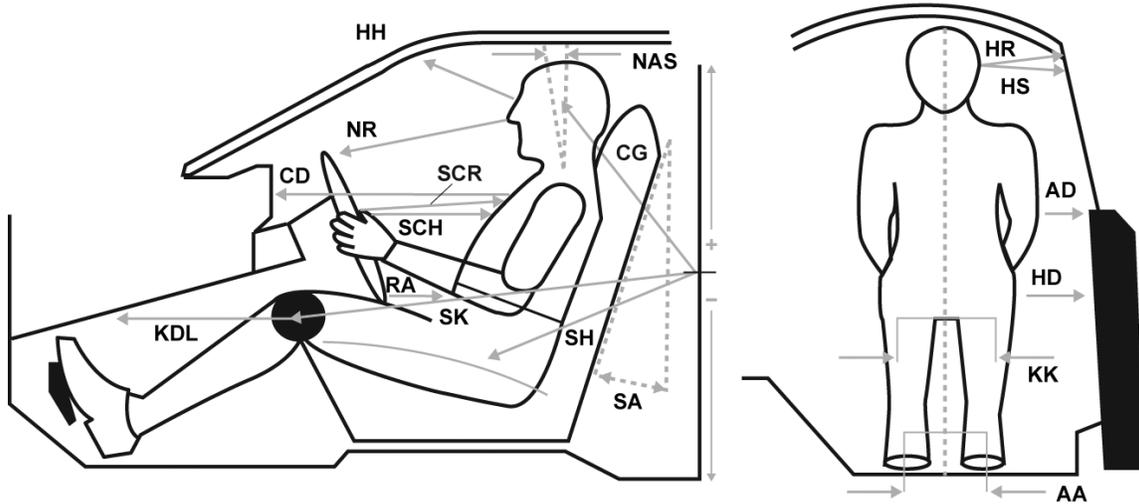
- Vector resultant of the head acceleration
- 3 ms clip of the vector resultant head acceleration
- Head injury criterion (HIC-36 and HIC-15)
- Neck N_{ij} (calculated using formulas presented in *65 Fed. Reg. 30680* [2000])
- Vector resultant of the spine accelerations
- 3 ms clip of the vector resultant thoracic spine acceleration
- Viscous criterion
- Sternum deflection rate
- Vector resultant of the tibia bending moments (using the adjusted tibia A-P moments [IIHS, 2014; Zuby, Nolan, & Sherwood, 2001])
- Tibia index (using the adjusted tibia A-P moments [IIHS, 2014; Zuby, Nolan, & Sherwood, 2001])
- Vector resultant of the foot accelerations.

All calculations comply with the recommendations of *SAE Surface Vehicle Recommended Practice J1727* (2015). The sternum deflection rate is calculated from the sternum deflection filtered to SAE CFC 60.

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APPENDIX: 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 the level of the chest landmark.
Head to A-pillar	HA	Horizontal measurement taken from the center of the outboard target to the A-pillar (not shown in figure).
Hub to chest, minimum	HCM	Minimum horizontal distance measured from the hub to the dummy's chest (not shown in figure).
H-point to door	HD	Taken from the H-point hole to the first contact point of the door panel.
Head to header	HH	Taken from center point between the dummy's eyes to the header directly in front of the 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 long 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 long 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 left 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 right 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 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 (not shown in figure).
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's 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's 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	The angle 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 (not shown in figure).