Crashworthiness Evaluation Offset Barrier Crash Test Protocol (Version III)

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INSURANCE INSTITUTE
FOR HIGHWAY SAFETY

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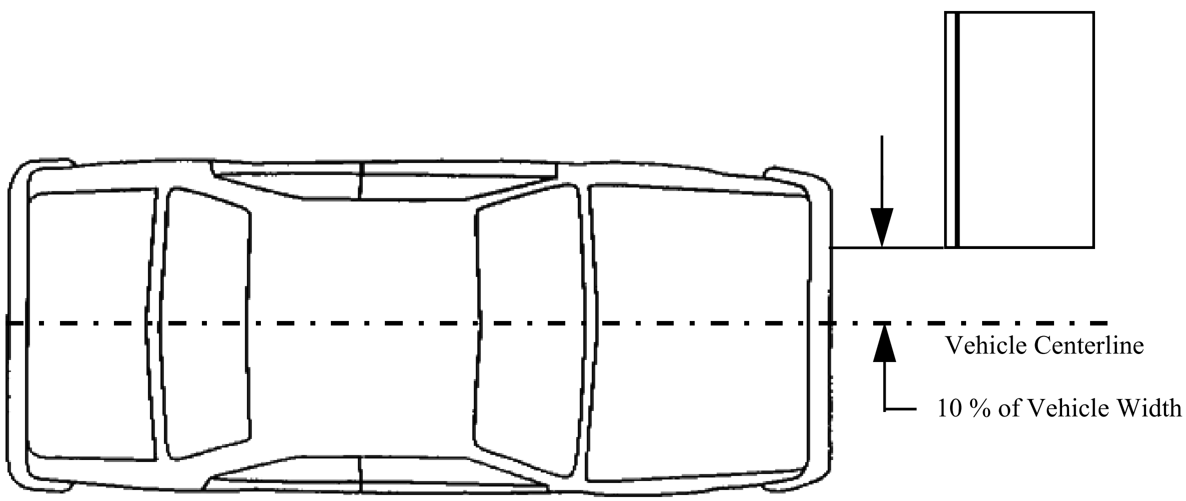
TEST CONDITIONS

Impact Speed and Overlap

Offset barrier crash tests are conducted at 40 mi/h (64.4 km/h) and 40 percent overlap. 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 percent of the vehicle's width (Figure 1). The vehicle width is defined and measured as indicated in 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 Deformable Barrier

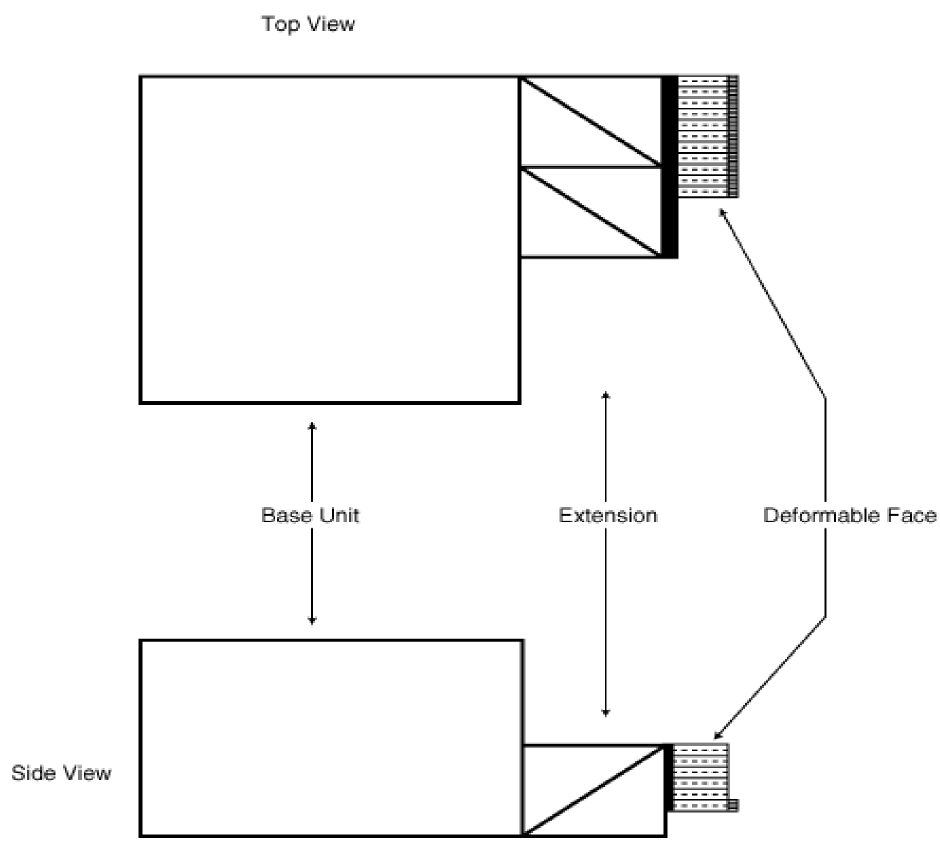


The vehicle is accelerated by the propulsion system at an average of 0.3 g until it reaches the test speed and then is released from the propulsion system 1.5 m before the barrier. The onboard braking system, which applies the vehicle's service brakes on all four wheels, is activated 1.0 seconds after the vehicle is released from the propulsion system. A tether between the vehicle and the propulsion system breaks when the vehicle is released and thus initiates the onboard braking sequence.

Barrier Composition and Preparation

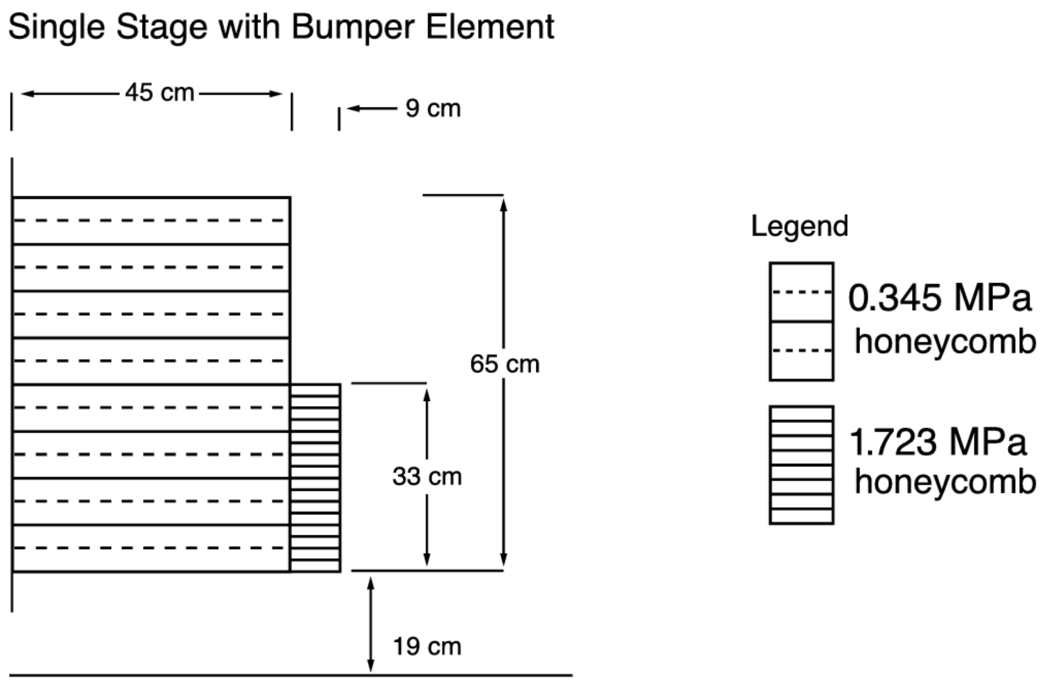
The barrier is composed of three elements: base unit, extension, and deformable face (Figure 2). The base unit is 184 cm high, 366 cm wide, and 542 cm deep. It is composed of laminated steel and reinforced concrete with a total mass of 145,150 kg. The extension is 91 cm high, 183 cm wide, and 125 cm 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 122 cm 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 19 cm from the ground. The profile (height and depth) of the deformable face is shown in Figure 3.

Figure 2. Deformable Barrier Elements



Inch tape (1 inch increments alternating in black and yellow) 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 61 cm length gage consisting of two circular photographic targets (yellow and black reference points).

Figure 3. Deformable Barrier Face Profile and Dimensions



Test Vehicle Preparation

Each vehicle is inspected upon arrival at the research center. The vehicles are checked for evidence of prior collision damage or repair. Previously damaged vehicles are not tested. 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.

Many of the vehicles evaluated in the offset test have been used in the Institute's Low-Speed Crash Test Program. Such vehicles have been subjected to an impact on the front corner of the passenger side at 5 mi/h (8 km/h) into a 30-degree angle barrier and a rear impact at the same speed into a full-width flat barrier. All structural damage on the front of the vehicle is repaired before the 64 km/h offset test. Cosmetic damage is repaired at the Institute's discretion. Parts are replaced or repaired as appropriate based on the judgment of two professional insurance appraisers.

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 full capacity. Stoddard solvent is added to the fuel system within 48 hours of the test. The electrolyte is drained from the battery.

The front of the vehicle is attached to the propulsion system with a hook, steel chain, and turnbuckle assembly. Steel hooks are welded to the left and right sides of the front axle. The steel chain and turnbuckles, which are open toward the rear of the vehicle and closed toward the front, connect the hooks to the propulsion system. The front attachment hardware weighs 7 kg.

The rear of the vehicle is attached to the propulsion system with a nylon strap and ratchet strap assembly. Nylon straps are wrapped around the left and right sides of the rear axle. The straps are linked together at the center by an attachment that is secured to the propulsion system by a nylon strap assembly. The rear attachment hardware weighs 2 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. The instrumentation rack weighs 19.5 kg, and the total weight of the rack and mounted test equipment is 78 kg. The following test equipment is installed on the instrumentation rack located in the cargo area:

> *Onboard emergency braking system:* This system applies hydraulic fluid under pressure to the vehicle's brakes on all four wheels when activated. Flexible hoses are routed from the emergency braking system to the engine compartment. The brake lines on the vehicle are cut at the master cylinder, and the onboard brake lines are attached to the cut lines. The onboard braking system weighs 12.3 kg.
>
> *12 volt battery:* This battery supplies electrical power for the vehicle and test equipment. A two-conductor cable connects this battery to the vehicle's battery terminals. The battery and mounting hardware weigh 25.8 kg.
>
> *Electrically isolated 12 volt battery:* This battery provides power for the Denton Intelligent Dummy Data Acquisition System (IDDAS). The battery weighs 12.8 kg.
>
> *System monitor:* This system records and transmits test equipment operational data to the test operator. The status of the onboard brake charge pressure, vehicle battery voltage, and IDDAS are monitored. The monitor and mounting hardware weigh 7.6 kg.

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.

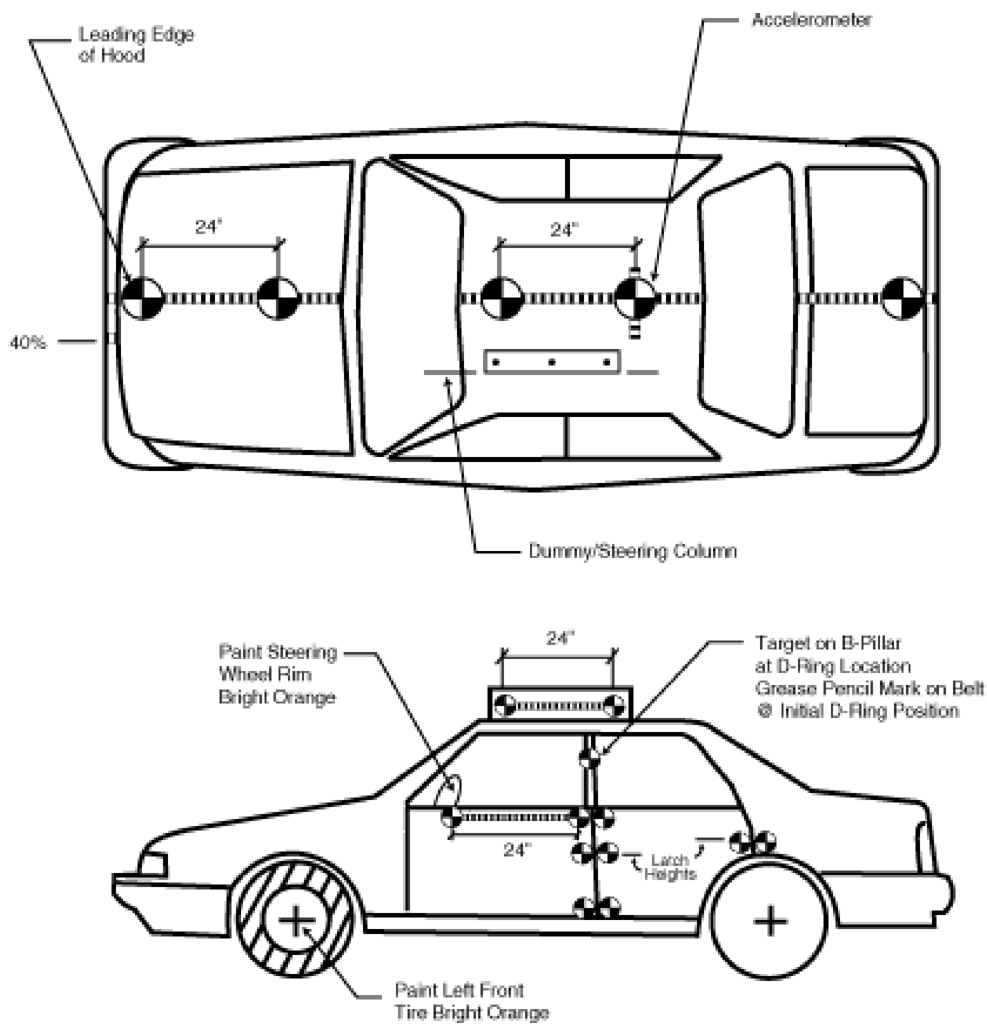
The antilock braking system (if equipped) and daytime running lights (if equipped) are disabled.

A plastic block containing an array of high-intensity light emitting diodes (LEDs) 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 inch tape and photographic targets to facilitate analysis of the high-speed crash films (Figure 4). The scheme consists of four 61 cm length gages in four separate reference planes: the surface of the roof, the surface of the hood, the surface of the driver door, and 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 driver door latch, left rear door latch, and driver D-ring are marked on the side surfaces with photographic targets. The steering wheel and front left wheel are highlighted with bright contrasting paint.

Figure 4. Exterior Surface Marking



The driver seat and adjustable steering controls are adjusted according to 49 *CFR* 571.208. The seat back angle and position of the adjustable seat belt upper anchorage are set according to the specifications provided by the manufacturers. After the driver seat has been adjusted, the adjustment latching mechanism is examined to note whether all the components of the mechanism are interlocked. If partial interlocking is noted and normal readjustment of the seat does not correct the problematic misalignment, the condition is noted and the test is conducted without repairing the mechanism.

The steering column tilt mechanism (if equipped) is set to its most forward position.

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 Hybrid III 50th percentile male dummy (49 *CFR* 572 (E)) with instrumented lower legs is positioned in the driver seat according to 49 *CFR* 571.208 unless otherwise noted. The dummy's feet have been modified to include two accelerometers and to have a 45 degree dorsiflexion range. In addition, the dummy's thoracic spine has been modified to accommodate an onboard data acquisition system. The mass and moments of inertia of the modified thoracic spine are similar to those of the standard dummy.

Three separate Hybrid III dummies are used in the program. These dummies are initially calibrated according to 49 *CFR* 572 (E), and individual parts are recalibrated if levels exceed published tolerance thresholds during a test or 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 at the beginning of the runway where the temperature is maintained at 20.6–22.2 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. 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 documented on 35 mm color slide photographs. Two precrash views and two postcrash views show the side and left front quarter of the test vehicle.

Five different views of the underbody are recorded for both precrash and postcrash conditions. These photographs are taken by rotating the vehicle 90 degrees around its longitudinal axis onto its passenger side. The postcrash series of photographs includes three overhead views.

Additional photographs include a minimum of four views that document the precrash position of the driver dummy and close-up views of the dummy's legs.

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

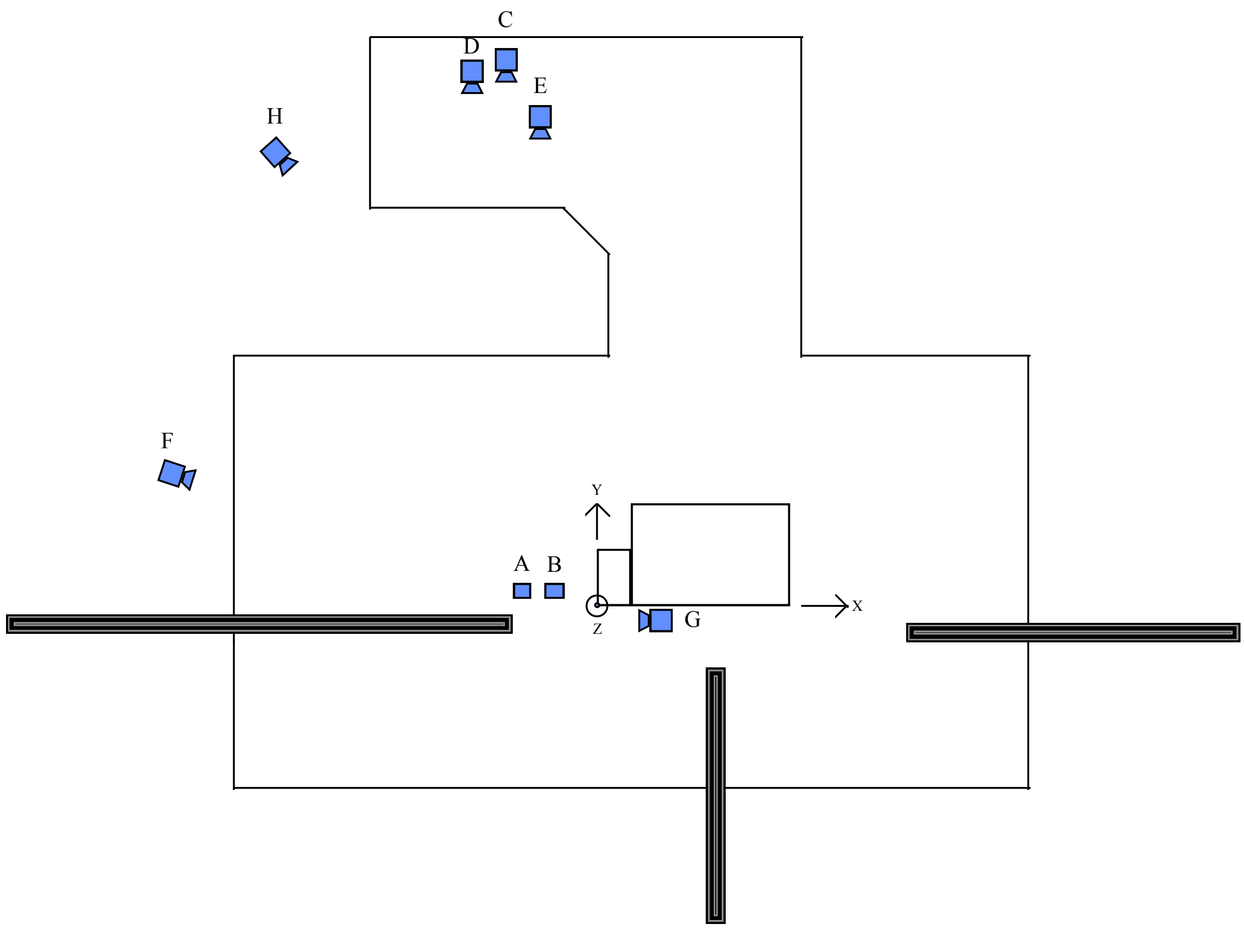
High-Speed Motion Picture Photography

Motion picture photography is taken of the test with seven Model 51 Locam II cameras and one Arriflex 16 camera. The lens size and frame rate of each camera are described in Table 1. Frame rates for the Locam II 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

Camera Position	A Wide Over-head	B Tight Over-head	C Wide Left	D Med. Left	E Tight Left	F Down Left Side	G Front Wind-shield	H Real-time Left Pan
Coordinate X (cm)	-121	0	-97	-132	-274	-1,918	208	-645
Coordinate Y (cm)	0	0	1,420	1,367	1,262	396	-13	1,288
Coordinate Z (cm)	894	894	119	130	155	157	140	152
Lens (mm)	16	25	25	50	75	50	25	25
Film Speed (frames/sec)	500	500	500	500	500	500	500	24

Figure 5. High-Speed Camera Positions



Measurements/Observations

Test Weight

The test weight of the vehicle is determined using an Intercomp model SW 8800 scale 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.

Overlap

The actual overlap is determined from the film taken by the high-speed camera tight overhead view (Position B in Figure 5). The lateral distance between the centerline of the vehicle and the right edge of the deformable barrier is measured using a film analyzer and software package. This measurement is used with the vehicle's overall width to determine the actual overlap percentage. The photographic targets applied to the top surfaces of the deformable barrier are used for the image scaling.

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 accelerometers) and recorded by the IDDAS. Positive vehicle accelerations are forward along the longitudinal axis, to the left along the lateral axis, and upward along the vertical axis. The data are presented filtered according to the frequency class 180 as defined in SAE J211 - Instrumentation for Impact Tests.

Fuel System Integrity

Observations about fuel system integrity are recorded for each test. Any Stoddard fluid leaked from the fuel system within one minute after the impact is collected as the first sample. This typically is done by soaking up the Stoddard fluid with an absorbent pad of known mass. The second sample of leaked Stoddard fluid is collected over the 5 minutes immediately following the collection of the first sample. This sample is typically 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.

Additional Stoddard fluid that is leaked when the test vehicle is turned onto the passenger side for underbody photography also is collected. Six samples are collected if appropriate. The first sample is collected during the interval of time required to rotate the vehicle 90 degrees from upright (typically less than 5 minutes). The remaining samples are taken each minute for the next 5 minutes. The samples either are collected in pans or soaked up with absorbent pads of known mass, depending on the nature of the leak. The volume of each sample is determined as described in the preceding paragraph.

Crush Profile

The profile of the vehicle's front bumper is measured both before and after the crash. The reference for these measurements is tangent to the undeformed bumper and perpendicular to the vehicle's longitudinal centerline. Eleven measurements equally spaced along the reference line are recorded. In addition, the position of the right end of the bumper, relative to the undeformed centerline, is recorded. All measurements are made to the nearest one-half centimeter.

Intrusion Measurements

A total of 15 locations are marked on the driver side interior and exterior of the vehicle, and their longitudinal, lateral, and vertical coordinates are recorded using a FARO Technologies Inc. Bronze Series FARO ARM. These same marks are measured after the crash using the same reference coordinate system, and the differences are reported.

> *Coordinate system definition:* A three-axis orthogonal coordinate system is used for these measures: longitudinal (rear to front is positive), lateral (right to left is positive), and vertical (bottom to top is positive). The lateral and vertical axes and the origin are defined and marked on the vehicle prior to the crash. These also necessarily define the longitudinal axis. The axis marks are used after the crash to reestablish the coordinate system.

The precrash coordinate system is defined with the vehicle unloaded on a level floor. The lateral axis is defined by placing a level rod against the right and left B-pillars inside the front window frames (with the front doors open) as close to the intersection of the B-pillars and roof rails as possible. The origin is then defined as the intersection of this level rod (lateral axis) and the most inboard trim piece on the right B-pillar and marked. A plumb line suspended from this point to the right rear floor defines the vertical axis. The lateral axis is marked on both B-pillars and the origin point is marked on the right B-pillar. A mark is made on the right rear floor that corresponds to the plumb line location.

The postcrash coordinate system is reestablished by first defining the plane created by the previously created marks on the B-pillars and on the right rear floor. The vertical axis is then explicitly defined as the line between the right B-pillar mark and the plumb mark on the right rear floor. Note that defining the vertical axis on the lateral-vertical plane necessarily defines the lateral axis. The precrash origin mark is used again to define the origin, which along with the vertical axis, necessarily defines the longitudinal axis.

***Measurement Point Locations*:**

Lower instrument panel (two points): The left and right lower instrument panel 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), measured plumb.

Shear module (two points): The center of the left and right steering column shear modules.

Steering column (one point): The marked reference is the geometric center of the steering wheel, typically on the airbag door.

Brake pedal (one point): The geometric center of the brake pedal pad (top surface).

Toepan (four points): The vertical coordinate for all toepan measurement locations is the vertical coordinate of the brake pedal reference. The lateral coordinate 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 placed at the locations on the toepan. A utility knife is used to ascertain the depth of the carpet and associated padding. The carpet and padding depths are added to the longitudinal coordinate. The accelerator pedal toepan mark is the point on the toepan with the same lateral and vertical coordinates as the geometric center of the accelerator pedal.

Left footrest (one point): The geometric center of the left footrest pad. For vehicles without a footrest pad, the geometric center of the floor in the area that many manufacturers install a footrest is used.

A-pillar (two points): The upper A-pillar is marked on the outside of the vehicle at the intersection of the roof and A-pillar. The lower A-pillar is marked on the outside of the vehicle at the same vertical coordinate as the base of the left front window.

B-pillar (two points): The upper B-pillar is marked on the outside of the vehicle at the longitudinal center of the pillar at a height level to the upper A-pillar mark. The lower B-pillar is marked on the outside of the vehicle at the longitudinal center of the pillar at the same vertical coordinate as the lower A-pillar mark.

Underbody Structures Deformation

Eight locations are marked on the underside of the frame rails of the vehicle, and their longitudinal, lateral, and vertical coordinates are recorded using a FARO Technologies Inc. Bronze Series FARO ARM. These eight marks are measured after the crash using the same reference coordinate system. In addition, the contour of the underside of the frame rails between the front bumper and the point on the frame rail corresponding to the longitudinal position of the B-pillar is measured before and after the crash using the same reference coordinate system. The resulting precrash and postcrash contours are plotted.

> *Coordinate system definition*: A three-axis orthogonal coordinate system is used for these measures: longitudinal (front to rear is positive), lateral (right to left is positive), and vertical (bottom to top is positive). The longitudinal and lateral axes and the origin are defined on the vehicle prior to the crash, and also necessarily define the vertical axis.

The longitudinal-lateral plane is defined by points on the bottom of the left and right door sills, 20 cm rearward and forward of the front and rear wheelwells, respectively. The longitudinal axis is defined by the centerline of the vehicle, and the origin is defined as the most forward portion of the front bumper on the centerline. Three points are chosen and marked on the rear of the right frame rail, and their coordinates are recorded. The postcrash coordinate system is reestablished by assigning the precrash coordinates to these three points.

***Measurement Point Locations*:**

> *Front bumper mount:* The intersection of the underside of the left and right frame rails and the front bumper.
>
> *A-pillar:* The point on the underside of the left and right frame rails that corresponds to the longitudinal coordinate of the base of the A-Pillar.
>
> *B-pillar:* The point on the underside of the left and right frame rails that corresponds to the longitudinal coordinate of the base of the B-Pillar.
>
> *Rear bumper mount:* The intersection of the underside of the left and right frame rails and the rear bumper.

Seat Belt Retractor Spool-Out

Slack seat belt webbing that is allowed to spool off the retractor is measured during the crash. Only the maximum length of spool-out is measured and recorded. After the seat belt is fastened around the dummy, a piece of string is stitched into the belt webbing just outside the retractor housing. The free end of the string is pulled taut and taped against the retractor housing. The precrash position of the string relative to the tape is marked. After the crash, the position of the string relative to the tape is marked. The reported maximum belt spool-out is the distance between the precrash and postcrash marks on the string measured to the nearest millimeter.

Dummy Kinematics and Contact Locations

Dummy kinematics are assessed using two methods: postcrash inspection of the dummy's position and contact points with the vehicle and high-speed film analysis using a Visual Instrumentation Corporation Model 1214A Motion Analysis System and Motion Analysis Systems Package, Version 6.22A analysis software.[1]

The dummy is inspected in its undisturbed postcrash position. The condition of the ankle joints, resting positions of the feet, and positions of the knees are recorded, and photographs are taken of these components. Any damage to the dummy or unusual dummy resting position information also is noted.

The dummy's contact with the vehicle during the crash is determined by the transfer of grease paint from the dummy to the vehicle (see Crash Dummy Preparation and Setup). These contact points and associated dummy components are noted, and the contacted structure is photographed. The grease paint transferred from the dummy's face to the airbag is used to measure the lateral and vertical distance of the dummy's nose from the center of the airbag at initial contact.

The high-speed film record is used to estimate the time after the start of the crash that 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 per second, the estimate of the start time of the crash 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.

A film analyzer and analysis software are used to measure the movements of the dummy and vehicle components at various times during the crash.[1] The photographic target scale mounted on the roof of the vehicle or the scale on the driver door is used for scaling images on the film.

Dummy Responses

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

Head
Triaxial accelerations (three Endevco 7231C-750 accelerometers)

Neck
A-P shear force
Axial force
A-P bending moments (R.A. Denton model 2564 or 1716A upper neck load cell)

Chest

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

Lower Extremities

Femur axial forces (R.A. Denton model 2121A load cell)
Tibia-femur displacements
Upper tibia A-P moments
Upper tibia L-M moments (R.A. Denton model 1583 load cell)
Lower tibia A-P moments
Lower tibia L-M moments
Lower tibia axial forces (custom R.A. Denton model 3093 load cell)
Biaxial foot accelerations (A-P and I-S) (2 Endevco 7264A-2000 accelerometers)

All instruments are regularly calibrated to a known standard by R.A. Denton. Accelerometers and load cells are calibrated every six months.

Positive accelerations of the dummy's head, chest, and feet are forward along the A-P axis, to the left along the lateral axis when applicable, and upward along the I-S axis. Compression of the neck produces positive axial forces, bending the neck to tip the head forward produces positive A-P moments, and pushing the head forward while restraining the torso produces positive A-P shear forces. Compression along the long axes of both the femur and tibia produce positive forces. Rearward displacement of the proximal tibia relative to the distal femur is positive. Tibia bending moments are defined in terms of example load configurations. If a tibia is fixed below the lower load cell, a force that bends the tibia to the anterior will produce a positive lower A-P moment and a force that bends the tibia to the right will produce a positive lower L-M moment. If a tibia is fixed above the upper load cell, a positive upper A-P moment bends the tibia to the posterior and a positive upper L-M moment bends the tibia to the left.

The Denton IDDAS is installed in the thorax of the Hybrid III dummy and used for all dummy and vehicle data acquisition. During the crash, all measurements are recorded in the system's random access memory with 12-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 2.5 kHz cut-off frequency.

After the data have been downloaded from the IDDAS, any initial offset from zero is removed from each channel using SoMat EASE v1.2a.[2] This process consists of computing the mean value for between 100 and 500 data points preceding the crash event for each channel and subtracting each mean from the respective data channel. The data are filtered digitally before subsequent analysis as follows:

Head, neck, leg, and feet:	SAE Class 1000
Thoracic spine acceleration:	SAE Class 180
Chest compression:	SAE Class 600

SoMat EASE v1.2a is used for filtering data to SAE Class 1000,[2] other filters and calculations are executed using DSP Development Corporation's DADiSP v3.01D.[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)[*], vector resultant of the spine accelerations, 3 ms clip of the vector resultant thoracic spine acceleration, viscous criterion, vector resultant of the tibia bending moments, tibia index, and vector resultant of the foot accelerations. The 3 ms clips and the HIC are calculated using C programs that were adapted from Fortran programs used by the National Highway Traffic Safety Administration. The source code for these programs can be found in the Appendix, Injury Calculation Programs.

The viscous criterion is calculated as follows:

1. The chest compression data are digitally filtered to SAE frequency class 600.
2. The filtered data are differentiated using Simpson's rule to obtain the velocity of compression.
3. The velocity of compression is converted from mm/s to m/s and multiplied by the scale factor 1.3.
4. The compression is normalized by chest depth of Hybrid III 50th percentile male dummy (multiplied by 1/229 mm).
5. The normalized chest compression and velocity of chest compression are multiplied together.

A tibia index is calculated for both the upper and lower tibia using the following formula:

$$\text{Tibia Index} = (M_{\text{Vector Resultant}} / 225\ \text{Nm}) + (F_{\text{axial, measured at the lower tibia}} / 35.9\ \text{kN}).$$

The reported maximum tibia index and all other summary metrics from the dummy's legs are adjusted to ameliorate the effect of high frequency oscillations that result when the metal ankle shaft forcefully contacts the metal ankle rotation stop. The adjustment consists of first identifying time intervals when the vibration is observably active in the foot acceleration measurements. The maximum tibia index and the maximum of each of the other leg measurements (excluding the tibia-femur displacement, which is not affected by the vibration) are taken as the maximum values recorded outside the exclusion intervals identified from the foot acceleration recordings.

The neck A-P and axial forces and the femur axial forces are compared against the force-duration corridors suggested by Backaitis and Mertz[4]. The C programs used to calculate the time during which the load exceeded each force level are adapted from the 3 ms clip program used by the National Highway Traffic Safety Administration. The source code for these programs can be found in the Appendix, Injury Calculation Programs.

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[*] The HIC is calculated two ways. The first limits the maximum HIC interval to 36 ms; the second limits the maximum HIC interval to 15 ms (HIC-15).

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