



Hand Held Force Input Frequency Response Function Acquisition Master Test Procedure

1 Introduction

Note: Nothing in this standard supercedes applicable laws and regulations.

Note: In the event of conflict between the English and domestic language, the English language shall take precedence.

1.1 Purpose. To provide guidelines for setting up and performing a hand held impact hammer or hand held shaker test for noise and vibration validation procedures.

1.2 Applicability. This test procedure is appropriate for the evaluation of all subsystems, components, and vehicles.

This test is applicable to both drive point Frequency Response Function (FRF) measurements as well as cross (transfer) FRF measurements.

FRFs at mechanical interface locations in full vehicles or components characterize dynamic structure-borne noise and vibration characteristics.

FRFs between mechanical interface locations and response locations are used for various test based analyses, for example, experimental modal analysis.

1.3 Remarks. Impact and hand held shaker testing provides a means through which the dynamic characteristics of a structure can be obtained in a relatively short amount of time.

2 References

Note: Only the latest approved standards are applicable unless otherwise specified.

2.1 External Standards/Specifications.

None

2.2 GM Standards/Specifications.

GMW14172

2.3 Additional References.

- Structural Impact Testing Force Spectra, M. W. Trethewey, Proceedings from IMAC 15, February 1997.
- The Strengths of Impact Testing, C. D. Van Karsen, E. F. Little, Proceedings from IMAC 15, February 1997.
- Weaknesses of Impact Testing, D. L. Brown, Proceedings from IMAC 15, February, 1997.
- Windows Used for Impact Testing, W. A. Fladung, Proceedings from IMAC 15, February, 1997.

3 Resources

3.1 Facilities. Facility requirements may vary depending on the type of test setup. For example, a hemi-anechoic chamber may be required for microphone measurements.

All facilities shall have the ability to create appropriate boundary conditions. Boundary conditions are typically defined as in-situ, to ground or free-free. (See 4.1.1 for more details.)

All facilities shall be free of extraneous noise and vibration sources (e.g., electromagnetic interference, 60 Hz in the U.S.).

3.1.1 Calibration. The test facilities and equipment shall be in good working order and shall have a valid calibration label.

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3.1.2 Alternatives. Alternative test facilities and equipment may also be used. However, all measuring variables as specified in this standard shall be determined correctly with respect to their physical definition.

3.1.3 Room Properties. Noise and vibration test rooms have varying properties based on their function. The following examples are intended to define some different room types and properties.

3.1.3.1 Hemi-anechoic chamber (car test room and chassis dynamometer rooms).

The ambient background noise levels measured inside the car shall meet the following criteria:

- 10 dB (Re: 20×10^{-6} Pa) lower than the noise levels generated inside the car during the test in a $\frac{1}{3}$ octave format, see Appendix C.
- Should be no greater than 40 dB (Re: 20×10^{-6} Pa), and should facilitate Sound Pressure Level over Force (P/F) coherence values of at least 0.95 at all P/F maxima in the frequency range of interest.

3.1.3.2 Bedplate/Test Room. The bedplate/test room facility may be any interior environment with a hard level surface to mount the test piece and test equipment with background vibration levels that facilitate coherence values greater than 0.95 at all FRF maxima over the frequency range of interest.

3.2 Equipment.

3.2.1 Test Equipment. Appendix A contains more detailed information regarding Data Acquisition System (DAS) requirements and transducer examples.

- Data acquisition system. An acquisition system with at least two channels shall be used.
- An impact hammer with the appropriate load cell.
- A hand held shaker with the appropriate load cell.
- Accelerometers, microphones, or any other appropriate transducer for a response measurement.
- Miscellaneous equipment including but not limited to, appropriate cables, adapters, adhesive substances (see Appendix B), and transducer signal conditioning (as required).

3.2.2 Test Fixtures.

3.2.2.1 General Guidelines. The test item shall be constrained in a realistic fashion. The general recommendation is that test fixtures are used which reflect a boundary condition that reflects what the test item experiences in operation. This implies that the force and response are to be located as close as possible to what the test item experiences in operation. Appendix E illustrates examples of fixtures.

Fixtures and other hardware attached to test structures will affect measurement quality. For this reason, measurements should be made without the use of fixtures whenever possible.

When fixturing is necessary, vehicle hardware should be used wherever possible. In some cases, however, shop made fixtures will be required to execute the desired measurements.

Fixtures should be designed to have minimal influence on the measurement. This is because the measurement should characterize the test structure and not the fixture.

3.2.2.2 Design Guidelines for Fixtures. Fixtures or brackets used to measure vehicle, subsystem, or component frequency response functions should not significantly alter the local stiffness or mass of the test item. Refer to Appendix E for common fixture examples. The fixtures would ideally be of infinite stiffness and zero (0) mass. Fixtures shall be made in such a way that the force can be applied to a flat surface, not cylindrical or spherical. If the surface is not flat or big enough for force to be applied in a consistent way, a small aluminum cube shall be attached to the structure in such a way that it does not increase the applied torque.

Fixtures shall be lightweight and stiff. Aluminum of 6.3 mm to 12.7 mm thickness is preferred for most applications. Fixtures should be solidly bolted to the adjacent structure, if possible. Epoxy or any other type of adhesive between the fixture and the test object should be of minimum thickness and the use of this technique should be minimized, especially when characterizing the shear direction. The lowest natural frequency of any bracket or fixture should be ten (10) times greater than the frequency range of interest. Bolting the fixture to a bedplate and measuring the FRF can be used to verify that this requirement has been met.

3.3 Test Vehicle/Test Piece. This test procedure is good for any subsystem, component, or vehicle level test. For the purpose of validation, the subsystem, component or vehicle to be tested shall be fully assembled and design intent. The condition of the subsystem, component or vehicle will be noted on the test log sheet.

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3.4 Test Time.

Calendar time: Variable days
Test time: Variable hours
Coordination time: Variable hours

3.5 Test Required Information.

 Not applicable.

3.6 Personnel/Skills. To complete this test, at least one (1) technician and/or one (1) engineer skilled in vibration data acquisition, analysis, equipment use, and test setup is required.

4 Procedure

4.1 Preparation. Refer to the following superscripted notes, identified in the paragraphs of this entire section.

Note 1: Natural frequencies of test fixtures and free-free components can be evaluated by making driving point measurements in three (3) perpendicular directions at the attachment points between the fixture and the component (see 4.1.1.2 and 4.1.1.3.3).

Note 2: A trigger delay should be implemented so that the analyzer recalls buffered time data and considers the initial impulse and response data. It is typically set as a negative number (i.e., -40 ms) and may vary in sign depending on the type of analyzer used (see 4.3.2.1).

Note 3: To prevent leakage, the response should decay such that the magnitude of the windowed response signal at the end of the time segment is less than 5% of the magnitude of the peak of the signal at the beginning of the time segment. If the accelerometer response has decayed to less than 5% of the magnitude of the peak of the time signal, a uniform window should be used. The force window should be set such that it is long enough to capture all of the force time signal not equal to zero (see 4.3.2.1). Refer to "Windows Used for Impact Testing" for additional information (see 2.3).

Note 4: The number of averages used may also vary depending on the number needed to obtain a consistent FRF. Six (6) averages represent the minimum number needed for statistical significance (see 4.3.2.1).

Note 5: If the hardest tip yields a pulse that is still too **soft**, it may be due to the local compliance of the structure being too **soft**. Try an alternate input location that is more **rigid**. If a more **rigid** part of the structure is not available, the tester can accept and note the conditions at the current location (see 4.3.2.5).

4.1.1 Boundary Conditions. Choose one of the following which is appropriate for the testing being performed.

4.1.1.1 In-Situ Boundary Condition. Corresponds to testing a component or subsystem in a trimmed body, body structure, or vehicle (whichever is appropriate for the component).

Mount the component or subsystem into vehicle per recommended installation, bolt torque should be checked to ensure that the attachment stiffness is correct or production intent.

4.1.1.2 Rigid Fixture Mounting. May require custom fixturing. For example, a fabricated test fixture can be mounted to ground (bedplate or rigid fixture) for component mounting.

The fixture shall have a first mode that is at least ten (10) times the desired flexure natural frequency of the component. If this is not possible, make sure that the fixture and component drive point mobilities have at least 20 dB of separation in all three (3) directions. The first natural frequency of the fixture should be evaluated with a rigid mass equal to that of the component attached to it. ^{Note 1}

4.1.1.3 Free-Free Mounting. In this condition, the test piece has no constraints. This is not achievable realistically, so they are approximated by using compliant springs. Determining spring compliance is dependent on certain test information. For example:

An acoustic sensitivity test requires that the test piece be dynamically isolated from ground by at least one order of magnitude. (Test piece should be at least ten (10) times stiffer than the compliant spring whenever possible). Isopads (soft rubber pads) suffice for this requirement, since isopad stiffness is typically well below $1/10^{\text{th}}$ of the test piece stiffness.

A free-free boundary condition in lab can include but is not limited to the following suggestions:

4.1.1.3.1 Hanging the test piece from bungee cords or coil springs. The test piece shall be secured appropriately and the loading limits shall not be exceeded.

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4.1.1.3.2 For low frequency (0 Hz to 64 Hz) trimmed body or body structure testing, mount the test piece on pneumatic isolators. Due to practical reasons, it is acceptable to have the highest rigid body mode as high as $\frac{1}{3}$ of the lowest flexural body mode.

4.1.1.3.3 For high frequency (20 Hz to 800 Hz) trimmed body or body structure testing, place the test piece on lightweight damped material. For example, isopads. The test piece should be mounted so that the highest system rigid body mode natural frequency is at most $\frac{1}{10}$ th of the lowest flexural natural frequency of the component.

The first natural frequency of the free-free mounting system should be determined with a mass equal to that of the component attached to it. This is because fixture resonant frequencies are inversely proportional to the square root of the mass. ^{Note 1}

4.1.1.3.4 For some component body attachment point testing a free-free condition may imply a full vehicle, on its wheels, with the component removed. For example, a wiper motor attachment may be tested in this condition.

4.1.2 Component Preparation.

4.1.2.1 If the component being evaluated features a radiator, coolant bottle, fuel tank etc., it shall be filled to the desired level per the evaluation procedure.

4.1.2.2 If the component is adjustable (steering column, seat, etc.), set it to the nominal position in all adjustable directions unless otherwise specified in the evaluation procedure.

4.1.2.3 The component (steering column, suspension, powertrain, etc.) should not be bound up or restrained in a way that is not intended. This may add nonlinear constraints to the system.

4.1.2.4 Any part of the component that rattles shall be secured.

4.1.2.5 In the case of sound pressure measurement, ensure vehicle cavity is sealed (windows up, doors closed, cracks taped, etc.)

4.1.2.6 The test piece temperature shall be at equilibrium with the ambient temperature. (See 4.2.1.)

4.1.3 Verify Instrument Calibration.

4.1.3.1 Verify Transducer System Calibration. See GMW14172.

4.1.3.2 Verify Acquisition System Calibration. The DAS calibration shall be periodically verified by the appropriate instrumentation personnel.

4.2 Conditions.

4.2.1 Environmental Conditions. The ambient temperature should be between 18 °C and 29 °C and temperatures should not vary more than 6 °C during a given test unless otherwise specified.

4.2.2 Test Conditions. Deviations from the requirements of this standard shall have been agreed upon. Such requirements shall be specified on component drawings, test certificates, reports, etc.

4.3 Instructions. Typically, the cable for the input force should be connected to Channel 1 of the analyzer or front end and the response channels should begin with Channel 2.

4.3.1 Measurement Location - General.

4.3.1.1 The measurement locations (input force and output acceleration) should be points on the component where all the modes of interest are captured.

4.3.1.2 Transducer Mounting. Vibration transducers (accelerometers, strain gages, etc.) should be mounted to a flat surface on the test structure using the appropriate adhesive (see Appendix B). For consistency, it is advised that measurement coordinate axes adhere to standard General Motors drafting vehicle coordinates, i.e.,

- + X = longitudinal/rearward.
- + Y = lateral/right hand rule.
- + Z = vertical/upward.

Microphones should be mounted using a microphone stand, or a microphone hanger.

Note: If the results of this test are used for modal analysis, geometry shall be measured. Record the relative locations and orientations of each response transducer with respect to the global vehicle coordinate system. An example transducer location/orientation recording sheet is contained in Appendix D.

4.3.1.3 Measurement Location – Attachment Stiffness Measurements. In the case of attachment stiffness measurements, the input force and response should be measured only at the attachments of interest. The

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coordinate axis used should be measured relative to the bushing coordinate system of the attachment being measured. When possible the global coordinate system should be used to identify the direction of the measurement. Care should be taken to document and label the measurements with photos so direction of the measurement can be identified once the test is complete.

4.3.2 Impact Hammer Testing. Refer to “The Strengths of Impact Testing”, and “Weakness of Impact Testing” highlighting the strengths and weaknesses of impact testing (see 2.3).

4.3.2.1 Typical Acquisition Parameters. The following acquisition parameters are recommended but may vary depending on the dynamics of the component being tested and the desired frequency span and resolution.

- Trigger 10% to 50% slope channel. Sign of the slope may vary depending on transducer type and data acquisition system.
- 1% (of time block) trigger delay (pre-trigger) for all channels. ^{Note 2}
- Capture enough time for the event to be completely observed in a Uniform Window. ^{Note 3}
- If event cannot be completely observed, use Force/Exponential Windows. ^{Note 3}
- AC Coupled (1 Hz high pass filter).
- Six (6) Averages ^{Note 4} (minimum).
- Enable overload detection.

4.3.2.2 Impacting the Structure.

4.3.2.2.1 Force Levels. Force levels should be used that result in successive impacts producing the same driving point FRF. This indicates that the structure is responding in a linear fashion (see Appendix F, F2.4). If the driving point FRF from successive impacts produces different FRFs, then the input force level should be changed, generally decreased. Refer to “Structural Impact Testing Force Spectra” for additional information (see 2.3).

4.3.2.2.2 Hammer Impacts. Hammer impacts should be at a level that is appropriate to the size of hammer used (mini-sledge for large component/large force level, small hammer for small component/small force level, etc.)

4.3.2.2.3 Setting Dynamic Ranges. Channel gain levels. Range should be set such that at least half of the Analog-to-Digital Conversion (ADC) range is utilized. This is usually done through an autoranging process of the measurement channels.

4.3.2.2.4 Double Hits. Hammer impacts should also be performed quickly enough so that double hits do not occur. Double hits occur under two (2) circumstances:

- When the impact hammer is too heavy.
- When the structure is too compliant. This happens because the structure rebounds and makes contact with the hammer before the hammer is moved away from the structure.

Double hits can be observed in the force time domain trace as two (2) (or more) pulses. This causes multiple decaying responses. Double hits can also be observed as holes or dropouts in the input (force) autopower spectrum. Windows **will not** correct for double hits. Data containing double hits should be deleted and re-acquired.

4.3.2.2.5 Hammer Tip Selection. Impact the structure and observe the input force spectrum. If the input force spectrum rolls off by more than 20 dB over the frequency range of interest, then a harder hammer tip should be used. If the input force spectrum rolls off by less than 2 dB over the frequency range of interest, then a softer hammer tip should be used for better input characteristics. ^{Note 5}

If the hammer tip is changed, it is necessary to re-verify the hammer calibration and verify the input range.

4.3.2.3 Data Acquisition.

4.3.2.3.1 Observe the windowed time signal of the accelerometer. The acceleration signal should decay to no greater than approximately 1% of the full scale value. If the signal has not decayed to this level, increase the time constant associated with the exponential window on Channel 2. If the signal has effectively decayed by the end of the time segment, the time constant can be reduced. Window length can be increased as an alternative to adjusting the exponential window time constant. If there is enough structural decay such that the time signal dies out before the end of the window, a uniform window should be used on the acceleration signal. In general, use a uniform window whenever possible.

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4.3.2.3.2 Acquire the data carefully. The hammer hits should be consistent and repeatable. The direction of hit should be the same for each hit, which is more easily achievable if the surface is flat and big enough to hit properly. In addition, the strength of each hit should be consistent. After the structure has been impacted and the measurement is complete, place your hand on the structure to damp out any residual vibrations before the next impact is made. (If your hand can sense vibration, the accelerometer will sense it as well.) Do not strike the structure again until the vibrations cannot be felt. The operator should verify that no rattles exist in the system. If there are any abnormalities in the data acquisition (e.g., double hits) restart the measurement.

4.3.2.3.3 Verify the measurement. Check the FRF magnitude and the measurement coherence. Refer to the following paragraphs in this section and Appendix F for more information.

The measurement coherence should generally be above 0.97 for measurements with good signal to noise ratio. Abrupt dips in coherence can be expected at frequencies where there is low signal to noise associated with the measurements. This typically occurs at frequencies of minimal response or at frequencies where there is minimal excitation energy.

A sinusoidal appearance in the coherence plot may indicate a double hit during the data acquisition. Generally low values of coherence (e.g., 0.7) within a frequency band may indicate system nonlinearities.

The FRF magnitude typically has both peaks and valleys, however the shape should be relatively smooth with minimal deviations (e.g., no hashy ripples in the measurement). A sinusoidal shape for the FRF magnitude may also indicate a double hit.

4.3.2.3.4 If the data quality is judged to be adequate, save the trace to a file, and record the impact location, direction, file name and remarks on the test documentation form.

4.3.3 Hand Held Shaker Testing.

4.3.3.1 Typical Acquisition Parameters. The following acquisition parameters are recommended but may vary depending on the dynamics of the component being tested and the desired frequency span and resolution.

- 50% Overlap.
- Hanning Window.
- AC Coupled (1 Hz high pass filter).
- Sixty (60) Averages.
- Resolution ≤ 1 Hz.
- Enable Overload Detection.

4.3.3.2 Force Input. A sinusoidal force input is used as the excitation between the upper and lower frequency limits of interest. The force shall be applied in a continuous UP/DOWN mode. Time for each run shall be at least 15 s. Force levels should be used that result in successive FRFs producing the same driving point FRF. This indicates that the structure is responding in a linear fashion (see Appendix F, F2.4). If the driving point FRF from successive measurements produces different FRFs, then the input force level should be changed, generally decreased.

4.3.3.3 Setting Dynamic Ranges. Channel gain levels. Range should be set such that at least half of the ADC range is utilized. This is usually done through an autoranging process of the measurement channels.

4.3.3.4 Data Acquisition.

4.3.3.4.1 Acquire the data carefully. The operator should verify that no rattles exist in the system. If there are any abnormalities in the data acquisition restart the measurement.

4.3.3.4.2 Verify the measurement. Check the FRF magnitude and the measurement coherence. Refer to the following paragraphs in this section and Appendix F for more information.

The measurement coherence should generally be above 0.97 for measurements with good signal to noise ratio. Abrupt dips in coherence can be expected at frequencies where there is low signal to noise associated with the measurements. This typically occurs at frequencies of minimal response or at frequencies where there is minimal excitation energy.

The FRF magnitude typically has both peaks and valleys, however the shape should be relatively smooth with minimal deviations (e.g., no hashy ripples in the measurement). A sinusoidal shape for the FRF magnitude may also indicate something erroneous.

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4.3.3.4.3 If the data quality is judged to be adequate, save the trace to a file, and record the impact location, direction, file name and remarks on the test documentation form.

4.3.4 General Multiple Input/Response Measurement Practices.

4.3.4.1 Ideally, mount response transducers at all measurement locations prior to test. This will eliminate operator interaction with the structure and also eliminate changing the mass distribution during testing. If pre-mounting all transducers is not possible and transducer roving is required, minimize mass loading effects by placing pairs of transducers in sets in symmetric locations. If more than two (2) sets are used, spread the sets along the length of the structure.

4.3.4.2 Minimize total elapsed time for data acquisition. Do not discontinue testing unless there is an equipment or software problem. If the problem causes a (more than) 1 h delay, the entire data acquisition sequence should be repeated.

4.3.5 Averaging Methods.

4.3.5.1 In many cases, the FRFs at the geometry center of a fixture or an existing vehicle component cannot be directly measured. Appendix G includes several averaging methods and their corresponding test techniques to follow.

5 Data

5.1 Calculations. FRFs are complex numbers. Therefore, they contain real and imaginary information. These can be displayed in several different ways. The following are some common examples:

5.1.1 Real and imaginary. The imaginary portion of an accelerance FRF contains normal mode information, which can be used to determine mode natural frequency as well as response location amplitude and phase relative to the excitation.

5.1.2 Amplitude and phase. Amplitude is the absolute value of the FRF, and phase is the angle. Data is commonly displayed in this format for mobility requirements. Although, phase is usually disregarded for this type of measurement. Amplitude can be displayed in three (3) commonly used formats:

5.1.2.1 Absolute Scale. The square root of the sum of the squares of the real and imaginary portions.

5.1.2.2 Log Scale. Typically log base ten.

5.1.2.3 Decibel Scale. A version of the log scale. Defined as ten (10) times the log base 10 of the squared ratio between an absolute and reference value.

Note: If the ratio is in power units, it shall not be squared. Acoustic sensitivity FRFs feature a 20 $\mu\text{Pa}/\text{N}$ reference value.

5.2 Interpretation of Results. Reference referring procedure(s).

5.3 Test Documentation.

5.3.1 Data Presentation. Data presentation is usually in the form of a plotted FRF. Most component specifications are set based on frequency targets. The FRF should contain the information necessary to determine if the component has met its dynamic specification.

All FRF plots shall include the following information.

5.3.1.1 Test Engineer's name (or initials), phone number and organization.

5.3.1.2 Date.

5.3.1.3 Type of Measurement (Accelerance, Mobility, etc.)

5.3.1.4 Component, Subsystem, or Vehicle Identification: A brief description of the design level of component, subsystem, or vehicle shall be included, preferably in the test name (see 5.3.1.5). A more detailed description with data acquisition parameters shall be included in the test documentation form.

5.3.1.5 Project name and test name. The project name shall be specified such that it includes information of interest such as the vehicle or component.

5.3.1.6 Axes labels shall be as follows:

- **x:** Frequency (Hz)
- **y:** Amplitude with units (and dB reference, if applicable)

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5.3.1.7 Force excitation location and direction.

5.3.1.8 Response location and direction.

5.3.2 Setup Documentation. Photos should be taken of all attachment locations measured during drive point FRF measurements. When the excitation and response are not measured in the global coordinate system document the directions in a photo. Photos should be stored with the project for reference.

6 Safety

This standard may involve hazardous materials, operations, and equipment. This standard does not propose to address all the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

7 Notes

7.1 Glossary.

7.1.1 Vehicle Construction Types.

- A. **Body-Frame Integral (BFI):** The primary structure for a BFI vehicle is provided by the body. In some cases, this primary structure is complemented by chassis structure at one or both ends of the vehicle (i.e., cradles or cross-members which may be rigidly attached to the body or attached using isolators). The front and rear chassis systems are typically structurally coupled via the body, except in certain cases of driveline configuration such as the drive shaft assembly in a torque tube system (e.g., Corvette platform).
- B. **Body-On-Frame (BOF):** The structure for a BOF vehicle is provided by both the body and frame. The body or cab is attached to the frame at discreet locations using body mounts (isolators). The suspension, powertrain and driveline are typically attached to the frame. If the product is a conventional pickup, the pickup box is generally rigidly attached to the frame structure only. If the product is an Ultimate Utility Vehicle (UUV), the pickup box is typically integral to the body and also attached to the frame using body mounts (isolators). The Front End Sheet Metal (FESM) can be integral to the body (generally welded) or non-integral (bolted to the body), isolators or body mounts also connect the FESM to the frame.

7.1.2 Body Configurations.

- A. **Body-In-White (BIW):** The configuration that leaves the paint booth or the basic structural shell of the vehicle including: floor pan, front of dash, door side ring, front radiator support, doors, FESM and deck lid/hatch prior to topcoat paint and trim.
- B. **Body Structure:**
 - 1. **BIW** with non-structural closures removed.
Note: A Body Structure typically does not include the hood, doors, deck lid/hatch or bolt-on fender outers unless these are assumed to be structural items. The use of closures as structural elements should be defined in the requirements for the vehicle program, and taken into consideration during development and validation testing.
 - 2. **Paint**, inclusive of Electro-deposition Primer (ELPO); E-Coat, and other properly cured sealers and adhesive(s).
 - 3. **Properly Bonded Fixed Glass**, such as windshield, backlight or fixed quarter windows, with any trim needed for glass installation and retention.
 - 4. **All Non-Isolated Structural Bolt-On Parts.** The specific parts included will vary depending on the vehicle design. Examples include: hard-mounted cradles (with braces if appropriate), non-integral FESM, Instrument Panel (IP) beam, pedal support bracket(s), bolt-on radiator supports, rear cross-members, diagonal braces, bumper beam(s) and tunnel straps.
 - 5. **Sunroof Module(s).** Generally included if anticipated to contribute to the structural stiffness.

7.1.3 Chassis Configurations.

- A. **Chassis Structure (BFI):** A cradle or cross-member that is attached to the body structure directly (i.e., non-isolated or hard-mounted) or by using isolators or mounts.

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- B. **Chassis Structure (BOF):** Frame with non-isolated bolt-on parts. The specific parts included will vary depending on the vehicle design. Examples include: transmission cross-member, spare tire support structure, Original Equipment Manufacturer (OEM) trailer hitch and bumpers.
- C. **Chassis Structure (BOF) Plus Pickup Box:** The Chassis Structure (BOF) Plus Pickup Box is defined as including the Chassis Structure (BOF) together with the pickup box structure.

7.1.4 Trimmed Body Configurations.

- A. **Trimmed Body (BFI):** A full vehicle without chassis, powertrain, exhaust or suspension. The Trimmed Body includes swing metal, reservoirs, body-mounted fuel tank, batteries, glass, seats, doors, interior trim, IP and console, rear window trim panel, acoustic treatments and other items that add mass to the body structure. The fuel tank should be full and all other fluids should be filled to the manufacturer recommended specification.

Note: A trimmed body does not include isolated cradles, but does include cradle bolt stabilizer brackets.

- B. **Trimmed Body (BOF):** The Trimmed Body (BOF) is defined as the collection of sub-assemblies supported by the Body Structure when separated from the frame/chassis at the body mounts. Both integral and non-integral (bolt-on) FESM should be included, together with a Condenser, Radiator, Fan Module (CRFM) if all mounts are to the body or FESM. The fuel tank should be full and all other fluids should be filled to the manufacturer recommended specification.
- C. **Trimmed Body (BOF) Without FESM:** The Trimmed Body without FESM configuration applies only to products with non-integral (bolt-on) FESM. The configuration is achieved by removing the FESM from the Trimmed Body.

7.1.5 Trimmed Chassis Configuration.

- A. **Trimmed Chassis Structure (BFI):** The Trimmed Chassis Structure (BFI) is defined as including the Chassis Structure together with all isolated or non-isolated components mounted to the structure, excluding the Body Structure, powertrain, driveline components, CRFM or suspension. Where practical, the portion of the powertrain mounts rigidly attached to the chassis structure should be included.
- B. **Trimmed Chassis (BOF):** The Trimmed Chassis (BOF) is defined as the components remaining when the Trimmed Body is separated and removed at the body mounts, and the pickup box if present, is separated and removed at the frame-to-pickup box attachments.
- C. **Trimmed Chassis Structure (BOF):** The Trimmed Chassis Structure (BOF) is defined as the Trimmed Chassis with the powertrain, driveline components and suspension removed. Where practical, the portion of the powertrain mounts rigidly attached to the frame structure should be included, i.e., frame side brackets.

7.1.6 Trimmed Structure Configurations.

- A. **Trimmed Structure (BFI):** The Trimmed Structure (BFI) is defined as the trimmed body attached to one or more Trimmed Chassis Structure assemblies (powertrain, driveline, exhaust and suspension are excluded). Both isolated and non-isolated cradles and cross-members should be included.
- B. **The CRFM (with fluid)** should be included for all cases including where the CRFM is mounted to both the Body Structure and the Chassis Structure, and thus was not part of either the Trimmed Body or Trimmed Chassis Structure.
- C. **Trimmed Structure (BOF):** The Trimmed Structure (BOF) is defined as the Trimmed Body attached to one or more Trimmed Chassis Structure assemblies (powertrain, driveline, exhaust and suspension are excluded). Bumper beams, OEM trailer hitches and pickup boxes are to be included.

7.1.7 Full Vehicle Configurations.

- A. **Full Vehicle (BFI/BOF):** Complete vehicle with a full fuel tank and all other fluids filled to the manufacturer recommended specification.

7.1.8 Isolators, Mounts and Bushings.

- A. **Elastic Center of an Isolator:** A point or points described as being the effective center of the rubber isolator (or hydraulic fluid). If the actual rubber or fluid were to be replaced by a theoretical spring or springs, the "elastic center" is the location where that spring would act. There may be a separate "elastic center" for each degree of freedom, and it should be noted that the elastic center can, in some cases,

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