GM	WORLDWIDE ENGINEERING STANDARDS	Test Procedure	GMW15189

Full Vehicle Multiaxial Inertially-Reacted Real-Time Laboratory Road Simulation Structural Durability Test

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. This procedure evaluates the structural durability of a vehicle by subjecting it to real time load and displacement profiles. These profiles are designed and developed to represent a road durability test at the proving ground. This procedure describes the test development process and durability test execution.

1.2 Applicability.

1.2.1 This procedure can be used to develop or validate the structural durability of a vehicle and its subsystems which are sensitive to road input and driveline torque reactions. These subsystems typically include chassis, body and driveline mounting structures. Components which are not sensitive to fatigue damage from road inputs may not experience the same level of correlation.

1.2.2 This procedure does not provide a total vehicle durability test. No powertrain or electrical system operation is included. Degradation modes of rotating components such as wheel bearings are not accurately reproduced. Environmental factors such as elevated temperature, humidity and dust are generally not included, except for special exposures for specific components. Degradation modes related to exposure time are usually not accurately reproduced.

1.2.3 This procedure can be used for passenger cars, Sport Utility Vehicle (SUV) or trucks. The Gross Vehicle Weight (GVW) of the vehicle determines which road simulator can be used. For example, a road simulator the: MTS 329 Light Truck (LT) (see Appendix G, Figure G1 and Figure G2) can be used for vehicles up to 5500 kg GVW, or a MTS 329 Passenger Car (PC) road simulator (see Appendix G, Figure G3 and Figure G4) can be used for vehicles up to 2700 kg GVW. Under some conditions, certain road events still may not be fully achievable even if these mass capacities are adhered to. If another type of road simulator is used, the user must verify that the mass capacity, force capability and displacement capability is sufficient to evaluate the test vehicle.

1.3 Remarks.

1.3.1 This procedure is primarily intended for laboratory test engineers and technicians. It does not cover every possible aspect of road simulation testing, and is not to be used as a standalone procedure. Successful road simulation testing inherently requires engineering judgment, and the ability to recognize and solve problems which are unexpected and/or complex.

1.3.2 The process diagram for real time project planning is located in Appendix A, Figure A1. The process diagram for a full vehicle road simulation test is located in Appendix B, Figure B1.

1.3.3 This procedure simulates road induced loading. These loads induce fatigue, interference and wear on the vehicle structure and subsystems.

1.3.4 This procedure reproduces one test equivalent of fatigue exposure in less time than it takes to perform the equivalent road durability test (see 3.4 for test time estimates).

1.3.5 This procedure typically requires a Road Load Data Acquisition (RLDA) or Virtual Road Load Data Acquisition (vRLDA), drive file development and correlation evaluation. The time required can be reduced if previously developed drive files can be used or modified, but this approach may result in reduced correlation to the proving ground road durability test.

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1.3.6 This procedure refers to other procedures which contain detailed information that is closely tied to specific equipment or software. These procedures are intended to be used with guidance from experienced personnel (see 2.2 for details).

1.3.7 This procedure is intended to produce a laboratory road simulation for a specific vehicle configuration. A set of drive files will closely reproduce responses from remote parameter and correlation transducers for a vehicle with a specific combination of ballast condition, ballast position, body stiffness distribution and chassis components. If any of these characteristics are changed, the laboratory to road correlation may be reduced. Experience has shown that the reduced correlation is minimized under some conditions, such as a small change in shock absorber damping or body stiffness distribution. If the areas of interest are remote from the suspension to body interfaces, the risk can be further reduced.

2 References

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

2.1 External Standards/Specifications.

None

2.2 GM Standards/Specifications.

GMW3425	GMW15222	GMW15231	GMW15245
GMW3428	GMW15223	GMW15232	GMW15268
GMW14048 (ID)	GMW15224	GMW15235	GMW15269
GMW15019 (ID)	GMW15225	GMW15240	GMW15445
GMW15219	GMW15226	GMW15242	GMW15980
GMW15220 (ID)	GMW15227	GMW15243	

(ID) = This standard is limited to internal distribution within General Motors and shall not be distributed outside this company. Contact the GM Lead Engineer for further instructions.

2.3 Additional References.

- Component Technical Specification (CTS)
- Durability Test Logbook (or equivalent)
- MTS Systems Corporation: Remote Parameter Control (RPC) Pro Software (Reference Manuals)
- Subsystem Technical Specification (SSTS)
- Test Development Logbook (or equivalent)
- Test Site Logbook (or equivalent)

2.3.1 Technical Specifications. This includes the Subsystem Technical Specification (SSTS), which defines the subsystem level testing and reliability requirements of the chassis assembly, and the Component Technical Specification (CTS), which defines the component level testing and reliability requirements of the component.

2.3.2 Release Documentation. This includes any documents which show product assembly, orientation, fit, assembly specifications, etc., for the system being evaluated.

3 Resources

Note: This procedure refers to typical facilities, equipment and software available in General Motors North America (GMNA). Alternate resources may be used, providing they meet the requirements specified in this document.

3.1 Facilities. This procedure assumes adequate physical testing facilities and infrastructure for full vehicle road simulation are available. This includes a bedplate (minimum size = 5 m x 9 m) with sufficient reaction mass.

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

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.

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3.2 Equipment. This procedure assumes adequate physical equipment for full vehicle road simulation is available and installed. This includes the road simulator (with associated servo-hydraulic controls) and Test Site Controller (TSC). The following sections provide a partial list of the equipment required.

3.2.1 Hub Adapters. Hub adapters are used to mount the spindle of the vehicle to the road simulator. The required information (number of lugs, bolt circle diameter, pilot hole diameter and wheel offset) should be given to the fixture designer early in the test planning stage, to allow adequate time for fixtures to be built.

3.2.2 Powertrain Torque Input Fixture. If powertrain torque input is to be simulated, the engine/transmission drawings are required to have fixtures built to attach the torque input to the engine/transmission. This fixture provides representative loads to the mounts, but does not load any axles or driveshafts. An example installation is shown in Appendix G, Figure G5, Figure G6, Figure G7 and Figure G8.

3.2.3 Rear Axle Torque Input Fixture. If rear axle torque input is to be simulated, the rear axle drawings are required to build fixtures to fasten the torque input to the rear axle. This fixture provides representative loads to the axle/differential housing attachments, but does not load the axles or driveshafts. In this procedure, the term "rear axle" is generically used to refer to a solid rear axle or independent rear suspension differential. An example installation is shown in Appendix G, Figure G5, Figure G6, Figure G9 and Figure G10.

3.2.4 Brake Pressure Intensifier. An air over oil pressure intensifier system is required for the actuation of the brake system during braking events. Refer to GMW15227 for brake system modifications and brake pressure intensifier setup.

3.2.5 Shock Absorber/Damper and Suspension Bushing Cooling. A system to cool the shock absorbers/dampers is required to keep them from overheating. GMW15226 describes a typical compressed air cooling system. An alternative method of cooling is to install water jackets around the shock absorbers/dampers. Suspension bushings may require cooling as well. Airflow amplifiers, referenced in GMW15226, can be used to provide cooling for the suspension bushings.

Additionally, many vehicle program teams also now require "cooling laps" (or road surfaces with limited dynamic content) between laps of rough road/blocks/pave.

3.2.6 Transducers. Remote Parameter Control (RPC) transducers, correlation transducers and associated signal conditioning are required if they are not provided with the RLDA vehicle. Typical RPC transducers are listed in GMW15268.

3.3 Test Vehicle/Test Piece.

3.3.1 Test Vehicle Overview. At a minimum, each test vehicle must have:

- Operational suspension with representative components
- Option content and vehicle ballast required to meet project goals defined by the test requester (see 4.1.7).

3.3.2 Operational Powertrains. Operational powertrains are usually not required in the durability test vehicle, but are needed for the RLDA vehicle. If a mini RLDA is to be performed, or if events are to be run on the proving ground road system, an operational powertrain is also required. The powertrain used in each test vehicle must include representative mass and mounts.

3.4 Test Time. The following is an estimate of the amount of time needed to perform this procedure. These time estimates are approximate. Actual times may vary considerably depending on availability of test vehicles, replacement parts, actual readiness of test vehicles upon receipt, running multiple samples/lives, etc. These times include preparation, planned downtime, actual test, and data analysis to calculate a total calendar time. Report writing is not included.

vRLDA (if needed):	4 to 8 weeks
RLDA (if needed):	8 to 12 weeks
Data Processing/Development:	4 to 8 weeks
Durability Test (per life):	10 to 30 days

3.5 Test Required Information. Not applicable.

3.6 Personnel/Skills. The project team must include members who are skilled in performing the critical tasks listed. At least one member of the team must be a person with previous road simulation experience. A single person may perform several roles.

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3.6.1 Test Material Acquisition. An operational RLDA/test development vehicle containing components of a level consistent with the project plan must be obtained. If the test development vehicle is not being used for durability testing, a second vehicle is also required. If existing drive files can be used, a RLDA/test development vehicle may not be required.

3.6.2 Vehicle Content Verification. The test vehicle content must be verified, including a visual inspection. This includes identifying information (such as part numbers) and measured engineering properties for key components.

3.6.3 Correlation Transducer Selection. In addition to RPC transducers, meaningful correlation transducers should be selected (4.1.6.2 describes the desired attributes of these transducers). If the channel count must be minimized, these transducers may have to be limited.

3.6.4 Logbook Documentation. A test development logbook (or equivalent) and a durability test logbook (or equivalent) should be kept. The test site logbook (or equivalent) should be updated with any maintenance operations or changes made to the test site during the course of the project.

3.6.5 Test Fixture Design. If existing test fixtures cannot be used, new fixtures must be designed and built. This typically includes wheel hub adapters and torque input fixtures.

3.6.6 Data Processing. Data integrity checks and data editing are required. This requires a thorough understanding of the RPC process and fatigue damage theory. See GMW15269 for some reference material on fatigue theory.

3.6.7 Instrumentation Setup. The transducers and associated instrumentation must be correctly installed and calibrated to ensure a successful test.

3.6.8 Hydraulic Maintenance. The hydraulic system must be checked prior to starting test development, and maintained throughout the test.

3.6.9 Loop Tuning. The test rig must be properly tuned to provide a stable and repeatable servo-hydraulic control loop.

3.6.10 Test Development. Successful test development requires a thorough understanding of the RPC iteration process, including time and frequency domain signal interpretation.

4 Procedure

4.1 Preparation.

4.1.1 RLDA Process. The RLDA or vRLDA processes are not defined in this procedure. Refer to the applicable RLDA procedure (GMW15019) or vRLDA group for documentation or specific details.

Note: The ballast condition(s) collected during the RLDA should comply with GMW15445. The ballast condition(s) used in the laboratory should match those used during the RLDA.

4.1.2 Test Checklist. There is a significant amount of preparation and attention to detail required when conducting a road simulation test. It is very easy to miss an important step unless a detailed checklist is strictly adhered to. It is critical that both experienced and inexperienced engineers use a checklist for any full vehicle road simulation test (customize the checklist shown in Appendix D, Table D1 as required).

4.1.3 Process Overview. The process diagram for a typical test development is in Appendix C, Figure C1. Refer to GMW15232 for a generic data processing flow chart.

4.1.4 Test Planning and Scheduling. Create a test plan that details the timeline of events that are required to execute this procedure. This may include fixture design or build, data editing, test system preparation, drive file development and durability test execution. Each activity should be listed on a timeline to identify sequential dependencies.

4.1.4.1 Timing. The test requester and test laboratory must agree on the scope of work and required delivery dates.

4.1.4.2 Test Purpose. The test requester must define if this test will be used for product development or validation.

4.1.4.3 Durability Schedule. The test requester must define an appropriate road durability schedule to use.

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4.1.4.4 Test Vehicles. Determine the number of test vehicles and number of test lives required to meet validation and timing requirements. Typically, this is one vehicle tested to a minimum of two lives and a maximum of three lives.

4.1.5 Choose Source for Drive Files.

4.1.5.1 Existing Drive File Applicability. The test requester and test laboratory must decide whether to use existing drive files, or to create new ones from measured road response or vRLDA data. If the drive files from a similar vehicle can be used, a RLDA is not required. Some experimentation and analysis are usually required to determine if the drive files can be used as is, or require redeveloping from existing road response data.

The fidelity of the test correlation should be proportional to the vehicle design level. Therefore, for development testing, existing drive files from a vehicle with similar mass distribution and suspension design may be sufficient to meet requirements. Use existing drive files only if they will produce adequate correlation. This decision can be made using vehicle content information from both the current test vehicle and the vehicle for which drive files were developed. The following parameters should be considered:

- Suspension configuration (four link, short-long arm, twist beam, etc.)
- Suspension bushing rate
- Vehicle mass for all test ballast conditions
- Stabilizer bar stiffness
- Suspension travel to jounce contact
- Tire size, stiffness and wheel diameter
- Unsprung mass
- Spring rate
- Shock absorber damping rates
- Wheelbase
- Track width
- Ride control algorithms
- Brake system (Antilock Brake System (ABS) or non-ABS)
- Powertrain mount locations and rates
- Driveline (All Wheel Drive (AWD), Front Wheel Drive (FWD) or Rear Wheel Drive (RWD))
- Engines used, including torque curves
- Transmissions used, including gear ratio, final drive ratio, and torque management algorithms

It is possible that some existing drive files may be usable despite differences in vehicle configurations. The information listed above can help an experienced test engineer determine whether the drive files can be used. Usually, existing drive files will need some adjustment before they can be used on a different vehicle.

4.1.5.2 Drive Files from Other Test Sites. Drive files developed on one road simulator cannot be directly played out on a different road simulator. Consult an experienced test engineer before recreating drive files at an alternate site.

4.1.5.3 Synthetic Road Data. If a valid math model exists, and the proving ground has been digitally characterized, it may be possible to generate synthetic real time data using a vRLDA. If this option is chosen, care must be taken to ensure that no significant road events are being omitted. vRLDA does not adequately characterize any events where the vehicle loses contact with the road surface (some driveways, panic brake stops, chatter bump stops, antilock braking or traction control events). Future Road-Lab-Math development will target these types of road events.

4.1.5.4 New Drive Files. If conditions in 4.1.5.1 through 4.1.5.3 cannot be met, conduct a RLDA and create new drive files. If existing drive files can be used without adjustment, continue with 4.1.7.

4.1.6 Plan RLDA. A RLDA can either include only the transducers needed to quantify correlation and/or all transducers needed to develop drive files. The decision regarding drive file source directs the type of RLDA required. If new drive files will be developed, the planning outlined in 4.1.6.1 is required. Otherwise, continue with 4.1.6.2.

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4.1.6.1 RPC Transducers. RPC transducers are required for test development. Refer to GMW15268 for a list of typical RPC transducers.

4.1.6.2 Correlation Transducers. Correlation transducer selection should be made with the intent of providing information regarding the accuracy of the road simulation at locations other than the RPC transducers. They can also be used as alternative RPC transducers if the chosen RPC transducers do not provide the expected performance or are damaged. Correlation transducers which have been previously used include: shock tower vertical load, upper spring seat vertical load, ball joint lateral load, ball joint longitudinal load, strain gages, trailing arm axial load, etc.

4.1.6.3 Additional Transducers. There are several additional transducers that should be collected during the RLDA to provide understanding of the data set. These include vehicle speed, brake activation switch and steer angle. Additionally, if the vehicle is equipped with electronic level control or electrically variable shocks, these parameters (e.g., pressure, voltage, etc.,) need to be recorded and subsequently controlled in the test laboratory.

4.1.6.4 RLDA Road Events. Select the road events (also referred to as durability modules, schedules or maneuvers) to record. For an example of typical road events collected, refer to GMW3425, GMW3428, or GMW15980. A road event may be omitted only if the areas of interest are not affected. Road events not achievable on the road simulator still should be measured during the RLDA. To avoid invalidating the road response data, do not perform bumper impact testing, run any air bag immunity events or conduct any other type of destructive testing on the RLDA vehicle. The most severe road events should be run first, in order to minimize changing the vehicle response during the RLDA, or being different between the road and lab.

4.1.7 Gate Review - Project Plan. Obtain test requester sign off on the project plan, road events to record, channel list and vehicle content/design level.

4.2 Conditions.

4.2.1 Environmental Conditions. Unless otherwise specified, the typical environmental conditions for this procedure are the temperature, humidity and pressure at the major test facility. Unless otherwise noted, these conditions are typically 22 °C to 25 °C, relative humidity of 40% to 60%, and atmospheric pressure equivalent to the local barometric pressure.

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.

4.2.2.1 Shock Absorber/Damper Cooling. A shock absorber/damper cooling system needs to be operational whenever the road simulator is used for continuous testing. Reference GMW15226.

4.3 Instructions.

4.3.1 Edit Data.

4.3.1.1 Data Verification. The road response data received by the laboratory should be checked and prepped to ensure that it is in the standard laboratory configuration and free from anomalies. GMW15243 details the data validation process, and gives typical examples of data anomalies. Ball joint load data should be steer angle corrected for laboratory use, unless the road simulator has a steering degree of freedom. GMW15222 details the steer angle correction process.

4.3.1.2 Standard Directory Structure. Before data editing begins, a directory structure should be set up for all of the files that will be created. All critical files (files that cannot be easily recreated) should be backed up on a separate storage device.

4.3.1.3 Baseline Fatigue Damage. The baseline fatigue damage represents the overall fatigue damage for the RPC and correlation transducers for the road response data (after data verification). The baseline for a given channel represents the sum of the calculated damage from each road event multiplied by the repetitions specified in the test procedure. Refer to GMW15269 for details on this calculation, including instructions for using the available computer programs.

4.3.1.3.1 Calculation Considerations. When calculating a baseline fatigue damage, consideration must be given to the way the road events will be separated for the test development. For example, if the braking events are developed as separate files from the acceleration events, the rainflow counting algorithm will count these events differently than if they were intermixed in a single file. Therefore, if they are separate files in the laboratory, they need to be separate files in the baseline calculation. Additionally, when using a Wheel Force Transducer (WFT) to collect road response data on a drive axle, both acceleration torque and brake torque are measured, but in the laboratory only the brake torque will exist. Therefore, the acceleration torque should be zeroed out in

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the road response data. Failure to implement these types of corrections will result in a misleading fatigue damage retention calculation. When these corrections are implemented, the baseline fatigue damage is referred to as the true baseline fatigue damage.

4.3.1.4 Eliminate Road Events. If a road event represents < 1% of the calculated fatigue damage for the overall test across all channels, and that road event does not contain a significant peak event (> 50% of the overall peak), it is typically eliminated from the laboratory durability test. Therefore, it need not be included in further editing steps. Be aware that if a component under evaluation is not instrumented, and cannot be represented by a transducer in the load path, it may not be advisable to remove certain road events even if the calculated fatigue damage is low (use engineering judgment). Additionally, pothole events are never eliminated from the test.

Any event that is not achievable on the road simulator would also be eliminated from the data editing process. At the request of the test engineer, with concurrence from the test requester, the content of the unachievable road events may be substituted into the durability test with synthetic files or executed on other laboratory or road tests.

Events typically not run on the full vehicle simulator include shipping simulation, Pothole Number three (3) and panic brake road events. Shipping is performed once at the start of the durability test on a transportation simulator. Pothole Number three (3) and the panic brake are usually performed on the road system, since those events are often not achievable on current versions of full vehicle road simulators, and have very low repeat counts. Note that even if these events can be achieved on the road simulator, the number of iterations required to develop them will likely exceed the number of repeats in a test. Therefore, if the test development vehicle is also the durability vehicle, this would not be desirable.

4.3.1.5 Data Editing Philosophies. The main reason for running a road simulation test is to shorten the time required to conduct durability testing. This requires meeting several potentially conflicting objectives:

- Reduce test time
- Retain sufficient test severity
- Physically realizable on the road simulator
- Accurate reproduction of the road events

Data editing to meet these objectives is accomplished by removing less severe sections of data from the road response files. Test severity is quantified by fatigue damage and/or pseudo fatigue damage calculations based on fatigue theory. It is evaluated by comparing the fatigue damage retained in the edited data with that calculated from the road response data. Both the test duration and retained fatigue damage must be considered when evaluating the success of editing.

4.3.1.6 Select the Data Editing Method(s). There are four main approaches to data editing (graphic, bulk, time compression and synthetic). Optimal editing methods for individual road events should be determined by an experienced test engineer.

4.3.1.7 Perform Graphic Editing. In the graphic data editing method, the operator views the road response data on the computer screen and uses a cursor to select sections of data for removal. This method is used for road events containing a few easily identifiable, non-damaging sections. These surfaces usually produce such high fatigue damage density that only the ends of the time history file need to be removed.

When graphically editing a transient event, it is recommended to keep 1 s to 2 s before and after each event. Consideration should be given for removal of extraneous data such as braking events after pothole strikes. The event must be reasonably centered in the editing window to prevent tapering routines from creating unrealistic or attenuated data. Refer to GMW15224 for details on this process. Sometimes these events are bulk edited (see 4.3.1.8) with the intention that the bulk editing process will pass them through unchanged. If this is done, a visual examination of the edited data is required to confirm the absence of any edit operations on critical portions of the event.

4.3.1.8 Execute Bulk Editing. Bulk data editing allows the user to automatically reduce the length of the road response data while retaining most of the fatigue damage. In this method, a computer program is used to compare data statistics with user defined thresholds to identify sections of data to be removed. It should be used only on files containing a few nonlinear vehicle responses. Some road events are also then graphically edited to remove specific non-damaging sections that may not be appropriately removed by the bulk edit process.

There is also software available that allows the data to be edited based on a fatigue damage timeline, and this

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technique can also be used (if available).

Although the computer program can make this process highly automated, it is recommended that the user reviews the comparative data statistics, fatigue damage comparisons and time history plots after bulk editing.

4.3.1.9 Time Compression. There are several road events that primarily contain low frequency lateral forces. These forces cause the vehicle to translate a distance much greater than the displacement capability of the road simulator. Therefore, when using inertial reaction, the difference between road simulator displacement capability and actual road event requirements must be addressed. The technique of time compression provides a solution. Time compression is a method of shortening the road response data by decimating or eliminating sampled data points. When the compressed file is played at the original sample rate, the event is executed faster than real time. That means the frequency spectrum of the event is shifted along the frequency axis. Inertial reaction forces increase in proportion to the square of frequency, and in direct proportion with displacement amplitude. Gain can be achieved by trading off the amplitude required to generate load with an increase in frequency. Refer to GMW15235 for time compression details.

4.3.1.9.1 Compress High G Lateral Event. Low frequency, high G lateral loading events contain frequency content that is outside the control bandwidth of the simulator. These events are modified by selecting a single lap from the road response data file. This lap is then event time compressed (94% to 98%), resulting in frequency content achievable within the lateral displacement available on the road simulator. Multipliers are then adjusted to account for the single lap file. It is critical to provide adequate pause between events to minimize unrealistic body roll. For more information on time compression, reference GMW15235.

4.3.1.9.2 Create Supplemental Lateral Files. When simulating a durability schedule on an inertially-reacted road simulator, the lateral damage into the vehicle will likely be lower than desired. One method to increase the lateral damage content is to create supplemental lateral files. These files represent the low speed turning maneuvers found during road events such as: City Traffic, Square Turns or Circle Turns. This is very similar to what is done for high G road events, but less compression is required. It is important to maintain the phase relationship between the lateral force and camber moment channels when creating these files. Refer to GMW15235 for details on this process.

4.3.1.10 Create Synthetic Body Torsion Events. Test development using low frequency accelerometer responses is typically very inaccurate. It is equally difficult to iterate to low frequency displacement responses with an inertially-reacted road simulator. Therefore, synthetic drive files are created for the torsion events (such as Driveways and Twist course) by directly programming the road profile as a displacement of the vertical actuator. These files are created based on track and wheelbase measurements input into a computer program, and then manually scaled to reproduce the desired torsion into the vehicle. The desired response files can also be created from vehicle responses from road events. Lateral, longitudinal, powertrain and rear axle drive file inputs are zero for these simulated events.

4.3.1.11 Create Braking Events. When developing a test for a road simulator, part of the editing objective is to remove the damaging brake events occurring on smooth surfaces from the road response files. To reproduce the fatigue damage that has been removed due to brake editing of road response files, it is recommended to iterate to synthetic desired brake responses. This involves the use of synthetic desired response files that produce the longitudinal force and brake moment inputs required to produce vehicle brake moment and dive associated with road braking events. The synthetic brake desired responses are scaled and polarized to represent various amplitudes of forward or reverse braking events. Refer to GMW15225 for details.

4.3.1.12 Data Editing Pitfalls. There are some potential pitfalls common to all data editing methods. For example, tapers between edited frames of data can produce undetectable anomalies in the desired response that are not physically realizable on the road simulator. These motions adversely affect test correlation. Therefore, highly dynamic data, such as that found during rough road events, should only be edited after consulting with an experienced test engineer. Also, editing never should be done on developed drive files. Editing steps should be documented according to the guidelines described in 5.3.2.

4.3.2 Calculate Summaries of Editing Results.

4.3.2.1 Calculate Retained Fatigue Damage. Calculate fatigue damage on the edited data using the same input parameters that were used in the baseline calculations in 4.3.1.3 (e.g., bin size, scale factor, notch factor, polarity, material, mean stress correction, material model and noiseband). Fatigue damage for all events to be used in the laboratory durability test should be included. Therefore, results from fatigue damage calculations on data from 4.3.1.7 through 4.3.1.11 should be combined. Damage from any events that were run on the road

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must also be included (use the road response data file for both data sets). Note that some edited files cannot be included (body torsion events), since they exist only as drive files at this point. The road response data should be used for these files until the laboratory responses are collected.

4.3.2.2 Calculate Retained Peaks. Calculate the peak values.

4.3.2.3 Calculate Test Duration. Determine the time retained from each edited road event, multiply by the repetition factors and sum the results.

4.3.3 Evaluate Editing Results.

4.3.3.1 Review Retained Fatigue Damage. Compare edited fatigue damage with the baseline fatigue damage.

4.3.3.2 Review Retained Peaks. Make sure that no significant peak data were removed.

4.3.3.3 Review Resulting Test Duration. The result from 4.3.2.3 should be multiplied by a factor of 1.2 to 1.5 to account for downtime due to inspections, observation resolution and fixture maintenance. This value should be compared to the test duration goal. For example, a typical test duration target for one life of a passenger car major durability test equivalent is 15 days or less.

4.3.3.4 Implement Corrective Actions. If editing goals are not met, review the road events to see if any can be eliminated (4.3.1.4), and repeat bulk data editing with modified thresholds (4.3.1.8). One way to select road events for further editing is to rank them based on fatigue damage density (fatigue damage per road event divided by the time required to run the road event). Road events that have a high number of repetitions are also candidates for further editing.

Another technique to improve damage retention and/or reduce test time is to perform a multiplier optimization of the drive files based on the laboratory response files. This is normally done after completing the test development. Consult with an experienced test engineer before attempting this method.

4.3.4 Internal Gate Review - Editing Results. During this gate review, the edited data is compared to the road response data. The criteria specified in the project objectives are the basis for determining adequate results. Reports usually required for this review include fatigue damage retention by channel comparison tables and peak/range ratios by channel comparison tables. Other reports are sometimes useful, such as selected Auto-Spectral Density (ASD) plots, XY plots and time history comparisons for transient events. Formats for these reports are discussed in 5.3.4. Once these results are approved, the edited road responses become the unfiltered desired response files in the iteration process.

4.3.5 Prepare for Test Development.

4.3.5.1 Road Simulator Preparation. The road simulator should be prepared as follows.

4.3.5.1.1 Track, Wheelbase and Rolling Radius. Proper positioning of the fixture base plates is required to reflect the track and wheelbase dimensions of the test vehicle. The plates should be positioned square to each other and within ± 1 mm in both track and wheelbase dimensions. Set the lateral input attachments to the vehicle wheel rolling radius. Previous results have shown a shorter radius may be needed to reduce excessive camber moment (assuming the road simulator has only one control degree of freedom available for the combined lateral load and camber moment control).

4.3.5.1.2 Calibration. Road simulator calibration should be performed at the intervals specified by local laboratory procedure. All calibration information and documentation should be included in the road simulator site documentation.

4.3.5.2 Prepare Development Vehicle. Refer to 4.3.18.5, 4.3.18.6, 4.3.18.12, 4.3.18.13, 4.3.18.14 and 4.3.18.15. These paragraphs apply to the test development vehicle. In some cases, the test development vehicle will also be the durability vehicle.

4.3.5.3 Install Vehicle. Install the test development vehicle on the road simulator. If WFTs are being used, the WFT cables should be carefully routed and restrained to minimize the cable strain induced noise and cable fatigue.

4.3.5.4 Nitrogen Static Lift (Optional). Refer to local procedures for detailed operation instructions for a nitrogen static lift system.

4.3.5.5 Steering Column Lock. An unlocked steering column may lead to degraded dynamic performance due to under damped and uncontrolled steer resonance in the road simulator. Therefore, the steering column ignition lock should normally be engaged during all phases of road simulator operation, or an external mechanical restraint installed.

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4.3.6 Test System Response. The Frequency Response Function (FRF) is the math model that characterizes RPC transducer responses to the servo-hydraulic drive signals in the frequency domain. The inverse of the FRF is used to predict the motion of the hydraulic cylinders required to reproduce the RPC transducer road responses. The system characterized by the FRF includes the mechanical fixturing, servo-hydraulics, test development vehicle, transducers and data acquisition system.

4.3.6.1 Measure RPC Responses/**Calculate FRF.** Excite the road simulator and test vehicle with command signals containing frequencies and amplitudes slightly beyond the range of a rough road input (excluding transient events). The typical frequency range of the data is between 0.4 Hz to 40 Hz, depending on the types of transducers being used, vehicle dynamic response and the interaction with the hydraulic actuator dynamic characteristics and the constraints. Therefore, creating a white noise file with content to 45 Hz and calculating the FRF over a frequency range of 0.4 Hz to 40 Hz is usually acceptable. Note that if the vehicle had low profile tires, significant data may exist out to 60 Hz. Powertrain and rear axle torque are normally controlled between 0 Hz to 20 Hz.

4.3.6.2 Interpret FRF. The system FRF should be examined to determine if it makes physical sense. This requires knowledge of the physical attributes of the system. A FRF cannot be successfully interpreted without assistance from an experienced user. At a minimum, the following characteristics should be checked:

- Diagonal Nature (including sub-matrices)
- Static Checks
- Dynamic Checks
- Anti-Nodes
- Determinants and Singularities
- Phase Noise and Shift
- Nodes

4.3.6.3 Calculate Coherences. Coherence provides a measure of the degree to which an output may be described as the linear combination of the inputs, expressed in the frequency domain. Two types of coherence are calculated. Multiple coherence indicates the degree to which a response channel can be attributed to a combination of all the input channels. Partial coherence indicates what portion of a given response channel is due to a specific input channel. Both types of coherence range between zero (0) and one (1) for each frequency band. A value of one (1) indicates perfect correlation between the input and response channels. Lower values indicate the presence of measurement noise, system nonlinear characteristics and absent inputs that may or may not need to be addressed. Interpretation of coherence is described in GMW15223.

4.3.6.4 Apply Filters and Band Limits. An inertially-reacted road simulator has difficulty reproducing low frequency events (below approximately 0.4 Hz), due to actuator displacement limits. Road simulator resonant modes make responses uncontrollable above 60 Hz. Filters can be used to remove those frequencies from the desired response files. The most commonly used filter is a bandpass filter that passes frequencies between 0.4 Hz and 40 Hz. Other methods of compensating for the limitations of an inertially-reacted road simulator are discussed in 4.3.10.

System resonant modes sometimes exist within the 0.4 Hz to 40 Hz road simulator operating range. When this occurs, use of a notched bandpass filter may be appropriate. However, a notch filter may mask a vehicle anomaly and result in a poor simulation quality. Consult an experienced RPC user before using a notch filter.

4.3.6.5 Calculate Inverse FRF. An inverted FRF is required to calculate a drive file from the desired response. The inverted FRF must be mathematically well defined and noise free. It is usually necessary to condition the FRF and its inverse to ensure that these conditions are met. Consult an experienced test engineer before performing any clipping, smoothing, inversion or expanding operations.

The dynamic range of the inverted FRF is limited by using clipping. The clipping factor should be set to a minimum of 5000 to minimize excessive clipping. Smoothing is used to reduce the effect of noise at frequencies where the control transducers are less sensitive. Expanding compensates for the delay built into processing signals.

4.3.7 Drive Files.

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