



On-Road Vehicle Level Powertrain/Driveline Sound Quality Evaluation 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.

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

1.1 Purpose. The purpose of this test procedure is to document the methodology for acquiring on-road powertrain sound quality data.

1.2 Applicability. This procedure applies to vehicle tests for all passenger vehicles (including hybrids), and light commercial vehicles.

1.3 Remarks. This procedure is a guideline for measuring a vehicle's interior noise performance on road. Special emphasis has been given to noises produced by a hybrid vehicle's drivetrain components.

2 References

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

2.1 External Standards/Specifications.

None

2.2 GM Standards/Specifications.

GMW15927

GMW16178

3 Resources

3.1 Facilities. North America Smooth Asphalt road surface or equivalent with the following attributes:

- Test track shall be 400 m in length or greater with sufficient space to slow down from 140 km/h safely.
- The test site shall be free of reflecting obstacles, and the road surface shall be clear of debris and stones. Ambient noise should be low enough to not interfere with measurements. Fifty (50) m long sections of the track should be marked such that a driver can easily coordinate speed and distance while driving. Appendix D contains charts used in North America to achieve the required acceleration rates. Where a test cannot be completed in one pass down the track, multiple runs can be merged utilizing ArtemiS if the tachometers are recorded.

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.

3.2 Equipment.

3.2.1 Recording Equipment. Binaural recording system. The Head Acoustics Aachen head and SQuadriga II are examples of such systems.

3.2.2 Engine Tachometer. A tachometer signal from the engine is required. The tachometer signal should output at least 1 pulse per 2 revolutions of the engine with voltages consistent with the front end requirements. A Controller Area Network (CAN) engine speed signal may be used as a reference channel, but should not be used for tracking engine orders.

3.2.3 Driveline Tachometer. A tachometer signal from the driveline is optional. The tachometer signal shall output at least 1 pulse per revolution of the driveline with voltages consistent with the front end's requirements. An optical or laser tachometer pickup is the preferred choice to capture the propshaft (RWD) or drive axle (FWD) speed.

3.3 Test Vehicle/Test Piece. The vehicle shall be prepared to eliminate any unwanted content and noise related issues (squeak/rattles, verify Front of Dash (FOD) and door seals are correct). Verify and record the status of all relevant hardware relative to the current release status. Appendix E, Data Sheet E1 Vehicle Preparation Pre-Test Documentation can be used to record the information. Record VIN, fleet number, and the build stage if appropriate. Record engine displacement, orientation, configuration (V or in-line), and driveline configuration (Front Wheel Drive (FWD), Rear Wheel Drive (RWD), Four Wheel Drive (4WD), All Wheel Drive (AWD)), the number of forward gears, and whether the transmission is automatic, manual, or Electric Variable Transmission (EVT). Fully document any and all hybrid powertrain characteristics (Belt Alternator Starter (BAS), Flywheel Alternator Starter (FAS), Two Mode Hybrid (2MH), etc.) Record any other options that could influence interior noise levels. Record the testing date, time, and location and ambient weather conditions.

3.4 Test Time.

Calendar time:	1 d
Test hours:	6 h
Coordination hours:	2 h

3.5 Test Required Information. Vehicle information as required in section Personnel/Skills.

3.6 Personnel/Skills. The personnel conducting this test should be familiar with the following:

3.6.1 Binaural recording practices and procedures.

3.6.1.1 Technician should know how to capture accurate driveline and engine tachometer signals.

3.6.1.1.1 A qualified engineer or technician trained in the use of data acquisition and having knowledge of digital signal processing.

3.6.1.1.2 It is assumed that the person responsible for data processing will have a rudimentary knowledge of working with ArtemiS.

4 Procedure

4.1 Preparation.

4.1.1 Test Object Preparation.

4.1.1.1 Documentation. Using the vehicle preparation data sheet provided in Appendix E, record VIN, GM fleet number, and the build stage if appropriate. Record tire make and model, size and air pressure. Record the engine displacement, orientation, configuration (V or in-line) and fuel type. Record the driveline configuration FWD, RWD, AWD, 4WD, the number of forward gears and identify power source in the type information data entry field (i.e., hybrid fuel cell). Record whether the interior is leather or cloth, the seating capacity and whether the vehicle has a sliding roof or other options that could influence interior noise levels. Record the test date, time and location.

4.1.1.2 Static Preparation. Adjust tire pressure to nominal values as stated by the tire manufacturer (cold). Ensure the fuel tank is at least $\frac{3}{4}$ full and all occupant accessible accessory controls (including HVAC components) are switched to inactive. Verify that the vehicle meets the requirements of the necessary test content.

4.1.2 Binaural Recording Device Preparation. The binaural recording device should be placed in the front passenger seat so that the center point between the ears of the artificial head complies with GMW15927 guidelines. The settings of the binaural recording device should include equalization for the "independent of direction" (ID) sound field present in the interior. Dynamic range should be set at the most sensitive condition which allows all of the test conditions listed in 4.2.2 to be recorded without overloading.

4.1.3 Tachometer Preparation – Electrical.

4.1.3.1 Coil Pack Control/Ground Wire Tapping. For most GM gasoline engines, this signal can be tapped from the control and ground wires on any one of the active ignition coil packs. Care shall be taken to place the tap on a coil pack that will be live during both normal as well for Active Fuel Management modes of operation.

For competitor gasoline engines – use an isolated oscilloscope to determine the control and ground wires by slipping probe wires alongside the sheath of the wires until touching the metal connector terminal (see Appendix B and Figures B1 thru B5). Most coil pack connectors have 4 wires, and as a result, the number of pairs of wires that shall be checked is 6. If the coil pack harness connector does not allow for a probe wire to be slid behind the weather seal, then an optical tachometer shall be used.

4.1.3.2 Optical Tachometer Installation. Attach optical tachometer to the vehicle. Hot glue or epoxy has been used successfully in the past. When possible, attach the tachometer such that the relative transverse motion between the rotating parts and the tachometer light beam are minimized. Attach one piece of reflective tape to the rotating part. The tape shall be 45° minimum wide so that the tachometer gets a reasonable pulse width. The output from the tachometer needs to have at least a 5 V output for the Head acoustics system to read it consistently.

4.1.3.3 Tracking Setup. Verify the tachometers are functional and are recorded properly by the data acquisition system. Make a note of the vehicle N/v ratio. This is the ratio of the drive line tachometer speed to vehicle speed in high gear. This will be useful in post processing steps to calculate vehicle speed from the driveline tachometer signal. At this time a check of the vehicles speedometer should also be done. Corrected speeds should be used in all calculations and during data acquisition.

4.2 Conditions.

4.2.1 Environmental Conditions.

- Wind speed < 12 km/h.
- Dry road surface.
- No precipitation during test.
- GMNA Smooth Asphalt surface.

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.

Note: Repeat data acquisition procedure until sufficient, repeatable data has been acquired. At least 3 runs of each condition are recommended considering ambient noise contamination that might go unnoticed at the time of data acquisition. (See Appendix C, Figure C1 for a checklist of tests.)

4.2.2.1 Rolling Start to 140 km/h Full Pedal. Shift the vehicle into 1st gear or drive, depending on the transmission type. Establish a vehicle speed of 15 km/h. Start the recording. Accelerate the vehicle with full accelerator pedal application through all gears necessary to reach 140 km/h or highest speed that is safely achieved on the region's test track. Manual transmission cars shall be shifted at the indicated "redline" on the vehicles tachometer. At 140 km/h (or the highest speed achieved), immediately remove pedal application. Stop the recording.

Note: The highest speed achieved if not 140 km/h. Enter the smooth lane 5 km/h below the maximum previously achieved at Wide Open Throttle (WOT) in the same gear previously used and continue the test until 140 km/h is achieved or highest speed that is safely achieved.

4.2.2.1.1 Rolling Start to Maximum Revolutions per Minute (RPM) in 2nd Gear. Shift the vehicle into 2nd gear. Enter the smooth lane and establish a vehicle speed of 15 km/h or the lowest speed in which the vehicle will operate smoothly. Start the recording. Accelerate the vehicle with full accelerator pedal application until the tachometer indicates the maximum RPM recommended by the manufacturer. Stop the recording.

4.2.2.2 Driveaway Acceleration Sweeps. Put the transmission selector in "D" or equivalent position that enables the transmission to shift automatically. The energy group shall be consulted to determine the recommended manual transmission shift points. For recommended manual transmission shift points, the North America energy group's Federal Test Procedure (FTP) defaults shall be used. See Table 1.

Table 1: Default Manual Transmission Shift Points

Gear Change	km/h
1 to 2	25
2 to 3	40
3 to 4	65
4 to 5	70
5 to 6	80

If manual transmission vehicle has an up shift light, then this should supersede Table 1 and be used as the signal to shift.

For each of the driveway sweep velocity-time profiles specified in Table 2, the driver should increase the vehicle speed from 8 km/h vehicle speed to maximum speed specified, according to the velocity-time profiles specified.

(See Appendix D and Figures D1 thru D6)

Table 2: Driveway Sweep Velocity-time Profiles

Time (s)	Very Light (km/h)	Light (km/h)	Moderate (km/h)
0	8.0	8.0	8.0
5	14.4	27.7	40.6
10	19.7	42.2	62.5
15	24.4	53.6	79.0
20	28.5	62.7	92.3
25	32.2	70.6	103.4
30	35.5	77.3	113.0
35	38.6	83.3	-
40	41.4	88.6	-
45	43.9	93.5	-
50	46.4	97.9	-
55	48.6	102.0	-
60	50.7	105.8	-
65	-	109.3	-
70	-	112.6	-

The distance-time table can be seen in Table 3.

Table 3: Driveway Sweep Distance-time Profiles

Time (s)	Very Light Acceleration (m)	Light Acceleration (m)	Moderate Acceleration (m)
0	0	0	0
5	15	24	34
10	39	71	106
15	69	137	205
20	106	217	323
25	149	309	454
30	196	411	593
35	248	521	-
40	305	638	-
45	366	764	-
50	431	898	--
55	500	1041	-
60	573	1198	-
65	-	1369	-
70	-	1560	-

Acquire data for each run. Repeat each of the acceleration sweeps for a minimum of three runs or until data is repeatable. As shown in Appendix D, the acceleration rate is smoothly decreasing so quick throttle changes shall be avoided.

A manual blocked pedal fixture must be used to achieve the acceleration profiles described in Table 2 and Table 3. A picture of the blocked pedal device is shown in Appendix G, Figure G1.

While this approach will not follow the entire profile as closely as driver pedal control, it is much more repeatable. Repeatability shall be controlled by matching the target vehicle speed for each profile.

For each of the acceleration profiles, the single point vehicle speed target is specified in Table 4. Use the fixture to depress the vehicle accelerator to a fixed point and plot the vehicle speed from zero to 30 s. If the vehicle speed plot does not pass through the target point within $\pm 2\%$ while increasing, adjust the pedal position and repeat the run. A vehicle speed within $\pm 2\%$ of the target point is considered an acceptable run. Record at least two (2) runs to verify consistency.

Alternatively, engine control software can be used to limit pedal position. The same speed targets must be observed.

Table 4: Vehicle Speed Targets

Time [seconds]	Very light [km/h (mph)]	Light [km/h (mph)]	Moderate [km/h (mph)]
0	8.0 (5.0)	8.0 (5.0)	8.0 (5.0)
12.5	22.0 (13.7)	-	-
18.5	-	60.0 (37.3)	-
23.5	-	-	100.0 (62.1)

The very Light profile sweep is applicable only for EVT vehicles with electric drive capability (engine off).

- **For EVTs:** Run light and moderate sweeps with Engine-ON State of Charge (SOC), confirm that Internal Combustion Engine (ICE) is ON for entire test.
- **For Extended Range Electric Vehicles (EREV)/Battery Electric Vehicles (BEV):** Run very light, light and moderate sweeps with maximum SOC, confirm that ICE is OFF for entire test.

Refer to GMW16178 Appendix J for state-of-charge guidelines.

4.2.2.3 Exterior Drive-By Conditions.

4.2.2.3.1 Test Setup. Appendix A and Figures A1 thru A6 show the setup of the Aachen Head for this test.

4.2.2.3.2 100 km/h Drive By. The driver will reach 100 km/h before the measured portion of the track with the transmission selector in D or the highest manual gear possible. With the unattended Aachen Head recording, the driver should activate the horn 100 m before reaching the head and 100 m past the head.

4.2.2.3.3 Slow Drive By. The driver will reach 40 km/h before the measured portion of the track with the transmission selector in D or the highest manual gear for normal cruising operation. With the unattended Aachen Head recording; the driver should activate the horn 100 m before reaching the head and 100 m past the head.

4.2.2.3.4 Acceleration Drive By. The driver will reach 40 km/h before the measured portion of the track. With a manual transmission vehicle the gear selection shall be such that the engine comes close to redline by the end of this test. The gear selection shall also be such that shifting gears during the test shall be avoided. With the unattended Aachen Head recording, the driver shall activate the horn 50 m before reaching the head and apply wide open throttle pedal position. At 100 m past the head the driver shall again honk the horn.

4.2.2.3.5 Startup, Idle, Free Kick, Shut Down. This part of the test can be done in a hemi anechoic car test room or outside. Position the head at the centerline of the vehicle and 1 m in front of the vehicle. Repeat the measurements with the head positioned 1 m behind the rear of vehicle. Start the recorder. Start up the vehicle; allow it to settle to a steady state idle speed. Perform 3 free-kick throttle stabs, each time letting the engine come back to steady state idle. Shut down the vehicle. Stop the recorder.

4.2.3 Electrically Assisted Driveaway.

4.2.3.1 Electrical System Preparation. Electrically Assisted Driveaway requires that the Battery State of Charge (SOC) be near its maximum. This can be accomplished by performing several coastdown events from high speed. If equipped, monitor the battery charge/discharge mode and battery SOC with the vehicles gauges and/or driver information center.

If the vehicle does not have a battery state of charge indicator, the engineer will have to use their best judgment to estimate when the battery is near complete charge. For GM vehicles, this will occur after approximately 10 coastdown events from 140 km/h (or the highest speed possible for the regional track).

4.2.3.2 Data Acquisition. Once the battery is fully charged, bring the vehicle to a complete stop and wait for the ICE to shut down. Begin acquiring data, with the gear selector in drive; accelerate as aggressively as possible, without the ICE starting. Stop the data acquisition once the ICE starts. Repeat this data acquisition procedure until sufficient, repeatable data has been acquired.

4.2.4 Coastdown Background Level Measurement and Regeneration Noise during Coastdown.

4.2.4.1 Electrical System Preparation. Coastdown regeneration noise measurements require that the battery state of charge be near its minimum capacity. This can be accomplished by performing several aggressive accelerations from a standing start. Hybrid vehicles utilize the electric motors during this type of driving condition, and will deplete the battery state of charge relatively quickly. If equipped, monitor the battery charge/discharge mode and battery SOC with the vehicles gauges and/or driver information center. If the vehicle does not have a battery SOC indicator, the engineer will have to use their best judgment to estimate when the battery is near complete charge. For GM vehicles, this will occur after approximately 10 WOT acceleration events.

4.2.4.2 Data Acquisition. Once the battery is fully discharged, bring the vehicle to 50 km/h. Begin acquiring data, and lift foot from the throttle. Stop the data acquisition once the vehicle comes to a rest.

4.2.4.3 Coastdown. The data collected in this test will support the calculation of a masking noise criterion for the vehicle. This part of the procedure shall be done with the battery fully charged.

4.2.4.4 Bring the vehicle up to 112 km/h. Begin the recording. Coast down until the end of the test road is reached, or until the vehicle comes to a stop. If the end of the test road is reached before the vehicle comes to a stop, document the end speed and record a second run. Start the second run 5 km/h above the previous end

speed and coast down until the end of the test road is reached, or the until the vehicle comes to a stop. Repeat this procedure until an end speed of 0 km/h has been achieved.

4.3 Instructions. Acquire data for each of the required test conditions from paragraph 4.2 following the included data acquisition instructions. Repeat each required data acquisition procedure until sufficient, repeatable data has been acquired. At least 3 runs of each condition are recommended considering ambient noise contamination that might go unnoticed at the time of data acquisition. Process the data following the instructions in 5.1.

5 Data

5.1 Calculations. Merging the runs together to form a contiguous file requires the use of a signal that tracks vehicle speed. This signal is used to synchronize the various runs. After the runs are inserted in the source pool of ArtemiS, they can be compared to see if there is an overlap in driveline RPM (see Appendix F, Figure F1).

Use RPM cut as shown so there is a continuous RPM band (see Appendix F, Figure F2). This will create three files that can be merged using the merge editor (see Appendix F, Figure F3). Use the Fade in Fade out option set to 20 ms. This will result in a small gap in the sound to alert the analyst where the seam is. After merging with the append option the result is produced. Save that result using the “save result” option in the “File” menu. The resulting file produces the graphs shown in Appendix F, Figure F4. A continuous engine speed trace is the desired result.

5.2 Interpretation of Results.

5.2.1 Interpreting Binaural Data. Binaural data is often interpreted both quantitatively and qualitatively.

5.2.2 Quantitative Binaural Data Analysis. In addition to calculations mentioned earlier, binaural data may be quantified using specifically designed sound metrics which seek to more accurately describe human hearing. Loudness, in linear units of Sones, is a typical example.

5.2.3 Qualitative Binaural Data Analysis. Listening-based analysis of binaural data may involve evaluation of quietness, quality, preference, character depending on the objective of the tests.

5.3 Test Documentation.

5.3.1 Quantitative Documentation. In addition to documentation required by the relevant procedure, all plots shall include the following information:

- Binaural data shall be stored as time histories.
- Project files which include specific marks, filters and analyses should be stored.

5.3.2 Qualitative Documentation. In addition to documentation required by the relevant procedure, document results of jury testing, subjective ratings, focus group evaluations, etc.

6 Safety

This Engineering Standard may involve safety requirements for hazardous materials, the method of operations and equipment. This standard does not propose to address all the safety issues associated with its use. It is the responsibility of the user of this standard to ensure compliance with all appropriate safety and health practices. This would include any specific training that may be required. The safety and health standards include site specific rules and procedures, company rules and procedures, and Government Standards. Contact shall be made with the appropriate site Safety and Health personnel for further direction and guidance in these matters.

7 Notes

7.1 Glossary. Not applicable.

7.2 Acronyms, Abbreviations, and Symbols.

2MH	Two Mode Hybrid
4WD	Four Wheel Drive
AWD	All Wheel Drive
BAS	Belt Alternator Starter
BEV	Battery Electric Vehicle
CAN	Controller Area Network
EREV	Extended Range Electric Vehicle