



Exhaust System Tail Pipe - Sound Pressure Level (SPL) 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.

1.1 Purpose. To record exhaust system outlet (tailpipe) noise for the purpose of validating the noise requirements in the exhaust SSTs when testing a full vehicle on a chassis dynamometer. Operating conditions include a full engine load sweep in all cylinder mode, an engine speed sweep along the equal fuel consumption torque curve in cylinder deactivation mode, and a warm idle sweep with the transmission in drive and accessories on.

This procedure can be approximated or modified for benchmarking purposes in some instances; however, the ability to control the transmission gear state, torque converter state, Active Fuel Management (AFM) state and operating loads, and idle speed make this procedure primarily applicable to GM product development and validation.

1.2 Applicability. This procedure is appropriate for use with passenger cars, multi-purpose passenger vehicles, minibuses and light commercial vehicles with a maximum authorized total weight of 3500 kg (7716 lb). It is not applicable to vehicles with hybrid transmissions (Electrically Variable Transmission (EVT), Extended Range Electric Vehicle (EREV), or Battery Electric Vehicle (BEV). Some sections of the procedure are specific to transmission type. For the purposes of this procedure, the following transmission types are defined:

- **Automatic Transmission (AT):** Conventional, stepped gear ratio automatic transmission.
- **Manual Transmission (MT):** Conventional, stepped gear ratio manual transmission.
- **Continuously Variable Transmission (CVT):** Transmission with variable ratio achieved by mechanical power transfer.

The subsystem data resulting from this procedure is for comparison to the tailpipe noise requirements in the Exhaust Statement of Requirements (SOR) SSTs. The Vehicle Level Allocatable Test(s) (VLAT) Noise and Vibration Evaluation Procedure (GMW16178) shall not be used in place of this test.

1.3 Remarks. None.

2 References

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

2.1 External Standards/Specifications.

IEC 61672-1

2.2 GM Standards/Specifications.

GMW14891

GMW15764 (ID)

GMW16178

(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.

- Exhaust System Statement of Requirements - Subsystem Technical Specifications (SOR-SSTS, Appendix C2).
- ETAS INCA software support available at: www.etas.com/en/products/inca.php.

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- GT-Power Model software available at: www.gtisoft.com/gt-suite-applications/propulsion-systems/gt-power-engine-simulation-software.
- Siemens LMS Test.Lab software support at: www.plm.automation.siemens.com/en_us/products/lms/testing/test-lab.
- Temprel thermocouple(s) available at: www.temprel.com/products/thermocouples.aspx
- Vehicle Spy (Vspy) Professional software support at: <http://www.intrepidcs.com/VehicleSpy>.

3 Resources

3.1 Facilities. Vehicle chassis dynamometer. Refer to **GMW16178**.

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.

3.1.3 Environment. Refer to GMW16178.

3.2 Equipment.

3.2.1 Data Acquisition Equipment. The preferred digital data acquisition system (DAS) is a personal computer running Leuven Measurement Systems (LMS) Test Lab software connected to an LMS Scadas III front end, or equivalent as approved by the Global Noise and Vibration Center (GNVC) Infrastructure Team. This setup allows simultaneous digital recording of time domain data and online or post-processing of frequency and order domain data.

3.2.2 Microphones. Free-field microphones are preferred with appropriate signal conditioning and cables, meeting Class 1 accuracy corresponding to IEC 61672-1 or equivalent for the application (precision ± 0.7 dB or $\pm 8\%$) shall be used.

3.2.3. Engine/Transmission Control Software. ETAS INCA software (see 2.3), an instrumented controller compatible with the vehicle Engine Control Module (ECM) and Transmission Control Module (TCM) or equivalent. Vehicle Spy (Vspy) or other software allowing access and basic control of transmission gear state, torque converter state (ability to apply the torque converter or override release constraints) and AFM state are also allowed for parts of this test. INCA is required for the idle sweep section of this test.

3.2.4 Tachometers. Engine tachometer with output compatible with DAS input requirements. Angular resolution of one (1) or more pulses per revolution is required.

3.2.5 Thermocouples. K-type thermocouple, Temprel Part Number T25-MU-3K-AS-LE4R, see 2.3, (1.6 mm (1/16 in) Outside Diameter (OD) K-type thermocouple with 304 Stainless Steel (SS) sheath material; 101.6 mm (4 in) SS braided wire) is recommended. Refer to GMW14891 for installation.

3.3 Test Vehicle/Test Piece. The ECM software and calibration should be representative and current with the latest calibration release. It is preferable to test using a calibration level of 65% or better. The SSTS validation test reports should include the engine and transmission calibration files used and the calibration level represented. The exhaust system including emissions components shall be consistent with the design level being validated.

3.4 Test Time.

Calendar time: 1 d

Test time: 8 h

Coordination time: 2 h

3.5 Test Required Information. Vehicle information as specified in 4.1.1.1 ¾.

3.6 Personnel/Skills. One (1) qualified engineer or technician trained in the use of data acquisition equipment and having basic knowledge of acoustic and vibration signal processing. One (1) qualified engineer or technician familiar with ETAS INCA software and Vspy software. One (1) qualified chassis dynamometer operator.

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4 Procedure

4.1 Preparation.

4.1.1 Vehicle Preparation.

4.1.1.1 Documentation. Record the Vehicle Identification Number (VIN), GM fleet number, and the information listed in Appendix C, Data Sheet C1: Describe Vehicle and Exhaust Content. Record the ECM and TCM calibration file names. Record the exhaust part numbers for the emissions components and cold end tuning components.

4.1.1.2 Static Preparation. Verify that the tires are inflated to the nominal (cold) pressure as specified by the vehicle manufacturer. Refill the fuel tank if it is less than three-quarters ($\frac{3}{4}$) full. Inspect the exhaust system for leaks, ground outs, and misalignment. See Appendix B, Figure B1 and Figure B2 for suggested vehicle modification if testing to compare to the tailpipe SSTs:

4.1.1.3 Road Test. A road test must be conducted to ensure proper operation of the vehicle prior to testing on the chassis dynamometer. Proceed to a test track with smooth level road surface, with sufficient straightaway length to safely accomplish a full pedal drive away maneuver as described in GMW16178. Drive the vehicle to check for proper operation of the engine and transmission.

4.1.2 Vehicle Preparation on the Chassis Dynamometer.

4.1.2.1 Facility Setup.

- The test cell should be empty except for the test vehicle and equipment.
- If the rear wheels will be spinning on the dynamometer rolls, install the acoustic dynamometer roll covers and/or blank treaded tires to minimize data contamination due to tire noise.
- Movable chassis dynamometer floors shall be raised during testing. Floor opening cover panels shall be installed to cover openings in the vicinity of the tailpipe and microphone.

4.1.2.2 Vehicle Setup.

- Place spot cooling as near as possible to the engine air inlet, or snorkel, to maintain a normal Intake Air Temperature (IAT).
- Set up external cooling fan directed toward the engine cooling system.
- **Optional:** To maintain desired operating temperatures, install spot cooling hoses as required. Typical spot cooling locations include catalytic converter, muffler, and differential.
- Prepare vehicle as described in Appendix B, Figures B1 and B2 depending on the tailpipe termination location.
- Exhaust carbon monoxide collectors. The chassis dynamometer exhaust Carbon Monoxide (CO) collectors can affect the quality of the noise data due to acoustic reflections and broadband flow noise from the exhaust fan. These should not contact the tailpipes and should be as far from the tailpipe as is possible to maintain safe CO levels in the room. It is necessary to use a collector due to local safety criteria, perform testing to determine the location for the collectors that will have minimal effect on the measured tailpipe overall, firing order and first harmonic sound pressure levels.
- Install emergency engine shut-off lead. Check for proper orientation. Close hood.
- Install vehicle pedal (throttle) controller. The pedal controller must be self-supporting on the floor of the vehicle and must not contact the seat, dashboard or steering wheel.
- Install the tachometer probe or other equipment required to accurately capture the engine speed, in engine revolutions per minute (erpm).
- Install instrumentation to connect the Controller (Control) Area Network (CAN BUS) port to the DAS.
- Turn off the vehicle radio.
- Turn off the Air Conditioning (A/C). Set Heating, Ventilation and Air Conditioning (HVAC) fan speed to "off". If "off" is not available, set to minimum speed available. Set HVAC position selector to floor only. Do not use combination or defrost switch settings which engage air conditioning compressor for dehumidification.
- Verify that the parking brake is released.
- If applicable, remove rear camouflage for validation testing. Eliminate any unwanted content or problems, (e.g., ground-outs, heat shield rattles, etc.) Check that the spare wheel is securely seated.

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- Install a thermocouple on the exhaust downpipe downstream of the first emissions component for monitoring purposes. The choice of location is left to the test engineer.

4.1.2.3 Instrumentation Setup to Monitor Powertrain Status. Connect INCA or Vspy instrumentation to monitor engine coolant temperatures, IAT or Manifold Absolute Temperature (MAT) if available, engine torque, engine speed, AFM state, and TCC slip.

4.2 Conditions. Refer to GMW16178.

4.2.1 Environmental Conditions. Not applicable.

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.

4.3.1 Data Acquisition Preparation. Open data acquisition software capable of acquiring synchronously tracked orders of a tachometer (LMS Signature Testing Advanced, or equivalent).

4.3.1.1 Channel Assignments. Use the following recommended channel naming conventions.

- 50_CM_EXH_RHS: (50 cm exhaust sound pressure level on right hand side of vehicle).
- 50_CM_EXH_LHS: (50 cm exhaust sound pressure level on left hand side of vehicle).
- DYNO_SURF-FORCE: (Dynamometer Total Surface Force).
- TAILPIPE_TEMP: (Gas stream temperatures measured 3 in inside of the tailpipe with a K-type thermocouple).
- COLDINLET_TEMP: (Gas stream temperatures measured at the inlet to the cold end of the exhaust).

Mandatory Vehicle Bus Data Channels. See Appendix D, Table D1 for a list of variable names or contact local expert familiar with current naming conventions.

1. BRK_TORQUE (Engine Brake Torque from CAN BUS).
2. IND_TORQUE (Indicated torque when available from CAN BUS).
3. NET_TORQUE (Net torque when available from CAN BUS).

Optional Can Bus Channels (if required for model correlation purposes). See Appendix D, Table D1.

4.3.1.2 Calibration Validation. Check equipment for valid calibration date. Replace out-of-date equipment. Turn on all instrumentation 5 minutes prior to calibration verification. Verify calibration of the transducers as follows:

4.3.1.2.1 Microphone Calibration Verification. Mount the first measurement microphone on a certified calibrator and switch the calibrator on. Using the Calibration function of the software, enter the calibrator frequency and sound level, then measure the signal and observe the calculated sensitivity of the channel. If the calculated sensitivity of the channel is not within 15% of the latest calibration certificate for the microphone, replace the microphone and repeat. Before conducting verification of the next channel, accept the calculated sensitivity and store the sensitivity in the test setup. Repeat for each microphone.

4.3.1.3 Tracking Setup. Verify that the tachometer is functional and that the trigger levels are set to the appropriate level.

4.3.1.4 Acquisition Setup. Verify/accomplish the following acquisition settings:

- Maximum Order:
 - o Maximum order = $6 \times$ firing order. Acquire all orders and half orders from 0.5 order to $6 \times$ firing order in 0.5 order increments.

Note: If doing exhaust sound character development, the maximum order will be higher and unique to engine and program requirements. Orders up to 24 are often required.

- Order resolution: 0.1.
- Acoustic Channels.
- Bandwidth = 12.8 kHz.
- Resolution = 1.0 Hz.

4.1.3.5 Online Processing Setup for Conditions 1 and 2.

4.1.3.5.1 Verify/accomplish the following online processing settings for the acoustic channels:

- Format: Autopower Linear.

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- Window: Hanning (for fixed sampling).
- Final Weighting/Window: A-weighting for Acoustic channels.
- Format: Root Mean Square (RMS).
- Function: Order.
- Overall Level (22 Hz to 12.8 kHz).
- Bandlimited overall level (22 Hz to 1000 Hz) for comparison to GT-Power math results. Create a frequency section in the online processing section of Test Lab. Example shown in Figure 1.

Figure 1: Frequency Section Example

Sections						Order Sections	Frequency Sections
Frequency: 511		Enter frequencies separated by semicolons. For example 100; 200; 300					
	Frequency	Mode	Bandwidth	Lower	Upper		
1	511	Frequency	978	22	1000		

4.3.2 Transducer Setup. The microphone shall be placed at the same height as the midline of tailpipe, at a distance of 0.5 m and at a 45 degree angle outboard from the centerline of the tailpipe. One (1) microphone shall be used for each tailpipe.

Use a wind screen (foam ball). See Appendix A, Figures A1 through A5 for transducer location diagrams for free-field and pressure microphones for specific muffler and tailpipe configurations and locations.

4.3.3 Powertrain Operating Status.

4.3.3.1 Monitor.

- Prior to acquiring data, the vehicle is to be warmed-up (or cooled-down) and running at normal operating temperatures. Engine coolant temperatures should be stable and in the normal operating range at the beginning of each test run.
- The exhaust skin temperature at the start of each run should be within 30 °C of start of the previous run to improve run to run repeatability.
- Monitor IAT or MAT to ensure they read nominally 25 °C. The engine will run at nominal conditions if the temperature stays between 20 °C and 35 °C. If the temperatures are outside of this range the engine may not operate per its nominal state and noise levels may be affected. Spot cooling at the engine air inlet helps insure this condition is met.
- Monitor for variation in engine operating parameters. Changes to some parameters can significantly affect engine performance and affect tailpipe sound pressure levels. "Normal" operating criteria is specific to the operating condition, engine and vehicle and should be understood prior to testing. The program engine calibrator can provide this information. Cam phasing, valve lift, spark retard/advance, and torque can affect exhaust noise levels.
- Monitor the TCC slip during the test run and stop the test to prevent damage to the powertrain if you observe the following: noise indicative of TCC crashing; rapid changes in TCC slip speed indicative of poor slip control.
- Vehicle pedal position.
- Engine Throttle position.

4.3.3.2 Record for All Testing. Record data channels described in 4.3.1.1.

4.3.3.3 Record for Test-Math Correlation. If measurements are acquired for the purpose of correlation with a Computer Aided Engineering (CAE) model, it is suggested that the operating parameters described in Appendix D, Table D1 be recorded with INCA. For correlation purposes, record the gas stream temperature and total pressure at a location near the inlet to the cold end of the exhaust as agreed to with the CAE analyst. In addition, record data channels described in 4.3.1.1.

4.3.4 Measurement Variants.

4.3.4.1 Commanded Gear Maximum Engine Load Sweep [Condition 1].

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4.3.4.1.1 Overview:

- Measure tailpipe noise during an engine speed sweep from 1000 erpm to engine rated erpm ^{Note 1}.
- Sweep time = 30 s.
- Engine load = maximum engine torque from 1000 erpm to engine rated erpm ^{Note 1}.
- Number of test runs = three (3) minimum.
- Reported data set = remove outlying data due to temperature differences, engine torque differences, and poor repeatability and average the remaining data sets.
- It is critical to capture the 1000 erpm to 2500 erpm speed range along the maximum engine torque curve. The vehicle transmission and calibration may impact the ability to do so. Refer to 4.3.4.1.3.1 for instructions.

Note 1: In some instances, limiting the maximum engine speed to 5000 rpm or lower may be necessary to protect the hardware. Verify with program team experts.

4.3.4.1.2 Vehicles with Manual Transmissions (MT).

- Select 3rd gear. If tires slip on dynamometer rolls, select a higher gear.
- Dynamometer control mode = Throttle/V. Set chassis dynamometer to control throttle (pedal) position and vehicle speed.
- Establish dynamometer starting conditions: Adjust dynamometer speed control to achieve the vehicle speed corresponding to 1000 erpm. Adjust vehicle pedal position to the 100% pedal position as verified in INCA or Vspy.
- Establish dynamometer end conditions: Adjust dynamometer speed control to achieve the vehicle speed corresponding to rated engine speed. Adjust vehicle pedal position to the 100% pedal position as verified in INCA or Vspy.
- Sweep between the starting and ending condition in 30 s.
- Adjust equipment gain settings to optimize the dynamic range without overloading the channels.
- Record engine torque and verify that the engine torque achieved during the test is within 30 Nm of the maximum engine torque curve.
- Repeat test sequence a minimum of three (3) times allowing coolant, IAT, and exhaust skin temperatures to return to normal and nominal values between test runs.

4.3.4.1.3 Vehicles with Stepped-Ratio Gear Automatic Transmissions (AT).

For AT equipped with manual gear selection capability:

- Select 3rd gear with one (1) of the following: INCA, Vspy or the manual tap transmission shifter. If tires slip on dynamometer rolls, select a higher gear.
- Apply the torque converter using powertrain control software such as Vspy or INCA.
- Set Dynamometer control mode = Throttle/V. The chassis dynamometer will control throttle (pedal) position and vehicle speed.
- Establish dynamometer starting conditions: Adjust dynamometer speed control to achieve the vehicle speed corresponding to 1000 erpm. Adjust vehicle pedal position to the 100% pedal position as verified in INCA or Vspy.
- Establish dynamometer end conditions: Adjust dynamometer speed control to achieve the vehicle speed corresponding to rated engine speed. Adjust vehicle pedal position to the 100% pedal position as verified in INCA or Vspy.
- Sweep between the starting and ending condition in 30 s.
- Adjust equipment gain settings to optimize the dynamic range without overloading the channels.
- Record engine torque and verify maximum engine torque to within 30 Nm was achieved by comparing to Global Powertrain System (GPS) T1 test data.
- Repeat test sequence a minimum of three (3) times allowing coolant, IAT, and exhaust skin temperatures to return to normal and nominal values between test runs.

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