



Vehicle Exhaust Backpressure and Induction Pressure Loss Measurement

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. The purpose of this test is to measure vehicle exhaust system total backpressure and/or total induction pressure loss. Different procedures are used depending upon the Gross Vehicle Weight Rating (GVWR) and the engine power certification method.

1.2 Applicability. See CG3356 to associate specific procedures to world regions where peak power is to be certified.

1.2.1 Transient Backpressure (Section 4.3.1). Vehicles ≤ 3856 kg GVWR and SAE J1349 power certified. Transient total backpressure and/or total induction pressure loss test data is collected and data snapshots are evaluated as the engine reaches rated speed during a Wide Open Throttle (WOT) acceleration in a fixed gear from a standing start in accordance with SAE J1349.

Traction control must be turned off during test to avoid any potential interaction with WOT engine calibration.

It might be necessary to launch the vehicle in second gear to prevent wheel spin when traction control is turned off.

Vehicles equipped with torque managed transmissions typically make it necessary to select a non-torque managed gear to avoid any potential interaction with WOT engine calibration constraints that prevent peak power operating conditions from being attained.

Vehicles equipped with a Continuously Variable Transmission (CVT) do not have distinct shift points where the engine reaches rated speed during a WOT acceleration. Instead, the engine quickly reaches and maintains rated speed. The regions to be evaluated occur when the engine first reaches rated speed.

Note: Automatic transmissions typically shift at engine speeds greater than the rated engine speed. Do not assume rated engine speed and peak engine speed, at the transmission shift point is the same. Some applications may not reach rated engine speed prior to a transmission up shift. Vehicles shall be tested without software or hardware modifications so that rated engine speed is achieved in the same way as a customer's vehicle. A transmission up shift after reaching rated engine speed is permissible.

1.2.2 Steady State Backpressure (Section 4.3.2).

1.2.2.1 All vehicles, ISO 1585 power certified, or light and medium duty vehicles > 3856 kg GVWR. Steady state total backpressure and/or total induction pressure loss test data is collected using a towing dynamometer set to provide the appropriate load required to maintain rated engine speed or requested engine speed for the selected gear and desired road speed in accordance with ISO 1585 or SAE J1349.

1.2.2.2 Vehicle test alternative. Engine dynamometer test for ISO 1585 power certification. Steady state total backpressure and/or total induction pressure loss test data is collected using an engine dynamometer with a complete exhaust system and air induction system.

1.2.3 Induction Pressure Loss (Section 4.3.3). Any vehicle GVWR, induction data only. Run per appropriate transient or steady state exhaust backpressure test procedure for the collection of induction development data only.

Vehicle level inlet pressure loss measurements may be used during the vehicle integration and development process to determine total inlet pressure loss at various points in the induction system. These measurements

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are for reference only as inlet pressure loss is validated at a subsystem level via bench test, per test procedure GMW14908, Induction Air Flow Pressure Loss.

1.3 Remarks. This procedure is comprised of:

- Global test procedure format with details, Sections 1 through 9
- Three test procedures having similarities, 4.3.1, 4.3.2, and 4.3.3
- Technician instructions, Appendix A, Sections A1 through A8
- Transmission gear selection procedure for steady state tests (Appendix A, Section A8) and Vehicle Preparation Task Table (Appendix A, Table A2)
- Vehicle check-in/setup/checkout sheets, Appendix A, see Data Sheet A1
- Sample vehicle transient exhaust backpressure data plot, see Appendix A, Figure A1
- Sample vehicle transient backpressure data summary, Appendix A, Table A3

1.3.1 This procedure covers all vehicle level backpressure and induction pressure loss testing.

SAE J1349 and ISO 1585 define different methods to certify the vehicle engine power.

This test procedure is valid for both methods. Although automatic transmission vehicles are generally preferred for ease of testing, manual transmission vehicles are also used for backpressure and induction testing. For heavier vehicles with a GVWR > 3856 kg, choosing an appropriate gear for steady state data gathering does not depend on the transmission type.

1.3.2 The procedures for data acquisition vary depending on vehicle GVWR and the region of the world where engine power will be certified. They are the same for both exhaust backpressure and induction pressure loss data generation.

1.3.3 The transient backpressure test is applicable for passenger cars and light duty trucks with a GVWR $\leq$ 3856 kg for regions that comply with the SAE J1349 Net Power Rating Standard.

1.3.4 The steady state backpressure test is applicable for all vehicles in regions that comply with the ISO 1585 Net Power Rating Standard and all trucks with a GVWR > 3856 kg. An engine dynamometer can also be used in place of a vehicle.

1.3.5 Vehicle level induction pressure loss data is taken during transient and steady state backpressure tests, because the setups and driving procedures are the same for exhaust and induction testing. Collecting induction data during a backpressure test requires the addition of a pressure probe and a temperature probe in the inlet duct upstream of the throttle body.

1.3.6 Inlet and exhaust data is used to confirm that net engine power test cell conditions are set properly. If only induction data is requested, exhaust pressure measurements can be omitted. Actual data generation is unique depending upon test and vehicle. To run a test, choose the appropriate sections based on applicability stated in 1.3. Use the instructions and formats provided in Appendix A.

1.3.7 Backpressure measurements may be used during the exhaust system development process to document total backpressure at various points in the exhaust system or for validation purposes. Backpressure measurements may also be used to set fixed back pressure in exhaust systems for laboratory dynamometer WOT power tests when it is desirable to simulate a vehicle exhaust system backpressure level.

2 References

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

2.1 External Standards/Specifications.

80/1269/EEC	ISO 1585	NASA-TM-100430	SAE J1349
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2.2 GM Standards/Specifications.

GMW14908

2.3 Additional References.

- CG2557 Exhaust Backpressure and Flow Calculations Worksheet (External Supplement)
- CG3356 Specific Procedure Identification for Various World Regions

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- CG3357 Gear Selection Worksheet
- CG3358 Data Post Processing Macro
- CG4069 Backpressure Instrumentation Guideline
- CG4094 Fuel Selection Impact to Backpressure Test
- Exhaust Subsystem Technical Specification (SSTS) for respective program of the exhaust system being tested.
- Flow Systems, Incorporated, Berthoud, Colorado (www.flowsystemsinc.com)
- GM Engine Test Code

Note: GM Engine Test Code provides the general standards, tests, forms and correction factors that serve as a guide in laboratory engine test work. This test code is available from GM Powertrain. Data collected per GMW14891 supports the GM Engine Test Code and corresponds to the SAE J1349, ISO 1585 and 80/1269/EEC test codes with respect to net advertised power.
- McMaster Carr Supply Company, Aurora, Ohio (www.mcmaster.com)
- Temprel, Incorporated, Boyne City, Michigan (www.temprel.com)
- United Sensor Corporation, Amherst, New Hampshire (www.unitedsensorcorp.com)

3 Resources

3.1 Facilities.

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 Test Requirements. Appropriate road and dynamometer conditions for safe backpressure and induction testing are as in 3.1.3.1 through 3.1.3.3.

3.1.3.1 Transient. Circular track or long enough straightaway to accommodate WOT accelerations up to 130 km/h and a safe deceleration area, also for warm up and cool down laps.

3.1.3.2 Steady State. Circular track allows for steady speed and 30 s of data gathering at speeds up to 105 km/h towing a dynamometer. Circular track also allows room for warm up and cool down laps. An engine dynamometer test bench can be used as an alternative.

3.1.3.3 Chassis Dynamometer. Capable of running a lightly loaded medium duty diesel truck with a single rear axle at speeds up to 80 km/h while maintaining traction between tires and chassis rolls.

3.2 Equipment.

Note: Instrumentation is similar for both backpressure and induction testing.

3.2.1 Vehicle Speed Sensor. Instrumentation to electronically or optically measure and record vehicle speed. Serial communications protocol data is recommended. An optical speed sensor or fifth wheel is optional.

3.2.2 Engine Speed Sensor. Instrumentation to electronically or optically measure and record engine rpm. Serial communications protocol data is recommended. Use a conditioner with input to the data recorder, if required.

Note: Engine speed can be accessed through the Diagnostic Link Connector (DLC), see Appendix A, Table A2.

3.2.3 Pressure Transducers. A high response pressure transducer designed for the expected pressure range with a flat frequency response from 0 Hz to 100 Hz.

3.2.3.1 Typical pressure range for exhaust is 0 kPa to 103.4 kPa. Typical pressure range for induction is 0 kPa to 8.7 kPa.

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3.2.4 Total Pressure Probes. Kiel probes are utilized to collect total induction pressure loss and total exhaust backpressure data. Total pressure is equal to the dynamic plus the static pressure; it is also referred to as stagnation pressure. SAE J1349 (Engine Power Test Code Spark Ignition and Compression Ignition Net Power Rating) requires a total pressure measurement for induction and exhaust.

3.2.4.1 A Kiel probe consists of a venturi shaped tube shielding an open ended tube used to sense total pressure at the throat of the venturi. These probes are capable of operating in a high temperature environment. The shielding is designed so that the probe reads true in the presence of a limited amount of yaw and pitch variation, ± 10 degrees, from actual flow direction. Kiel probes may be obtained from United Sensor Corporation.

3.2.4.2 Model KBC-6-W and KBC-12-W probes are recommended. These Kiel probes feature a 3.2 mm diameter venturi and 3.2 mm diameter stem that is 150 mm or 300 mm long. The W designation indicates that the venturi is welded for heat resistance up to 927 °C.

3.2.4.3 Models KBC-6-N and KBC-12-N probes can also be used. These Kiel probes feature a 3.2 mm diameter venturi and 3.2 mm diameter stem that is 150 mm or 300 mm long. The N designation indicates that the venturi is attached with micro-brazing for heat resistance up to 982 °C. Nichrome is an alloy of nickel and chromium with high temperature capability.

3.2.4.4 Bending or cutting stems to accommodate vehicle installation can introduce measurement error. Utilize probes with unmodified 150 mm or 300 mm long stems appropriate for the specific vehicle installation.

3.2.4.5 Static pressure can be calculated from measured total pressure, gas stream temperature and flow data, provided the cross sectional area of the flow, typically the flow area of the pipe or duct, is known at the point where the measurement is taken. See 7.1 for additional detail.

3.2.5 Transducer Filtering. Six (6) dB per octave or better low-pass filter set to a 10 Hz cutoff frequency.

3.2.6 Accuracy and Resolution. Use a data acquisition system with accuracy of 1% of full scale or better and resolution of 0.1 kPa or better.

3.2.7 Transducer Tubing. A length of flexible tubing is required to connect the Kiel probe to the pressure transducer.

3.2.7.1 Tubing must be of sufficient strength so that it will not kink when bends are required for installation and it must be capable of making a robust, leak free seal at each connection. Reinforced, rubber fuel hose is recommended.

3.2.7.2 Minimize tubing length between pressure probes and pressure transducers to avoid measurement phase errors.

3.2.7.3 A path length of 450 mm to 500 mm between the head of the Kiel probe and the pressure transducer is required. Use tubing 150 mm long with 300 mm long stems and 300 mm long tubing with 150 mm long stems to maintain the desired path length of 450 mm to 500 mm.

3.2.7.4 The inner diameter of the tubing shall not create a blockage between the probe and transducer that causes measurement error. An inner diameter equal to 3.2 mm enables a robust leak free connection without creating a blockage between the probe and transducer.

3.2.7.5 Vacuum hose and un-reinforced tubing is not allowed.

3.2.7.6 See reference NASA-TM-100430 for information regarding the importance of tubing path length.

Note: For critical A to B comparisons, the tubing volume should be identical between two vehicles to eliminate measurement differences that may occur due to differing tubing volumes.

3.2.8 Pressure Probe Seals. Seals must provide a leak free connection between the Kiel probe and attachment fittings without causing any deformation to the probe stem.

3.2.8.1 Lava rock compression seals do not deform or crimp Kiel probe stems like metal compression seals do. Kiel probes that have not been deformed by metal compression fittings can be reused again and again. Therefore, lava rock compression seals are recommended for sealing the Kiel probe stem to attachment fitting interface. The lava rock compression seal is also reusable to a limited extent. Lava rock compression seals are available from Temprel, Incorporated.

3.2.8.2 Part Number F18L-125 is a 3.2 mm inner diameter lava rock seal only for use with 3.2 mm outer diameter Kiel probe stems. Part Number 18SL-125 is a complete 3.2 mm inner diameter metal fitting with lava rock seal for use with 3.2 mm outer diameter Kiel probe stems and 3.2 mm National Pipe Thread (NPT) taper couplings.

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3.2.9 Couplings. Stainless steel couplings provide a leak free method to attach probes to ducts and pipes. Use McMaster Carr 3.2 mm NPT half coupling, Part Number 4464K221 and 9.53 mm NPT half coupling, Part Number 4464K223 or equivalent.

3.2.10 Thermocouples. Measure and record gas stream temperature near pressure probe locations. Fast response radiation shielded open junction K-type thermocouples with input to the data recorder are required for transient tests. Sheathed thermocouples are required for steady state tests.

3.2.10.1 Gas stream temperature is the predominant variable that influences pressure measurements. A higher gas stream temperature at the same flow rate and cross section always results in a pressure increase. Accurate temperature readings enable consistent and repeatable test conditions required for repeatable pressure measurements.

High temperature shielded thermocouples are available from Temprel, Incorporated.

3.2.10.2 K Temp thermocouple, Part Number T25-MU-3K-AS-LE4R (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.

3.2.11 Data Recorder. One (1) of several commercially available data recorders can be used for backpressure and/or induction testing. The recommended recorder is the Backpressure Test Measurement System by Flow Systems, Incorporated.

3.2.12 Towing Dynamometer. A steady state backpressure test requires a towing dynamometer of appropriate capacity to hold the test vehicle at WOT for the desired engine and road speeds, see 4.3.2.

3.2.12.1 Dynamometers Range in Size Between 2 kN and 25 kN. Selection is based on engine power and weight. As power and weight increase, the size of the dynamometer increases. Typically, 15 kN dynamometers are used with 3900 kg to 4309 kg GVWR vehicles, and 25 kN dynamometers are used with > 4309 kg GVWR vehicles. A 3 kN dynamometer is typical for a small to medium size car.

3.3 Test Vehicle/Test Piece.

3.3.1 Vehicle Configuration.

3.3.1.1 Transient Backpressure Test (Section 4.3.1).

3.3.1.1.1 Run at curb weight.

3.3.1.1.2 Either an automatic or manual transmission is acceptable. Test data is taken in one gear. No shifting is required.

3.3.1.1.3 Traction control setting requirements. Traction control function of all test vehicles should be disabled prior to backpressure testing.

3.3.1.1.4 Start/Stop Function. Ensure engine remains running.

3.3.1.1.5 It is recommended to consult with Validation Engineer for specific fuel selection prior to backpressure testing, especially if the test vehicle comes from a region other than region doing the test. Use CG4094 for further fuel selection impact reference.

3.3.1.1.6 Vehicles with diesel engines must have a forced Diesel Particulate Filter (DPF) regeneration prior to test.

3.3.1.2 Steady State Backpressure Test (Section 4.3.2).

3.3.1.2.1 Run at curb weight. Running with ballast is allowable to save unloading time and labor. A dynamometer is being towed anyway. Warm ups and cool downs are affected slightly, but for an A to B comparison, ballast should not be a concern.

3.3.1.2.2 Either an automatic or manual transmission is acceptable. Test data is taken in one gear. No shifting is required.

3.3.1.2.3 Traction control setting requirements. Traction control function of all test vehicles should be disabled prior to backpressure testing.

3.3.1.2.4 Start/Stop Function. Ensure engine remains running.

3.3.1.2.5 It is recommended to consult with Validation Engineer for specific fuel selection prior to backpressure testing, especially if the test vehicle comes from a region other than region doing the test. Use CG4094 for further fuel selection impact reference.

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3.3.1.2.6 Vehicles with diesel engines must have a forced DPF regeneration prior to test.

3.4 Test Time.

Calendar time:	3 days to 5 days
Test hours:	2 hours (on test track)
Technician hours:	24 hours
Engineer hours	4 hours
Total hours	40 hours

Note: Considered in the test time is vehicle preparation, downtime, actual test time and an analysis of data in establishing a total requirement. The time table is for the first configuration, one test.

Note: One (1) test requires at least two runs. Additional test configurations require less technician time to revise the original build.

3.5 Test Required Information. Vehicle level data is utilized to determine in service operating conditions that may be used to set fixed restrictions in exhaust systems for laboratory dynamometer WOT power tests, when it is desirable to simulate a vehicle exhaust system backpressure level.

3.5.1 Ambient temperature, pressure and humidity, engine speed, inlet air temperature, inlet air pressure, air/fuel ratio, mass air flow, manifold absolute pressure, exhaust gas stream temperature, exhaust total backpressure, coolant temperature, spark advance, cam phaser position, and knock control are utilized to establish the correlation between vehicle environment and engine test cell. Other time based engine control parameters may be needed for specific design configurations.

3.6 Personnel/Skills. Technician basic skills needed:

- Ability to perform welding and exhaust and induction component changes
- Skilled in instrumentation set up and data recorder usage
- Skilled and knowledgeable in procedures and use of existing test facility road system
- Special driver license for operating high GVWR vehicles may be required. An air brake endorsement may be required for vehicles of even higher GVWR.

4 Procedure

4.1 Preparation. Use Vehicle Preparation Task Table, Appendix A, Table A2 as a guide for checking, building, and instrumenting of the test vehicle.

4.1.1 Setup and Test Procedure Instructions. The test request engineer prepares a test vehicle specific package for technician use during build and test, Appendix A, Tables A1, A2 and A3.

Documentation includes:

- Vehicle check-in (Appendix A, Data Sheet A1)
- Data channels to be used with the data recorder, including notes
- Transmission gear selection calculation, for steady state backpressure tests. See Appendix A, Table A1. Vehicle weight with instrumentation and fuel.
- Warm up procedure
- Test procedure
- Data processing

4.1.2 Identify Measurement Locations.

4.1.2.1 Determine all pressure, gas stream temperature and skin temperature measurement locations. Exhaust pressure shall be measured in a manner to obtain the total (stagnation) pressure immediately downstream from the exhaust system's first major restrictive element. Exhaust system temperature shall be measured in approximately the same location as the pressure measurement.

4.1.2.2 Program specific exhaust backpressure measurement locations are documented in the Program Specific Exhaust Subsystem Technical Specification (SSTS).

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4.1.2.3 Measurement locations must be documented in the header comments of all data files.

4.1.2.4 Any proposal to relocate the measurement point to an area of turbulent flow violates the intent of SAE J1349. SAE J1349 states that if a complete vehicle exhaust system is not used, the laboratory system must include the vehicle system at least through the first major restriction, e.g., closed coupled catalytic converter.

4.1.2.5 Exhaust total pressure probes shall be placed in a fully developed flow region downstream of the catalytic converters.

4.1.2.6 Manifold applications fitted with integral catalytic converters are not exempt from this requirement. The measurement location shall always be in a fully developed flow region downstream of the irregular fluctuations generated by turbulent flow in the manifold. Probes placed at the flange or in the manifold upstream of an integral catalyst produce inaccurate results due to irregular pressure pulses created by turbulent flow.

4.1.2.7 Turbocharged engine applications may require additional distance between the turbo outlet and the downstream exhaust pressure probe to avoid turbine disturbance.

4.1.2.8 Pressure probe placement in a fully developed flow region is essential for obtaining accurate measurements.

4.1.2.9 Gas stream temperature is a key variable affecting all pressure measurements. Determine where any additional exhaust and/or induction temperature data is required to supplement the standard setup defined in 4.1.4. Extra development locations and/or channels may be utilized to establish a baseline for future testing.

4.1.2.10 Exhaust skin temperature measurements are helpful for correlating analytical models. Ambient roof air temperature, snorkel air inlet temperature, and serial communications engine data is helpful for correlating lab test conditions.

4.1.3 Data Channels. Install the data recorder to measure and record:

- Engine Speed
- Vehicle Speed
- Fuel Equivalency Ratio
- Mass Air Flow
- Exhaust Gas Stream Temperature
- Exhaust Backpressure
- Exhaust Skin Temperature
- IAT (Induction Air Temperature)
- Induction Total Pressure Loss
- Ambient Air Temperature
- Coolant Temperature
- MAP (Manifold Absolute Pressure)

When applicable:

- Spark Advance
- Intake Cam Phaser Position
- Exhaust Cam Phaser Position
- Knock Control
- Charge Air Cooler Temperature
- Charge Air Cooler Pressure
- Other Time Based Engine Control Parameters

Note: See DLC clarification in Vehicle Preparation Task Table, Appendix A, Table A2. Some of the serial communications protocol data channels may not be readily available.

4.1.4 Pressure and Temperature Probe Mounting. Before removing the induction or exhaust system from the vehicle, determine and mark pressure and temperature probe locations on components to allow for installation access and clearance.

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