



Mass Airflow Sensor Testing in an Air Induction System

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. Described herein are procedures for characterization of a Mass Airflow (MAF) Sensor signal output versus airflow in an Air Induction System (AIS) on an airflow test stand(s) in a laboratory. Two types of air induction systems that are covered by these procedures are:

- Single Box Single Outlet (SBSO) AIS
- Single Box Dual Outlet (SBDO) AIS

Procedures include:

- Quantification of Gage Repeatability and Reproducibility of the laboratory test stand.
- Establishment of Master Transfer Function(s) for Vehicle Calibrations. Robust Assessment of AIS/MAF subsystems to spatial flow field variation effects.
- Branch Bias Robustness Assessment of AIS/MAF subsystems with two MAF sensors to special flow field variation effects induced by varying mass flow in each of two outlet branches.
- Transparency confirmation of Secondary Air Injection (SAI) On versus Off.

This document describes test setup, data collection, interpretation, presentation and transmission processes as well as related requirement criteria for the aforementioned.

1.2 Applicability. These procedures should be conducted on new AIS or MAF sensor designs, or whenever design or manufacturing changes occur to an existing AIS or MAF sensors that might impact airflow in the AIS or measurement capability of the MAF sensor.

These procedures are applicable for vehicle applications utilizing the Engine Management System (EMS) per the MAF Sensor Component Technical Specification (CTS).

These procedures are also meant to complement the AIS performance demonstrations required for source award, as well as during preproduction and production tool confirmations.

These procedures assume the MAF sensor has completed technical compatibility assessment via the approval process defined in the MAF Sensor CTS. This process includes a line-by-line review of component level data against the requirements in the device technical specification. Flow tests with unapproved MAF devices are not recommended.

1.3 Remarks. MAF sensor is part of the EMS. The output of a MAF sensor is used by the EMS to meet drivability and tailpipe emissions requirements. MAF sensor(s) are located on the clean side of the AIS filter in the flow centroid and convert air speed in the AIS to voltage and then frequency. By assuming area and air density are constant, MAF sensor output is directly related to mass airflow. Airflow turbulence in the AIS can result in MAF sensor signal output variation from air velocity fluctuations. MAF sensor performance can also be affected by ducting geometry of the AIS. Therefore, airflow characterization in a representative AIS is necessary.

2 References

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

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2.1 External Standards/Specifications.

None

2.2 GM Standards/Specifications.

None

2.3 Additional References.

- AIS Subsystem Technical Specification (SSTS)
- MAF Sensor CTS

3 Resources

3.1 Facilities. These procedures assume the MAF sensor supplier shall conduct the tests using suitable steady airflow sonic nozzle type laboratory airflow test stands (two airflow test stands are required for SBDO AIS) and can accommodate inspection by the AIS supplier if necessary. These procedures also assume the airflow stands can, as may be necessary, operate in a coordinated automated manner to step through a range of airflow points to establish MAF sensor output relationships. Airflow test stands are assumed to be in an air conditioned room such that air temperature and humidity are controlled to conditions listed in the MAF Sensor CTS. All airflow tests shall be conducted with air at the aforementioned conditions. Room ambient temperature, barometric pressure and relative humidity shall be monitored.

Voltage supplied to MAFs shall be 13.5 V unless directed otherwise. Voltage shall be monitored.

Each procedure described herein shall utilize Steady Flow test stands.

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. These procedures assume the availability of suitable data recording and reporting equipment. The recording equipment shall have no signal filtering beyond that shown for the controller interface circuit in the MAF device specification. All data shall be recorded at a sample rate of at least 500 Hz. Any changes to the raw MAF output data collected during any test shall be justified and documented.

AIS samples shall be mounted on the test stand to represent in-vehicle nominal static location. Mechanical devices to support various locations of the AIS shall be used to present the AIS sample to the flow test stands. It is assumed that these related fixtures will be provided by the AIS supplier.

3.3 Test Vehicle/Test Piece. Each of the procedures described herein has unique requirements for test parts.

Unless otherwise specified, MAF sensors for these tests shall exhibit nominal output at all calibration and audit points used in the manufacture of the device.

3.4 Test Time.

	Single MAF	Dual MAF
Calendar time:	1 day	2 days
Test hours:	6 hours	12 hours
Coordination hours:	2 hours	4 hours

Note: Each of the procedures described herein are anticipated to take 1 day to 2 days to complete per set of AIS samples tested. See Section 4 for procedure details.

3.5 Test Required Information. These procedures require creation and submission of test reports as described in Section 5.3. Capability to transmit reports via electronic mail or internet is required.

3.6 Personnel/Skills. Test stand operator should have knowledge of:

- General fluid dynamics
- MAF sensor operation
- AIS manufacturing methods

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- Data recording methods
- Statistical analysis methods
- Applicable test facility requirements

See Section 4 for procedure details.

4 Procedure

Note: Unless indicated, all procedures for SBSO systems apply to SBDO systems as well. Results will apply for each of two MAF sensors.

4.1 Preparation.

4.1.1 Gage Repeatability and Reproducibility (R&R). These procedures assume that airflow test stands are essentially a gage and are intended to assess the repeatability and reproducibility of any stands and associated data capturing equipment. These procedures are not applicable to the production manufacturing airflow stand equipment, but rather the laboratory airflow stands utilized to establish master transfer functions and gather data for other engineering related tests. Gage R&R demonstrations must be performed (or the results of a prior demonstration must be still applicable) prior to conducting any other flow test. Demonstration shall consist of review and approval from the MAF Sensor Technical Specialist and appropriate Supplier Quality Engineer (SQE).

4.1.1.1 Gage R&R - Repeatability. Repeatability shall be demonstrated via control charts of actual airflow as measured by the test stands using an ideal induction system and master MAF sensor. Control charts for each master MAF sensor frequency output shall also be maintained. Control charts shall be available for each desired airflow point used to create the MAF sensor output frequency characterization curve. An ideal induction system is a 10-diameter tube (a piece of tube with the same diameter as the test piece and a length equal to 10x this diameter), round air cleaner or equivalent, and is intended to greatly minimize variations from duct geometry and mounting. A master MAF sensor shall have nominal output and represent a current or past model production part. Gage R&R demonstrations can be conducted using a voltage out MAF Sensor. Repeatability test shall be conducted and charts updated at the start of the day prior to any flow test. Charts shall be maintained to show trends over past year based on appropriate moving averages. Trends that fall out of control shall instigate corrective actions prior to conducting any other flow tests. See Section 5.3 for reporting methods.

4.1.1.2 Gage R&R - Reproducibility. Reproducibility shall be demonstrated via three (3) repeated airflow tests of the ideal induction system and master MAF sensor. The ideal induction system with master MAF sensor shall be removed and reinstalled prior to each test run. Room ambient conditions are assumed to change very little during this demonstration. This demonstration shall be conducted on an annual basis (or approximately every 2000 h of test stand operation).

These assessments shall also include confirmation that any methods of moving between flow points in an automated fashion, include sufficient settling time prior to capturing pertinent data.

Results from these tests shall not exceed $\pm 0.4\%$. See Section 5.3 for reporting methods.

4.2 Conditions. Establish Master Transfer Function(s). This procedure is intended to characterize the output of MAF sensor versus airflow, also known as the Master Transfer Functions (MTF), in a particular new and representative Air Induction System. The MTF is used by EMS. Traditionally the MTF has been generated using a method referred to as **5x5** run.

Note: Allowable deviation and signal noise can be found in the AIS SSTS.

4.2.1 Environmental Conditions.

The airflow test stand is assumed to be in an air conditioned room such that air temperature and humidity are controlled to conditions listed in of the MAF Sensor CTS.

4.2.1.1 SBSO AIS. One airflow test stand is required. The airflow test stand assumed to be in an air conditioned room such that air temperature and humidity are controlled to conditions listed in the MAF Sensor CTS.

4.2.1.2 SBDO AIS. Two airflow test stands are required for this test. These airflow test stands are assumed to be in an air conditioned room such that air temperature and humidity are the same for each stand and controlled to conditions listed in the MAF Sensor CTS.

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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.

Unless otherwise provided, the flow range for this test shall be 0.5 m/s to 50 m/s (0.25 m/s to 50 m/s for wide dynamic range meters). This airspeed range will be converted to flow by assuming an air density shown in the MAF Sensor CTS and knowledge of the duct area at the MAF sensor for the given AIS/MAF hardware.

Tests shall also include assessment starting at 0 g/s.

4.2.3 Test Samples.

4.2.3.1 SBSO AIS. See the Air Induction SSTS for part and test requirements.

Parts used for a traditional **5×5** characterization:

- Five (5) representative AIS (same as parts used for builds)
- Five (5) intent MAF sensors with nominal output

4.2.3.2 SBDO AIS See the Air Induction SSTS for part and test requirements.

Parts used for a traditional **5×5** characterization:

- Five (5) representative AIS (same as parts used for builds)
- Ten (10) intent MAF sensors as per 4.3.2 with nominal output

Note: If each branch is to receive a different MAF device design, five (5) of each design with nominal output will be required.

4.3 Instructions.

4.3.1 SBSO AIS. Characterize the device output versus airflow. Airflow range is 0 g/s to maximum air flow (maximum air flow is listed in AIS SSTS), and shall proceed from highest to lowest air flow rate. Typical characterization is done by conducting a **5×5** test where each MAF is tested in each AIS.

Conduct the data reduction and analysis as described in 5.3 on the 25 runs. Output deviation exceeding the ranges specified in the Air Induction SSTS shall require corrective actions which might include, but not limited to, AIS geometry revisions, air filter revisions, flow straightener addition, MAF sensor relocation or utilization of a more accurate MAF sensor.

4.3.2 SBDO AIS. Concurrently characterize both MAF outputs versus airflow. For SBDO AIS systems the airflows are defined as “bulk” and “branch”. For this test instruction, bulk airflow is the total airflow passing thru the AIS for any flow set point in the airflow range. For this test instruction, branch airflow is airflow for each of two outlet branches, and is equal to one half of the bulk airflow for any flow point in the airflow range. Bulk airflow range is 0 g/s to maximum air flow (maximum air flow is listed in AIS SSTS), and shall proceed from highest to lowest air flow rate. Typical characterization is done by conducting a **5×5** test where MAF sensors are paired by branch (i.e., branch1_M1, branch2_M1 defines meter-pair (MP- No. 1)) and tested in each AIS (i.e., five (5) AIS and five (5) meter-pairs). Meter-pairs are not to be separated or interchanged between branches during testing. A table defining each meter in each meter-pair shall be supplied (Appendix A, Figure A16). Tests results shall refer to this meter-pair in every instance where typical reference to a SBSO system meter is made.

Conduct the data reduction and analysis as described in 5.3 on the 25 runs. This will generate output for each branch, or twice that of a SBSO system. Output deviation exceeding the ranges specified in the Air Induction SSTS shall require corrective actions which might include, but is not limited to, AIS geometry revisions, Air filter revisions, flow straightener addition, MAF Sensor relocation or utilization of a more accurate MAF sensor.

4.4 AIS/MAF Robust Assessment (R/A). Also known as the Blocked Filter Test, these procedures are intended to characterize the performance of the complete Air Induction System using Taguchi noise methods. (A P-diagram is included in Appendix A, Figure A1). Tests are constructed to assess MAF output variation in disturbed flow fields. For these procedures, disturbed flow fields shall be achieved by altering the flow of a section of the air filter. The underlying assumption is that Air Induction Systems robust to these noise factors will have superior robustness to lesser noises, i.e., an AIS that is robust to this test will not be affected by typical upstream variation sources like filter media or pleat inconsistency, AIS mounting in-vehicle, etc.

Air Induction Systems offering lower MAF output variation during these conditions are beneficial to the EMS. As such deviation from the undisturbed or baseline condition to any disturbed condition shall not exceed:

See Deviation and Signal Noise requirements in Air Induction SSTS.

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4.4.1 AIS/MAF R/A - Test Equipment.

4.4.1.1 SBSO AIS. Steady sonic flow test stand mentioned in Section 3.1.

4.4.1.2 SBDO AIS. Two steady sonic flow test stands mentioned in Section 3.1. Each stand shall be attached to one AIS outlet branch. These stands must be capable of operating in a coordinated manner necessary to present a range of equal split mass flow rate conditions to the SBDO AIS in an automated fashion.

4.4.2 AIS/MAF R/A - Test Samples

4.4.2.1 SBSO AIS. This procedure utilizes the following test hardware:

- One (1) AIS representative of program phase
- One (1) intent MAF with nominal output

4.4.2.2 SBDO AIS. This procedure utilizes the following test hardware:

- One (1) AIS representative of program phase
- Two (2) intent MAF with nominal output (one each for two branches)

4.4.3 AIS/MAF R/A - Test Conditions. Flow field distortion shall be achieved by blocking one third of the dirty side of the air filter using grey duct tape. Tape shall be applied in an edge to edge arrangement. Both horizontal and vertical blocking orientation shall be tested for a given AIS/MAF application, resulting in six (6) runs.

See Appendix A, Figures A2 and A3 for example of a blocked filter.

4.4.4 AIS/MAF R/A - Instructions. Characterize the device output in the design intent AIS during a flow test at room standard laboratory temperature/humidity and voltage conditions.

Measure the length and width or diameter of the air filter dirty side and divide into thirds. Block one third of the air filter dirty side and repeat the characterization. Block the remaining thirds each in turn and repeat the characterization. Repeat the characterizations with the filter blocked in the perpendicular direction one third at a time. Only one third of the length or width of the air filter dirty side should be blocked for each characterization.

For irregular shaped filters, divide the filter into three (3) equal areas in both directions.

For cylindrical filters, divide filter into six (6) equal areas in the axial direction and three (3) equal areas in the radial direction.

Conduct the data reduction and analysis as described in 5.3 on the seven (7) runs (one (1) baseline + six (6) blocked). Output deviation exceeding the ranges in the Air Induction SSTS shall require corrective actions which might include AIS geometry revisions, flow straightener addition, MAF sensor relocation or utilization of a multiple element MAF.

See Deviation requirements in Air Induction SSTS.

4.5 SBDO AIS Branch Bias Robustness Assessment (BBR/A). SBDO AIS subsystems feature an architecture in which the air flow is drawn thru the system housing via inlet(s) and two outlet branches. Typically, these outlets feed separate turbochargers. As such, airflow separates within the housing to supply each outlet. Given potential variation in turbocharger operation, biasing of flow rates between outlet branches (also known as branch biasing) is to be expected. Insomuch as this biasing can affect the flow fields feeding each MAF sensor, shifts in each MAF sensor transfer function can occur as compared to an equal unbiased split transfer function. This can occur across the full range of bulk air flow. Robustness to this branch biasing phenomenon is desirable. This procedure provides a systematic method for evaluating flow induced Branch Bias Robustness (BBR).

4.5.1 SBDO AIS BBR/A - Test Equipment. Steady sonic flow test stand mentioned in Section 3.1

4.5.2 SBDO AIS BBR/A - Test Samples.

- One (1) representative AIS (same as used for builds).
- Two (2) intent MAF Sensors (one pair) with nominal output.

4.5.3 SBDO AIS BBR/A - Test Conditions.

- For this test instruction, bulk airflow is the total airflow passing thru the AIS for any flow set point in the airflow range.
- The bulk airflow range is defined in the AIS SSTS and testing shall proceed from highest to lowest airflow rate.

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- For this test instruction, branch airflow is airflow for each of two outlet branches. Test conditions include both equal and non-equal branch flow rates.
- For this test instruction, branch biasing occurs when branch airflow rates are not equal. This is defined by a percentage of airflow rate from a baseline equal branch airflow rate.
- Bulk airflow is controlled by each of two steady flow benches in a coordinated systematic way to create both equal and biased branch airflow.
- Biasing amount, intervals/levels, and deviation limits are defined for differing ranges of bulk airflow, and are supplied in the AIS SSTs.

4.5.4 SBDO AIS BBR/A - Instructions. For each bulk set point in the airflow range, two studies are set up, one for each branch. First, at each set point, meter output data is acquired for each meter with equal mass airflow in each branch, i.e., 0% branch biasing. This becomes BBR baseline data for comparison with data taken during biased conditions. Then, for each bulk set point, one branch airflow rate is held constant at one half the set point bulk airflow rate while the other varies through predefined range and levels (percentages) of “biased” branch airflow. Meter output data is collected for the branch being held constant and used to compare to the equal mass condition baseline data for that branch. Then the same study is conducted for the opposite branch. The test progresses from high to low bulk flow rates and acquires equal mass and biased meter output data for each branch before proceeding to the next bulk airflow set point.

Deviation results shall be plotted for **each** branch separately using the equal mass data as the baseline and “bias” responses as deviation data. This will be represented by a deviation plot where each line represents a deviation bias level (%) and demonstrates the shift (dQ/Q (%)) of the biased level Transfer Function (TF) from the equal mass baseline TF. Tests may be conducted in several bulk ranges and presented separately, i.e., low, medium, and high flow ranges, to correspond with flow bench/system capabilities and requirement ranges. See Appendix A, Figure A17 for an example of a BBR test deviation plot with the same bias ranges and intervals, but different limits.

Note: Each bias level must be clearly labeled so as to identify Test Date, Hardware Description, Branch of Study, Biased Branch, and Bias Level.

Signal noise shall be processed and presented in the same fashion as all other noise data with the exception that each line represents a bias level instead of a hardware configuration. See Appendix A, Figure A18 for an example of a BBR test signal noise result plot.

4.6 SAI On versus Off Confirmation. Certain applications utilize SAI to reduce cold start emissions by providing excess oxygen to the Exhaust System to complete the reaction of Hydrocarbon + Carbon Monoxide ($HC + CO$) into Carbon Dioxide (CO_2) and water vapor. All GM SAI applications utilize SAI air feed from the clean side of the air filter. Inappropriate SAI port location can result in flow field distortion and MAF Sensor output biasing. These procedures are intended to confirm equivalent MAF sensor output in the complete air induction system for SAI On versus Off.

SAI On represents essentially a disturbed flow field case akin to the Robust Assessment described above. As such, similar requirements shall apply. Air Induction Systems offering lower MAF output variation during these conditions are beneficial to the EMS. As such deviation from the undisturbed or baseline condition to any disturbed condition with SAI On shall not exceed:

See Deviation and Signal Noise requirements in Air Induction SSTs.

4.6.1 SAI On/Off - Test Equipment.

4.6.1.1 SBSO AIS. Steady sonic flow test stand mentioned in Section 3.1. A means to simulate SAI is also necessary either via a representative pump or a second flow stand.

4.6.1.2 SBDO AIS. Two steady sonic flow test stand mentioned in Section 3.1. Each stand shall be attached to one AIS outlet branch. These stands must be capable of operating in a coordinated manner necessary to present a range of equal split mass flow rate conditions to the SBDO AIS in an automated fashion. A means to simulate SAI is also necessary either via a representative pump or an additional flow stand.

4.6.2 SAI On/Off - Test Samples.

4.6.2.1 SBSO AIS.

- Five (5) representative AIS (same as used for builds)
- One (1) intent MAF with nominal output

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