U.S. EPA STEADY STATE AND TRANSIENT TESTING EQUIPMENT AUDIT GUIDANCE

Purpose

Auditing of the test systems conducting steady state (ASM) or transient (mass based) testing using ASM-style equipment is necessary to ensure all applicable inspection equipment accuracy requirements are met. The basic requirements for passing an audit are to have properly functioning, accurate test equipment that can correctly perform the prescribed inspection procedures and provide highly reliable accurate results.

The ultimate objective of performing overt equipment audits is to maximize the overall effectiveness of the program through ensuring accurate and consistent testing.

Audit Criteria

Audits of test systems in emissions testing stations are conducted on a random, unscheduled basis. The station manager is not given advance notice of the audit, but is instead informed of the audit at the time of the auditor=s arrival at the station.

The audits are performed using the Audit Inspection Report (AIR), a copy of which is attached.[*] An example of a completed AIR worksheet is also attached. The location of certain test menus or displays will vary by manufacturer.

The equipment audit will consist of testing the analyzer, dynamometer, VMAS unit, gas cap tester, RPM measurement, OBDII communication link, and weather station to ensure each is functioning properly.

Audit Procedures

Upon entering the station, the auditor will identify himself to the station manager and inform the manager that an audit is being conducted. Tell the manager that the audit will consist of testing each test system and all peripheral equipment (e.g., dynamometer, VMAS unit, gas cap tester, etc.) at the station to verify they are functioning properly. The auditor will then perform the audit following the procedures outlined below.

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[*]This form should be replaced with audit software installed on a laptop computer that each auditor will be issued. The software should have essentially the same format as the audit inspection report (AIR) form; however, all the calculations will be performed automatically. For audits conducted on a routine basis as part of I/M program administration, all resulting data need to be entered electronically into a centralized database for both analysis and reporting. The software must therefore be customized to match the program's design parameters (e.g., the applicable types of test procedures and equipment, type of data system, etc.). For EPA audits that are conducted at a much lesser frequency and on more of an intermittent basis, connectivity to the central database is not required.

Begin by printing the information requested at the top of each page on the AIR form. For "Time," record the time the audit is started. The facility number, test system number, and software version number should be available in the test system software under "Station Information," and the test system serial number should be on an identification plate attached to the unit. Auditors should print their name under "Auditor Name."

Most audits will be performed through the QA/State Menu. Auditors are typically required to scan their ID badge or enter their ID number manually, and enter their PIN to make the system go into "state audit mode." Auditors must ensure that no one sees their ID number or PIN. Every time an auditor enters "state audit mode," a special audit record should be written to the test system hard disk. This record should be automatically transmitted to the network's host computer the next time the inspector does an inspection, unless an equally valid method is being used to ensure capture of all audit records.

Experience in several states indicates that auditing an ASM system with a gas cap tester takes an experienced auditor about 45-60 minutes. An additional 30 minutes will be needed to audit a VMAS unit, and auditing a transient dynamometer requires another 30 minutes. It may take inexperienced auditors as much as twice these time estimates to conduct the various audit elements.

Audit Failures

Any component of the test system that fails an audit check is to be recalibrated (if applicable) by the inspector after completion of the audit procedures described below. If the equipment still fails after recalibration, the auditor shall lock out the unit from further testing. A manufacturer=s service representative must then inspect the equipment, and identify and correct the cause of failure. If the failure cannot be corrected, the test equipment must be replaced with either a new or a loaner unit. Following the required service call, a follow-up audit should be performed and the lockout cleared if the equipment passes the follow-up audit.

Audit Modules

Module 1. Test System Visual Audit

The auditor will confirm that all required test equipment (i.e., analyzer, dynamometer, VMAS unit, gas cap tester, and all other equipment) is in proper working order by visually inspecting the items listed in Module 1 of the AIR form that are applicable to the program being audited. This includes the items below.

1. All pieces of equipment are properly housed.
2. All pieces of equipment are clean and orderly.
3. Vehicle restraints are present (if a dynamometer is used).
4. There are no signs of tampering.

5. Any evaporative emissions test equipment is properly connected to the test system (if used).
6. The dynamometer is properly connected to the test system and power (if used).
7. The VMAS unit is properly connected to the test system and power (if used).

Next, the auditor will print out the status page for the test system and attach it to the AIR form for future reference.

Module 2. Weather Station Audit

The ambient temperature, relative humidity, and barometric pressure are used in adjusting emissions measurements. The equipment required includes the following:

1. Psychrometer
2. Barometer

To perform the audit, the auditor should first set up the psychrometer. This requires wetting the sleeve on the wet bulb thermometer and turning on the fan. The psychrometer should be placed on or near the test system, but away from direct sunlight, obvious air flow, or a fan in the analyzer. The electronic barometer should be turned on and also set near the analyzer. The test system should be set to display the weather station readings. Allow both the analyzer and the reference instruments two minutes to equilibrate. Record the ambient temperature, humidity, and barometric pressure readings from the analyzer and from the reference instruments. The difference between the measured and reference values for temperature, humidity, and barometric pressure should be calculated. The auditor should note whether the measurements pass or fail by checking the appropriate box in Module 2 on the left of the AIR form.

Module 3. Analyzer Gas Audit

<u>Leak Check</u> - To verify there are no leaks in the system before performing a gas audit, a leak check must be performed. To confirm that the leak check is working, the auditor must first run a leak check without the cap in place. The system should fail the leak check. If the system fails the leak check without the cap in place, this is considered passing the test, and the pass box in Module 3 of the AIR form should be checked. The end of the probe should then be capped and the test rerun. If the unit passes the leak test, the pass box on the audit form should be marked. If the unit fails either test, the auditor should have the lead inspector check all of the hose fittings on the system to ensure they are tight. If the system does not pass after tightening all of the fittings on the hose, the gas audit should not be performed.

<u>Analyzer Accuracy</u> - Accuracy of the analyzer should be tested by flowing gases of known concentration through the analyzer. The following equipment is required to perform the audit:

1. 1/4" ID x 3/8" OD Tygon tubing
2. Bubble tubing (used to adapt the tubing to the analyzer probe tip)
3. Hose tee, 1/4" x 1/4" x 1/4"
4. Balloons
5. Audit gases (described below)
6. Audit gas regulators

The following gases shall be used for the five-point calibration audit:

(A) Zero Audit Gas

O_2	=	20.9%
HC	$<$	1.0 ppm THC
CO	$<$	1.0 ppm
CO_2	$<$	200 ppm
NO	$<$	1.0 ppm
N_2	=	Balance 99.99 % pure

(B) Low-Range Audit Gas

HC	=	200 ppm propane
CO	=	0.5 %
CO_2	=	6.0 %
NO	=	300 ppm
N_2	=	Balance 99.99 % pure

(C) Low-Middle Range Audit Gas

HC	=	960 ppm propane
CO	=	2.4 %
CO_2	=	3.6 %
NO	=	900 ppm
N_2	=	Balance 99.99 % pure

(D) High-Middle Range Audit Gas

HC	=	1920 ppm propane
CO	=	4.8 %
CO_2	=	7.2 %
NO	=	1800 ppm
N_2	=	Balance 99.99 % pure

(E) High-Range Audit Gas

HC	=	3200 ppm propane
CO	=	8.0 %
CO_2	=	12.0 %
NO	=	3000 ppm
N_2	=	Balance 99.99 % pure

The gases used for the audit shall be traceable to National Institute of Standards and Technology (NIST) standards ±1%. Gases shall have a 2% blend tolerance. The audit procedure is as follows:

1. Module 3 of the AIR form contains sections for each of the audit gases used. In the column labeled "Standard," the concentrations on the label for each of the audit gases cylinders should be written. On the example worksheet, the Low gas has 300 ppm of NO, the Mid #1 has 900 ppm of NO, the Mid #2 has 1800 ppm of NO, and the High has 3000 ppm of NO. 1% oxygen in nitrogen should also be used to check the oxygen sensor in the analyzer.

2. The auditor should connect an outlet hose with a balloon attached to the "tee" to the Zero audit gas regulator.

3. Confirm that the analyzer has been zeroed before starting the audit. On some analyzers a zero is automatic, on others it may need to be manually initiated.

4. Put the analyzer in gas audit mode. There should be a display of the gas readings (and possibly the PEF value). The HC reading MUST be in "ppm Propane." On some systems it will be necessary to change the readings from "ppm Hexane" to "ppm Propane."

5. Insert the sample probe into the gas line from the Zero audit gas cylinder.

6. Open the valve on the top of the Zero audit gas cylinder and the valve at the outlet (at the end by the hose).

7. Watch the balloon and adjust the regulator (the valve in the middle) until the balloon stands upright but is not fully inflated.

8. After one minute and when the HC, CO, CO_2, and NO readings have stabilized, record the readings in the "Measured" column of Module 3 of the AIR form in the Zero air rows.

9. Disconnect the probe from the sample line and allow it to sample ambient air until the NO reading is below 20 ppm or until two minutes have elapsed.

10. Repeat the procedure using the 1% oxygen in nitrogen audit gas if the analyzer is used with a VMAS unit.

11. Repeat the procedure with the other four audit gases.

12. Calculate the high and low limits for each gas:
    a. High limit = Standard + Allowed error
    b. Low limit = Standard - Allowed error

All results shall be recorded in Module 3 of the AIR form. The high and low limits shall be calculated by adding and subtracting the calculated allowed error to/from the cylinder concentrations. The allowed error is calculated based on the greater of either the absolute accuracy of the analyzer, or the percent of point accuracy required of the analyzer. An example of the calculation of the allowed error is shown in Table 1. A blank electronic copy of the spreadsheet is available on EPA's website.

Table 1

Spreadsheet for Calculating ASM Audit Tolerances										
Range	Gas	Gas Concentration		Audit Tolerance			Applied Tolerance (greater of % or point)	Audit Limits	
		Recom-mended	Actual Cylinder	%	% (as point)	Point		Low	High
High	HC (ppm)	3200	3191	4.0%	128	40	128	3063	3319
	CO (%)	8.00	8.11	4.0%	0.32	0.10	0.32	7.79	8.43
	CO2 (%)	12.00	11.90	4.0%	0.48	0.42	0.48	11.42	12.38
	NO (ppm)	3000	2987	5.0%	149	55	149	2838	3136
Mid High	HC (ppm)	1920	1918	4.0%	77	27	77	1841	1995
	CO (%)	4.80	4.83	4.0%	0.19	0.07	0.19	4.64	5.02
	CO2 (%)	7.20	7.15	4.0%	0.29	0.37	0.37	6.78	7.52
	NO (ppm)	1800	1801	5.0%	90	43	90	1711	1891
Mid Low	HC (ppm)	960	960	4.0%	38	18	38	922	998
	CO (%)	2.40	2.39	4.0%	0.10	0.04	0.10	2.29	2.49
	CO2 (%)	3.60	3.57	4.0%	0.14	0.34	0.34	3.23	3.91
	NO (ppm)	900	902	5.0%	45	34	45	857	947
Low	HC (ppm)	200	203	4.0%	8	10	10	193	213
	CO (%)	0.50	0.49	4.0%	0.02	0.02	0.02	0.47	0.51
	CO2 (%)	6.00	6.01	4.0%	0.24	0.36	0.36	5.65	6.37
	NO (ppm)	300	299	5.0%	15	28	28	271	327
Zero	HC (ppm)	0	0	4.0%	0	9	9	-9	9
	CO (%)	0.00	0.00	4.0%	0.00	0.02	0.02	-0.02	0.02
	CO2 (%)	0.00	0.00	4.0%	0.00	0.30	0.30	-0.30	0.30
	NO (ppm)	0	0	5.0%	0	26	26	-26	26
	O2	20.9	20.9	6.0%	1.3	0.5	1.3	19.6	22.2
VMAS	O2	1.00	1.05	6.0%	0.06	0.31	0.31	0.74	1.36
In the "Actual Cylinder" column, enter the gas concentrations from the audit cylinders The audit low and high tolerances are calculated in the columns on the right									

The measured value should be compared to the high and low limits, and the appropriate "pass/fail" box should be checked. If the analyzer fails for any gas, a gas calibration should be performed with the approval of the shop and the audit should be repeated. The first audit check should be marked as an "initial test," and any recheck performed after an initial audit failure and subsequent calibration should be marked as a "retest," in the appropriate boxes near the top of Module 3 of the AIR form. If the analyzer passes on the second attempt, this will serve as the official audit result. If it fails the retest, an overall gas audit failure should be recorded. Both sets of analyzers audit results should be reported.

Module 4. RPM Measurement Audit

The test system is required to include a tachometer capable of detecting engine speed using various probes, including an OBDII connection on 1996 and newer vehicles. Equipment required for this procedure includes the following:

1. RPM simulator with an inductive (or “clip on”) probe
2. EASE Diagnostics OBDII verification tester OVT-2020-SW (or equivalent)
3. 1996 or newer vehicle (optional)

The OBDII verification tool is relatively expensive. If the analyzers are not going to be audited for OBDII testing (see Module 8), it may therefore not be cost-effective to purchase the audit tool just to verify that the RPM can be properly obtained through the OBDII port. Alternatively, if the OBDII tester is not going to be purchased, a 1996 or newer vehicle can be used to conduct the audit and confirm OBDII communications for retrieval of RPM, but no quantitative data can be gathered (the system will pass if it can obtain a reasonable RPM reading from the vehicle).

A blank section is included in Module 4 of the AIR form for entering additional RPM measurement probes. Each additional probe type should be listed, and if possible should be audited with one of the audit tools or a vehicle. If quantitative data cannot be gathered, the probe will pass if it can obtain a reasonable RPM reading from the vehicle.

To conduct the audit, the test system should be placed in RPM audit mode so that the RPM is displayed. If required by the system (some systems will otherwise not display RPM), the auditor should enter the number of cylinders as A4@ and that the vehicle is non-DIS if using the RPM simulator, or enter the actual data from the vehicle being used to check the other probes. For the inductive probe, the auditor should use the RPM simulator to test it at both 700 and 2500 RPM, and record the reference and measured values under Module 4 of the AIR form. For other probes, the test should be conducted using a vehicle. If the vehicle does not have a tachometer, the auditor should simply check at idle and verify that the tachometer probe is functioning and providing a reasonable reading.

For the OBDII method, the cable and connector must be checked visually to ensure that they are in good shape. If the cable and connector are in good condition, the “pass” box under OBDII Cable in Module 4 of the AIR form should be checked. The OBDII simulator should be used to test the system; however, if a simulator is not available, a vehicle with a tachometer can be used to perform an approximate check of the system. The communications protocol of the vehicle being simulated should be entered in the box contained in Module 4 of the AIR form. If a vehicle is used, then the make, model and year of the vehicle should be entered on the form. The auditor should connect the RPM lead to the simulator, set the simulator on 700/2500, and record the high and low readings displayed by the analyzer. The auditor should then calculate the % difference for each of the methods, using the equation below. It should also be noted whether each method passed or failed based on a standard of 3% for all measurements (unless the OBDII tester was not available). If a vehicle was instead used to audit the OBDII RPM measurement, a pass/fail standard of 10% should be applied.

$$\%\ Difference = 100\ x\ \frac{Standard\ -\ Analyzer}{Standard}$$

Module 5. Dynamometer Audit

Steady State and Transient Testing -The ability of the dynamometer to account for the drag in the mechanical system is tested by spinning the dynamometer up to approximately 35 mph and recording the time it takes for the dynamometer to coast down from various speeds. There are no special tools required for this portion of the audit.

The auditor should follow the test system=s instructions to perform an automated coast-down test. Auditors should ensure that all personnel are away from the dynamometer and that there is nothing on the rolls. The dynamometer will spin up and while coasting down automatically apply a randomly selected horsepower setting between 8.0 hp and 18.0 hp. The measured coast down time (MCDT) from both 30 to 20 mph and 20 to 10 mph is recorded. The power applied is used by the analyzer to calculate the theoretical coast down time (TCDT) for the dynamometer from the formula given below:

$$TCDT = \frac{U \times DIW}{HP}$$

Where:

U = Unit conversion factor:
- for 30 to 20 mph coast down, U = 0.03037
- for 20 to 10 mph coast down, U = 0.01822

DIW = Dynamometer inertia weight (from certification label)

HP = Horsepower applied during coast down

The percent difference in the coast-down time is calculated using the following formula:

$$\% \ Difference = 100 \ x \ \frac{MCDT - TCDT}{TCDT}$$

All of these functions and calculation should be performed automatically by the dynamometer; at the end of the test, the test system will display the coast down test results (pass or fail). If the results are calculated by hand, the difference should be less than 7% in order to pass the coastdown. The results should be recorded in Module 5 of the AIR form.

Transient Testing - If the dynamometer is using transient testing, the inertia simulation error should be checked using a dynamometer tester capable of measuring the instantaneous horsepower simulation error (IHPSE) of the dynamometer. The equipment required for this testing includes the following:

1. Dynamometer tester

The tester works by collecting data from the dynamometer on speed and load applied, and comparing the load applied to the theoretical load that should have been applied. These two values are used to determine the IHPSE of the dynamometer.

IHPSE is calculated as the average difference between the desired power (DP) and the achieved power (AP) in 10 measurements taken at 0.5-second sequential intervals over the previous 5 seconds, divided by the total power (TP = inertia plus road load). However, if augmented braking is applied or the desired PAU power is less than or equal to zero* during any 0.5-second measurement, the difference between the desired and achieved power for that 0.5-second measurement shall be set to 0. Values set to be 0 shall be used in calculating the 5-second moving averages. If TP is less than 5HP over the 5-second period, TP should be set to 5HP.

$$IHPSE = \frac{\sum_{i}^{i-10} (DP - AP)}{\sum_{i}^{i-10} (TP)}$$

Where: i = current 0.5-second interval, starting at second 5
DP = desired power
AP = achieved power
TP = total power (inertia plus road load)

The audit equipment (tester) should be set up on the dynamometer and the standard transient emissions test for the program (including a full-duration driving cycle) performed while the tester collects the audit data. The vehicle should be driven over the entire drive cycle, with the speed varying over and under the perfect trace as much as is possible without causing a speed violation. The vehicle loading information should be entered into the dynamometer tester, which will then calculate the IHPSE. If the IHPSE is less than ±0.25% for every second of the test, the system passes and the Pass box in Module 5 of the AIR form should be checked.

Module 6. Gas Cap Tester Audit

The gas cap tester audit includes verifying that all of the color-coded gas cap tester adapters are available, and the tester properly passes and fails caps. Equipment needed to perform this test includes the following:

1. Flow calibrated pass master cap
2. Flow calibrated fail master cap

The auditor should first check that all of the color-coded adapters and the pass/fail calibration device or caps are present. A pass or fail should be recorded in Module 6 of the AIR form.

The gas cap test should be performed following the directions on the screen with the pass and fail reference caps. Both should pass the audit. As each is passed, the test result should be recorded on the AIR form under Module 6.

* This shall only apply to eddy current dynamometers, not full electric dynamometers.

Module 7. Pressure Tester Audit

The pressure tester audit includes verifying that all vehicle adapters are available, and the tester properly passes and fails vehicles. The following equipment is required:

1. Pressure test auditing tool

The auditor should first verify that all of the required adapters and the pass/fail calibration device are present, and record the results as either pass or fail in Module 7 of the AIR form. The pressure test audit tool should then be used to conduct the pressure test, following the directions provided on the screen. The device will simulate a gas tank with a variable leak that can simulate both a passing tank and a failing gas tank. The test should be performed first with the device set to pass, and then a second time with the device set to fail. The tester should pass when set to pass and fail when set to fail. As each audit is performed, the test result should be recorded on the AIR form under Module 7.

Module 8. OBDII Tester Audit

The test systems must include the hardware and software necessary to access the onboard computer systems on 1996 and newer vehicles, check for proper MIL (Malfunction Indicator Light) command, determine OBDII readiness, and recover stored fault codes using the SAE standardized link. In addition to the physical cable check included in Module 4 of these procedures, the system needs to be subjected to additional audit checks to ensure communications functionality and verify proper fault code retrieval from test vehicles. The following equipment is required for this procedure:

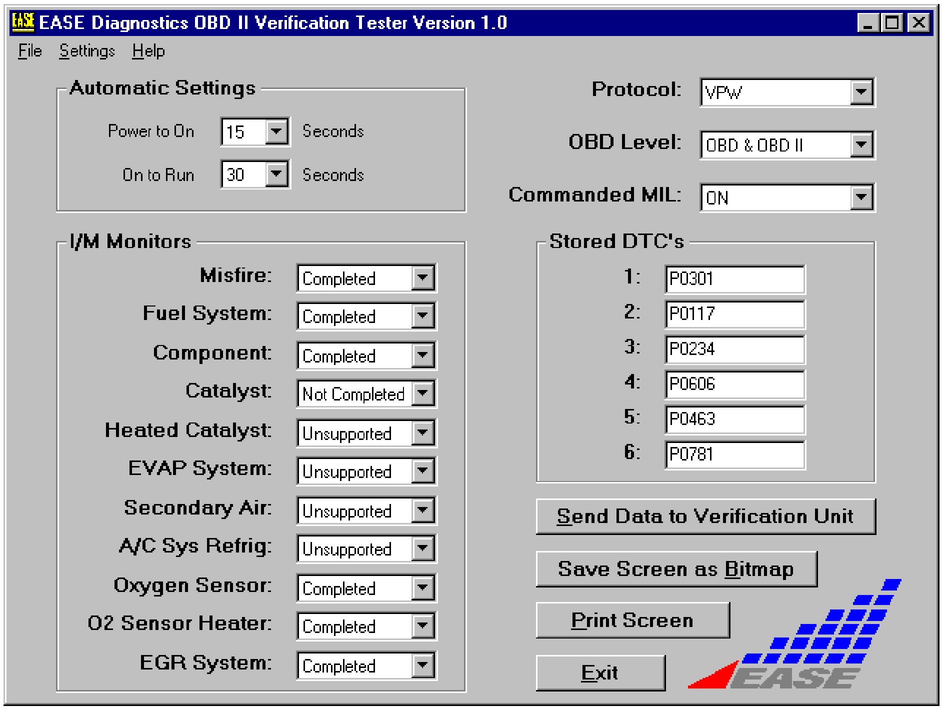
1. EASE Diagnostics OBDII verification tester OVT-2020-SW (or equivalent tester)

The first step in the testing is to configure the tester using the OBDII verification tester driver software running on the audit laptop. The software setup screen for the EASE tester is shown in Figure 1. (If a different tester is used, these instructions should be modified as needed to match the particular design of the test unit.) Under the Automatic Settings category, the auditor should set the "Power to On" time to 15 seconds, and "On to Run" time to 30 seconds. The auditor should then select either "Completed," "Not Completed," or "Unsupported" for each of the 11 monitors under I/M Monitors, and note the setting of each on the audit form in Module 8. A protocol should then be randomly selected in the upper right of the screen. Three selectable protocols are provided to test the various OBDII Interface Types, as shown in Table 2.

Table 2
Available OBDII Protocol Types

Protocol	Protocol Description	Applicable Vehicles
ISO	ISO-9141-2	European, most Asian, pre-1998 Chrysler
PWM	J1850, Pulse Width Modulation	Ford
VPW	SAE J1850, Variable Pulse Width	General Motors, 1999+ Chrysler

Figure 1
OBDII Verification Tool Set up Page



The OBD Level should be set to "OBD & OBDII" and a status for the MIL selected. The protocol chosen and the MIL status selected should be recorded in Module 8 of the AIR form. From 1 to 6 emissions-related diagnostic trouble codes (DTCs) should be entered in the Stored DTC section of the screen and recorded on the AIR form.

Once all of the desired test settings are configured on the software screen, the verification tool (see Figure 2) should be connected to the serial (COM) port on the computer with the supplied cable. The auditor should then click on the "Send data to Verification Unit" button to download the set-up data that were entered onto the display screen of the test unit software.

The auditor should take the unit to the test system to be audited and set the "IGN KEY" switch to "AUTO" and the RPM to 700/2500. The OBDII connector from the test system should then be plugged into the J1962 diagnostic connector on the endplate of the verification tool. The analyzer should be set in OBDII Scan mode and the prompts on the screen followed to have the test system scan the verification tool. The results of the scan should be displayed on the screen. The status of the MIL and monitors should be recorded on the right side of Module 8 of the AIR form, along with any retrieved DTCs.

The result for each item should be marked on the left side of the form. For each item, if the monitor, the MIL status, and the DTCs retrieved match, the "pass" box should be marked; otherwise the "fail" box should be marked.

Figure 2
EASE Diagnostics Verification Tester

Module 9. Flow and Dilution VMAS Audit

There are three checks of the VMAS system that can be conducted. The "hose off flow check" is a procedure that requires only limited equipment (a screwdriver to remove the hoses) and can indicate if the system is experiencing any degradation in either the blower or the flow measurement system. This is a recommended check for inspectors to perform on a regular basis and should also be performed by auditors. The "Dilution Measurement Accuracy" check evaluates the performance of the oxygen sensor in the VMAS, which is used to determine the dilution ratio of the exhaust flowing through the VMAS. This check should be performed during each audit. The "SAO Flow Measurement Accuracy Check" is a more complicated procedure requiring special equipment. The auditor should perform this check at least annually on each VMAS system. Further details on each of these checks are provided below.

<u>Hose Off Flow Check</u> – The flow rate measurement by the VMAS unit should be checked using the hose off flow check to determine if the system is experiencing any degradation. The auditor will need a screwdriver to perform this check.

This check is performed by (a) placing the unit in the audit mode, which displays the VMAS flow rate; (b) having the inspector remove the hoses from the VMAS unit at the inlet to the blower and the exit port of the VMAS; and (c) turning on the blower. The unit should be allowed to operate for at least one minute. The measured flow rate and the factory-calibrated hose off flow rate for the unit should both be displayed on the screen in ACFM.* The auditor should record the rates in Module 9 of the AIR form. If the difference between the measured and factory-calibrated hose off flow rates is more than

* Sensors, the manufacturer of the VMAS units, recommends this check be performed by comparing the ACFM values, as opposed to the SCFM values.

10% of the factory-calibrated rate (either higher or lower), the VMAS unit should be turned off and the auditor should ask the inspector to clean the strut. Once the strut has been cleaned, the check should be run again. If the measured value still differs by more than 10% of the factory-calibrated hose off flow rate, then the VMAS unit fails the hose off flow check and service should be called to check the unit.

$$\%\ Difference = 100\ x\ \frac{HoseOff\ - VMAS}{HoseOff}$$

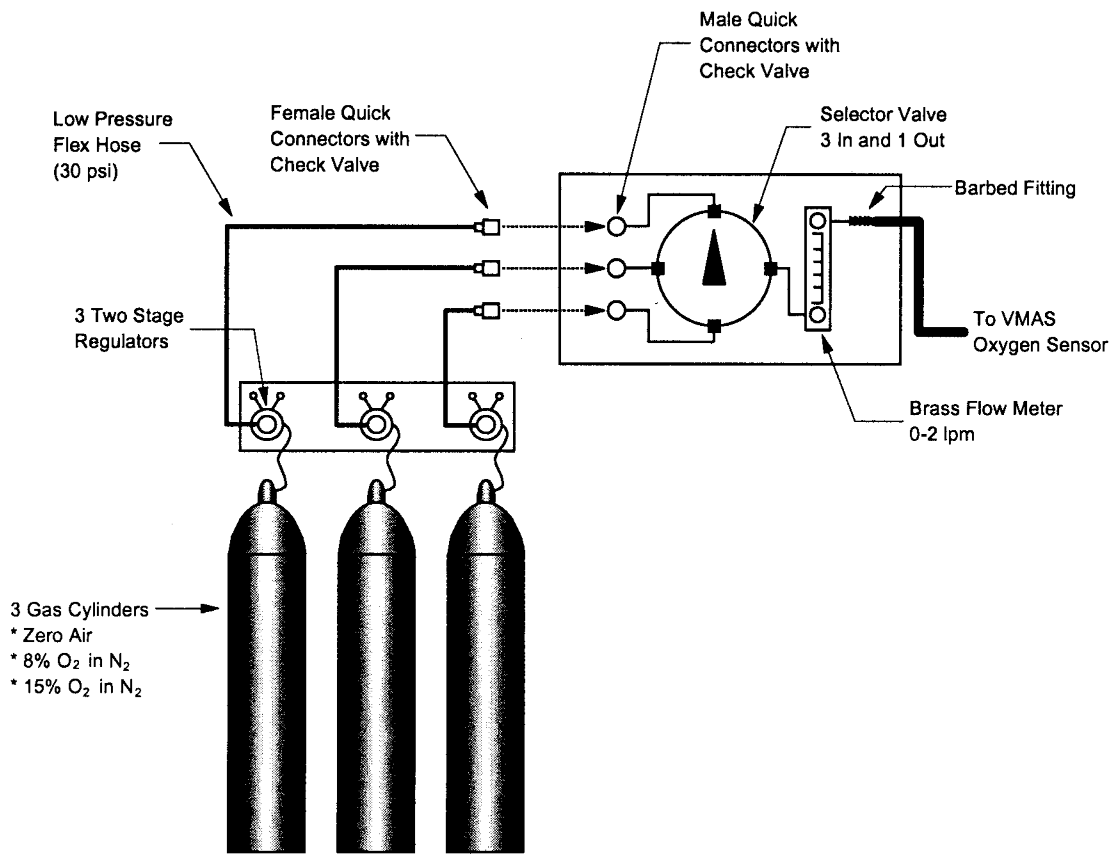
<u>Dilution Measurement Accuracy</u> – The dilution ratio calculated by the system is a function of measurements taken by the oxygen sensor in the analyzer (checked earlier in Module 3) and the oxygen sensor in the VMAS unit. In this portion of the audit, the auditor will check the accuracy of the oxygen sensor in the VMAS unit. Equipment needed to perform this test includes the following:

1. Zero air
2. 8% oxygen in nitrogen (1% accuracy gas, 2% blend tolerance)
3. 15% oxygen in nitrogen (1% accuracy gas, 2% blend tolerance)
4. Three gas regulators for the gas cylinders
5. Bubble style flow meter with a 1.5LPM maximum range
6. Three position selecting valve with flow meter
7. Tygon tubing 1/4" ID

The check is performed by placing the test system in the audit mode that displays the reading of the oxygen sensor in the VMAS unit. The zero air (20.9% oxygen), 15% oxygen in nitrogen, and 8% oxygen in nitrogen should be connected to a switching device and flow meter. The outlet hose from the switching device should then be connected to the oxygen sensor opening farthest inside the VMAS unit (see Figure 3). The auditor should flow each of the three gases one at a time through the switching device to the oxygen sensor and ensure each is set to flow at a rate of 1 liter per minute. The auditor should then flow the zero air; after one minute and when the O_2 reading has stabilized, the analyzer should be instructed to zero the oxygen sensor. The auditor should then switch to the 15% oxygen and again flow the gas for one minute; when the O_2 reading has stabilized, the measured concentration should be recorded after one minute, again five seconds later, and again five seconds after that.

The three readings and the exact cylinder-labeled oxygen concentration should be recorded for the 15% reading in Module 9 of the AIR form. The auditor should then switch to the 8% oxygen and follow the same procedure. The resulting three readings and the exact cylinder-labeled oxygen concentration should be recorded in Module 9 under the 8% reading.

Figure 3
Gas Switching System for Auditing VMAS Oxygen Sensors



The calculation of the pass/fail limits for both the 15% and 8% oxygen in nitrogen blends is shown in Table 3. For both the 15% and 8% oxygen gas readings, the auditor should average the three readings, and enter the high and low limits by adding and subtracting 0.3% from the cylinder concentrations. A "pass" applies if the average oxygen concentration is between the limits; otherwise the "fail" box should be marked. If the VMAS unit fails the check, the test system should be locked out until a manufacturer's service representative can identify and correct the cause of the failure.

Table 3

Spreadsheet for Calculating VMAS Audit Tolerances

Range	Gas	Gas Concentration		Accuracy			Audit Tolerance			Applied Tolerance (greater of % or point)	Audit Limits	
		Recom-mended	Actual Cylinder	% of Reading	Point	Gas	% of Reading	% (as point)	Point		Low	High
Analyzer O2	O2 (%)	1.00	1.00	5.0%	0.10	1.0%	6.0%	0.00	0.11	0.11	0.89	1.11
VMAS O2	High (%)	15.0	15.0	0.3%	0.00	1.0%	1.3%	0.20	0.45	0.45	14.55	15.45
	Low (%)	8.0	8.0	0.3%	0.00	1.0%	1.3%	0.10	0.38	0.38	7.62	8.38

In the "Actual Cylinder" column, enter the gas concentrations from the audit cylinders
The audit low and high tolerances are calculated in the columns on the right

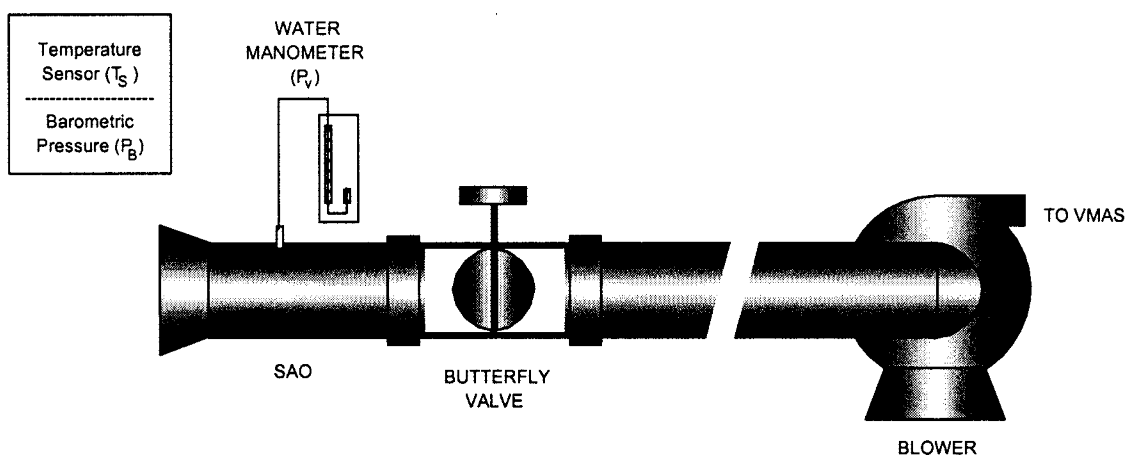
SAO Flow Measurement Accuracy Check – At least once a year, a specially equipped auditor will check the accuracy of the flow measured by the system. This check, as opposed to the hose off flow check, makes an actual measurement of the flow rate at several points and compares these measurements to the system-calculated flow rates. Equipment needed to perform this test includes the following:

1. Smooth Approach Orifice (SAO) with a calibration range of 200 to 500 SCFM
2. Barometer
3. Manometer
4. Thermometer
5. Butterfly or gate valve
6. Screwdriver

The first four of these items are very specialized and should be NIST traceable. These items should be treated with care by the auditors.

The system will be tested by attaching the SAO to the intake end of the VMAS hose as shown in Figure 4. All seals must be secure to ensure there are no leaks. If the butterfly valve is used, it should be placed in line as shown in the figure. If a gate value is used, as opposed to a butterfly valve, it should be attached to the end of the hose on the outlet from the VMAS.

Figure 4
SAO Calibration Set Up



The accuracy check is to be conducted at three flow readings. The first reading is taken with the butterfly or gate valve completely open, the second using the valve to reduce the flow to approximately 225 SCFM, and the third approximately halfway between the first and second measurements. For instance, if the first measurement is made at 335 SCFM and the second at 225 SCFM, the third reading should be taken at approximately 280 SCFM. The exact flow rates at which the second and third readings are taken can vary somewhat as long as the second one is somewhat over 200 SCFM (i.e., the minimum specified VMAS flow rate) and the third one is at roughly the mid-point of the possible range of flow rates.

To perform the audit, the auditor should place the test system in the audit mode where the VMAS flow rate is displayed, and zero the reading on the manometer. The barometric pressure (in inches mercury (Hg)) and the ambient temperature (in degrees C) near the SAO should be recorded. The VMAS blower should be turned on and the flow should be allowed to stabilize for at least one minute. After one minute, the auditor should record the VMAS flow rate and the vacuum at the manometer. The flow rate should be adjusted down to approximately 225 SCFM (± 10 SCFM) and then allowed to stabilize again for at least one minute. After one minute, the auditor should record the VMAS flow rate and the vacuum at the manometer. The procedure should be repeated again at the approximate mid-point between the first and second measurements. After completion of the measurement, the VMAS blower can be turned off.

For each set of readings, the actual flow rate at the SAO should be calculated using the formula and calibration data supplied by the SAO manufacturer.

$$\%\ Difference = 100\ x\ \frac{SAO - VMAS}{SAO}$$

The difference between the SAO flow rate and the VMAS system flow rate should then be calculated. If the difference is more than 10%, the system fails the audit. All readings and the resulting pass/fail determinations should be entered in Module 9 of the AIR form.