Society of Automotive Engineers, Inc.
TWO PENNSYLVANIA PLAZA, NEW YORK, N.Y. 10001

AEROSPACE RECOMMENDED PRACTICE

ARP 1179

Issued 5-4-70
Revised

AIRCRAFT GAS TURBINE ENGINE EXHAUST SMOKE MEASUREMENT

SCOPE

The purpose of this Aerospace Recommended Practice is to standardize test equipment and procedures for the measurement of smoke emission from aircraft gas turbine engines. The procedures included are for determining and reporting the amount of smoke emission.

This document is divided into the following sections:

1. Definitions and Terminology
2. Equipment
3. Test Procedures
4. Information and Data to be Recorded
5. Data Reduction and Analysis
6. Presentation of Results

1. DEFINITIONS AND TERMINOLOGY

The following apply to the terms indicated as they are used in this document.

1.1 Aircraft Gas Turbine Engine: Any gas turbine engine used for aircraft propulsion or power generation, including those commonly called turbojet, turbofan, turboprop, or turboshaft type engines.

1.2 Power Setting: A value of the quantity used to rate the power output of an engine. The power setting of turbojet and similar engines should generally be expressed in terms of net thrust (corrected). For turboprop and similar engines, power setting should generally be in terms of shaft horsepower.

1.3 Smoke: Small gas-borne particles, including but not limited to black carbonaceous material from the burning of fuel in sufficient concentration to create visible capacity.

1.4 Sampling: The collection of an exhaust sample under controlled conditions for the purpose of analysis.

1.5 Filter Material: Filter material shall be Whatman No. 4 filter paper.

1.6 V: The measured sample size (volume), in units of cubic feet.

1.7 W: The calculated weight of the measured sample volume (pounds). W is defined in 5.2.

1.8 SN: Smoke Number, the dimensionless term quantifying smoke emission. SN varies with smoke density and is defined in 5.1 continuously from 0 to 100.

2. EQUIPMENT

2.1 System Scheme: Figure 1 is a schematic diagram of a proper system.

2.2 Sample Size Measurement: A wet or dry positive displacement meter shall be used to measure sample size to an accuracy of ± 0.01 standard cubic foot (scf). Pressure and temperature shall be measured immediately upstream of the meter. Accuracy shall be no less than ± 0.10 in. Hg and ± 4 F, respectively. If a dry type meter is used, it may be located between the filter holder and the vacuum pump.

2.3 Sample Flow Rate Measurement: Sample flow rate shall be measured with a rotameter with accuracy of no less than ± 0.02 cubic feet per minute (cfm).

2.4 Filter Holder: The filter holder shall firmly clamp the filter material so that overall system leakage is in accordance with 3.9. The holder internal geometry shall be such that the variation of SN over the sample spot surface is not greater than 2. Suggested and required elements of the filter holder design are given in Figure 2. The filter holder shall be made of corrosion resistant material.

2.5 Sampling Probe: The single orifice total pressure type probe of Figure 3 shall be used. Probe material shall be stainless steel or nickel-base alloy.

2.6 Sampling Lines: The sampling lines shall be straight through with no kinks or loops, and no bends having a radius of less than 10 line diameters. Sampling line inside diameter shall be within 0.18 to 0.32 inch. The sampling line section from the probe exit to valve A entrance shall be of minimum length, not greater than 75 ft, with no fittings or other breaks. The section of line from valve A exit to the filter holder entrance shall be no longer than 1.0 ft with no fittings or other breaks. Line material shall be such as to not encourage build-up of either particulate matter or static electric charge; stainless steel and copper meet these requirements.

2.7 Valving: Four valve elements shall be provided. Valve A shall be a quick acting, full-flow, flow diverter with "closed," "sample," and "by-pass" positions. Valve A may consist of two valves, provided that they are interlocked so that one of the pair cannot act independently of the other. Valves B and C shall be throttling valves used to establish a system flow rate. Valve D shall be a shut-off valve used in isolating the filter holder. All valves shall be made of corrosion resistant material.

2.8 Vacuum Pump: The vacuum pump shall have a no-flow vacuum capability of at least 22 in. HgV, and full flow capacity of 1.0 scfm minimum.

2.9 Reflectometer: A reflectometer conforming to ASA standard for Diffuse Reflection Density, number Ph 2.17-1958, shall be used. The diameter of the reflectometer light beam on the filter paper shall be no more than 1/2 of "D," the diameter of the filter spot. The allowable range of "D" is given in Figure 2.

3. TEST PROCEDURES

3.1 Precautions: The material being measured is composed of low-micron and/or submicron size agglomerated particles. Precautions must be taken to assure that steady-state conditions have been achieved prior to taking a sample. To prevent material accumulation, the system should never be left in a no-flow condition when exhaust gas is contained. The following procedures are designed to produce consistent and precise results.

3.2 Probe Orientation: The tip of the sampling probe shall be located between the engine exit plane and 6 in. downstream. The probe shall be oriented normal to the engine exit plane.

3.3 Initial Traverse: On any given engine model or installation, an initial traverse shall be made at each specified power setting. The traverse is to be made radially at two locations 90 deg apart with 5 equal area sampling locations on each radial traverse. For each power setting, the point nearest the arithmetic average SN of the 10 points shall be identified and entered as a permanent record of the particular engine or installation. All subsequent samples for that particular power setting shall be taken at this location. The sampling traverse should be repeated after any engine modification involving possible aerodynamic changes.

3.4 Sampling: Sufficient time (not less than one minute) shall be allowed to assure that the system is fully charged with a representative gas sample. The sampling flow rate shall be maintained at 0.50 ± 0.02 cfm. At least four sample sizes shall be taken within the range of 0.00765 to 0.115 lb of exhaust gas per sq in. of filter. Samples shall be taken both above and below 0.0230 lb of exhaust gas per sq in. of filter.

3.5 Temperature Control: The gas temperature from the sampling probe entrance to the filter material shall be above the dew point temperature. All lines and valves shall be lagged and/or heated as necessary to meet this requirement.

3.6 Preparation for Each Power Setting: The leak check and cleanliness requirements of 3.8 and 3.9 shall be confirmed. The following shall then be done to prepare the system at each power setting:

(a) Set Valve A to "by-pass," close Valve D.

(b) Draw exhaust gas for 5 minutes minimum, then use Valve C to set flow rate at 0.50 ± 0.02 cfm.

(c) Clamp clean filter material into the holder.

(d) Open Valve D.

(e) Set Valve A to "sample" and use Valve B to again set the flow rate to 0.50 ± 0.02 cfm. This must be done quickly before particulate build-up on the filter causes excessive pressure drop.

(f) Set Valve A to "by pass" and close Valve D.

(g) Clamp clean filter material into the holder.

3.7 Sampling Procedure: The procedure for smoke sampling at each power setting shall be as follows:

(a) With Valve D closed and Valve A set at the "by pass" position, charge the lines with exhaust gas for one minute minimum. Re-establish flow rate at 0.50 ± 0.02 cfm as required, using Valve C.

(b) Open Valve D.

(c) Set Valve A to "sample," allow the chosen sample volume to pass, then set Valve A to "by-pass."

(d) Close Valve D and clamp clean filter material into the holder.

(e) Repeat (b) through (d) for at least 3 more sample sizes in accordance with 3.4.

3.8 System Maintenance: The need for cleaning or replacement shall be determined by conducting the following cleanliness check:

(a) Full open Valves B, C, and D.

(b) Use the vacuum pump and alternately set Valve A to "by-pass" and "sample" to purge the entire system with clean air for at least 5 minutes.

(c) Set Valve A to "by pass."

(d) Close Valve D and clamp clean filter material into the holder. Open Valve D.

(e) Set Valve A to "sample," reset back to "by-pass" after 1.0 cubic foot of air has passed through the filter material.

If the filter spot exhibits SN greater than 3, the system lines must be cleaned or replaced. The system shall not be used until this cleanliness requirement has been met.

3.9 Leak Check: The following procedure shall be used to leak check the system:

(a) Clamp clean filter material into the holder.

(b) Close Valve A, full open Valves B, C, and D.

(c) Run the vacuum pump for exactly 5 minutes.

The system shall be satisfactory if no more than 0.20 cubic foot passed through the volume meter during 5 minutes. The system shall not be used until this requirement has been met.

4. INFORMATION AND DATA TO BE RECORDED

4.1 Information:

4.1.1 General:

(a) Facility performing test

(b) Date of test

(c) Description of test equipment

(d) Probe location as determined in accordance with 3.3

4.1.2 Aircraft Description (If Applicable):

(a) Manufacturer

(b) Model Number

(c) Serial Number

(d) User or Operator

(e) Engine installation position

4.1.3 Engine Description:

(a) Manufacturer

(b) Model Number

(c) Engine configuration/special configuration identification

(d) Time since overhaul and other pertinent maintenance information

4.2 Test Data: At least the following shall be recorded:

(a) Engine power setting and speed

(b) Engine exhaust gas temperature

(c) Time of day and data number

(d) Ambient conditions (pressure, temperature, humidity)

(e) Fuel Flow rate

4.2 Continued:

(f) Fuel type; additives, if used

(g) Leak and cleanliness checks substantiation

(h) Sample temperature

(i) Sample pressure

(j) Actual sample volume at sampling conditions

(k) Actual sample flow rate at sampling conditions

5. DATA REDUCTION AND ANALYSIS

5.1 Determination of SN: Smoke spot analysis shall be made with a reflectometer as specified in 2.9. This instrument shall be calibrated on an absolute basis with secondary standards traceable to the National Bureau of Standards' standard for diffuse reflectance. The backing material shall be black with a maximum absolute reflectance of 3 percent. The reflectance reading of each spot shall be used to calculate SN by:

$$SN = 100 \left(1 - \frac{Rs}{Rw}\right)$$

Rs: absolute reflectance of the sample spot
Rw: absolute reflectance of clean filter material

5.2 Calculation of W: The sample weight (W) shall be calculated by:

$$W\ (lb) = 1.326 \frac{PV}{T}$$

P, T: Sample pressure and temperature, in units of in. Hg Abs. and °R, respectively, measured immediately upstream of the volume meter.

V: Measured sample volume (cubic feet)

5.3 Calculation of W/A: The sample weight in pounds, per sq in. of filter spot area, (W/A) shall be calculated for each sample size taken.

5.4 Plotting SN versus W/A: All SN shall be plotted versus W/A on semi-log coordinates, with W/A as the logarithmic abscissa. A straight line shall be fitted to these points using the method of least squares. Such a line shall be produced for each power setting specified.

5.5 Plotting Reporting Values of SN versus Power Setting: Values of SN shall be read from the straight line functions of 5.4 for W/A = 0.0230 lb/sq in. These SN are the reporting values, and shall be presented by plotting them as ordinate versus power setting as abscissa on rectangular coordinates. Preliminary tests indicate that significance (accuracy) of these SN values is within ± 3 when the system is properly used as outlined herein.

6. RESULTS PRESENTATION

At least the following shall be reported:

(a) All information and data required by Section 4.

(b) All W calculated in accordance with 5.2

(c) The plots of SN versus W/A from 5.4

(d) The plot of SN versus Power Setting from 5.5

PREPARED BY
SAE COMMITTEE E-31, AIRCRAFT EXHAUST EMISSION MEASUREMENTS