SAE Aerospace
An SAE International Group

AEROSPACE RECOMMENDED PRACTICE

SAE ARP1179 | REV. D

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Superseding ARP1179C

Aircraft Gas Turbine Engine Exhaust Smoke Measurement

RATIONALE

ARP1179 was originally developed in 1970 (with subsequent updates) as the measurement technique for Smoke Number (SN) that has been used as the basis of regulatory standards for ensuring that the exhaust plumes from aircraft engines are essentially non-visible. It has, and still does, serve this purpose.

More recent concerns relate to the health and climate impacts of particulate matter emitted by aircraft engines. Particle size, number and mass are all seen as relevant parameters as is the issue of "volatility".

The SAE E-31 Committee is currently using all its resources in developing a new ARP on the mass and number measurement of non-volatile particles at the exhaust of aircraft engines.

Hence the Committee recommends keeping ARP1179 as it still serves its purpose of quantifying the visibility at the exhaust of aircraft engines; it does not recommend any revision of it.

STABILIZED NOTICE

This document has been declared "Stabilized" by the E-31 Technical Committee and will no longer be subjected to periodic reviews for currency. Users are responsible for verifying references and continued suitability of technical requirements. Newer technology may exist.

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http://www.sae.org/technical/standards/ARP1179D

1. SCOPE:

This SAE Aerospace Recommended Practice (ARP) standardizes 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. Tests have indicated that the practically achievable precision of the smoke number is within ±3 when the system is properly used as outlined herein. This procedure is not intended for in-flight testing, nor does it apply to engines operating in the afterburning mode.

2. APPLICABLE DOCUMENTS:

The following publications form a part of this specification to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this specification and references cited herein, the text of this specification takes precedence. Nothing in this specification, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1 SAE Publications:

Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

ARP1256 Procedure for the Continuous Sampling and Measurement of Gaseous Emissions from Aircraft Turbine Engines

2.2 ANSI Publications:

Available from ANSI, 11 West 42nd Street, New York, NY 10036-8002.

ANSI PH 2.17

3. SECTIONS:

This document is divided into the following sections

4 Definitions and Terminology
5. Equipment
6. Test Procedures
7. Information and Data to be Recorded
8. Data Reduction and Analysis
9. Presentation of Results
10. Comments
11. Key Words

4. DEFINITIONS AND TERMINOLOGY:

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

A: Area of the smoke filter spot.

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.

FILTER MATERIAL: Filter material shall be Whatman No. 4 filter paper.

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.

PRECISION: The closeness with which a measurement upon a given, invariant sample can be reproduced in short-term repetitions of the measurement with no intervening instrument adjustment.

SN: Smoke Number, the dimensionless term quantifying smoke emission. SN increases with smoke density and is rated on a scale from 0 to 100. SN is evaluated for a sample size of 16.2 kg of exhaust gas/m^2 (0.0230 lb/in^2) of filter area.

SN': Smoke number obtained from an individual smoke sample. SN' is defined in 8.2, and is evaluated from the spot reflectance irrespective of the sample size.

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

SMOKE: Small gas-borne solid particles, including but not limited to black carbonaceous material from the burning of fuel, which in sufficient concentration create visible opacity.

4. (Continued):

STANDARD VOLUME: A standard volume of gas defined as the volume at 288 K (15 °C, 59 °F) and 101.32 kPa (29.921 in Hg absolute).

V: The measured sample size (volume).

W: The calculated mass of the measured sample volume.

5. EQUIPMENT:

5.1 System Scheme:

Figure 1 is a schematic diagram of a proper system. An optional bypass around the volume meter may be installed to facilitate meter reading. It simplifies automation of the smoke meter to acquire a preset sample volume.

5.2 Sampling Probe:

The probe shall be made of stainless steel. If a mixing probe is used, all sampling holes shall be of equal diameter and total probe orifice area shall be such that at least 80% of the pressure drop through the probe assembly (from free stream to probe outlet) shall be taken at the orifices. Probe orientation and sampling locations shall be as follows:

a. A minimum of 12 sampling points shall be used. Either mixing or individual probes are acceptable.

b. The axial location of the sampling plane shall be as close to the plane of the exit nozzle as engine performance parameters permit but in any case shall be held within 0.5 exit nozzle diameter of the exit plane.

c. The sampling points shall be arranged over the exhaust nozzle exit area for straight turbojet, turboprop, turboshaft, and mixed flow (or confluent flow) fan engines, and over the core nozzle exit area for nonmixed fan engines.

d. In order to promote uniformity of smoke measurements, a specific probe design should be standardized for use with a given type or series of engines. It must be demonstrated, by means of detailed traverse measurements in the sampling plane, that this probe design provides a representative smoke sample.

e. If it is desired to draw a higher sample flow rate through the probe than through the filter holder, an optional flow splitter may be located between the probe and Valve A (Figure 1), to dump the excess flow. The dump line should be as close as possible to probe off take and should not affect the ability of the sampling system to maintain the required 80% pressure drop across the probe assembly. The dump flow may also be sent to the CO_2 analyzer or complete emissions analysis system thus eliminating the need for Valve E.

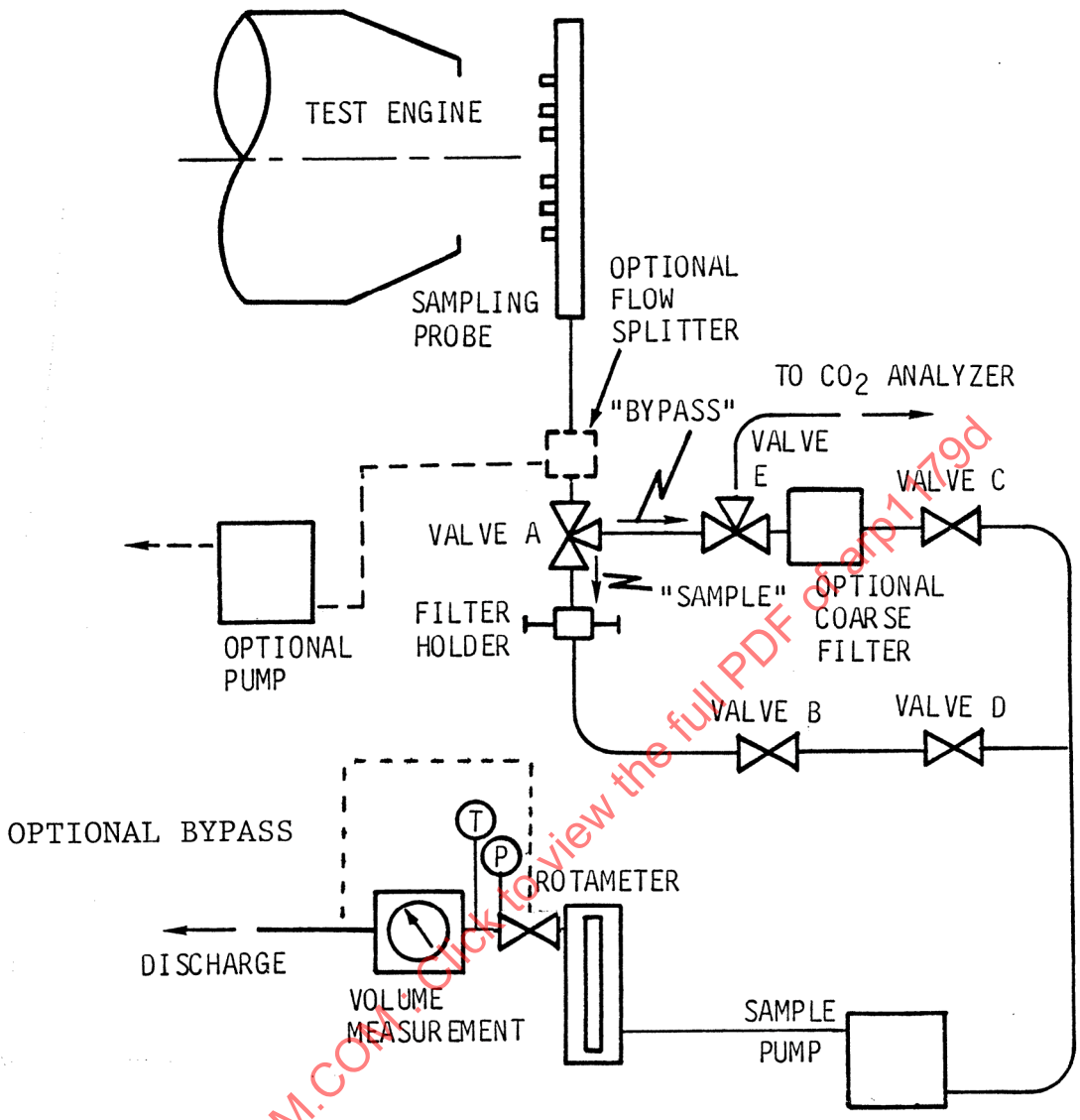


FIGURE 1 - Sampling System Schematic Diagram

5.2 (Continued):

If a flow splitter is used, a test shall be conducted to demonstrate that the flow splitter does not change the smoke level passing to the filter holder. This may be accomplished by reversing the outlet lines from the flow splitter and showing that, within the accuracy of the method, the smoke level does not change.

5.3 Sampling Lines:

The sampling lines up to the filter holder entrance shall be straight through with no kinks or loops, and a maximum of 4 bends having a radius of less than 10 line diameters. Sampling line inside diameter shall be 4.0 to 8.5 mm (0.16 to 0.33 in). The sampling line section from the probe exit to filter holder entrance shall be of minimum length, not greater than 25 m (82 ft) and with no unnecessary fittings or other breaks. Line material shall be such as to not encourage buildup of either particulate matter or static electric charge. Stainless steel, copper, and carbon-loaded grounded PTFE (polytetrafluoroethylene) line meet these requirements.

5.4 Filter Holder:

The filter holder shall firmly clamp the filter material so that overall system leakage is in accordance with 6.2. Suggested and required elements of the filter holder design are given in Figure 2. The filter holder shall be made of corrosion resistant material.

5.5 Valving:

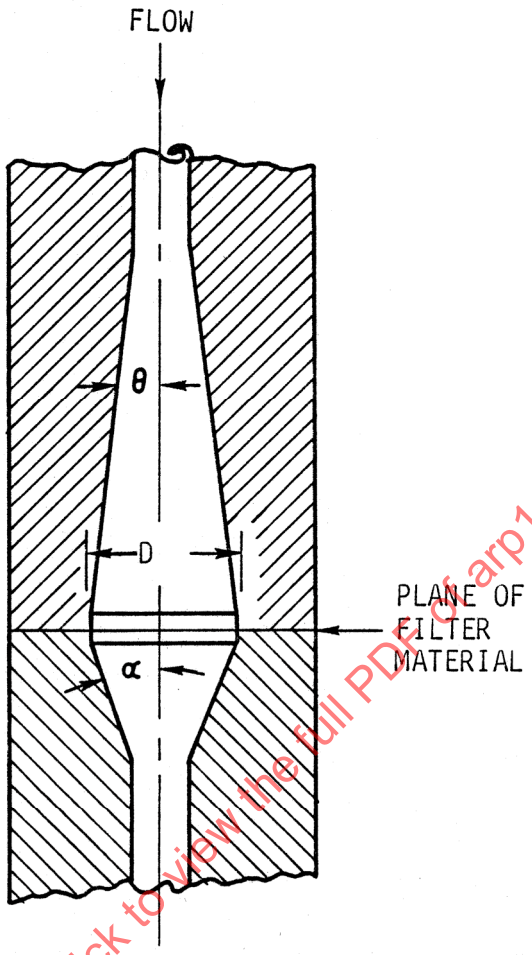
Five valve elements shall be provided. Valves A and E shall be quick acting, full flow, flow diverter valves with “closed”, “sample”, and “bypass” positions. Valve A may consist of two valves, provided that they are interlocked so that one of the pair cannot act independently of the other. Valves B and C shall be throttling valves used to establish a system flow rate. Valve D shall be a shutoff valve used to isolate the filter holder. All valves shall be made of corrosion resistant material. If an optional flow splitter is used, Valve E is not required.

5.6 Temperature Control:

The temperature of the line including fittings and breaks from the sampling probe entrance to the filter material shall be maintained between 333 K (60 °C, 140 °F) and 448 K (175 °C, 347 °F), except for the distance required to cool the gas from the engine exhaust temperature down to the line temperature. The line temperature shall be maintained with a stability of ±15 K (±15 °C, ±27 °F) during the period of measurement.

5.7 Sample Pump:

The sample pump should have a no-flow vacuum capability of 25 kPa (22 in HgV) or better, and full flow rated capacity of 28 standard L/min (1.0 scfm) minimum.



D (SPOT DIAMETER) = 19.0 to 37.5 mm (REQUIRED)
(0.75) to 1.50 in)
θ = 5 to 7.5 deg
α = 20 to 30 deg

FIGURE 2 - Filter Holder Schematic Diagram

5.8 Sample Size Measurement:

A wet or dry positive displacement meter shall be used to measure the sample volume needed to satisfy the requirements of 6.6 to an accuracy of ±2%. Pressure and temperature shall be measured immediately upstream of the meter. Pressure shall be measured to an accuracy of ±0.2% of the absolute pressure value. Temperature shall be measured to an accuracy of ±2 K (±2 °C, ±3.6 °F). If a dry type meter is used, it may be located between the filter holder and the vacuum pump.

5.9 Sample Flow Rate Measurement:

Sample flow rate shall be measured with a rotameter or equivalent flow measuring device. Accuracy shall be within ±5%.

5.10 Reflectometer:

A reflectometer conforming to ANSI PH 2.17 (latest version), “Annular 45°: 0° (or 0°: 45°) Optical Reflection Measurements (Reflection Density)”, shall be used. The diameter of the reflectometer light beam on the filter paper shall be within 0.1 and 0.5 D, where D is the diameter of the smoke stain. The allowable range of D is given in Figure 2.

6. TEST PROCEDURES:

6.1 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 sampling system should never be left in a no-flow condition during test operation. The following procedures are designed to produce consistent and precise results.

6.2 Filter System Leak Check:

The following procedure shall be used to leak check the filter system before and after each engine test:

a. Clamp clean filter material into the holder.
b. Close Valve A. Fully open Valves B, C, and D. Set Valve E (if used) to “smoke sample”.
c. Turn on sample pump and run for at least 1 min. When the system is stabilized, run the leak check for 5 min.
d. Observe and record volume measurement.

The system shall be satisfactory if no more than 5.0 standard liters (0.18 standard ft^3) pass through the volume meter during the 5 min period.

6.3 Sample Line Leak Check:

Before and after each engine test, a leak check of the sample line shall be made as follows:

a. Seal off all the probe orifices (preferably). Alternatively, seal off the sample line inlet.
b. Set Valve A to ‘’bypass”, and Valve E (if used) to ‘“smoke sample.” Fully open Valve C. Close Valve D.
c. Turn on the sample pump and run for at least 1 min. When the system is stabilized, run the leak check for 5 min.
d. Observe and record volume measurement.

The system shall be satisfactory if no more than 2.0 standard liters (0.07 standard ft^3) pass through the volume meter during the 5 min period.

The system shall not be used until the leakage requirements of 6.2 and 6.3 have been met.

6.4 System Cleanliness Check:

The need for cleaning or replacement shall be determined by conducting the following cleanliness check prior to each engine test:

a. Fully open Valves B, C, and D. Set Valve E (if used) to “smoke sample”.
b. Turn on the sample pump and alternately set Valve A to “bypass” and “sample” to purge the entire system with clean air for at least 5 min.
c. Set Valve A to “bypass”.
d. Close Valve D and clamp clean filter material into the holder. Open Valve D.
e. Set Valve A to “sample”, reset back to “bypass” after 50 kg of air/m^2 (0.071 lb/in^2) of filter area has been passed through the filter material.

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

6.5 Preparation for Test:

The following shall be done to prepare the system prior to test:

a. Set Valve A to “bypass”, open Valve C, close Valve D. Set Valve E (if used) to “smoke sample”.
b. Draw exhaust gas for 5 min minimum, then use Valve C to set flow rate at 14 L/min ± 0.5 L/min (0.50 cfm ± 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 14 L/min ± 0.5 L/min (0.50 cfm ± 0.02 cfm). This must be done quickly before particulate buildup on the filter causes excessive pressure drop.
f. Set Valve A to “bypass” and close Valve D.
g. Unclamp the filter holder, remove the filter material and discard. Clamp clean filter material into the holder.

6.6 Sampling:

Sufficient time (not less than 1 min) shall be allowed to assure that the system is fully charged with a representative gas sample. The sampling flow rate shall be maintained at 14 L/min ± 0.5 L/min (0.50 cfm ± 0.02 cfm). At least three samples shall be taken within the range of 12 to 21 kg of exhaust gas/m^2 (0.017 to 0.030 lb/in^2) of filter area. Samples shall be taken both above and below 16.2 kg of exhaust gas/m^2 (0.0230 lb/in^2) of filter area. Instead of taking different samples sizes, an acceptable alternative shall be to take consecutive samples at 16.2 kg/m^2 ± 0.7 kg/m^2 (0.0230 lb/in^2 ± 0.0010 lb/in^2) until at least three samples are obtained which agree within ±3 smoke numbers.

6.7 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 “bypass” position, charge the lines with exhaust gas for 1 min minimum. Re-establish flow rate at 14 L/min ± 0.5 L/min (0.50 cfm ± 0.02 cfm) as required, using Valve C.
b. Open Valve D.
c. Set Valve A to “sample”, check and re-establish flow if necessary at 14 L/min ± 0.5 L/min (0.50 cfm ± 0.02 cfm), allow the chosen sample volume to pass, then set Valve A to “bypass”.
d. Close Valve D, unclamp the filter holder and remove the filter material. Clamp clean filter material into the holder.
e. Repeat b through d for additional samples, as required in 6.6.

6.8 Operational Check:

The average fuel air ratio, as calculated from average measured CO_2 values obtained in accordance with the procedures given in ARP1256, shall agree within 15% at idle and 10% at higher power settings with values calculated from air and fuel data. The fuel-air ratio may be adjusted for estimated exhaust carbon monoxide and hydrocarbon concentrations. Fuel flow and CO_2 measurements should be taken at the same time. Airflow data preferably are from direct measurements but if such measurements are impractical, the data may be taken from air consumption curves generated for the particular model of the engine under test, corrected to actual temperature and pressure conditions. This check shall be conducted only at the power setting giving the highest or near the highest smoke level for the particular engine model under test.

7. INFORMATION AND DATA TO BE RECORDED:

7.1 Information:

7.1.1 General:

a. Facility performing test
b. Date of test
c. Description of test equipment
d. Probe location as determined in accordance with 5.2
e. Weather conditions (wind direction and velocity, precipitation)

7.1.2 Aircraft Description (if Applicable):

a. Manufacturer
b. Model number
c. Serial number
d. User or operator
e. Engine installation position

7.1.3 Engine Description:

a. Manufacturer
b. Model number
c. Engine configuration/special configuration identification
d. Time since overhaul and other pertinent maintenance information

7.2 Test Data:

At least the following shall be recorded:

a. Engine power setting and rotor speed(s)
b. Date, time of day, and data point number
c. Ambient conditions (barometric pressure, engine inlet temperature, humidity) at beginning and end of test.
d. Fuel flow rate
e. Fuel type, fuel additives (if used)
f. Leak and cleanliness check values
g. Volume meter sample temperature
h. Volume meter sample pressure
i. Actual sample volume at sampling conditions
j. Sample line type, length
k. Sample line temperature