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MEASUREMENT OF FAR FIELD NOISE FROM GAS TURBINE ENGINES DURING STATIC OPERATION

INTRODUCTION:

Measurement of noise from gas turbine engines during static operations is a major element of engine research and development programs. Test objectives include evaluation of the impact on noise caused by various engine or nacelle design changes, definition of engine noise characteristics, identification of specific engine noise sources using diagnostic procedures, and acquisition of noise data for use in assessing compliance with airplane noise certification requirements. When planning a static engine noise test, major items that deserve careful consideration include (1) test site characteristics, (2) data acquisition and reduction systems, (3) microphone locations, (4) acoustical calibration and measurement procedures, and (5) meteorological conditions.

This document provides recommended practices in the form of objectives and engineering procedures based on extensive static engine noise measurement experience gained over a period of many years. However, the description of specific test practices does not mean that there are no other valid and acceptable means to satisfy static test objectives. The specific nature of each test should be considered and instrumentation and data analysis methods assessed when selecting the specific practices that will be employed in a test.

1. PURPOSE:

The purpose of this document is to describe recommended practices for measurements of far-field sound pressure levels during static operation of gas turbine engines installed on an outdoor engine test stand.

2. SCOPE:

Recommendations presented in this document are intended primarily for the acquisition of far-field acoustical data. The test engine is to be appropriately configured and operated so that the acoustical signals generated are consistent with the specific objectives of the test. The principal output of the data reduction system is one-third octave band sound pressure levels. However, broader or narrower bandwidth analysis of the recorded data may also be accomplished when appropriate.

Although not specifically intended to apply to special purpose engine noise testing (for example, tests involving unique instrumentation or procedures to identify specific noise sources), some of the practices described herein may be appropriate for such testing.

Specification of reference conditions is outside the scope of this document although procedures to adjust data to a reference condition are described in 7.2.4.

3. REFERENCES:

1) Practical Methods to Obtain Free Field Sound Pressure Levels from Acoustic Measurements Over Ground Surfaces, Society of Automotive Engineers Aerospace Information Report AIR 1672B (June, 1983).

2) Sound Level Meters, International Electrotechnical Commission Publication No. 651 (First Edition, 1979).

3) Recommendations for Octave, Half-Octave, and Third Octave Band Filters Intended for the Analysis of Sounds and Vibrations, International Electrotechnical Commission Publication No. 225 (1966).

4) American National Standard Specification for Octave-Band and Fractional-Octave-Band Analog and Digital Filters, ANSI S1.11-1986.

5) American National Standard Specification for Acoustical Calibrators, ANSI S1.40-1984.

6) Standard Values of Atmospheric Absorption as a Function of Temperature and Humidity for Use in Evaluating Aircraft Noise, Society of Automotive Engineers Aerospace Recommended Practice ARP 866A (March 1975).

4. TEST SITE CHARACTERISTICS:

The test site shall have negligible influence on the engine's noise generating processes and, except for ground surface effects, negligible influence on the propagation of sound from the engine to the microphones.

4.1 Overall Site Selection: The test site shall be located in an open area having relatively flat terrain which is free of structures and other obstacles that affect far-field sound pressure measurements.

One-third octave band sound pressure levels of ambient noise shall be sufficiently below the one-third octave band sound pressure levels from engine noise sources so that engine noise measurements are not significantly contaminated by noise from environmental sources.

4.2 Engine Support Structure: The engine support structure shall have minimal sound interference characteristics. That is, the structure should not impede sound propagation nor have any acoustically reflective surfaces close to noise radiating regions. If structure surfaces exist that significantly influence engine noise radiation patterns, they shall be covered with materials that are acoustically absorptive in the frequency range of interest. Furthermore, the structure shall not influence sound generation by distorting airflow into the engine inlet or by being subjected to impingement by engine exhaust gases.

Test engines shall be supported such that the engine centerline is above the ground by at least one and one-half times the maximum diameter of the larger of either the fan or compressor blades. If an engine centerline is closer to the ground than one and one-half diameters, then an assessment shall be made to determine if the measured sound pressure levels are influenced by inflow distortions or by exhaust impingement on the ground.

4.3 Acoustical Arena: The acoustical arena is the surface area that extends from beneath the engine to a distance that is at least 3 m beyond all microphones.

The arena shall have the following characteristics:

- Flat with no undulations that cause focusing or scattering of sound or collect standing water (A slight slope or curvature subtending an angle of approximately one degree may be desirable to aid in drainage.)

- Thermally reflective, light in color to minimize solar heating and thermal gradients near the ground. (Sound pressure levels measured by microphones mounted close to the ground surface can be significantly affected by strong thermal gradients. See Reference 1.)

- Uniformly smooth and hard so as to approximate a perfect sound reflector over the frequency range of interest. Where such a surface is not possible, the difference between the acoustical impedance of the actual surface and that of a smooth, hard surface shall be taken into account in the evaluation of the engine noise data. (Some guidance on these ground reflection effects is provided in Appendix C of Reference 1.)

4.3 (Continued):

- Free from all obstacles that significantly influence sound propagation or engine operation and thus affect far-field sound pressure measurements in the frequency range of interest. The control room or other structures shall be located outside the arena such that they do not interfere with sound propagation from the engine to the microphones. External surfaces that could significantly affect far-field sound pressure measurements shall be covered with sound absorbing materials effective over the frequency range of interest.

5. DATA ACQUISITION AND REDUCTION SYSTEMS:

Data acquisition and reduction systems that provide reliable and repeatable measurements of sound pressure signals, meteorological conditions and engine performance shall be used. The characteristics of the instruments shall be consistent with those in the following Sections.

5.1 Acoustical Data Acquisition System: The acoustical data acquisition system consists of microphones, signal conditioning and transmission components (for example, preamplifiers, power supplies, and cables) and may include analog or digital data storage and retrieval equipment. The objective of this system is to acquire accurate measurements of engine sound pressure levels over the range of one-third octave bands having nominal center frequencies from 50 Hz to 10,000 Hz. Deviations from a uniform frequency response shall be determinable from instrument manufacturer's data, user calibrations, or combinations of both. The system sensitivity to variations in environmental conditions shall be consistent with the requirements for Type 1 instruments of the latest edition of IEC 651 (Reference 2). The range in which the system is insensitive to temperature change shall be broad enough to include the temperature range expected during testing.

5.1.1 Microphones and Related Components: Microphones and related signal conditioning and transmission components shall have the following characteristics:

- The system output for a constant acoustical input shall change by no more than 0.3 dB within any one hour.

- The free field frequency response of the microphone in the reference incidence direction shall lie within an envelope having the following limits:

Frequency Range, Hz	Tolerance Limits, dB
45 to 4500	±1
4500 to 11 200	±1.5

NOTE: The reference incidence direction is the incidence angle for which the microphone was designed by the manufacturer to provide the most uniform free field response over the widest range of frequencies.

5.1.1 (Continued):

- The change in sensitivity of the microphone over the incidence angle range of ±30 deg relative to the reference incidence direction shall not exceed the following:

Frequency Range, Hz	Change in Sensitivity, dB
45 to 2240	0.5
2240 to 4500	1.0
4500 to 5600	2.5
5600 to 7100	4.0
7100 to 11 200	5.0

- Microphone windscreens shall be employed with microphones during all measurements when the wind speed at the height of the microphones exceeds 11 km/hour. If used, microphone windscreens shall not have an effect on microphone sensitivity of more than 1 dB at any frequency from 45 Hz to 11 200 Hz. The effects of a windscreen on microphone response shall be determined as a function of frequency and sound incidence angle. These effects shall be accounted for as calibrations in the data analysis.

5.1.2 Data Storage and Retrieval System: The data storage and retrieval system normally consists of multi-channel analog or digital recording and reproducing systems and associated signal conditioning equipment (for example, amplifiers and attenuators installed between the microphone preamplifier and recorder).

Data storage and retrieval systems shall have the following characteristics:

- At the standard recording level for analog systems or 10 dB below maximum input level for digital systems, within each one-third octave frequency band having nominal midband frequencies between 180 and 11 200 Hz, the frequency response shall be flat within ±0.2 dB and within each one-third octave band having nominal midband frequencies between 45 and 180 Hz the frequency response shall be flat within ±0.5 dB.

  The above requirement considers the standard recording level for analog systems to be 10 dB below ±40% deviation for FM recording and 10 dB below the 3% harmonic distortion level for direct recording.

- Background electrical noise produced by the system in any one-third octave band covering the frequency range from 45 to 11 200 Hz shall be at least 35 dB below the standard recording level so that measured sound pressure levels are not contaminated.

- Attenuators included in the measuring chain to permit range changing shall operate in intervals of integral steps with a cumulative error between any two settings not more than 0.2 dB.

5.1.2 (Continued):

- For a direct recording system the amplitude fluctuations of a constant level 1000 Hz sinusoidal input signal recorded at the standard recording level shall be within ±0.5 dB throughout any reel of magnetic tape from the same manufacturer's batch as the one utilized for the engine noise measurement. Measurements to verify compliance with this specification shall be made using a device with time averaging properties equal to those used for the engine noise measurements.

- If a digital data system is used to store information, the signal sampling rate shall be sufficient to achieve the system frequency response defined above. This system shall have an error detection capability such that no more than five percent of the data are excluded.

5.2 Acoustical Data Reduction System: The acoustical data reduction system consists of those components that convert the output of the acoustical data acquisition system into time-averaged one-third octave band sound pressure levels. The objective is to filter the signal into one-third octave bands, to square the filtered signal, determine the time-mean-square sound pressures, and to produce the result as sound pressure levels in decibels. The data reduction system may use analog, digital, or a combination of analog and digital techniques. The acoustical data reduction system shall comply with the following specifications:

- The filtering process shall include the 24 one-third octave bands having preferred frequencies from 50 Hz to 10 000 Hz. The performance of the filters shall be consistent with the requirements of the latest edition of IEC 225 (Reference 3) or the equivalent performance as specified for Type 1 filters in ANSI S1.11-1986 (Reference 4).

- The analyzer shall produce a set of twenty-four one-third octave band sound pressure levels, in decibels, represented mathematically as:

$$L_p(f) = 10 \lg \left\{ \left[1/T \int_0^T p_f^2(t)dt \right] / p_o^2 \right\} \quad (1)$$

  where $p_f(t)$ is the instantaneous time-varying sound pressure signal (or its electrical or numerical analog) at the output of a filter (of band center frequency f), T is the averaging time, p_o is the reference sound pressure (20 micropascals), and lg is the symbol for a base 10 logarithm.

- The resolution of the one-third octave band sound pressure levels that result from performing the operation defined by Equation (1) shall not exceed 0.3 decibel.

5.3 Linear Operating Range of Acoustical Data Acquisition and Reduction Systems: Linearity error is the departure from an ideal linear relationship between the indicated one-third octave band sound pressure at the output of the data reduction system and the level of a steady sinusoidal electrical signal at the microphone preamplifier. The error shall not exceed ±0.7 dB over the operating range of input voltage levels from 0 to 30 dB below the full scale reading and not exceed ±1.0 dB between 30 and 40 dB below the full scale reading. Compliance with this limit on linearity error shall be demonstrated for test signal frequencies of 63, 1000, and 8000 Hz. Errors that may be introduced by level-range-control attenuators are included within the limits on linearity error.

5.4 Meteorological Measurement System: The meteorological measurement system consists of instruments to measure wind speed, wind direction, ambient air temperature, relative humidity and atmospheric pressure. The objective is to monitor meteorological conditions to ensure that static noise tests are conducted within specific meteorological limits and to provide information needed for acoustical data normalization to reference meteorological conditions, see 7.2.4. Methods and instruments shall conform with the following:

- The meteorological sensors shall be located in the vicinity of the microphone array over or adjacent to the same surface that extends from the engine to the far-field microphones, but located such that they do not cause acoustic interference effects at any microphone station. Also, the sensors shall be at locations not influenced by engine inlet and exhaust flow fields.

- Ambient air temperature shall be measured at engine centerline height. If ground plane microphones are used, an additional temperature measurement shall be made of the air within 5 mm of the ground plane microphone diaphragm height. This can be accomplished by positioning either the temperature sensor or the air intake of an aspiration system at this specified height. The ground temperature sensor shall be located in the general area beneath the engine centerline height sensors. (Reference 7.1.4).

- Ambient atmospheric pressure shall be measured in the vicinity of the acoustical arena.

- Wind speed and direction shall be measured at engine centerline height.

- Relative humidity shall be determined from measurements taken at a height between one-half the engine centerline height and the engine centerline height.

- The accuracy of the instruments shall be equal to or better than the following:

Parameter	Accuracy
Wind Speed	±2.0 km/h above 1 km/h
Wind Direction	±5 degrees
Air Temperature	±0.5°C
Relative Humidity	±3 percentage points
Atmospheric Pressure	±0.5 kPa

5.5 Engine Performance Measurements: As a minimum instruments shall be provided to define the prime engine power setting parameter (for example, fan rotor speed, engine pressure ratio, or thrust). The objectives are to ensure that the engine is set at the desired operating condition and is stable when sound pressure signals are recorded. The instruments shall have the capability of determining the value of the power setting parameter within an accuracy consistent with a rotor speed measurement accuracy of one percent. Ambient temperature and pressure measurements also are required to adjust engine performance data to applicable reference conditions.

Instruments installed in flow paths can create noise sources that produce unwanted signals in the measured far field sound pressure levels. Thus, additional engine parameters that may be needed for analysis and interpretation of noise data (for example, airflows, fan pressure ratio, and other pressures and temperatures) are defined from relationships between the prime engine power setting parameter and the additional parameters developed from either separate engine performance tests of the noise test engine, from another engine having identical hardware, or from the standard performance defined by the manufacturer for that bill-of-material configuration. Only essential instruments (that is, bill-of-material instruments for a particular engine model) shall be installed in engine flow paths.

6. MICROPHONE LOCATIONS AND INSTALLATIONS:

The objectives are to locate microphones (1) far enough from the engine so that the measured sound pressure levels can be extrapolated to greater distances without the need to consider the detailed distribution of individual noise sources, and (2) at appropriate angular intervals to define sound field directional characteristics.

To meet the above objectives, the microphones shall be located a distance from the engine of at least 15 times the diameter of the larger of either the fan or compressor blades. A minimum radial distance of 45 m for large engines and 30 m for small engines is commonly used. Special considerations for cases where jet noise is of prime interest are described in Section A2 of the Appendix.

The angular location of the microphones shall be identified relative to an engine station along the engine centerline such as the plane of the fan inlet, fan face, fan discharge nozzle exit or primary nozzle exit. Over the angular range of interest, which typically is from 10 deg (forward) to 160 deg (aft) the angular interval between microphones shall not exceed 10 deg. Microphones shall be located at increments less than 10 deg (for example, 5 deg increments) over that angular range in which the highest turbomachinery noise levels are expected in order to determine directional characteristics of those noise sources. Under certain conditions traversing microphones may be used. See Section A4 of the Appendix.

6. (Continued):

Two types of microphone installations are recommended. In one installation a mast or pole is used to support the microphone at engine centerline height. Either a "pressure-type" (that is, random-incidence) microphone at grazing incidence or a "free-field type" at normal incidence may be used. When installed, the pole mounted microphones shall be oriented such that sound waves propagating directly from the engine noise sources arrive at approximately the incidence angle that is appropriate for the microphone type and its reference incidence direction.

In the other type of installation a "pressure-type" microphone is located sufficiently near the ground plane so that the direct and reflected sound waves are essentially in phase over the frequency range of interest (one example of a ground plane microphone installation is shown in Appendix B of Reference 1). The microphone shall have uniform pressure response as a function of frequency.

7. ACOUSTICAL CALIBRATION AND MEASUREMENT PROCEDURES:

When conducting a static noise test and performing the subsequent data analysis, the objective is to obtain valid, repeatable sound pressure level measurements. This section presents the calibration, measurement, and analysis procedures to accomplish that objective. Special test considerations are discussed in the Appendix.

7.1 General Test Procedures:

7.1.1 Calibrations - Frequency Response: Calibrations shall be performed to determine deviations of the entire recording and reproducing system from a uniform frequency response. The non-uniformities shall be determined in terms of time averaged one-third octave band sound pressure levels relative to the sound pressure level in the band containing the acoustical calibration reference frequency. The one-third octave band corrections required to adjust the recording and reproducing systems to a uniform frequency response shall be applied to the measured data (Reference 7.2.3.).

The following defines two terms used in this section.

Test Period - normally the duration of time during which an engine is continuously operated, meteorological conditions are monitored, and acoustical data are obtained. The duration of a test period normally is less than 24 hours.

Test Series - normally one or more test periods during which the engine remains installed at the test site although the configuration may change. The duration of a test series normally is measured in weeks, depending on the number of configurations to be tested and the duration of time meteorological conditions are within acceptable test limits.

7.1.1 (Continued):

- Obtain an acoustical free field frequency response in the specified reference incidence direction for each microphone within three months prior to the test. This calibration may be determined by measuring the microphone's pressure response (for example, by use of an electrostatic calibrator in combination with manufacturer provided corrections) or by tests in a anechoic free field facility. The resulting response shall be within the tolerance limits given in 5.1.1. One-third octave band corrections required to adjust the actual response of a microphone to a uniform frequency response are referred to as the microphone frequency response nonuniformities.

- If microphone windscreens are necessary (Reference 5.1.1) the effect of each windscreen on microphone sensitivity shall be determined. Manufacturer provided corrections may be used for new wind screens. (Note: windscreens that have been in service should be inspected to assure that they are free from dust, liquids or other items that could alter the windscreen response. If there is evidence that the windscreen response may have been altered, it should either be discarded or recalibrated.) Windscreen responses shall be within the tolerance limits defined in 5.1.1. One-third octave band corrections required to adjust the actual response of a windscreen to a uniform frequency response are referred to as the windscreen frequency response nonuniformities.

- The electrical frequency response of the components of the acoustical measurement system shall be determined. This response shall be determined either by calibrating the system in its entirety or by calibrating the system in sub-sections and then summing the response from each sub-section. Both methods require the insertion of pink noise or equal amplitude sinusoidal signals at the nominal center frequency of each one-third octave band. The inserted signals shall be at a constant level within a range of 0 to -10 dB relative to the full scale setting of the measurement system. This calibration shall be performed within two weeks prior to and within two weeks after each test series.

  When the system is calibrated in its entirety, the calibration signals are inserted or input at the microphone pre-amplifier and the measured levels are obtained from the output of the analysis system. The electrical frequency response is the deviation from a uniform frequency response as determined from the one-third octave band output of the analysis system.

  If the system is calibrated in sub-sections (for example, pre-amplifier through microphone cables as one sub-section and recording system through analysis system as the other sub-section) the calibration signals are inserted at the input of each sub-section and the output is obtained at the last component of each sub-section. The system electrical response in each one-third octave band using this method is the arithmetic sum of the responses from each sub-section. All components from the microphone pre-amplifier through the analysis system must be included in the summation process.

7.1.2 Calibrations - Acoustical Sensitivity:

- Before and after each test period determine the overall electro-acoustical sensitivity of the measurement system by use of a signal from an acoustical calibrator generating a known sound pressure level at a known frequency.

  For systems that remain energized throughout the test series, this calibration shall be performed within one week prior to the start of the test series, at weekly intervals during the test series, and within one week after the test series. In addition, the calibration shall be conducted immediately following any component change.

- The acoustical calibrator shall comply with the requirements of Reference 5 and shall produce the nominal sound pressure level in the coupler of the cavity with an accuracy within ±0.5 dB under the reference environmental conditions of Reference 5.

- Prior to each test period the reference sound pressure level calibration signal shall be recorded at near-standard recording level (Reference 5.1.2) through each data channel for a period of at least 30 seconds. The source of the reference signal shall be either the acoustical calibrator or an electrical signal of the same frequency as the signal from the acoustical calibrator and at a voltage that can be related to the sound pressure level produced by the acoustical calibrator from the calibration conducted prior to the test period.

7.1.3 Calibrations - Stability: Before and after each test period record a pink noise signal through each data channel for a duration of at least 30 seconds. The input level should be at the standard recording level.

7.1.4 Test Environmental Conditions:

- Conduct tests when meteorological conditions are within manufacturer stated limits on the use of their acoustical test instruments.
- There shall be no precipitation when obtaining acoustical data.
- Wind speed during acoustical data acquisition shall not exceed a mean of 22.5 km/h (12 knots) nor a maximum of 27.8 km/h (15 knots).
- Mean cross wind components perpendicular to the engine axis and averaged over 30 s shall not exceed 10.0 km/h (5.4 knots) during acoustical data acquisition.
- No condensation on noise measurement instruments.
- The acoustical arena shall be free from any covering (for example, snow) that could alter the nominal acoustical characteristics of the surface.
- One-third octave band levels of ambient noise should be 10 dB or more below the measured engine noise level in each one-third octave band in the frequency range of interest. (Reference 7.2.3)

7.1.4 (Continued):

- Additionally, when ground plane microphones are used special precautions shall be employed to ensure that measurements are not significantly influenced by factors such as acoustic shadowing or scattering, particularly at high frequencies. One approach is to limit testing to temperature gradient and wind conditions that preclude the likelihood of shadowing or scattering. The weather criteria defined in Fig. 1 are those that have been determined from previous testing to yield a high degree of data repeatability over the range of temperature and wind conditions shown in the Figure. A high degree of data repeatability over this range of atmospheric conditions suggests the absence of significant shadowing or scattering effects.

7.1.5 <u>Test Data Acquisition</u>:

- For each acoustical data channel, record ambient noise for at least 30 s within 15 min before starting the engine.

- For each test condition, before initiating data recording stabilize the engine such that the appropriate engine power setting parameter (for example, fan rotational speed, engine pressure ratio, or thrust) does not vary more than that which is equivalent to a $\pm 1\%$ variation in the relevant engine shaft rotational speed.

- Record far-field sound pressure signals at each test condition for at least 30 seconds.

- Obtain periodic recordings of temperature, relative humidity and atmospheric pressure during the period of time when sound pressure signals are being measured. Wind speed and direction shall be recorded continuously or sampled at a sufficiently high rate such that a continuous representation of these parameters may be inferred.

- At each test condition, continuously record the prime engine performance parameter (for example, low-pressure shaft rotational speed) or sample at a sufficiently high rate such that a continuous representation of this parameter may be inferred. Periodically sample other pertinent engine performance parameters when sound pressure signals are being recorded.

- Following completion of each period of testing (within 15 min after the engine has been shut down) record a post test sample of ambient noise through each acoustical data channel for at least 30 seconds.

7.2 Acoustical Data Processing Procedures:

7.2.1 Data Reduction: All data shall be processed through a data reduction system that complies with the requirements of 5.2.

- Analyze recordings of the pink noise or sinusoidal calibration signals (Reference 7.1.1 and 7.1.3) to yield one-third octave band sound pressure levels averaged over a period of at least 15 s for sinusoidal signals and 20 s for pink noise. Determine system frequency response corrections from the resulting data relative to the sound pressure level in the one-third octave band containing the reference acoustical calibration frequency.

- Analyze the single frequency reference acoustical sensitivity calibration signals (Reference 7.1.2) to yield sound pressure levels averaged over a period of at least 15 s for the one-third octave band containing the calibration frequency.

- Analyze each set of recorded far-field sound pressure signals and ambient noise signals (Reference 7.1.5) to yield one-third octave band sound pressure levels averaged over a period of at least 20 seconds.

- The reference amplitude calibration is the average of the calibrations recorded prior to and after the test period. (Reference 7.1.2.)

7.2.2 System Stability: Calibration data shall be used to determine that the stability of each channel of the data acquisition system was acceptable during the test period.

- In any one-third octave band pre and post test stability calibration sound pressure levels (Reference 7.1.3) for each data system channel shall not differ by more than 0.8 dB.

- The acoustical sensitivity calibration sound pressure levels obtained before and after each test period as described in 7.1.2 for each microphone or data system channel shall not differ by more than 0.5 dB.

- For a sudden change in a microphone or data system channel that leads to non-compliance with the above stated stability requirements, the time when the change in sensitivity occurred may be obvious from a review of data. If this is the case, data obtained up to the sensitivity-change time may be considered valid. If the time when the sensitivity changed is not obvious, the data obtained from that microphone or data system channel shall be considered invalid.