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Measurement of Far Field Noise from Gas Turbine Engines During Static Operation

RATIONALE

This ARP is in need of an update. Work is being done by industry on this topic, but much of it is proprietary in nature. Should the need arise, and support and resources become available, A-21 can create a WIP to do a new document or revision. In the meantime, the document should be stabilized.

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This document has been declared "Stabilized" by the SAE A-21 Aircraft Noise Measurement Aviation Emission Modeling 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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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 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 for 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 and installations, (4) acoustical calibration and measurement procedures, (5) test environmental conditions, and (6) data processing and adjustments.

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 test objectives. The specific nature of each test should be considered and measurement and data reduction methods assessed when selecting the specific practices that will be employed in a test.

1. SCOPE

Recommendations presented in this document are intended primarily for the acquisition of far-field noise data. The test engine is to be appropriately configured and operated so that the sound pressure levels obtained 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, when appropriate, data may be recorded for purposes of broader or narrower bandwidth analysis.

1.1 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. REFERENCES

1. Methods of Controlling Distortion of Inlet Airflow During Static Acoustical Tests of Turbofan Engines and Fan Rigs, Society of Automotive Engineers Aerospace Information Report AIR1935 (February 1985).

2. Practical Methods to Obtain Free Field Sound Pressure Levels from Acoustic Measurements over Ground Surfaces, Society of Automotive Engineers Aerospace Information Report AIR1672B (June 1983).

3. Annex 16 to the Convention on International Civil Aviation, Environmental Protection, Volume I Aircraft Noise, as amended.

4. Electroacoustics – Instruments for measurement of aircraft noise - Performance requirements for systems to measure one-third-octave band sound pressure levels in noise certification of transport-category aeroplanes, International Standard IEC 61265: (1995-04) and Corrigendum (1995-06), International Electrotechnical Commission, Geneva, Switzerland.

5. 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 ARP866A (March 1975).

3. TEST SITE CHARACTERISTICS

The test site should 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.

3.1 Overall Site Selection

The test site should 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 should 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 non-engine sources.

Multiple test sites may be selected for testing engine configurations, provided the acoustic measurements from the different sites can be adjusted to a common reference condition.

3.2 Engine Support Structure

The engine support structure should 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 should be covered with materials that are acoustically absorptive in the frequency range of interest. Furthermore, the structure should not influence sound generation by distorting airflow into the engine inlet or by being subjected to impingement by engine exhaust gases.

Test engines should 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 should be made to determine if the measured sound pressure levels are influenced by inflow distortions or by exhaust impingement on the ground.

3.2.1 Engine Inlet Bellmouth

The installation of a bellmouth forward of the engine inlet may be used during static engine noise tests. Such an installation is used to provide a simulated flight condition of inlet flow during static testing. Production inlet acoustic lining and spinners are also to be installed during noise testing. The position of the inlet and exhaust planes relative to the center of the microphone array should be determined.

3.2.2 Inflow Control Devices (ICD)

For any test of high bypass ratio engines (BPR > 2.0) where fan noise is important, an Inflow Control Device (ICD) should be used. The diameter of a such a device should be approximately three or more times the diameter of the fan (as discussed in Appendix A, Paragraph A1, with supporting information on ICD design being given in AIR1935, Reference 1).

The ICD should meet the following requirements:

- The ICD must be free from damage and contaminants that may affect its acoustic performance.

- The ICD must be acoustically calibrated by an approved method (such as that provided in Section 4) to determine its effect on sound transmission in each one-third octave band.

- Data obtained during static engine noise testing must be adjusted to account for sound transmission effects that are caused by the ICD. The adjustments are to be applied to each one-third octave band of data measured.

- The ICD position relative to the engine inlet lip must be determined and the calibration must be applicable to that position.

- No more than one calibration is required for an ICD hardware design, provided that there is no deviation from the design for any one ICD serial number hardware set.

It is not necessary to apply the ICD calibration adjustments to a comparison of the data from two engine tests if the same ICD hardware (identical serial number) is used, and the fan tones for both engines remain in the same one-third octave bands.

3.3 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. In addition to the requirements for microphone location with respect to the engine given in Section 6, the impact of wind shadowing effects as described in 7.2.5 and Figure 1 may need to be considered.

The arena should 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 as described in the Appendices of Reference 2.)

- 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 should 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 2.)

- 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 should 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 should be covered with sound absorbing materials effective over the frequency range of interest.

4. ICD CALIBRATION

An acceptable ICD calibration method is as follows:

Place one or more acoustic drivers on a simulated engine centerline in the plane of the engine inlet lip. Locate the calibration microphones on the forward quadrant azimuth at a radius between 15 m (50 ft) and 45 m (150 ft) that provides a good signal-to-ambient noise ratio and also at each microphone angle to be used to analyze static engine noise data. Locate a reference near-field microphone on the centerline of and within 0.6 m (2 ft) of the acoustic center of the acoustic driver(s).

Energize the acoustic driver(s) with pink noise without the ICD in place. Record the noise for a minimum of 60-second duration following system stabilization. The procedure must be conducted at a constant input voltage to the acoustic driver(s).

Repeat the previous step, alternately with and without the ICD in place. A minimum of three tests of each configuration (with and without ICD in place) is required. To be acceptable, the total variation of the 55 degrees microphone on-line Overall Sound Pressure Level (OASPL) signal (averaged for a 1-minute duration) for all three test conditions of each configuration shall not exceed 0.5 dB.

Note: Physically moving the ICD alternately in and out of place for this calibration may be eliminated if it is demonstrated that the ICD positioning does not affect the calibration results.

All measured data are to be adjusted for sound pressure level variations as measured with the near-field microphone and for atmospheric absorption to 25 °C and 70 percent relative humidity (RH) conditions by using the slant distance between the outer microphones and the acoustic driver(s).

The calibration for each one-third octave band at each microphone is the difference between the average of the adjusted one-third octave band sound pressure levels (SPL) without the ICD in place and the average of the adjusted one-third octave band sound pressure levels with the ICD in place.

The tests must be conducted under wind and thermal conditions that preclude acoustic shadowing at the outer microphones and weather-induced variations in the measured sound pressure level data. (Refer to Figure 1 and 7.2.4.)

In some cases large fluctuations in the value of the calibrations across adjacent one-third octave bands and between closely spaced angular positions of microphones can occur. These fluctuations can be related to reflection effects caused by the calibration procedure and care must be taken to ensure that they do not introduce or suppress engine tones. When calibrations are to be used for noise certification purposes, procedures to assess the effects of these fluctuations are subject to approval by certificating authorities.

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 are to be used. The characteristics of these systems shall be consistent with those in the following sections.

5.1 Noise Measurement System

The noise measurement system consists of components to obtain time-averaged one-third octave band sound pressure levels of far field engine noise during static operation, and includes: calibrators, microphones, equipment for signal conditioning, transmission, and recording/reproducing, and one-third octave band spectrum analysis instrumentation.

The performance characteristics of all components of the noise measurement system shall meet the specifications set forth in Reference 4. For aircraft noise certification purposes, the relevant specifications of Section 3 of Appendix 2 of Reference 3 regarding noise measurement shall apply, and all noise measurement instrumentation and methods shall be subject to approval by the cognizant certificating authority. In situations where the specifications of Annex 16 can not be reasonably applied to measurements of far field engine noise during static operation, procedures proposed by the applicant shall be subject to approval by the certificating authority.

Note: When static engine acoustic measurements are being used for aircraft noise certification purposes, the measurement distances associated with static tests are substantially less than those encountered in flight testing and may permit testing in atmospheric conditions not otherwise permitted for flight testing by Reference 3. Moreover, since static engine noise is a steady sound pressure level rather than the transient noise level of a flyover, the measurement and analysis techniques may be somewhat different for static noise testing.

5.2 Meteorological Measurement System

5.2.1 General Description

The meteorological measurement system consists of components 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 7.3.4). Methods and instruments shall conform with the following:

- 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 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 (see 7.2.5).

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

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

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

- The calibrated accuracy of the instruments shall be equal to or better than the limits specified in Table 1.

TABLE 1 - INSTRUMENTATION ACCURACY REQUIREMENTS

Parameter	Accuracy
Wind Speed	±0.6 m/s (**±2.0 km/h**) (±1.1 kt) above 0.3 m/s (**1 km/h**) (0.5 kt)
Wind Direction	±5 degrees
Air Temperature	±0.5 °C
Relative Humidity	±3 percentage points
Atmospheric Pressure	±0.5 kPa

Note: Conversions of some non-critical values from Imperial to SI units are shown in the context of acceptable approximations, and rounding has been applied. The primary unit from which the others have been derived is shown in bold type.

5.2.2 Definitions Applicable to Wind Measurement

For the purposes of measuring wind conditions and meeting the limits of 7.2.4, the following definitions apply:

Time constant (of a first order system) is the time required for a device to detect and indicate 100*(1-1/*e*) percent (about 63%) of a step function change. (The mathematical constant, *e*, is the base number of the natural logarithm, approximately 2.7183 - also known as *Euler's number*, or *Napier's constant.*)

Distance constant (or response length) is the passage of wind (in meters) required for the output of a wind speed sensor to indicate 100*(1-1/e) percent (about 63%) of a step-function increase of the input speed.

Wind speed sample (at a certain moment) is the value measured at that moment for wind speed using a sensor/system with characteristics as follows:

- Range: **1 m/s** (3.6 km/h) (2 kt) to more than **10 m/s** (36 km/h) (20 kt);
- Linearity: **±0.5 m/s** (1.8 km/h) (1 kt) over the specified range;
- Distance constant (response length) for systems having dynamic behavior best characterized by a distance constant: less than 5 meters; and
- Time constant for systems having dynamic behavior best characterized by a time constant: less than 3 seconds for wind speeds at or above **5 m/s** (18 km/h) (10 kt).

Wind direction sample (at a certain moment) is the value obtained at that moment from a wind direction sensor/system with characteristics as follows:

- Wind speed operating range: **1 m/s** (3.6 km/h) (2 kt) to more than **10 m/s** (36 km/h) (20 kt);
- Linearity: ±5 degrees over the specified range; and
- Resolution: 5 degrees.

*For the entire wind sensing system used to obtain wind speed and direction samples, the combined dynamic characteristics, including physical inertia of the sensor(s), and any temporal processing, such as filtering of the sensor signal(s), or smoothing or averaging of the wind sensor data, shall be equivalent to a first order system (such as an R/C circuit) with a time constant of no greater than 3 seconds at a wind speed of **5 m/s** (18 km/h) (10 kt).*

Wind vector (at a certain moment). At least once every second the wind vector shall be determined. Its magnitude will be represented at a certain moment by the wind speed sample at that moment and the direction of the vector shall be represented by the wind direction sample at that moment.

Average wind speed shall be determined from the series of individual wind speed samples obtained during the engine test run, using a linear averaging process over a period that spans the acoustic data averaging period. Alternatively, each wind vector shall be broken down into its “along-engine centerline” (u) and “cross-engine centerline” (v) components. The u and v components of the series of individual wind samples obtained during the engine test run shall be separately averaged using a linear averaging process over a period that spans the acoustic data averaging period. The average wind speed and direction (with respect to the engine centerline) shall then be calculated from the averaged u and v components according to Pythagorean Theorem and “arctan(u/v)”.

Average cross-wind component shall be determined from the series of individual values of the “cross-engine centerline” (v) component of the wind samples obtained during the engine test run, using a linear averaging process over a period that spans the acoustic data averaging period.

Maximum wind speed. The maximum value within the series of individual wind speed samples recorded every second over a period that spans the acoustic data averaging period.

Maximum cross-wind component. The maximum value within the series of individual values of the “cross-engine centerline” (v) component of the wind samples recorded every second over a period that spans the acoustic data averaging period.

5.3 Engine Performance Measurement System

An engine performance measurement system shall be used to measure the prime engine power setting parameter (for example, fan rotor speed, engine pressure ratio, or thrust). The objective is to ensure that the engine is set at the desired operating condition and is stable at that condition when sound pressure signals are recorded or are being analyzed. The system shall have the capability of measuring the power setting parameter within an accuracy consistent with a one percent accuracy in rotor speed measurement. Ambient temperature and pressure measurements are required consistent with the measurement practices in 5.2.1 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 with an identical bill of material, or from the standard performance defined by the manufacturer for that bill-of-material configuration. Only essential bill-of-material sensors for a particular engine model shall be installed in engine flow paths.

For certification tests, bleed and stator vane schedules shall conform to bill of material schedules. These schedules may be varied only for the purpose of measuring noise as a function of these schedules.

6. MICROPHONE TYPES, 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 should be located at a distance from the engine of approximately 15 times the diameter of the larger of either the fan or compressor blades. Typical radial distances for current static engine noise test facilities are **45 m** (≈150 ft) for large engines and **30 m** (≈100 ft) for small engines. Special considerations for cases where jet noise is of prime interest are described in Section A.2 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 degrees (forward) to 160 degrees (aft) the angular interval between microphones shall not exceed 10 degrees. Microphones shall be located at increments less than 10 degrees (for example, 5 degree increments) over that angular range in which the highest turbomachinery noise levels are expected in order to determine directional characteristics of those noise sources.

Two types of microphone installations are recommended. In one 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 2).

In the other type of 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" microphone at normal incidence may be used. When installed, the pole mounted microphones should be oriented such that sound waves propagating directly from the engine noise sources arrive at approximately the sound incidence angle that is appropriate for the microphone type and its reference direction. If the wind speed at the height of the microphones exceeds 3 m/s (**11 km/h**) (6 kt) windscreens shall be employed with microphones during all measurements.

Note: When static engine acoustic measurements are being used for aircraft noise certification purposes, inverted “pressure-type” microphones are the appropriate type of installation.

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 Appendix A.

7.1 Data System Compatibility

If more than one data acquisition system and/or data analysis system is used for the acquisition or analysis of static data, compatibility of the systems is necessary. Compatibility of the data acquisition systems can be accomplished through appropriate calibration. Compatibility of the data analysis systems can be verified by analyzing the same data samples on both systems. For purposes of noise certification these procedures are subject to approval by the certificating authority

The use of pseudo-random noise signals with spectral shape and tonal content representative of turbofan engines is an acceptable alternative to the use of actual engine noise measurements for determining analysis system compatibility.

7.2 Noise Measurement Procedures

7.2.1 Frequency Response Calibrations

7.2.1.1 Definitions

Test Period. Normally the duration of time during which an engine is continuously operated, meteorological conditions are monitored, and acoustical data are acquired. However, the engine may be shut down for brief periods, for example, to inspect hardware, to check microphone systems, or to wait for more favorable weather conditions. 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 days or weeks, depending on the number of configurations to be tested and the duration of time meteorological conditions are within acceptable test limits.

Windscreen Insertion Loss. The indicated sound pressure level in decibels at a stated nominal one-third octave midband frequency, and for a stated sound incidence angle on the inserted microphone without the windscreen installed around the microphone minus the sound pressure level with the windscreen installed.

7.2.1.2 Microphone System Free Field Frequency Response

The free-field frequency response of the microphone system may be determined by using an electrostatic actuator in combination with the manufacturer's data or by testing in an anechoic free-field facility. The adjustment for frequency response shall be determined within 90 days of each test series. The adjustment for non-uniform frequency response of the microphone system shall be applied to the measured one-third octave band sound pressure levels determined from the output of the analyzer.

7.2.1.3 Noise Measurement System Frequency Response

The frequency response of the entire measurement system while deployed in the field during the test series, exclusive of the microphone, shall be determined at a level within 5 dB of the level corresponding to the calibration sound pressure level on the level range used during the tests for each one-third octave nominal midband frequency from 50 Hz to 10 kHz inclusive, using pink-random or pseudo-random noise. The output of the noise generator shall be determined by a method traceable to a national standards laboratory within six months of each test series, and tolerable changes in the relative output from the previous calibration at each one-third octave band shall be not more than 0.2 dB. The adjustment for frequency response shall be applied to the measured one-third octave sound pressure levels determined from the output of the analyzer.

7.2.1.4 Windscreen Insertion Loss

In the absence of wind and for sinusoidal sounds at grazing incidence, the insertion loss caused by the windscreen of a stated type installed around the microphone shall not exceed ±1.5 dB at nominal one-third octave midband frequencies from 50 Hz to 10 kHz inclusive. The free-field insertion loss of the windscreen for each one-third octave nominal midband frequency from 50 Hz to 10 kHz inclusive shall be determined with sinusoidal sound signals at appropriate incidence angles on the inserted microphone. For a windscreen which is undamaged and uncontaminated, the insertion loss may be taken from the manufacturer's data. In addition, the insertion loss of the windscreen may be determined by a method traceable to a national standards laboratory within six months of each test series, and tolerable changes in the insertion loss from the previous calibration at each one-third octave frequency band shall be not more than 0.4 dB. The adjustment for the free-field insertion loss of the windscreen shall be applied to the measured one-third octave sound pressure levels determined from the output of the analyzer.

7.2.2 Acoustical Sensitivity Calibrations

Before and after each test period (as defined in 7.2.1.1) the reference sound pressure level calibration signal from the sound calibrator shall be recorded through each data channel for a period of at least 30 seconds. Adjustments for differences in sound calibrator signal output from the nominal output level (due to environmental effects, coupler volume, etc.) during acoustical sensitivity calibrations shall be applied to the measured one-third octave sound pressure levels determined from the output of the analyzer.

7.2.3 Stability Calibrations

Before and after each test series record a pink noise signal through each data channel for a duration of at least 30 seconds.

7.2.4 Test Environmental Conditions

The following conditions shall be met:

- Conduct tests when meteorological conditions are within the noise measurement system manufacturer stated limits.

- There shall be no precipitation during acquisition of noise data.

- The wind limits specified in Table 2 shall not be exceeded during acquisition of the sample of noise data that is analyzed.

TABLE 2 - WIND LIMITS

Quantity	Limit
Average wind speed	6.2 m/s (22.2 km/h) (**12.0 kt**)
Average cross-wind speed component	2.8 m/s (10.0 km/h) (**5.4 kt**)
Maximum wind speed	7.7 m/s (27.8 km/h) (**15.0 kt**)
Maximum cross-wind component	5.1 m/s (18.5 km/h) (**10 kt**).

*Note: The average cross-wind speed component limit of 2.8 m/s (10 km/h) (**5.4 kt**) is more restrictive than that specified in Section 2 of Appendix 2 of Annex 16 (Reference 3). The more restrictive limit has historically been applied to static engine testing.*

- There shall be 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.
- 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 (see 7.3.3).

7.2.5 Acoustic Shadowing

Where ground plane microphones are used, special precautions are necessary to ensure that consistent measurements free from “acoustic shadowing” (refraction) effects will be obtained. When there is a wind in the opposite direction to the sound wave propagating from the engine, or when there is a substantial thermal gradient in the test arena, refraction can influence near ground plane microphone measurements to a larger degree than measurements at greater heights.

Previous evidence or supplemental data may be used to demonstrate that testing at a particular test site results in consistent measurements, including the absence of shadowing. In lieu of this evidence, a demonstration test should include an approved method to indicate the absence of shadowing effects on the ground-plane measurements. For purposes of noise certification, this method is subject to approval by the certificating authority.

Measurements of three weather parameters are typically used to define “acoustic shadowing.” They include:

- average wind speeds at engine centerline height (WCL);
- air temperature at engine centerline height (TCL); and
- air temperature within ±5 mm of ground microphone diaphragm height (TMIC).

The following criteria are suggested for certain test geometries:

- Measurements should be co-located and placed close to the 90 degrees noise measurement position without impeding the acoustic measurement.
- Suggested wind limits are additional to the wind limits established by other criteria (such as the maximum wind speed at the microphone if wind screens are not used).
- Wind and temperature regimes that have been observed to provide consistent measurements that preclude any influence of acoustic shadowing effects on ground-plane measurements are defined in Figure 1.

Figure 1 defines a boundary between the absence of shadowing and the possible onset of spectral deficiencies in the very high frequencies. Testing is permitted provided that the test day conditions are such that the average wind speed at engine centerline height, recorded over a period that spans the acoustic data averaging period, falls below the line shown, and that wind gusting does not exceed the value of the line shown by more than 1.5 m/s (**5.5 km/h**) (3 kt). Wind speeds in excess of the linear relationship shown, between 2 and 6 m/s (**7** and **22 km/h**) (4 and 12 kt), may indicate the need to demonstrate the absence of spectral abnormalities, either prior to or at the time of test when the wind direction opposes the direction of sound propagation.

When the temperature at the ground microphone height is less than 4 °C above the temperature at the engine centerline height, shadowing effects due to temperature gradients can be expected to be negligible.

Note: Theoretical analyses and the expression of wind criteria in terms of absolute speed rather than the vector reduction suggest that the noted limits may be unduly stringent in some directions.

7.2.6 Test Data Acquisition

- For each acoustical data channel, record ambient noise for at least 30 seconds within 15 minutes 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 ±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 rate of at least 1 sample per second.

- At each test condition, continuously record the prime engine performance parameter (for example, low-pressure shaft rotational speed) or sample at a rate of at least 1 sample per second. Periodically sample other pertinent engine performance parameters when sound pressure signals are being recorded.

- Following completion of each test period (within 15 minutes 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. In some cases, however, a post-test ambient measurement cannot be obtained (e.g., due to rain).