DTS-75-FA653-LR5

AIRCRAFT NOISE MEASUREMENT
Instrumentation & Techniques

Office of Environment
and Energy
Washington, DC 20591

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Letter Report
August 1996

U.S. Department of Transportation

Federal Aviation Administration

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1. NOISE MEASUREMENT INSTRUMENTATION

This letter report describes aircraft noise measurement instrumentation to be used in the field. It includes guidance on good field-measurement practice, general rules-of-thumb, as well as references to appropriate national and international standards, so that more detailed information can be obtained. It also includes a list of instrumentation manufacturers.

Figure 1 presents a generic noise-measurement system. Subsequent sections of this letter report address individual components of the generic syste

All noise-measurement instrumentation should be calibrated annually by its manufacturer, or other certified laboratory to verify accuracy. Where applicable, all calibrations shall be traceable to the National Institute of Standards and Technology (NIST).

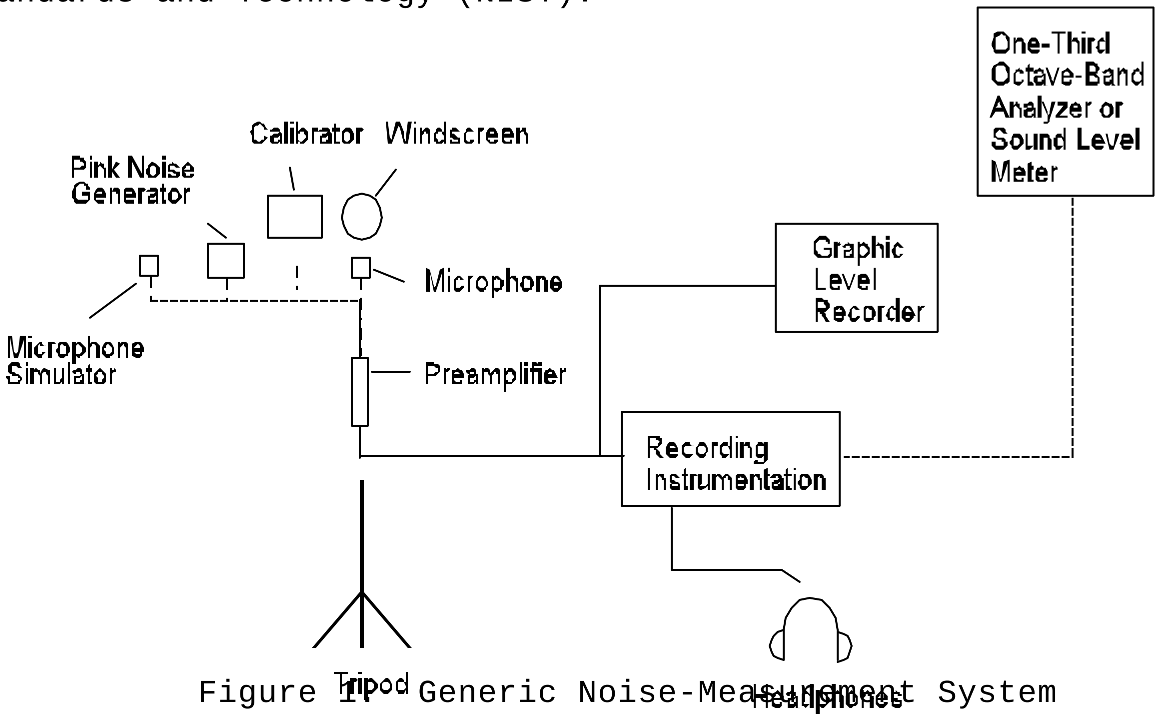

Figure 1. Generic Noise-Measurement System

1.1 Microphone System (Microphone and Preamplifier)

A microphone transforms sound-pressure variations into electrical signals, which are in turn measured by instrumentation such as a graphic level recorder (GLR), a sound level meter or a one-third octave-band spectrum analyzer. These electrical signals are also often recorded on tape for later off-line analysis. Microphone characteristics are further addressed in IEC 1265, IEC 1094-1, IEC 1094-4, and ANSI S1.4-1983 (R 1990).[1,2,3,4]

A compatible preamplifier, if not engineered as part of the microphone system, should also always be used. A preamplifier provides high-input impedance and constant, low-noise amplification over a wide frequency range. Also, depending upon the type of microphone being used (See Section 1.1.1), the preamplifier may provide a polarization voltage to the microphone.

The microphone system (microphone and preamplifier) should be supported using a tripod, or similar device, such as an anchored conduit. Care should be taken to isolate the microphone system from the support, especially if the support is made up of a metal composite. In certain environments, the support can act as an antenna, picking up errant radio frequency interference which can potentially contaminate data. Common isolation methods include encapsulating the microphone system in non-conductive material, e.g., nylon, prior to fastening it to the support.

Once supported appropriately, the microphone should be positioned as discussed in Section 1.1.3. The microphone system should then be connected to the measuring/recording instrumentation via an extension cable. At least 15 m (50 ft) of cable is recommended. Thus, any potential contamination of the measured data due to operator activity can be reduced to a negligible level.

1.1.1 Microphone Type

Condenser (i.e., electrostatic or capacitor) microphones are recommended for a wide range of measurement purposes because of their high stability, reasonably high sensitivity, excellent response at high frequencies, and very low electrical noise characteristics. There are two types of condenser microphones: conventional and electret.

Conventional condenser microphones characterize magnitude changes in sound pressure in terms of variations in electrical capacitance. Sound pressure changes incident upon the diaphragm of a microphone change the spacing between the diaphragm and the microphone backplate. This dynamic change in the gap between the diaphragm and backplate translates to a change in electrical capacitance.

In the case of a conventional condenser microphone, a polarization voltage must be applied to the backplate. Typically, a polarization voltage of between 50 and 200 V is applied to the microphone backplate by the preamplifier. Due to the requirement that a polarization voltage be supplied from a source external to the microphone (i.e., the microphone is not a “closed” system) measurements made with a conventional condenser microphone are often adversely effected by atmospheric conditions, especially high humidity. High humidity can result in condensation between the microphone diaphragm and backplate. Condensation can, in turn cause arcing of the polarization voltage, rendering the measured data essentially useless. To minimize condensation effects, the use of de-humidifying chambers, desiccants, and non-conductive back coating, such as quartz, can be used. Several manufacturers provide devices which can help to minimize this often-overlooked potential problem.

Electret condenser microphones, on the other hand, use a thin plastic sheet with a conductive coating on one side as a backplate. This design allows the microphone to maintain its own polarization, i.e., often referred to as a “pre-polarized” design. "Pre-polarization" allows the electret microphone to be essentially a “closed” system, eliminating the potential for condensation in high humidity environments.

The drawback to electret microphones is that they are often less sensitive at high frequencies. In addition, there are currently no electret microphones which provide their flattest response characteristics at grazing incidence, which is the incidence of choice for aircraft-related noise measurements (See Section 1.1.3).

1.1.2 Microphone Size

The diameter of a microphone diaphragm directly affects its useable frequency range, dynamic range (or level sensitivity), and directivity. For example, as the microphone diameter becomes smaller, the useable frequency range increases; however, sensitivity decreases. Thus, the selection of a microphone often involves a compromise of these elements. Unless measurements at extremely low sound pressure levels (SPLs) are required, e.g., below 20 dB SPL, a ½-inch diameter microphone (or **d**-inch microphone as characterized by some manufacturers) is suitable for most situations. For low-SPL measurements, a 1-inch diameter microphone may be necessary.

1.1.3 Microphone Incidence

The sensitivity of a microphone varies with the angle of incidence between the sound waves and the microphone diaphragm. Two microphone system orientations and their specific applications are discussed below: normal and grazing incidence.

Normal incidence, also referred to as 0 degrees incidence, occurs when sound waves impinge at an angle perpendicular, or normal, to the microphone diaphragm (See Figure 2). This orientation is best used for situations involving point-source measurements, in which the sound being measured is coming from a stationary, single, known direction, e.g., an aircraft engine test stand, a stationary aircraft or an auxiliary power unit (APU).

Grazing incidence, also referred to as 90 degrees incidence, occurs when sound waves impinge at an angle that is parallel to, or grazing, the plane of the microphone diaphragm (See Figure 2). This orientation is preferred for moving, or line-source measurements, since the microphone presents a constant incidence angle to any source located within the plane of the microphone diaphragm.

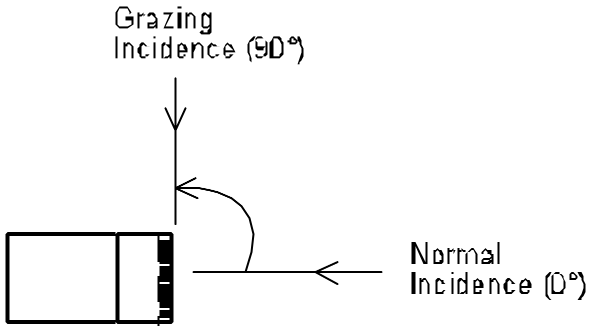

Figure 2. Microphone Incidence

Grazing incidence is commonly used for the measurement of aircraft noise. If other than grazing incidence is used, correction of the measured data in accordance with manufacturer-published response curves is required. This process can be quite complex because the incidence angle is continually changing, thus requiring continuously varying corrections.

It is perfectly acceptable to position a microphone for grazing incidence even if it has its flattest frequency response characteristics in a normal incidence configuration, as long as the appropriate manufacturer-published corrections are applied, and as long as the required corrections do not exceed certain limits. These limits are specified in Table 1 of IEC 1265.[1] If the manufacturer does not provide the appropriate incidence corrections, testing must be performed in accordance with IEC 1094-2, IEC 1094-3, ANSI S1.10-1966(R 1986), and ANSI S1.12-1967(R 1986).[5,6,7,8]

For the unique situation of measuring randomly occurring sounds, such as is the case with ambient noise measurements, or community noise measurements where the location of the sound source can be arbitrary, incidence corrections should be based on random response curves.

1.2 Recording System

Components of the measurement system are discussed separately in Section 1.3, so as to make a distinction between the actual recorded data, as would be heard by the human ear, and the actual sound level data computed as a result of some form of electrical/arithmetic process.

There are two basic types of tape recorders: analog and digital. Analog recorders store signals as continuous variations in the magnetic state of the particles on the tape. Digital recorders store signals as a combination of binary “1s” and “0s.” Most digital recorders represent a continually-varying analog level using many discrete 16-bit words, i.e., a unique combination of 16 “1s” and “0s.” The number of 16-bit words depends upon the sampling rate of the particular recorder.

Digital theory requires that the sampling rate of a recorder be at least twice the highest frequency of interest, which in often 20 kHz for transportation-related measurements. In theory, this means that one second of continuously varying analog data is represented by at least 40,000 discrete 16-bit combinations of “1s” and “0s.” However, practically, due to the design limitations on anti-alias filters (anti-alias filters are described later in this section), a sampling rate of 44,000 to 48,000 is common, i.e., 44,000 to 48,000 discrete 16-bit combinations of “1s” and “0s.”

Not all field measurement systems will include a tape recorder. A recorder offers the unique capability of repeated playback of the measured noise data, thus allowing for more detailed analyses. The electrical characteristics of a tape recorder shall conform to the guidelines specified in IEC 1265[1] and ANSI S1.13-1971 (R 1976)[9] for frequency response and signal-to-noise ratio.

The advantages of modern digital over analog recorders are numerous. Digital recorders typically have much wider frequency response characteristics, as well as a much larger dynamic range. About the only advantage analog recorders have is that they typically are less expensive, although the cost difference is decreasing.

When selecting a specific model of tape recorder, there are three important issues and/or differences associated with the use of digital versus analog recorders that require consideration. They are as follows:

- Anti-Alias Filters: An anti-alias filter is a low-pass filter applied to the input of a digital system prior to the digitization process. This filter, unique to digital systems, ensures that spurious signals (alias signals) resulting from the digitization process are not contributing components of the sampled signal. An anti-alias filter must have attenuation characteristics which ensure the contribution of aliased frequency components in the output are reduced to a negligible level.

- System Overloads: The overload point in a digital system is a well-defined point controlled by the maximum size of the bit-register used in the digitization process. When the size of the bit-register is exceeded, "hard" limiting occurs, followed by instantaneous distortion. In most cases, the dynamic range of a digital recorder is specified from this "hard" limiting point, and the overload and full-scale indicators are referenced to it.

  In contrast, analog recorders have no clearly defined overload point and generally "soft" limiting (a gradual process) begins around 6 dB above full scale (0 dB) on a volume unit (VU) meter, with a subsequent gradual increase in distortion.

  A safety margin of at least 10 dB , and preferably 20 dB , between the overload point and the expected maximum level of the data to be digitally recorded, including calibration data, should be maintaine

- Dynamic Range: A significant advantage of digital recorders is that they offer an extended dynamic range, resulting in an extended operating range. Dynamic range is typically specified from the "hard" overload point, and to guard against overload, a 10 to 20 dB safety margin is recommended, thus reducing the effective operating range. Additionally, the amplitude linearity error of a digital recorder increases as signal levels decrease, thus, reducing the effective operating range of the recorder. These characteristics are also true of analog recorders.

See Appendix A for a copy of a Volpe Center memorandum which further discusses recording systems, including a list of digital recorders which are acceptable for certification-related activity.

1.3 Measurement System

There are three general noise measurement systems discussed in this section: graphic level recorders (GLRs), sound level meters (SLMs), and one-third octave-band analyzers.

1.3.1 Graphic Level Recorder

A graphic level recorder (GLR) connected to the analog output of the measuring or recording instrumentation is typically used in the field to provide a visual, real-time history of the measured noise level. A GLR plot varies in level at a known, constant pen-speed rate and response time that may be adjusted to approximate exponential-time-averaging, i.e., fast-scale and slow-scale response characteristics (See Section 1.3.4.4). Such a plot is valuable in visually judging ambient levels and verifying the acoustic integrity of individual events.

1.3.2 Sound Level Meter

For the purposes of all measurements discussed herein, sound level meters (SLMs) should perform true numeric integration and averaging in accordance with IEC 651, IEC 804, and ANSI S1.4-1983 (R 1990).[10,11,4] Components of an SLM include (See Figure 3): a microphone with preamplifier, an amplifier, frequency weighting (See Section 1.3.4.2), input gain control (See Section 1.3.4.3), exponential time-averaging (See Section 1.3.4.4), and an output indicator or display. Selection of a specific model of sound level meter should be based upon cost and the level of accuracy desired.

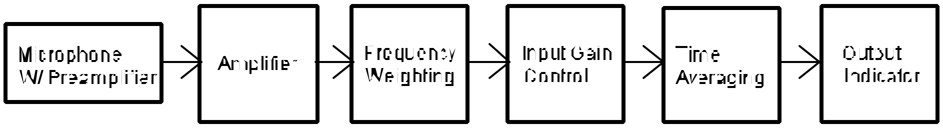

Figure 3.

Components of a Sound Level Meter

The accuracy of an SLM is characterized by its "type." There are three types of sound level meters available: Types 0, 1, and 2. Type 0 sound level meters are used for laboratory reference purposes, where the highest precision is required. Type 1 sound level meters are designed for precision measurements and research, and are the preferred type for use in the field. In fact Type 1 sound level meters are required for certification-related measurements. Type 2 sound level meters may be used for applications where high precision is not needed.

1.3.3 One-Third Octave-Band Analyzer

When the frequency characteristics of the sound source being measured are of concern, a one-third octave-band analyzer should be employed. In most cases, such a unit would not be employed directly in the field, but would be used subsequent to field measurements in tandem with tape-recorded data (See Section 1.2). Such units can be employed to determine noise spectra, as well as compute various noise descriptors, such as sound exposure level (SEL), denoted by the symbol L_{AE}, and equivalent sound level (TEQ), denoted by the symbol L_{AeqT}.

If consistency with previously measured data is desired, as is the case with certification-related measurements, one-third octave-band filters must be shown to comply with a Type 1-D Butterworth filter, as defined by ANSI S1.11-1986 (R 1993).[12] The Type 1-D Butterworth filter design has existed in analyzers for decades. However, at least one manufacturer is now providing filter-shape algorithms which depart from the traditional Butterworth design, and more closely resemble “ideal” filters, which allow essentially no energy outside of the pass-band.

To further ensure consistency with previously measured data, certification regulations require that a filter bandwidth error correction be applied to all one-third octave-band data. This correction accounts for small differences associated with the shape of each filter relative to that of an ideal band pass filter. The bandwidth error correction should be determined in accordance with IEC 1260.[13] Typically the correction is less than 0.1 dB for any given one-third octave-band filter.

1.3.4 Characteristics of the Measurement System

1.3.4.1 Bandwidth

The bandwidth of a measurement system refers to its frequency range of operation. Most Instrumentation of interest for readers of this letter report will accurately measure levels in the frequency range 20 Hz to 20 kHz, the audible range for humans. Measurement of one-third octave-band data between 50 Hz and 10 kHz are all that’s required for certification-related activity. However, it should be kept in mind that to meet certification requirements, most digital measurement systems, as well as most digital recording systems, must be configured to operate over a 20 kHz bandwidth to reliably obtain one-third octave-band data to 10 kHz. This requirement is due to the design limitations associated with anti-alias filters.

1.3.4.2 Frequency Weighting

Different weighting schemes are used to account for changes in sensitivity of the human ear as a function of frequency. Three standard weighting networks, A, B, and C, are used to account for different responses to sound pressure levels (See Figure 4 and Table 1) Note: The absence of frequency weighting is referred to as "flat" response.

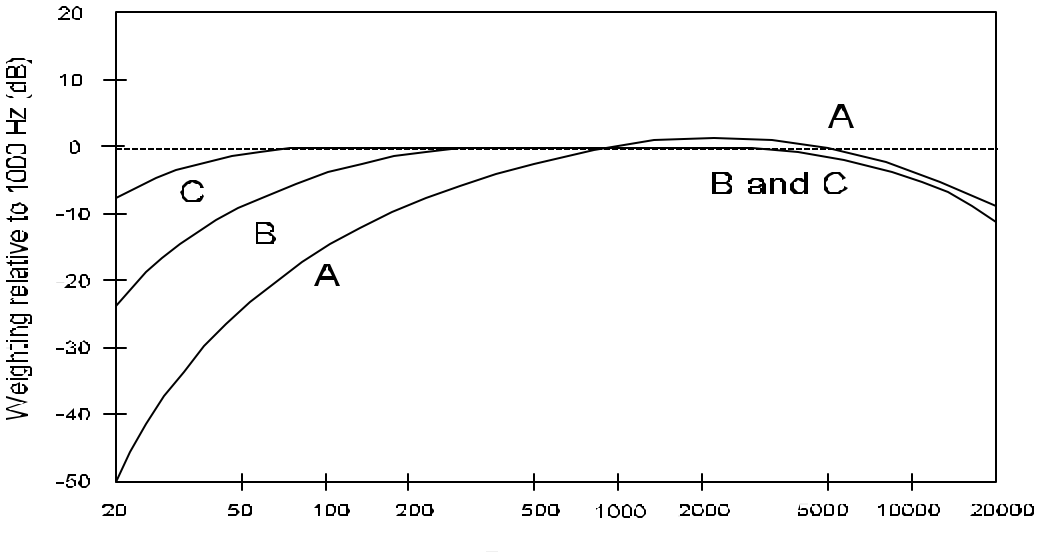

Figure 4. Frequency Weighting

C-weighting is essentially linear. B-weighting reflects the ear's response to sounds of moderate pressure level. A-weighting reflects the ear's response to sounds of lower pressure level. A-weighting is the most widely used system for assessing transportation-related noise, including aircraft noise. In fact, unless otherwise stated, noise descriptors are assumed to be A-weighted. Most SLMs and one-third octave-band analyzers offer A- and C-weighting options. B-weighting has essentially become obsolete. It is also important to note that the response for the A-, B-, and C-weighting curves are all referenced to a frequency of 1 kHz. In other words, the weighting at 1 kHz for all three curves is zero.

Table 1. Frequency Weighting

One-Third Octave-Band Center Frequency	A	B	C
20	-50.4	-24.2	-6.2
25	-44.8	-20.5	-4.4
31.5	-39.5	-17.1	-3.0
40	-34.5	-14.1	-2.0
50	-30.3	-11.6	-1.3
63	-26.2	-9.4	-0.8
80	-22.4	-7.3	-0.5
100	-19.1	-5.6	-0.3
125	-16.2	-4.2	-0.2
160	-13.2	-2.9	-0.1
200	-10.8	-2.0	0
250	-8.7	-1.4	0
315	-6.6	-0.9	0
400	-4.8	-0.5	0
500	-3.2	-0.3	0
630	-1.9	-0.1	0
800	-0.8	0	0
1000	0	0	0
1250	0.6	0	0
1600	1.0	0	-0.1
2000	1.2	-0.1	-0.2
2500	1.3	-0.2	-0.3
3150	1.2	-0.4	-0.5
4000	1.0	-0.7	-0.8
5000	0.6	-1.2	-1.3
6300	-0.1	-1.9	-2.0
8000	-1.1	-2.9	-3.0
10000	-2.5	-4.3	-4.4
12500	-4.3	-6.1	-6.2
16000	-6.7	-8.5	-8.6
20000	-9.3	-11.2	-11.3

1.3.4.3 Input Gain Control

The input gain of a measurement system should be adjusted to provide for maximum dynamic range while preserving a modest safety factor to avoid overload. Dynamic range is the difference, in decibels, between the maximum and minimum levels that can be accurately measured. To avoid system overload, it is recommended that the gain be set, such that the expected maximum level of the noise source being measured be 10 to 20 dB below overload. It is recommended that the linear operating range of the measurement system be in accordance with tolerances specified in IEC 1265.[1]

1.3.4.4 Exponential Time-Averaging

Exponential time-averaging is a method of stabilizing instrumentation response to signals with changing amplitudes over time using a low-pass filter possessing a known, electrical time constant. The time constant is defined as the time required for the output level to reach 67 percent of the input, assuming a step-function input. Also, the output level will typically reach 100 percent of an input-step-function after approximately five time constants.

The exponential time-averaged output produced by the low-pass filter is a running average dominated by the most recent value but smoothed out by the contribution of the preceding values. Two exponential time-averaging, response settings are commonly used: fast and slow, with time constants (J) of 0.125 and 1 second, respectively (See Figure 5).

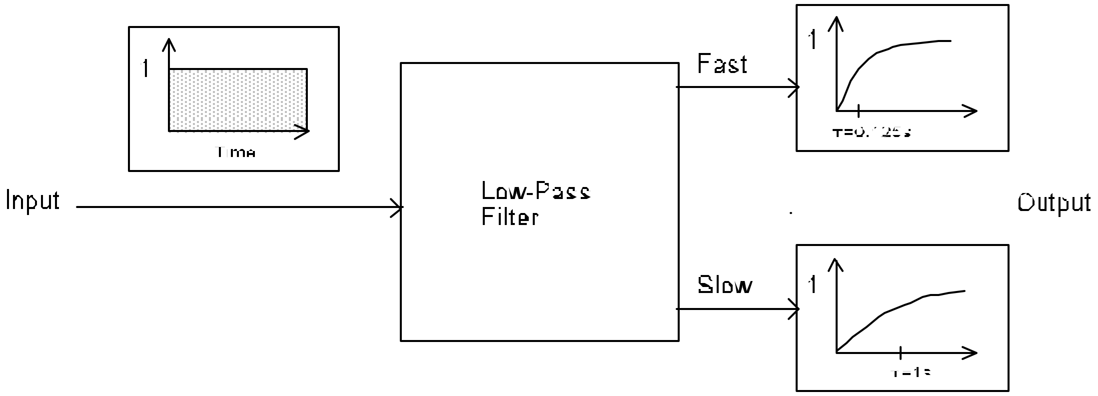

Figure 5. Exponential Time-Averaging

Slow response is typically used for measurements of sound source levels which vary slowly as a function of time, such as is the case for most aircraft. In fact, for certification-related activities slow exponential response characteristics should be assumed. Fast response is primarily used for measuring most highway-related noise, but is being considered for measurement of noise associated with propeller-driven aircraft.

For certification-related activity it is fairly commonplace for applicants to initially process data without exponential time-averaging, i.e., as linearly averaged data, and than to simulate exponential time-averaging mathematically, within their computer process.

1.3.4.5 Temperature and Humidity Effects

Temperature and humidity can affect the sensitivity of many types of instrumentation, including microphones and spectrum analyzers. For example, most current-generation digital audio tape (DAT) recorders have a built-in dew sensor which monitors condensation, and will prevent operation under high-humidity situations. As discussed in Section 1.1.1, non-electret condenser microphones are subject to arcing under high-humidity conditions. Also, battery life is significantly shortened when subject to prolonged low temperatures.

Manufacturers' recommendations for acceptable temperature and humidity ranges for equipment operation should be followed. Typically, these ranges are from -10°C to 50°C (14°F to 122°F) and from 5 to 90 percent relative humidity

1.4 Calibrator

An acoustic calibrator provides a means of checking the entire noise measurement system’s (i.e., microphone, cables, and recording instrumentation) sensitivity by producing a known sound pressure level (SPL) at a known frequency. Calibrators used for certification-related measurements shall meet the Type 1L performance requirements of IEC 942.

It should be kept in mind that for certain model calibrators a correction to the output SPL is required when ambient atmospheric pressure deviates from a sea-level pressure of 29.92 in-Hg. This pressure correction is commonplace for pistonphone calibrators.

Calibration of acoustic instrumentation must be performed at least at the beginning and end of each measurement session, and before and after any changes are made to system configuration or components. In addition, it is strongly recommended that calibration be performed at hourly intervals, throughout the measurements.

The following procedure should be used to determine calibration (CAL) adjustments prior to data analysis:

> If the final calibration of the acoustic instrumentation differs from the initial calibration by 0.5 dB or less, all data measured with that system during the period between calibrations should be adjusted by arithmetically adding to the data the following CAL adjustment:
>
> $$\text{CAL adjustment} = \text{reference level} - [(\text{CAL}_{\text{BEFORE}}+\text{CAL}_{\text{AFTER}}) / 2]$$
>
> If the final calibration of the acoustic instrumentation differs from the initial calibration by greater than 0.5 dB , all data measured with that system during the period between calibrations should be discarded and repeated; and the instrumentation should be thoroughly checked.

1.5 Microphone Simulator

In accordance with ANSI S1.13-1971 (R 1976),[9] the electronic noise floor of the entire acoustic instrumentation system should be established on a daily basis by substituting the measurement microphone with a passive microphone simulator (dummy microphone) and recording the noise floor for a period of at least 30 seconds.

A dummy microphone electrically simulates the actual microphone by providing a known fixed (i.e., passive) capacitance. This allows for valid measurement of the system's electronic noise floor.

With the microphone removed and the simulator inserted in its place, all input channels of the instrumentation system should be monitored using headphones. Extraneous signals, such as radio interference or hum, can result when the system is located near antennae, power lines, transformers, or power generators. The system can be especially susceptible to such interference when using long cables which essentially act as antennae for such signals. Extraneous signals detected must be eliminated, or reduced to a negligible level, i.e., at least 40 dB below the expected maximum level of the noise source being measured. This can usually be accomplished by re-orienting the instrumentation and/or cables, using shorter cable, checking and cleaning grounding contacts, or in a worst-case scenario, moving the instrumentation system away from the source of the interference, if the position of the source is known.

1.6 Pink Noise Generator

The frequency response characteristics of the entire acoustic instrumentation system should be established on a daily basis by measuring and storing 30 seconds of pink noise. Pink noise is a random signal for which the spectrum density, i.e., narrow-band signal, varies as the inverse of frequency. In other words, one-third octave-band spectral analysis of pink noise yields a flat response across all frequency bands.

1.7 Windscreen

Windscreens should be placed atop all microphones used in outdoor measurements. A windscreen is a porous sphere placed atop a microphone which reduces the effects of wind-generated noise on the microphone diaphragm. The windscreen should be clean, dry, and in good condition. A new windscreen is preferred.

In many cases, the effect on the measured sound level due to the insertion of a windscreen into a noise measurement system can be neglected. However, for certification-related activity in which the highest possible precision is required windscreen corrections are almost always applied.

As an example, Table 2 shows typical corrections to be added to measured data to account for the insertion of a Brüel & Kjær Model 0237 windscreen into a noise measurement system (The Model 0237 is the most commonly used windscreen for noise measurements). These corrections should not be considered typical for other model windscreens. If a manufacturer does not provide corrections, and high precision measurements (i.e., certification measurements) are being performed, tests in an anechoic chamber would be required.

Table 2. Typical Corrections to be Added to Measured Noise Data to Account for a Brüel & Kjær Model 0237 Windscreen

	FREQ													
Incidence Angle (°)	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6130	8000	10000
0	-0.1	-0.2	-0.2	-0.3	-0.3	-0.5	-0.6	-0.6	-0.5	0	0	0.1	0.2	0.5
30	-0.2	-0.3	-0.3	-0.4	-0.4	-0.5	-0.5	-0.8	-0.6	0	0.2	0.1	0.5	0.6
60	0	-0.1	-0.2	-0.3	-0.3	-0.4	-0.6	-0.9	-0.8	-0.2	0.4	0.1	0.4	0.6
90	-0.1	-0.2	-0.3	-0.4	-0.5	-0.6	-0.7	-0.8	-0.8	-0.3	0.5	0.6	0.5	1
120	0	0	-0.1	-0.2	-0.3	-0.3	-0.5	-0.7	-0.6	0	0.7	0.5	0.9	1.2

Incidence Angle (°)	FREQ													
	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6130	8000	10000
150	0	0	0	0	-0.1	-0.2	-0.3	-0.4	-0.3	0	0.8	0.7	0.6	1.3
180	0	0	-0.1	-0.2	-0.3	-0.4	-0.5	-0.5	-0.4	0	0.5	0.9	0.8	1.4

2. MANUFACTURERS AND VENDORS

The following is a suggested list of sources for the instrumentation discussed in Section 1. It is not an endorsement by the FAA, nor is it meant to be complete, but is intended solely as a guide for readers.

2.1 Noise Measurement Instrumentation

2.1.1 Microphone System

- ACO Pacific, Inc., 2604 Read Avenue, Belmont, CA 94002, (415) 595-8588
- Brüel & Kjær Instruments, Inc., 2364 Park Central Blvd., Decatur, GA 30035, (800) 332-2040
- Cirrus Research p/c, Acoustic House, Bridlington Road, Hunmanby, Y014 OPH UK, 44-1723-891655
- Hewlett-Packard Company, P.O. Box 95052-8059, Santa Clara, CA 95052, (800) 333-1917
- Ivie Technologies, Inc., 1366 West Center Street, Orem, UT 84043, (801) 224-1800
- Larson Davis Laboratories, 1681 West 820 North, Provo, UT 84601, (801) 375-0177
- Lucas CEL Instruments, 1 Westchester Drive, Milford, NH 03055, (800) 366-2966
- Metrosonics, Inc., P.O. Box 23075, Rochester, NY 14692, (716) 334-7300
- Ono Sokki Technology, Inc., 2171 Executive Drive, Suite 400, Addison, IL 60101, (708) 627-9700
- Quest Technologies, 510 South Worthington Street, Oconomowoc, WI 53066, (414) 567-9157
- Scantek, Inc., 916 Gist Avenue, Silver Spring, MD 20910, (301) 495-7738
- Zonic Corporation, 50 West Technecenter Drive, Milford, OH 45150, (513) 248-1911

2.1.2 Recording System

- Brüel & Kjær Instruments, Inc., 2364 Park Central Blvd., Decatur, GA 30035, (800) 332-2040
- Hewlett-Packard Company, P.O. Box 95052-8059, Santa Clara, CA 95052, (800)

333-1917

- JVC Company of America, 41 Slater Drive, Elmwood Park, NJ 07407, (201) 794-3900
- Larson Davis Laboratories, 1681 West 820 North, Provo, UT 84601, (801) 375-0177
- Lucas CEL Instruments, 1 Westchester Drive, Milford, NH 03055, (800) 366-2966
- Metrosonics, Inc., P.O. Box 23075, Rochester, NY 14692, (716) 334-7300
- Quest Technologies, 510 South Worthington Street, Oconomowoc, WI 53066, (800) 245-0779
- Racal Recorders, Inc., 15375 Barranca Parkway, Suite H-101, Irvine, CA 92718, (714) 727-3444
- Scantek, Inc., 916 Gist Avenue, Silver Spring, MD 20910, (301) 495-7738
- Sony Electronics Inc., 3300 Zanker Road, San Jose, CA 95134, (408) 432-1600
- TEAC, 7733 Telegraph Road, Montebello, CA 90640, (213) 726-0303
- Technics, Panasonic East, 50 Meadowlands Parkway, Secaucus, NJ 07094, (201) 348-7250
- Tritek, Inc., 155 Middlesex Turnpike, Burlington, MA 01803, (617) 272-4550
- Zonic Corporation, 50 West Technecenter Drive, Milford, OH 45150, (513) 248-1911

2.1.3 Measurement System

2.1.3.1 Graphic Level Recorder

- Brüel & Kjær Instruments, Inc., 2364 Park Central Blvd., Decatur, GA 30035, (800) 332-2040
- Hewlett-Packard Company, P.O. Box 95052-8059, Santa Clara, CA 95052, (800) 333-1917

2.1.3.2 Sound Level Meter

- ACO Pacific, Inc., 2604 Read Avenue, Belmont, CA 94002, (415) 595-8588
- Brüel & Kjær Instruments, Inc., 2364 Park Central Blvd., Decatur, GA 30035, (800) 332-2040
- Cirrus Research p/c, Acoustic House, Bridlington Road, Hunmanby, Y014 OPH UK, 44-1723-891655
- Hewlett-Packard Company, P.O. Box 95052-8059, Santa Clara, CA 95052, (800)

333-1917

- Ivie Technologies, Inc., 1366 West Center Street, Orem, UT 84043, (801) 224-1800
- Larson Davis Laboratories, 1681 West 820 North, Provo, UT 84601, (801) 375-0177
- Lucas CEL Instruments, 1 Westchester Drive, Milford, NH 03055, (800) 366-2966
- Metrosonics, Inc., P.O. Box 23075, Rochester, NY 14692, (716) 334-7300
- Ono Sokki Technology, Inc., 2171 Executive Drive, Suite 400, Addison, IL 60101, (708) 627-9700
- Quest Technologies, 510 South Worthington Street, Oconomowoc, WI 53066, (800) 245-0779
- Scantek, Inc., 916 Gist Avenue, Silver Spring, MD 20910, (301) 495-7738
- Tritek, Inc., 155 Middlesex Turnpike, Burlington, MA 01803, (617) 272-4550
- Zonic Corporation, 50 West Technecenter Drive, Milford, OH 45150, (513) 248-1911

2.1.3.3 One-Third Octave-Band Analyzer

- ACO Pacific, Inc., 2604 Read Avenue, Belmont, CA 94002, (415) 595-8588
- Brüel & Kjær Instruments, Inc., 2364 Park Central Blvd., Decatur, GA 30035, (800) 332-2040
- Cirrus Research p/c, Acoustic House, Bridlington Road, Hunmanby, Y014 OPH UK, 44-1723-891655

- Computational Systems, Inc., 835 Innovation Drive, Knoxville, TN 37932, (423) 675-2400
- GW Instruments, 35 Medford Street, Somerville, MA 02143, (617) 625-4096
- Hewlett-Packard Company, P.O. Box 95052-8059, Santa Clara, CA 95052, (800) 333-1917
- Ivie Technologies, Inc., 1366 West Center Street, Orem, UT 84043, (801) 224-1800
- Larson Davis Laboratories, 1681 West 820 North, Provo, UT 84601, (801) 375-0177
- Lucas CEL Instruments, 1 Westchester Drive, Milford, NH 03055, (800) 366-2966
- Metrosonics, Inc., P.O. Box 23075, Rochester, NY 14692, (716) 334-7300

- Ono Sokki Technology, Inc., 2171 Executive Drive, Suite 400, Addison, IL 60101, (708) 627-9700
- Quest Technologies, 510 South Worthington Street, Oconomowoc, WI 53066, (800) 245-0779
- Scantek, Inc., 916 Gist Avenue, Silver Spring, MD 20910, (301) 495-7738
- Tektronix, Inc., P.O. Box 500, Beaverton, OR 97077, (503) 627-7111
- Tritek, Inc., 155 Middlesex Turnpike, Burlington, MA 01803, (617) 272-4550
- Zonic Corporation, 50 West Technecenter Drive, Milford, OH 45150, (513) 248-1911

2.1.4 Calibrator

- Brüel & Kjær Instruments, Inc., 2364 Park Central Blvd., Decatur, GA 30035, (800) 332-2040
- Cirrus Research p/c, Acoustic House, Bridlington Road, Hunmanby, Y014 OPH UK, 44-1723-891655
- Larson Davis Laboratories, 1681 West 820 North, Provo, UT 84601, (801) 375-0177
- Metrosonics, Inc., P.O. Box 23075, Rochester, NY 14692, (716) 334-7300
- Scantek, Inc., 916 Gist Avenue, Silver Spring, MD 20910, (301) 495-7738

2.1.5 Microphone Simulator

- Brüel & Kjær Instruments, Inc., 2364 Park Central Blvd., Decatur, GA 30035, (800) 332-2040
- Larson Davis Laboratories, 1681 West 820 North, Provo, UT 84601, (801) 375-0177

2.1.6 Pink Noise Generator

- Brüel & Kjær Instruments, Inc., 2364 Park Central Blvd., Decatur, GA 30035, (800) 332-2040
- Ivie Technologies, Inc., 1366 West Center Street, Orem, UT 84043, (801) 224-1800

2.1.7 Windscreen

- Brüel & Kjær Instruments, Inc., 2364 Park Central Blvd., Decatur, GA 30035,

(800) 332-2040

- Larson Davis Laboratories, 1681 West 820 North, Provo, UT 84601, (801) 375-0177

3. REFERENCES

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APPENDIX A: VOLPE CENTER MEMORANDUM ON RECORDING SYSTEMS