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DRAFT GUIDELINES FOR THE MEASUREMENT AND ASSESSMENT OF LOW-LEVEL AMBIENT NOISE

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This document describes an “ambient noise measurement protocol”, a detailed methodology for characterizing ambient noise in low-level environments such as the National Parks. It presents definitions of terminology useful for understanding the measurement and assessment guidelines. Also included are a general overview, an historical perspective, and a statement of purpose and objective. Specific details of characterizing a study area’s ambient noise are outlined, including measurement site selection, instrumentation, and general field measurement procedures. Particular attention is given to the data reduction and analysis methodology, including guidance on assigning actual measured ambient noise to all specific locations within a study area. Proposed field testing of the methodology and subsequent refinement are also discussed. Additionally, specifics on a low-level noise measurement system developed by the Volpe Center Acoustics Facility are included.

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Glossary

This section presents pertinent terminology used throughout the document. These terms are highlighted with boldface type when they first appear herein. Note: Definitions are generally consistent with those of the American National Standards Institute (ANSI)[1] and References 2 and 3.

Term/Acronym	**Definition/Full Name**
A-Weighted	A weighting methodology used to account for changes in level sensitivity as a function of frequency. The A-weighting network de-emphasizes the high (6.3 kHz and above) and low (below 1 kHz) frequencies, and emphasizes the frequencies between 1 kHz and 6.3 kHz, in an effort to simulate the relative response of human hearing.
Acoustic Energy	Commonly referred to as the mean-square sound-pressure ratio, sound energy, or just plain energy, acoustic energy is the squared sound pressure (often frequency weighted), divided by the squared reference sound pressure of 20 FPa, the threshold of human hearing. It is arithmetically equivalent to $10^{(LEV/10)}$, where LEV is the sound level, expressed in decibels.
Acoustically Unique Categories	For the purposes of this document, there are three acoustically unique categories or strata to which all areas within a National Park are mapped: (1) trails; (2) developed areas; and (3) water. These categories may be appropriate for other low-level ambient environments.
Ambient Noise	The composite, all-inclusive sound that is associated with a given environment (usually from many sound sources), excluding the analysis system's electrical noise and the sound source of interest, which in most cases is aircraft (see Section 5.1 for a more detailed discussion).
Audibility	The ability of a human observer to detect an acoustic signal in the presence of noise (e.g., aircraft detection in the presence of ambient noise).
Backcountry	Any location in a study area subject to minimal human activity, such as designated wilderness areas or restricted, hiking and camping areas (destinations generally located 1 hour or more from frontcountry locations).
Commercial tour and sightseeing aircraft	Any aircraft operation with a primary purpose of providing scenic views of an area and whose primary objective is passenger revenue.

Day-Night Average Sound Level	(DNL, denoted by the symbol L_{dn}): A 24-hour time-averaged sound exposure level (see definition below), adjusted for average-day sound source operations. In the case of highway noise, a single operation is equivalent to a single vehicle pass-by. The adjustment includes a 10 dB penalty for vehicle pass-bys occurring between 2200 and 0700 hours, local time. L_{dn} is computed as follows: $L_{dn} = L_{AE} + 10 \text{ x } \text{Log}_{10} (N_{day} + N_{eve} + 10 \text{ x } N_{night}) - 49.4 \text{ (dB)}$ where: L_{AE} = Sound exposure level in dB (see definition below); N_{day} = Number of vehicle pass-bys between 0700 and 1900 hours, local time; N_{eve} = Number of vehicle pass-bys between 1900 and 2200 hours, local time; N_{night} = Number of vehicle pass-bys between 2200 and 0700 hours, local time; and 49.4 = A normalization constant which spreads the acoustic energy associated with highway vehicle pass-bys over a 24-hour period, i.e., 10 x Log_{10}(86,400 seconds per day) = 49.4 dB.
Decibel	(abbreviated dB): The decibel is a unit of measure of sound level. The number of decibels is calculated as ten times the base-10 logarithm of the squared sound pressure (often frequency weighted), divided by the squared reference sound pressure of 20 FPa, the threshold of human hearing.
Detectability	The ability to detect a given signal in the presence of some type of noise (not necessarily related to audible signals).
Dose-response	A study in which quantitative dose data (in this case noise data measured in the field), is correlated with qualitative response data (in this case visitor's responses to a questionnaire).

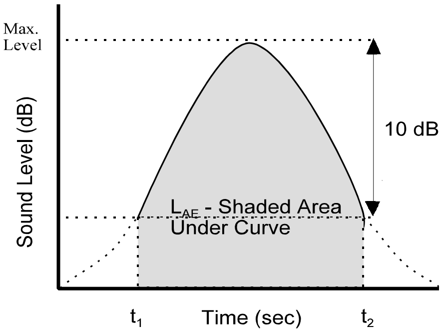
Equivalent Sound Level	(TEQ, denoted by the symbol L_{AeqT}, also often referred to as LEQ): Ten times the base-10 logarithm of the time-mean-square, instantaneous A-weighted sound pressure, during a stated time interval, T (where $T=t_2-t_1$,in seconds), divided by the squared reference sound pressure of 20 FPa, the threshold of human hearing. L_{AeqT} is related to L_{AE} by the following equation: $L_{AeqT} = L_{AE} - 10 \times \mathrm{Log}_{10}(t_2-t_1)$ (dB) Where L_{AE} = Sound exposure level (see definition below). The L_{Aeq} for a specific time interval, T1 (expressed in seconds), can be normalized to a longer time interval, T2, via the following equation: $L_{AeqT2} = L_{AeqT1} - 10 \times \mathrm{Log}_{10}(T2/T1)$ (dB)
Frontcountry	Any location in a study area subject to substantial human activity, such as scenic overlooks, visitor centers, recreation areas, or destinations reached by short hikes (1 hour or less).
Low-Level Noise	An outdoor sound environment typical of a remote suburban setting, or a rural or public lands setting. Characteristic average day-night sound levels (DNL, represented by the symbol L_{dn}) would generally be less than 45 dB, and the everyday sounds of nature, e.g., wind blowing in trees and birds chirping would be a prominent contributor to the DNL.
Maximum Sound Level	(MXFA or MXSA, denoted by the symbol L_{AFmx} or L_{ASmx}, respectively): The maximum, A-weighted sound level associated with a given event (see figure with definition of sound exposure level). Fast exponential response (L_{AFmx}) and Slow exponential response (L_{ASmx}) characteristics effectively damp a signal as if it were to pass through a low-pass filter with a time constant (J) of 125 and 1000 milliseconds, respectively.

Natural quiet	The natural sound conditions found in a study area. Natural quiet is a subset of ambient noise. Traditionally, it is characterized by the total absence of human or mechanical sounds, but includes all sounds of nature, such as wind, streams, and wildlife. In a park environment, the National Park Service (NPS) on Page 74 of their Report to Congress defines natural quiet as the absence of mechanical noise, but containing the sounds of nature, such as wind, streams, and wildlife, as well as human-generated "self-noise" (e.g., talking, the tread of hiking boots on the trail, a creaking packframe, the rattle of pots or pans). See Section 5.1 for a more detailed discussion.
Noise	Broadly described as any unwanted sound. "Noise" and "sound" are used interchangeably in this document.
Noise dose	A measure of the noise exposure to which a person is subjected.
Noticeability	The level of noise (above detectability) at which a representative individual engaged in a particular activity other than listening for a particular sound source (e.g., aircraft) becomes aware of the source without other cues or prompts.
Offset Calibration Technique	A method used to adjust some conventional acoustic instrumentation for measuring and storing extremely low sound level data.

Sound Exposure Level

(SEL, denoted by the symbol L_{AE}): Over a stated time interval, T (where $T=t_2-t_1$, in seconds), ten times the base-10 logarithm of a given time integral of squared instantaneous A-weighted sound pressure, divided by the product of the squared reference sound pressure of 20 μPa, the threshold of human hearing, and the reference duration of 1 sec. The time interval, T, must be long enough to include a majority of the sound source's acoustic energy. As a minimum, this interval should encompass the 10 dB down points (see figure below).

Graphical Representation of L_{AE}



The L_{AE} can be developed from 1-second A-weighted sound levels (L_{Ak}) by the following equation:

$$L_{AE} = 10 \text{ x } \text{Log}_{10}[\sum_{k=t1}^{t2} 10\text{^}(L_{Ak})/10] \qquad \text{(dB)}$$

In addition, L_{AE} is related to L_{AeqT} by the following equation:

$$L_{AE} = L_{AeqT} + 10 \text{ x } \text{Log}_{10}(t_2-t_1) \qquad \text{(dB)}$$

Where L_{AeqT} = Equivalent sound level in dB (see definition above).

Sound pressure level	(SPL): Ten times the base-10 logarithm of the time-mean-square sound pressure, in a stated frequency band (often weighted), divided by the squared reference sound pressure of 20 FPa, the threshold of human hearing. $SPL = 10 \times \mathrm{Log}_{10}[p^2/p_{ref}^2]$ Where p^2 = time-mean-square sound pressure; and $p_{ref}{}^2$= squared reference sound pressure of 20 FPa.
Spectrum	A signal's resolution expressed in component frequencies or fractional octave bands.

1.0 Introduction

The Federal Aviation Administration's Office of Environment and Energy (FAA/AEE), with the assistance of the Acoustics Facility at the United States Department of Transportation's John A. Volpe National Transportation Systems Center (U.S. DOT/Volpe Center) is conducting research in support of the National Parks Overflight Rule (National Rule).[4] A major element of the research program for the National Rule is the development of an **ambient noise**[*] measurement protocol, a detailed methodology for characterizing ambient noise in **low-level** environments such as the National Parks. It is expected that ambient noise will be a key component in the noise impact criteria established for the National Rule.

The presentation of this document, entitled *Draft Guidelines for the Measurement and Assessment of Low-Level Ambient Noise*, begins with a glossary of terminology. Section 1 presents a general overview, including an historical perspective of related work and a statement of purpose. Section 2 describes the process of measurement site selection, including the need to determine a sufficient number and variety of randomly-sampled sites to accurately characterize ambient noise levels throughout a study area (e.g., a National Park). Section 3 discusses instrumentation, including technical requirements and the recommendation of specific makes and models. Section 4 presents general field measurement procedures in an easy-to-read, step-by-step format. Section 5 discusses data reduction and analysis methodology, including guidance on assigning actual measured ambient noise to specific locations within a study area. Section 6 discusses proposed field testing of the methodology and possible subsequent refinement of this document. Section 7 presents related references. Appendix A presents a list of sources for the instrumentation discussed in Section 3. Appendix B contains information specific to the low-level noise measurement system developed by the Volpe Center.

[C] As noted in the Glossary, all specifically-defined terms are highlighted when they first appear in the main body of the text of this document.

1.1 Scope

At the outset, it is important to clarify what is meant by low-level ambient noise. For the purposes of this document, low-level ambient noise pertains to an outdoor sound environment typical of a remote suburban setting, or a rural public lands setting. Characteristic **average day-night sound levels (DNL, represented by the symbol L_{dn})** would generally be less than 45 **dB**, and the everyday sounds of nature, e.g., wind blowing in trees and birds chirping would be a prominent contributor to the DNL.

During the early morning hours when winds are extremely low, it is anticipated that the sound level in a low-level environment will approach the threshold of human hearing, or about 0 to 5 dB(A). Unfortunately, conventional noise measurement instrumentation is not capable of measuring below about 15 to 20 dB(A). As a result, the measurement of low-level ambient noise requires very special instrumentation. In addition, specific field measurement and data reduction procedures are required so that data are preserved in sufficient detail to allow for all anticipated analyses.

It is possible that in specific instances a simpler field measurement and data reduction procedure than that presented herein would suffice. For example, low-level ambient noise measurements in an extremely remote location subject to little or no human activity, including little or no aircraft activity, may be accomplished with unmanned instrumentation set to measure and store a long-term **A-weighted equivalent sound level (TEQ, denoted by the symbol L_{AeqT}, also often referred to as LEQ)**, or possibly set to store a statistical sound level descriptor such as an L_x, which represents the sound level exceeded x percentage of a given measured time interval. However, it is anticipated that such a simplistic approach will not work in most instances due to the dynamic, unpredictable nature of most outdoor sound environments. Because of the limited applicability of this type of an approach it is not discussed further herein.

1.2 Background

Several standardized procedures exist for the measurement and assessment of sound in an outdoor environment.[5-9] However the body of literature in the area of ambient noise measurement, and more specifically low-level ambient noise measurement is extremely limited. Of related work performed within the context of National Parks, the best known and most directly applicable work was performed in 1994 by the National Park Service (NPS)[10], which assembled a data base of ambient sound levels for Grand Canyon National Park (GCNP). Unfortunately, the methods used for collecting these data in the field and assigning values to areas of the park are not well documented. Consequently, the usefulness of this work is limited to its resulting data and not to the development of methodology.

Over the past six years, several **noise dose/visitor response** studies have been conducted in the National Parks. Although dose/response measurements are a highly-specialized type of field noise measurements, many of the procedures and instrumentation are directly applicable to low-level ambient noise measurements, and were therefore considered in the development of this document. In 1992, the NPS conducted dose/response studies in GCNP and in Haleakala and Hawaii Volcanoes National Parks. In 1997, the FAA conducted a dose/response study at Bryce Canyon National Park (BCNP), and the United States Air Force conducted a dose/response study at White Sands National Monument. Both 1997 studies were conducted in cooperation with the NPS.

Most recently, the NPS and Rocky Mountain National Park provided FAA with an outline for conducting ambient noise measurements in the National Parks. Many of the procedures in that outline have been incorporated herein.

1.3 Purposes and Objective

Ambient noise level data developed using this protocol will be used for the primary purposes of:

- Establishing baseline noise levels in a study area (both ambient and **natural quiet** - which are discussed extensively in Section 5.1), and documenting how these levels change as a function of various parameters, e.g., time-of-day, season, and types of human activity, both mechanical (aircraft, automobiles, buses, trail-grooming equipment, etc.) and non-mechanical (conversation, footsteps, etc.); and

- developing guidance for the incorporation of ambient noise data in aircraft noise modeling studies, for the purpose of evaluating low-level noise impacts.

The objective of the protocol is to provide the FAA, the aviation community, the NPS, and possibly others with a comprehensive set of guidelines for characterizing low-level ambient noise throughout a study area. The protocol is of sufficient detail such that properly-equipped individuals possessing minimal acoustic measurement and analysis experience will be able to successfully characterize ambient noise in any low-level environment, including National Parks.

2.0 Measurement Site Selection

As is the case with any study which involves a field measurement aspect, site selection is particularly important and must be one of the first steps. For the purposes of this document, the primary goal of the site selection process is to efficiently identify the minimum number of field-measurement sites which will provide adequate geographic coverage of the study area. The sites must be accessible (at least by foot) and should encompass the full range of unique ambient noise conditions within the study area.

2.1 Scoping Visit

More than other aspects of the ambient noise measurement protocol, the measurement site selection process is unique to the particular area being studied. Therefore, unless local personnel, e.g., park managers if the study area is a National Park, are conducting the entire ambient noise study themselves, the first step in the measurement site selection process is a scoping visit by the technical team to meet with local personnel. The three-fold purpose of the scoping visit is discussed below within the context of the study area being a National Park.

First, any field study in a National Park requires approval of the Park Superintendent. The approval process is unique to each park, and a clear understanding of the park procedures must be obtained during the scoping visit. In general, each park requires a research test plan; however the processes of reviewing, potentially re-submitting, and ultimately approving that plan can be different at each park. This visit is also an opportunity to establish contact with relevant park personnel, particularly natural resource staff and maintenance managers.

The second purpose of the visit is to explore tools maintained by the park which could assist in the measurement site selection process. For example, some parks maintain a Geographic Information System (GIS) which contains data related to vegetative cover, topography, access (including road and trail information) and visitor volume. As a minimum, each park has available maps and aerial photographs which can be used to help divide it into **acoustically unique categories**.

A third purpose of the scoping visit would be to view potential field-measurement sites. Depending upon the magnitude of the planned ambient noise study, which will be dictated primarily by the physical size and vegetative diversity of the park, viewing of potential measurement sites may have to take place during a second scoping visit, after categorization of all areas in the park has been completed.

If possible, a physical visit should be made to each proposed measurement site prior to actual measurements, in order to verify that it is suitable for performing the acoustical measurements. Additionally, preliminary noise measurements may be appropriate during the site visit. This visit may be included in the scoping visit (if practical), at the beginning of the scheduled measurement program, or as a separate visit, if funding and scheduling allow. Ideally, site visitation should be performed separately, after thorough and proper characterization of the study area, and with a sufficient time interval before actual measurements begin to allow for re-identification of sites as necessary. For study areas with few acoustically unique categories, it is more likely that site visitation can be successfully included in the scoping visit.

Many elements may prevent a proposed site from being useable, including accessibility, lack of a clear area for the microphone, etc. Characteristics of an acceptable measurement site include the following: (1) a flat open space free of large reflecting surfaces, such as boulders, or rock-covered hillsides; (2) a ground surface in the immediate vicinity of the microphone that is relatively flat with no major obstructions in any direction; and (3) if an objective of the study is the measurement of a particular noise source, e.g., aircraft, an unobstructed line of sight to the nominal path or location of that noise source.

2.2 Characterization of Study Area

Before measurement sites can be identified, the range of acoustically unique environs must be determined. Consideration should be given to topography, vegetation, wildlife, and human activity, so that measurement site selection criteria can be identified which will successfully characterize all existing ambient conditions. For National Parks, all areas within a candidate park should be classified into the following three acoustically unique categories or strata: (1) trails; (2) developed areas; and (3) water. **Backcountry** areas away from trails should be adequately represented by remote trail locations. Trails should be sub-classified according to vegetation types (e.g., tundra, deciduous forest, coniferous forest, wetland/swamp, meadow, desert, etc.). Developed areas should be sub-classified into transportation corridors (e.g., roadways, rail corridors, boating areas, snowmobiling areas, etc.), and high visitor use areas (e.g., overlooks, picnic areas, campgrounds, etc.). Water should be sub-classified into lakes, rivers and streams (with rapids identified), waterfalls, etc. Figure 1 depicts the three acoustically unique categories and their sub-classifications.

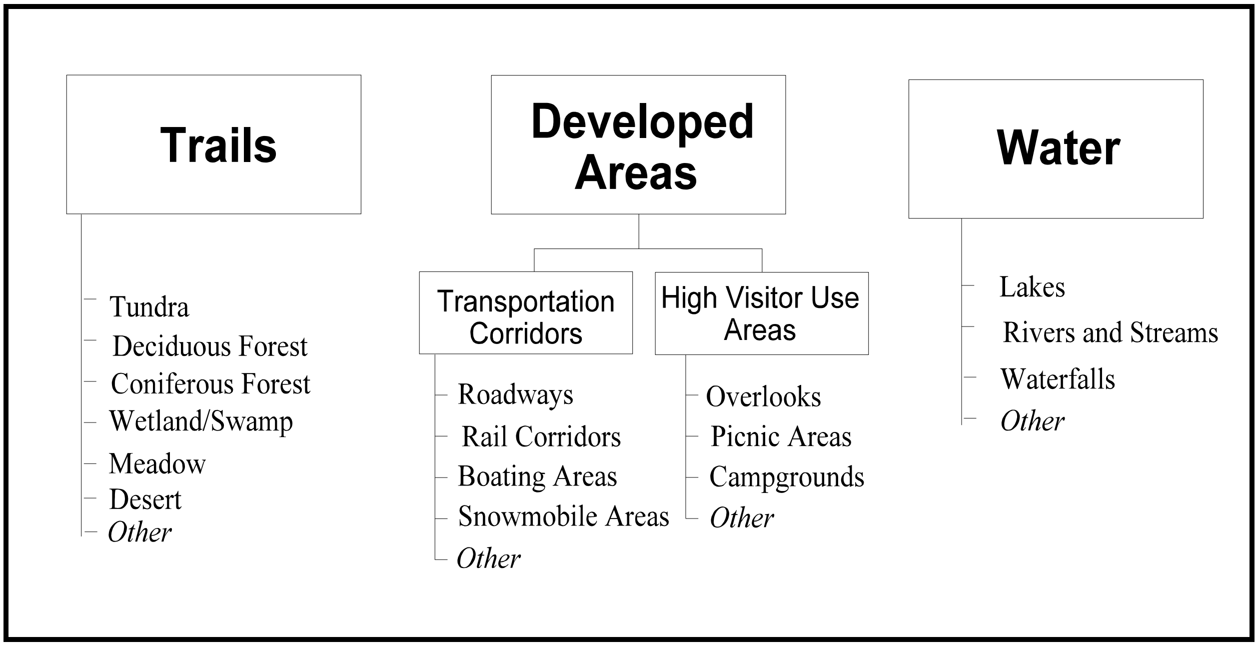


Figure 1: **Overview of Acoustical Categories and Sub-classifications for National Parks**

The next step is to divide each sub-classified area based on its physical size. In other words, suppose that a trail, which has been sub-classified as a tundra trail, is 10 miles long. For purposes of sampling, it should be divided into smaller segments of equal length -- 1 mile in length is suggested. In theory, if the trail has been sub-classified properly measurements made along any two 1-mile segments will yield essentially identical ambient data. Practically this will not be the case, but the data measured at any two sites should be similar in terms of both level and dependence on wind speed. Transportation corridors need only be subdivided at locations in which there are significant changes in vehicle speed and volume, e.g., at the intersection of another roadway, or on a long straight stretch of railway over which speeds are substantially greater than they are on segments of track in other areas of the park. High visitor use areas need not be subdivided. With the exception of waterfalls, water should be subdivided much in the same way as trails, i.e., into 1 mile long segments, where lakes would be segmented along their shoreline. Waterfalls need not be subdivided at all since they generally are considered a localized noise source which is not spread over a large area. Each of the subdivided areas will be considered as a candidate measurement site to be included in the random sampling process.

2.3 Identifying Measurement Sites (Random Sampling)

Proper measurement site selection to ensure adequate coverage of a particular study area is one of the most difficult, yet important steps in obtaining representative ambient noise level data. It is also one of the most difficult tasks for providing detailed procedures because of the diverse acoustical environment represented by most low-level areas. As mentioned previously, local personnel must play a major role in this task. Their knowledge of the area and access to GIS and other advanced data bases will provide the necessary tools for adequate and efficient measurement site selection.

A random sampling methodology should be employed to identify a sufficient number of measurement sites within each of the strata and associated sub-classifications. In other words, each of the subdivided areas is considered as a candidate measurement site, and a random selection process is employed until "n + 20%" sites are selected, where "n" is defined technically as the number of sites which will provide adequate coverage of the entire study area, but will unfortunately be dictated by more practical concerns such as available research funds. The 20 percent factor is included for practical reasons. Specifically, it is anticipated that approximately 20 percent of the sites identified in the random sampling process will not have a suitable measurement location, or will not be practically accessible. These additional sites should be considered as available backup measurement sites should any of the original "n" measurement sites be deemed unsuitable.

After "n+20%" measurement sites have been identified, if it turns out that all sub-classifications are not sufficiently represented, it may be necessary to employ some type of sample weighting (i.e., qualitative importance) factors. These factors would be applied to certain types of candidate measurement sites prior to sampling. The weightings could be based on such factors as access time to get to the site and site-size or length, in the case of a trail or a river in a National Park or similar study area. In other words, since access time directly effects cost, it may be logical to more heavily weight measurement sites which have easier access. For example, suppose that the average access time considering all candidate sites is estimated to be 30 minutes. Prior to sampling, sites with access times less than 30 minutes could be weighted to be twice as important as sites with access times greater than 30 minutes.

Likewise, any subdivided areas which were originally part of a single subclassified area, probably should not be weighted equally with a small uniquely-subclassified area. For example, in the case of a National Park, the 1-mile segments of a 10-mile trail which passes through the same coniferous forest should not be weighted equally with a 1-mile segment of trail which passes through an acoustically unique area. Further, it may be appropriate to weight the trail sites according to vegetation types. In other words, if the majority of the park is comprised of relatively congruous tundra, it may be appropriate to weight these types of measurement sites as less important compared with more unique types of sites. In other words, the percentage breakdown of strata represented by candidate measurement sites should not be forced to match the percentage breakdown of strata for the entire park.

As a minimum, one measurement site from each unique strata and sub-classification should be identified in the sampling process. If funding allows, at least two or three unique, identically-classified measurement sites are recommended so as to minimize the effect of site bias in the measured data.

For National Parks, measurement site sampling should be limited to the strata identified above. In other words, backcountry locations set-off from trails will be precluded from the sample, and instead data obtained from backcountry trail sites will be generalized to these locations set-off from trails. This is a reasonable approach assuming the trail structure covers the majority of the park (as is the case in most parks). A limited set of measurements in these backcountry locations (as a reasonableness check) may be needed to check the validity of this assumption.

2.4 Duration of Measurements at Each Site

At least two repeats at each site (three measurement visits total) are necessary to ensure statistical reliability in the data. A minimum of three hours of data should be obtained at each measurement site per visit. In general, the amount of measurement time spent at a site will be dictated primarily by the dynamics of the sound at the site. For example, in the case of a National Park, if the measurement site is an extremely remote (backcountry) segment of trail with little human activity and fairly consistent wind conditions, three hours worth of data will probably be adequate per visit to that site. However, if the site is in an area of highly variable visitor activity, e.g., an overlook, it may be necessary to collect as much as 6 to 9 hours of data per visit to that site.

An exception to the requirement for three measurement visits total would be for measurements at a roadway site which should only be done once as a reasonableness check for the applicability of existing Federal Highway Administration (FHWA) highway noise data bases.[11] Similar assumptions would be made for rail corridors. Further, acoustic measurements at a roadway or railway site would not be necessary, but rather information pertaining to vehicle volume and speed is all that is needed.

2.5 Seasonal and Daily Variations

In many study areas, ambient noise levels will be dependent upon the time-of-year, e.g., they may differ from one season to another because of factors such as human activity, ground cover, foliage, insect activity and wildlife activity. In such instances, a limited amount of data should be measured in the so-called off-season(s) so that a seasonal bias(es) can be established. A seasonal bias may be an important concern in areas that are subject to significant climatic changes, including snowfall, or areas where insect activity likely depends upon season; but it may be of little concern elsewhere (e.g., more temperate climates), where climatic conditions, as well as other conditions affecting ambient, depend little upon season.

In addition, ambient noise levels may vary as a function of time-of-day. For example, winds tend to increase later in the day, and as such it can be expected that higher ambient noise levels will be measured in the afternoon as compared with the morning. Accordingly, ambient noise level measurements at a given site should encompass the time period from 7 a.m to 4 p.m. local time, taking into account the required three separate visits to each site.

3.0 Instrumentation

Documented ambient noise levels measured in remote areas of the country under low wind conditions often approach the threshold of human hearing.[12] Consequently, special acoustic instrumentation is needed to accurately measure such data. This section discusses the instrumentation required for low-level ambient noise measurements. Examples of specific makes and models of individual components which can be used are also provided where appropriate. Appendix A provides a list of sources for the types of instrumentation discussed herein.

The NPS maintains a "turn-key" Low Noise Monitoring System (LONOMS) which, with minor modification, can be used for accurately measuring low-level ambient noise data, with a primary focus on measurements in the National Parks. The FAA, through the Volpe Center maintains its own modified version of the LONOMS system. The modification facilitates direct recording or on-site one-third octave-band analysis of measured low-level ambient noise data. Although planned, this modification has not been made to the original NPS LONOMS system, and as such its useability for performing low-level ambient noise measurements is limited (see Section 3.3). For a more complete discussion of the LONOMS system the reader is directed to the User's Manual for the unit.[13] The system will not be discussed further herein.

Appendix B provides detailed specifications for the Volpe Low-Amplitude Recording Equipment (VOLARE), a "turn-key" system developed by the Volpe Center Acoustics Facility for low-level ambient noise measurements. VOLARE has been extensively tested and successfully used in 1997 for dose-response measurements at BCNP.[14]

3.1 Microphone, Preamplifier and Windscreen

A microphone transforms sound-pressure variations into electrical signals, that are in turn measured by instruments such as a **sound level meter (SLM)** or a one-third octave-band analyzer (**spectrum** analyzer), and/or recorded by a tape recorder. The microphone in most conventional acoustic measurement systems is capable of measuring sound levels down to about 15 or 20 **dB(A)**, which is not adequate for the measurement of low-level ambient noise in many remote locations. From the standpoint of measuring ambient sound level data near the threshold of human hearing [approximately 0 dB(A)], which is truly a requirement for measurements in the National Parks, the microphone is the limiting component in a conventional measurement system.

The Brüel and Kjær (B&K) Model 4179 microphone is specially designed for very low-level sound measurements, and is the recommended microphone for measurement of low-level ambient noise. In fact, it is the only microphone known to the authors capable of measuring down to the threshold of human hearing. The Model 4179 is a highly-sensitive, 1-inch condenser microphone capable of measuring below 0 dB(A). B&K also offers the Model 2660 preamplifier and Model 2804 power supply which are recommended by the manufacturer for use with the Model 4179 microphone. The Model 2804 power supply requires some minor modification for use with these components, but the modification is clearly documented in the instruction manual for the unit.[15] The B&K Model 4179 microphone and modified Model 2804 power supply are used in both the VOLARE and LONOMS systems.

A conventional windscreen is a porous sphere [usually made of foam and about 3.5 inches (9 cm) in diameter] which is placed atop a microphone to reduce the effects of wind-generated noise on the microphone diaphragm. By reducing the wind-generated noise on the microphone diaphragm, the signal-to-noise (S/N) ratio of a sound measurement is effectively improved. Due to the low sound levels associated with ambient noise level measurements in remote locations, conventional windscreens alone do not provide enough of an improvement in the S/N ratio, especially in moderate to high wind conditions. As part of the development of the LONOMS system, the NPS funded the design and development of a tripod-mounted, two-stage windscreen to be used for measurements in low-noise-level environments, e.g., National Parks. The two-stage design, which is documented extensively in Reference 15, consists of a 20-inch-diameter (51 cm) fabric-covered outer stage, and a conventional B&K Model UA0207 windscreen making up the inner stage. This specially-designed two-stage windscreen is required for measurement of low-level ambient noise. To the knowledge of the authors, there are no other commercially-available windscreens which offer similar performance to the LONOMS two-stage design. This design is used in both the VOLARE and LONOMS systems.

3.2 Sound Level Meter (SLM)

Many of the SLMs available from B&K, Larson Davis Laboratories (LDL), as well as from other manufacturers are suitable for accurate measurement of low-level ambient noise. Candidate SLMs should be designated Type 1 or better and should perform true numeric integration and averaging in accordance with ANSI S1.4-1983.[16] The SLM should be set up to continuously measure and store at 1-second intervals the equivalent A-weighted sound level (with Slow exponential time weighting). Further, it should be capable of storing internally at least a measurement day's worth of data (typically as much as 12 hours including system calibration).

Depending upon the SLM selected, it may be necessary to "fool" the unit into accurately measuring and storing the sound level data. Most, if not all conventional SLMs are not capable of displaying or storing numbers below about 20 dB(A). However, this does not necessarily preclude measurement at lower sound levels. One way of circumventing this limitation is through the use of an **offset calibration technique**. For example, a typical sound calibrator provides an output of 94 dB at a frequency of 1 kHz. By instructing the SLM that the 94 dB level is actually 119 dB, a 25 dB offset calibration is applied. The net result is that all of the sound level data measured and stored by the SLM is erroneously high by a factor of 25 dB; but this 25 dB factor can be easily accounted for, as if it were a gain factor, in the data reduction and analysis. This technique will allow the SLM to accurately measure sound levels effectively down to the threshold of human hearing.

The LDL Model 820 SLM is recommended for measurement of low-level ambient noise. It is designated as a Type 1 SLM that has the ability to measure and store well over 12 hours of one-second data. The Model 820 is the SLM used in both the VOLARE and LONOMS systems.

3.3 Spectrum Analyzer or Tape Recorder

It is expected that a limited amount of one-third octave-band data will need to be obtained at each measurement site. This can either be accomplished directly through the use of a portable spectrum analyzer or indirectly through the use of a tape recorder and later off-line analysis. If a spectrum analyzer is used it should be set up to continuously measure and store at 1-second intervals the equivalent A-weighted sound level (with Slow exponential time weighting) in each one-third octave-band from 50 Hz to 10 kHz. Further, it should be capable of storing internally at least one, and preferably three, hour(s) worth of data. The LDL Model 2900 portable spectrum analyzer is recommended for measurement of frequency-based ambient noise levels. Note that internal memory expansion in the Model 2900 is required in order to meet the storage requirements described above. The LDL Model 2900 analyzer is an optional component of the VOLARE system.

An alternative to real-time one-third octave-band measurement and analysis in the field would be field tape recording and later off-line one-third octave-band analysis. This approach offers the benefit of repeated playback during analysis, and the option for narrow-band analysis if deemed necessary. There are many models of **digital audio tape (DAT)** recorders which would be suitable for such recordings, including the Sony Models TCD-D10 PRO II and PC208Ax and the TEAC Model RD100T. The DAT record speed and channel configuration (if available) should be set up so as to accurately record at least a 10 kHz bandwidth per channel. The Sony Model PC208Ax is used in the VOLARE system.

An important consideration in selecting instrumentation for capturing frequency-based data is equipment bulk and battery life. Both “portable” one-third octave-band analysis systems as well as many DAT recorders tend to be large in size and exceptionally “power hungry”. This becomes a significant concern when instrumentation and supplies must be transported to remote backcountry areas.

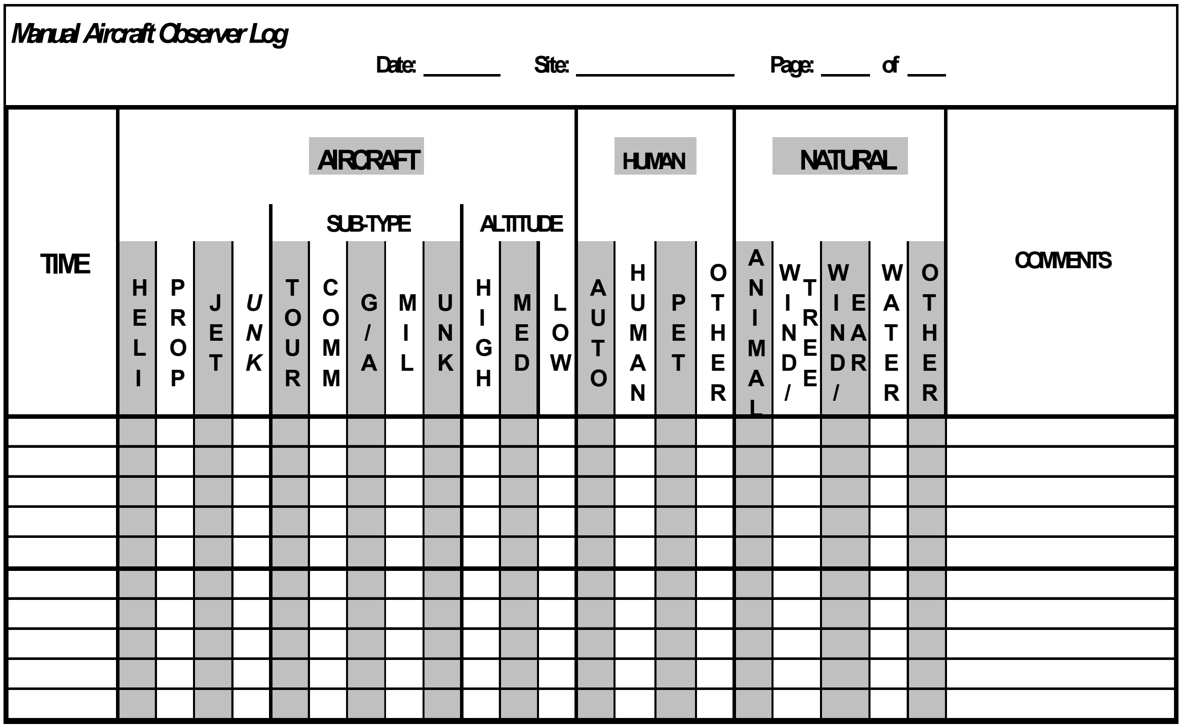
It is hoped that eventually the need for frequency data will be eliminated, and that a library of spectral shapes will suffice. In other words, in the future a user of the ambient noise protocol may only need to perform A-weighted ambient noise-level measurements, and then select from a library of data an appropriate spectral shape, simply based on the acoustic category and sub-classification (see Section 2.2).

3.4 Acoustic Observer Log

An acoustic observer log must be kept to maintain a continuous, timed record of **audible** sounds throughout the measurement time period. Requirements for the logging instrument include: overall reliability; accurate time-stamped records of changes in acoustic environment; consistent categorization of the acoustic environment; the ability to correct erroneous logging information quickly; minimal weight; and minimal time in terms of data reduction.

There are essentially two options for maintaining an acoustic observer log, a manual pen and paper method, or an automated software-orientated approach. Figure 2 depicts an example blank acoustic log sheet which could be used in the field. An alternative method would be to translate the manual log sheet into a more automated software spreadsheet. The Volpe Center has developed a Microsoft Excel Spreadsheet which provides for a fully-automated acoustic observer log. This spreadsheet, displayed in Figure 3, is available to users of the ambient noise protocol. The advantage of this method is that it provides an electronic log which can be used in data reduction immediately following field measurements, whereas a manual log requires subsequent data entry to facilitate processing. Further, the automated spreadsheet offers the ability to quickly "click" on buttons using a traditional mouse, as well as "hot-key" entry of menu items and keyboard entry of text. The obvious disadvantages of the spreadsheet method are the bulk and battery power requirements for the supporting laptop computer.

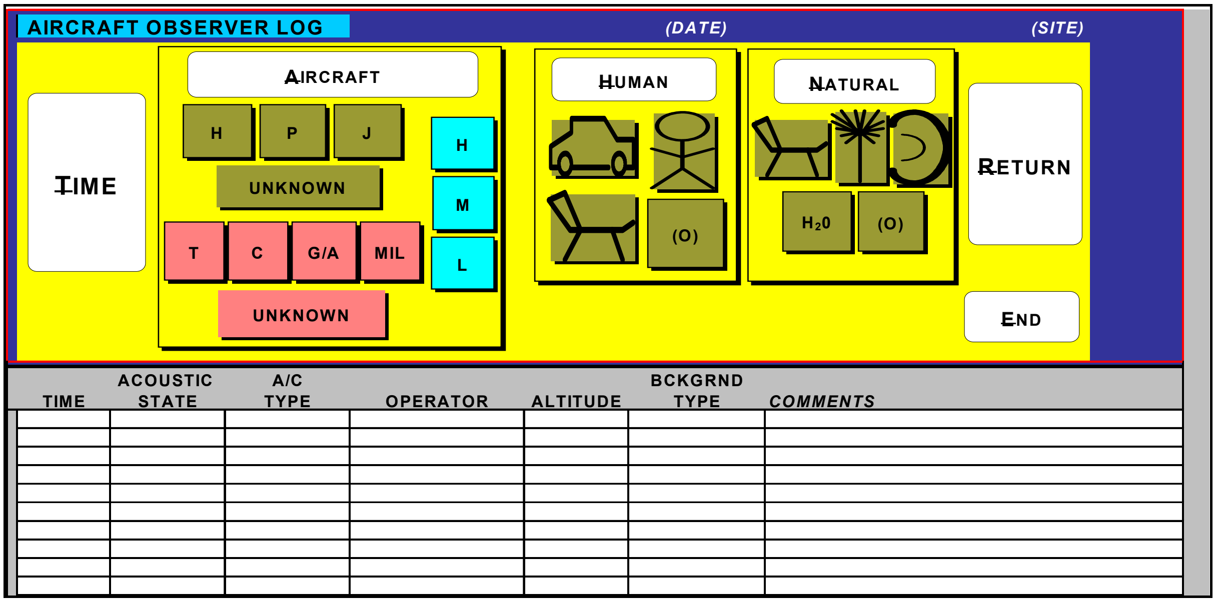
Figure 2: Manual Acoustic Observer Log



Manual Aircraft Observer Log

Date: ______ Site: ______________ Page: ____ of ___

TIME	AIRCRAFT												HUMAN				NATURAL					COMMENTS
					SUB-TYPE					ALTITUDE												
	HELI	PROP	JET	*UNK*	TOUR	COMM	G/A	MIL	UNK	HIGH	MED	LOW	AUTO	HUMAN	PET	OTHER	ANIMAL	WIND/ TREE	WIND/ EAR	WATER	OTHER	



TIME	ACOUSTIC STATE	A/C TYPE	OPERATOR	ALTITUDE	BCKGRND TYPE	*COMMENTS*

Figure 3: Automated Acoustic Observer Log

3.5 Meteorological Instrumentation

Meteorological instrumentation should be capable of measuring and storing temperature, relative humidity, wind speed, and wind direction at one-second intervals. In addition, if an environmentally-sensitive sound calibrator is used (see Section 3.6), instrumentation should be available for measuring ambient atmospheric pressure at least at the times corresponding to sound level calibration. An example of a portable, lightweight, turn-key unit which meets these requirements is the Qualimetrics Transportable Automated Meteorological Station (TAMS). TAMS can be easily interfaced with a laptop computer, which can be setup to store measured meteorological data once per second, via generic communications software.

3.6 Other Instrumentation

Two additional pieces of acoustic support instrumentation necessary to ensure a successful ambient noise measurement program are worthy of mentioning, extension cable and a sound calibrator. At least 200 ft (61 m) of extension cable should be placed between the microphone/preamplifier and the closest field personnel, presumably the acoustic observer. This will ensure that field personnel can move about and conduct whispered conversations without influencing the measured sound.

A sound calibrator is used for checking the sensitivity of the entire acoustic instrumentation system (i.e., microphone, preamplifier, cables, SLM, and DAT or spectrum analyzer) by producing a known **sound pressure level (SPL**, referred to as the calibrator's reference level) at a known frequency, typically 94 or 114 dB at 1 kHz. Many sound calibrators are sensitive to environmental conditions, in particular, atmospheric pressure. Generally, the calibrator's actual sound level output decreases (relative to its nominal or stated output) with decreasing atmospheric pressure; and since decreasing atmospheric pressure accompanies increasing altitude, this effect is a concern for measurements in many National Parks. For example, there are locations in GCNP with elevations as high as 10,000 ft (3048 m), where the actual output of a B&K Model 4228 pistonphone would be on the order of about 2 dB lower than at reference atmospheric pressure. The B&K Model 4231 calibrator, whose performance is essentially independent of off-reference atmospheric conditions, is recommended for measurement of low-level ambient noise. However, if an environmentally-sensitive sound calibrator is used, e.g., the B&K Model 4228, care must be taken to ensure that all measured sound level data is corrected in accordance with manufacturer's specifications.

Time synchronization of all pertinent instrumentation in the measurement chain is critical to the success of a low-level ambient noise measurement program. In particular, the SLM, spectrum analyzer or DAT, acoustic observer log and meteorological instrumentation must be synchronized to a single universal time base so that accurate data reduction and analysis can be accomplished. An inexpensive digital watch is adequate for this purpose. Experience has shown that the component in the measurement chain that is most susceptible to time drift is the laptop computer used for running the automated spreadsheet for the acoustic observer log. Prior to field use, it is a good idea to check the performance of the digital watch against several other watches or some known universal time base, e.g., global positioning system (GPS) time. Less than two seconds of time drift should be allowed over a week-long period. The two-second requirement translates into essentially no time drift over the course of a given 12-hour measurement day.

Other instruments which may be useful for low-level ambient noise measurements in remote environments include a compass or GPS unit for documenting locations, range finding instrumentation for documenting distances (in particular distances to noise sources such as aircraft) and plenty of spare batteries. If range finding is necessary the photo-scaling techniques outlined in Reference 17 may be employed. In addition, there are several hand-held, laser-based range finders which could be employed, e.g., the Bushnell Laser Range Finder, Yardage Pro Model 800.

4.0 Field-Measurement Procedures

This section discusses the general field measurement procedures which are to be followed when performing low-level ambient noise measurements. To a certain extent, specific detail will be dictated by the make and model of the instrumentation selected for use.

4.1 Personnel Requirements

A two-person crew is needed at each measurement site. At least one individual should be somewhat knowledgeable in acoustics, while the other may be a field-trained junior staff person (possibly from a local university or from local NPS staff).

Prior to deployment, all field personnel should be tested to ensure consistent, accurate hearing. The easiest way to accomplish this is to conduct a test at a remote outdoor location (not necessarily a setting identical to the proposed study area) prior to field deployment. During the test, proposed personnel should simultaneously log acoustic states as they would during actual ambient noise level measurements. The results of this test should be used to determine the capabilities of personnel. No one with a known hearing impairment should perform logging duties.

4.2 Measurement System Setup

Following is a step-by-step description of a generic system setup to be undertaken upon arrival at a measurement site:

1. Position the microphone/preamplifier/windscreen in a location representative of the surrounding acoustic environment (Microphone Location). The microphone diaphragm should be placed at a height of 5 ft (1.5 m) directly above the local ground surface and oriented vertically (microphone grid facing the sky).

2. Position an SLM, DAT or spectrum analyzer, acoustic data logging instrumentation, and any other supporting acoustic instrumentation at a position in full view of, but at least 200 ft (61 m) away from the Microphone Location (Observer Location).
3. Position the meteorological instrumentation at a location at least 200 ft (61 m) away from, but representative of the wind conditions at the Microphone Location. The 200 ft (61 m) requirement will ensure that the sound level measured by the microphone is not influenced by the movement of the meteorological sensors, e.g., the wind cup anemometer. If ultrasonic wind sensors are used, the meteorological system may be positioned closer to the microphone than 200 ft. The meteorological sensors should be placed at a height which corresponds to the height of the microphone sensing element, usually 5 ft (1.5 m) directly above the local ground surface, assuming that the surface at the microphone and meteorological station are relatively flat. Do not place the meteorological instrumentation 200 ft (61 m) away from the Microphone Location and behind a localized wind barrier, such as a berm or a dense stand of trees which could influence measured wind data.
4. Connect via cable the instrumentation at the Microphone Location and Observer Location.
5. Power up all instrumentation.
6. Establish that the internal clocks of all pertinent instrumentation (typically the SLM, DAT or spectrum analyzer, meteorological system and laptop) have been set to the time of a single universal time base (Master Clock).
7. With all electrical components of the acoustic measurement system connected and given adequate time to warm up (typically 10 to15 minutes), perform a preliminary sound level calibration of the system. The purpose of the preliminary calibration is to ensure the equipment is operating properly.
8. Perform a frequency-response calibration of the entire electrical system absent of the microphone (Not required for SLM-only measurements).
9. Establish the electronic noise floor of the entire electrical system absent of the microphone.
10. With all electrical components of the acoustic measurement system connected and given adequate time to warm up, perform the pre-measurement sound level calibration of the system.
11. Prepare acoustic measurement system for measurement of ambient noise level data, e.g., deploy two-stage windscreen, secure loose cables, etc.
12. Initiate ambient noise level measurements (SLM and spectrum analyzer), sound recordings (DAT), meteorological measurements, and logging of acoustic environment.

4.3 Measurements

During measurements, the acoustic observer must continuously document the acoustic environment at the site. In performing this activity, the acoustic environment is divided into three primary categories: (1) *Aircraft*; (2) *Non-Aircraft - Human*; and (3) *Natural*. These categories are arranged into a hierarchy, with *Aircraft* taking the highest priority; *Non-Aircraft - Human* taking second; and *Natural* third. This hierarchy allows the observer in the field to select one category if several are observed simultaneously. Thus, if an aircraft and a bus are audible simultaneously, the *Aircraft* category is documented. If a bus and a bird are simultaneously audible, the *Non-Aircraft - Human* category is documented. The *Natural* category is documented when no human-made sounds of any kind are audible. A particular category remains the documented category until a change in the acoustic state is heard by the observer.

The actual logging instrument is either the manual log shown in Figure 2, or the spreadsheet depicted in Figure 3. The three primary acoustic categories are described above. In addition, there are several subcategories in both the manual log and the spreadsheet. The components of the logging instrument, both the manual log and the spreadsheet (see Figures 2 and 3), are described in detail below:

TIME : designates the exact time associated with the start of the current acoustic environment, i.e., the end of the previous acoustic environment.

AIRCRAFT : designates *Aircraft* state. Note: The types of aircraft are presented in a hierarchal order. For example, if both a helicopter and a propeller-type aircraft are simultaneously audible, the helicopter is documented.

H : designates Helicopter-type aircraft.

P : designates Propeller-type aircraft.

J : designates Jet-type aircraft.

UNKNOWN : designates Unknown-type aircraft (invoked primarily for aircraft which are heard but not seen).

T : designates Tour operator.

C : designates Commercial operator.

G/A : designates General Aviation operator.

MIL : designates Military operator.

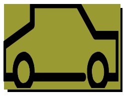
UNKNOWN : designates Unknown operator (invoked primarily for aircraft which are heard but not seen).

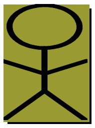
H : designates high altitude aircraft.

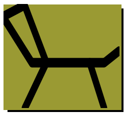
M : designates medium altitude aircraft.

L : designates low altitude aircraft.

HUMAN : designates *Non-Aircraft - Human* state.

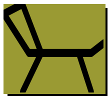

: designates noise produced by automobiles.


: designates noise produced directly by humans, e.g., voices.


: designates noise produced by pets, e.g., dog barking.

(O) : designates noise produced by other human-induced sources.

NATURAL : designates *Natural* state.


: designates noise produced by wildlife, e.g., birds.


: designates noise as “wind-in-the-foliage”.


: designates noise as “wind-in-the-ear”.

H_2O : designates noise produced by water sources.

(O) : designates noise produced by other natural sources.

RETURN : returns active cell to beginning of next spreadsheet line in preparation for next acoustic environment (only applicable to spreadsheet).

Depending upon the dynamics of the sound environment at the measurement site, maintaining the observer log can be an extremely tedious task in the field, and one that requires frequent breaks. This is one reason two field observers are needed at each measurement site. Experience has shown that alternating individuals hourly allows the observer to maintain the necessary level of alertness. At various points throughout the measurement period, the individual not performing the "official" logging activity should conduct limited "unofficial" logging for the purpose of determining consistency among different loggers. Inconsistencies may arise from differences in hearing, reaction time, etc. Any inconsistencies observed in the field should be minimal because of the requirements set forth in Section 4.1 for personnel hearing/sensitivity tests prior to field deployment; however, any observed inconsistencies should be clearly documented.

Periodic checks should be performed on both the acoustical and meteorological instrumentation for the following: available battery power, remaining internal memory for devices with internal data storage (SLM, portable spectrum analyzer and meteorological system), and remaining tape in the case of the DAT recorder.

It is expected that all programmable setup information will have been stored in the instrumentation prior to arriving at the measurement site. Consequently, generic system setup, e.g., setting the SLM up to measure and store one-second data, is not explicitly discussed herein.

4.4 Measurement System Breakdown

Following is a step-by-step description of a generic system breakdown to be undertaken upon completion of a measurement day:

1. End ambient noise level measurements (SLM and spectrum analyzer), sound recordings (DAT), meteorological measurements, and logging of acoustic environment.
2. Perform a post-measurement sound level calibration of the entire acoustical system, documenting any drift from the initial calibration. In addition, periodic calibrations throughout the measurement day at intervals of no greater than four hours are strongly recommended.
3. Document any time drift in the internal clock of all pertinent instrumentation (typically the SLM, DAT or spectrum analyzer, meteorological system and laptop) as compared with the Master Clock.
4. Power down all instrumentation.
5. Disconnect and break down the entire field measurement system.

Prior to data reduction and analysis (see Section 5.0), data stored in instrumentation memory must be transferred to permanent storage by downloading via laptop or personal computer (PC).

4.5 Other Considerations

For localized noise sources which don’t vary substantially in level, e.g., waterfalls and river rapids, acoustic data should be measured at a minimum of two distinct distances from the source, so as to characterize the rate at which sound level decreases with increasing distance from the source. This information will be useful when assigning ambient noise levels throughout the study area (see Section 5.6).

5.0 Data Reduction and Analysis

As described in Sections 5.1 through 5.5, the goal of the data reduction and analysis process is to establish for each measurement site the following parameters: (1) average ambient noise level; (2) average ambient noise one-third octave-band spectrum; (3) average wind speed; and (4) a relationship between ambient noise level and wind speed. Once these parameters are established for each measurement site, they can then be assigned to similarly-classified (see Section 2.2) sites throughout the study area. The assignment process is discussed in detail in Section 5.6.

Subsequent discussions assume that all data have been downloaded from the appropriate instrumentation, and it has been adjusted for any time-of-day or sound level calibration drift documented in the field, as well as for any calibration pressure adjustment (if applicable). In addition, if the offset calibration technique discussed in Section 3.2 has been employed it is assumed that the measured one-second equivalent sound level data has been adjusted accordingly.

Further, any acoustic data which was measured when wind speeds were greater than 15 mph must also have been eliminated from the data set used for analysis. Even the specially-designed, two-stage windscreen does not provide adequate protection against wind-induced noise on the microphone diaphragm at such high wind speeds.

5.1 Ambient Noise

A clear understanding of the term "ambient noise", within the context of the study being conducted, is an essential prerequisite to data reduction. Unfortunately, different organizations have adopted a wide array of definitions for this very traditional terms. This document does not attempt to provide the all-encompassing definition for ambient, but rather prescribes a method for collecting low-level noise data in sufficient detail to accommodate virtually any definition. As such, the appropriateness of a definition is very simply a data reduction, not a data collection issue.

Figure 4 summarizes four definitions of ambient, which are discussed in detail below. The figure highlights the acoustic categories applicable to each definition. It is highly likely that differing definitions may also be appropriate,* however the most important item to reiterate is that the data collection methodology outlined in Section 4 is structured such that data are collected with sufficient detail to allow for virtually any level of analysis.

Ambient noise is traditionally defined as the composite, all-inclusive sound associated with a given environment, excluding the analysis system's electrical noise and the sound source of interest, which in most cases related to the FAA would be aircraft (Traditional Ambient). For this definition of ambient noise, surface-transportation-vehicle noise, human voices, or other human-made sounds would be included. As such, in the data reduction process two of the three primary acoustic categories used to establish the acoustic environment at each measurement site are applicable: *Non-Aircraft - Human*, and *Natural* (see Section 4.3 and Figure 4a).

However, in some instances it may be appropriate to include aircraft as part of the ambient (Existing Ambient). For example, in a case where proposed future growth in aircraft activity would result in a significant change to the existing low-level ambient environment, it may be most appropriate to include existing aircraft activity as part of the ambient, since aircraft associated with the proposed future growth is the real sound source of interest. In this situation, ambient would include all three main acoustic categories presented in Section 4.3 and Figure 4b. In this instance, if characterizing ambient was the only goal of the study, then an unmanned monitor is all that is needed since a distinction between differing acoustic categories is not necessary.

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* For example, one continued area of debate is the appropriateness of excluding high-altitude jets from the definition of traditional ambient. Aircraft noise modeling analyses, including airspace redesigns in the parks, have historically been limited to **commercial tour and sightseeing aircraft**, effectively excluding high-altitude jet aircraft. Practically, redesigning national airspace so as to avoid a large study area such as the National Parks is not a realistic expectation, and in fact, such changes would be even more unlikely with the long-anticipated advent of so-called "free-flight". This obviously argues for including high-altitude jets in the traditional definition of ambient. However, for subsequent discussions presented herein it was decided that high-altitude jets would be excluded. Regardless, data are collected with sufficient detail to allow for either the inclusion or exclusion of high-altitude jets, based on the discretion of the organization performing the study.

Figure 4a: Traditional Ambient*

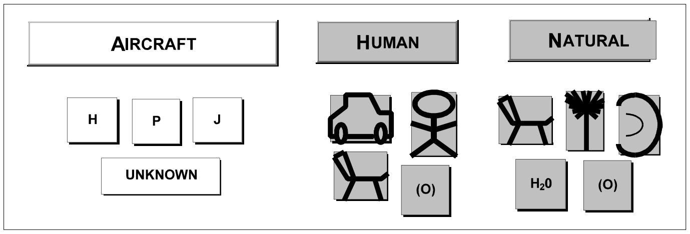


Figure 4b: Existing Ambient*

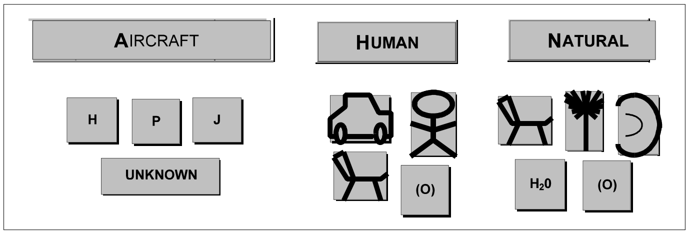


Figure 4c: Natural Ambient*

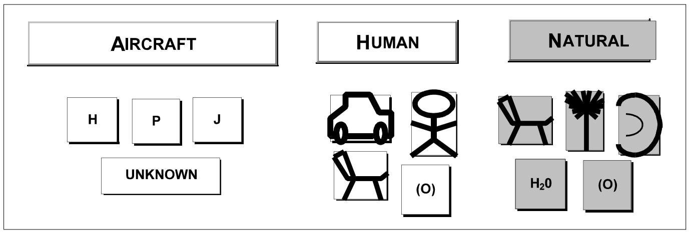


Figure 4d: NPS Natural Quiet*

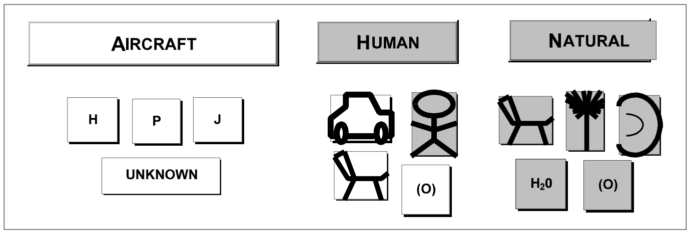


Figure 4: Definitions of Ambient

* Applicable acoustic categories highlighted in grey.
(See Section 4.3 for acoustic state designation definitions.)

A similar dichotomy exists in the definition of natural ambient. Traditionally, natural ambient is defined as the natural sound conditions found in a study area (Natural Ambient). It is a subset of ambient noise characterized by the total absence of human or mechanical sounds, but it includes all sounds of nature, such as wind, streams, and wildlife. Therefore it follows that the *Natural* acoustic category coincides with the definition of natural ambient (see Section 4.3 and Figure 4c).

However, in a park environment, the NPS on Page 74 of their Report to Congress defines natural ambient (i.e., "natural quiet") as the absence of mechanical noise, but containing the sounds of nature, such as wind, streams, and wildlife, as well as visitor-generated self-noise (e.g., talking, the tread of hiking boots on the trail, a creaking packframe, the rattle of pots or pans).[12] Within the NPS context, the *Natural* acoustic category as well as the *Non-Aircraft-Human (Human Subcategory)* would be applicable (see Section 4.3 and Figure 4d).

For all subsequent sections it is assumed that the goal is to characterize the traditional ambient. Consequently, data are included for acoustic categories of either *Non-Aircraft - Human* or *Natural*. Data for the *Aircraft* category are not included.

5.2 Average Ambient Noise Level

The one-second equivalent noise level data measured with the SLM can be easily combined with logged acoustic environment data to establish the average A-weighted ambient noise level at each measurement site. Specifically, the average A-weighed ambient noise level is defined as the

energy-average of the one-second equivalent sound level data obtained at a specific measurement site, during time periods in which the acoustic category was either *Non-Aircraft - Human* or *Natural*. Arithmetically the average A-weighted ambient noise level at a measurement site is computed as follows:

$$L_{\text{Aeq,(Site i)}} = 10 \text{ x } \text{Log}_{10} \{[\text{ ' } 10\text{\^{}}(L_{\text{Aeq,(t)}}/10)]/D\} \qquad \text{(dB)}$$

where: $L_{\text{Aeq ,(Site i)}}$ = the average A-weighted ambient noise level at measurement site i (dB);

$L_{\text{Aeq,(t)}}$ = the one-second equivalent sound level measured at time t, during time periods in which the acoustic category was either *Non-Aircraft - Human* or *Natural* (dB); and

D = the duration of time during which the acoustic category at measurement site i was either *Non-Aircraft - Human* or *Natural* (sec).

If measurements are made at multiple identically-classified sites and the relationships between ambient noise level and wind speed, and the average wind speeds computed for each site are similar to one another, the wind data from these sites should be averaged together as if they were all measured at a single site. Section 5.4 describes a method for assessing similarity of data at multiple identically-classified sites.

5.3 Average Ambient One-Third Octave-Band Spectrum

The process of computing the average A-weighted ambient one-third octave-band spectrum is virtually identical to the process for computing the average A-weighted ambient noise level at each measurement site. The only difference is that the energy-average value is computed for frequency-based sound levels rather than for broadband A-weighted sound levels. Specifically, the average A-weighted ambient noise level is computed individually for each one-third octave-band by computing the energy-average of the one-second equivalent sound level data obtained in a given A-weighted band, during the time periods in which the acoustic category was classified as either *Non-Aircraft - Human* or *Natural*. The twenty-four energy-averaged, A-weighted one-third octave-band sound levels (50 Hz to 10 kHz) computed for each measurement site define the average A-weighted ambient noise level spectrum. Arithmetically the average A-weighted ambient noise level at measurement site i for a given one-third octave band j is computed as follows:

$$L_{Aeq,(Site\ i,\ Band\ j)} = 10 \times \mathrm{Log}_{10} \{[\Sigma\ 10\text{^}(L_{Aeq,(t,j)}/10)]/D\} \qquad \text{(dB)}$$

where: $L_{Aeq,(Site\ i,\ Band\ j)}$ = the average A-weighted ambient noise level at measurement site i, for one-third octave band j (dB);

$L_{Aeq,(t,j)}$ = the one-second equivalent sound level measured at time t, for one-third octave band j, during the time periods in which the acoustic category was either *Non-Aircraft - Human* or *Natural* (dB); and

D = the duration of time during which the acoustic category measured at site i was either *Non-Aircraft - Human* or *Natural* (sec).

If measurements are made at multiple identically-classified sites and the relationships between ambient noise level and wind speed, and the average wind speeds computed for each site are similar to one another, the wind data from these sites should be averaged together as if they were all measured at a single site. Section 5.4 describes a method for assessing similarity of data at multiple identically-classified sites.

5.4 Average Wind Speed

For the purposes of this document, the average wind speed at a measurement site is the algebraic average of the one-second wind speed values measured at the site during the time periods in which the acoustic category was classified as either *Non-Aircraft - Human* or *Natural*. Arithmetically the average wind speed at measurement site i is computed as follows:

$$WS_{\text{Avg (Site i)}} = [\,'\ WS_{(t)}]/D \qquad \text{(mph)}$$

where: $WS_{\text{Avg (Site i)}}$ = the average wind speed at measurement site i (mph);

$WS_{(t)}$ = the wind speed measured at time t during the period in which the acoustic category was either *Non-Aircraft - Human* or *Natural* (mph); and

D = the duration of time during which the acoustic category at measurement site i was either *Non-Aircraft - Human* or *Natural* (sec).

If measurements are made at multiple identically-classified sites and the relationships between ambient noise level and wind speed, and the average wind speeds computed for each site are similar to one another, the wind data from these sites should be averaged together as if they were all measured at a single site. The following paragraph describes a method for assessing similarity of data at multiple identically-classified sites.

Specifically, a relationship between ambient noise level and wind speed should be developed using the data from all identically-classified sites (see Section 5.5). In addition, the average wind speed should be computed separately for each identically-classified site, using the equation presented above in this section. The average wind speed computed for each site should then be used along with the ambient noise level/wind speed relationship to determine the error associated with grouping together the data from all identically-classified sites. Until ambient noise level data are collected and analyzed for several low-level study areas, this document will not establish a firm criterion for acceptable error. In the meantime, if there is any doubt as to whether or not an error is acceptable, it is recommended that the identically-classified sites in question be maintained as unique sites, i.e., do not group together the data from these identically-classified sites.

5.5 Developing a Relationship Between Ambient Noise Level and Wind Speed

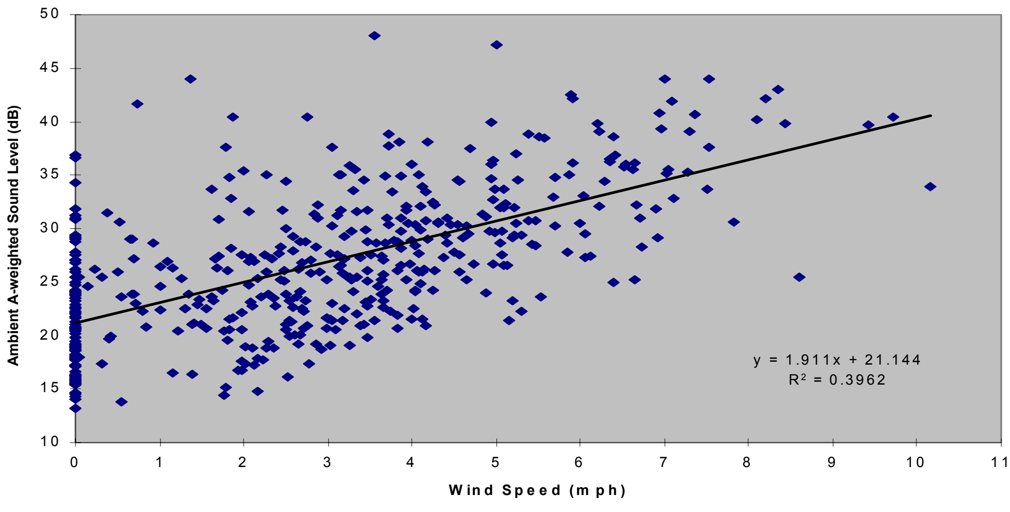
In general, ambient noise levels tend to increase with increasing wind speeds. Depending primarily upon the vegetative characteristics of the measurement site, a substantial change in noise level can occur as wind speeds increase. For example, ambient noise level data measured at a site containing dense foliage will indicate a strong dependence on wind, primarily due to the wind interacting with leaves. Conversely, measurements in a desert environment will likely indicate little or no dependence of ambient noise level on wind speed.

A fairly simple statistical analysis can be performed to develop a relationship between ambient A-weighed noise level and wind speed. First, the one-second equivalent sound level data measured during the time periods in which the acoustic category was either *Non-Aircraft - Human* or *Natural* should be separated into 30-second blocks of data (i.e., typically 120 blocks of acoustic data per hour of measurement if no aircraft are observed). Each block should be comprised of 30 sequential 1-second data records. Partial blocks should not be used, but if it turns out that a significant amount of aircraft are observed at a measurement site it may be necessary to decrease the size of the sample block from 30 to 20, or possibly even 10 seconds to ensure an adequate amount of samples are obtained. Reducing block size to below 10 seconds is not recommended due to the dynamic acoustical characteristics of most natural ambient conditions. A single energy-averaged equivalent sound level should then be computed for each block of acoustic data using the equation presented in Section 5.2 above.

In addition, the one-second wind speed data should be separated into 30-second (or 20 or 10 if that is the selected block size) blocks of data corresponding exactly in time to the 30-second blocks of acoustic data. A single algebraic average wind speed should then be computed for each block of wind data using the equation presented in Section 5.4 above.

The corresponding noise level and wind speed data should then be graphed on an X (wind speed) versus Y (ambient A-weighted noise level) scatter chart using a spreadsheet or other tool. The graph, which will show a large amount of scatter in the data, should, for most measurement environments, reveal an obvious increase in ambient A-weighted noise level with increasing wind speed. A regression analysis should be performed on the data, effectively establishing a numeric relationship between wind speed and ambient A-weighted noise level at each measurement site, or identically-classified group of sites. In most cases it is expected that a simple linear regression will suffice (see Figure 5 as an example), but a more sophisticated regression may be used if the data warrants it.

Figure 5: Example Relationship Between Ambient Noise Level and Wind Speed



An additional analysis is suggested to determine if the A-weighted one-third octave-band spectrum changes substantially with wind speed. Depending upon the expected use of the frequency-based data, it may be adequate to simply determine the spectral shape for the average wind speed (see Section 5.3) and conclude that it is representative of the range of speeds measured. However, it is likely that the dependency between wind speed and spectral shape will be measurement site dependent, and therefore have to be investigated specifically for each site.

In undertaking this investigation, it is suggested that an energy-averaged spectrum be determined separately for each of three ranges of measured wind speed, identified for reference herein as low, medium and high. For example, assuming that the wind speed ranges from 0 to 15 mph (which for most sites will be the case). The data should be separated into three groups: low (corresponding to 0 to 5 mph), medium (corresponding to 6 to 10 mph), and high (corresponding to 11 to 15 mph), and an energy-averaged ambient noise level spectrum for each should be determined (see Section 5.3).

The energy-averaged spectra corresponding to “high” and “medium” should be normalized in level to the spectrum corresponding to “low”. This is done by shifting all band levels in each spectrum, up or down by a constant amount, until the level of the 1 kHz one-third octave-band in that spectrum equals the level of the 1 kHz one-third octave band in the “low” spectrum. For example, presuming that the level in the 1 kHz one-third octave band for the spectrum corresponding to “low” is X dB, it therefore follows that the level in the 1 kHz one-third octave band for the spectrum corresponding to “medium” is X + Y dB (where Y would likely be positive, but could be negative), and the level in the 1 kHz one-third octave band for the spectrum corresponding to “high” is X + Z dB (where Z would likely be positive, but could be negative). Therefore all of the levels in the one-third octave band spectrum corresponding to “medium” should be algebraically shifted by a value of Y dB; and all of the levels in the one-third octave band spectrum corresponding to “high” should be algebraically shifted by a value of Z dB.

The A-weighted one-third octave-band SPLs in each normalized spectrum should then be summed (on an energy basis), and the resultant overall A-weighted SPLs for each spectrum compared to one another. The difference in the A-weighted levels provides a measure of the relationship between one-third octave-band ambient noise level spectrum shape and wind speed. In other words, it provides a measure of error if a single average ambient noise level spectrum is used to represent the entire range of wind speeds. Until ambient noise level data is collected and analyzed for several low-level study areas, this document will not establish a firm criterion for acceptable error.

5.6 Assignment of Ambient Noise to Study Area

The process of assigning ambient noise to all locations of the study area is a time-consuming but relatively straightforward process. The first step is to divide the study area into grid points in the following manner: using a map and standard latitude/longitude-to-X/Y coordinate transformations, determine the dimensions of the smallest rectangle which can be drawn to encompass the entire area. The rectangle should be subdivided into a regular grid of points with a suggested spacing of not greater than 1000 ft (300 m). For example, if the rectangle is 20-by-10 statute miles (105600-by-52800 ft) than a regular grid containing 5618 points is needed to cover the study area (assuming a 1000 ft spacing).

Since measurements were made for all unique land classifications within the study area, there will be ambient noise level data corresponding to each regular grid point. Appropriate ambient noise level data should be assigned to each regular grid point based on the information developed in the process of classifying locations within the study area (see Section 2.2).

The specific type of ambient noise level data that is assigned to a particular grid point depends upon the intended use of the data. For example, for FAA's Integrated Noise Model (INM),[18,19] the average ambient noise level is all that is needed (see Section 5.2). Other methodologies may require use of the average A-weighted ambient one-third octave-band spectrum (see Section 5.3). Further, a seasonal or time-of day bias (see Section 2.3) may be assigned to individual grid points. This bias maybe expressed in terms of an adjustment to the average ambient noise level, or possibly even the average ambient one-third octave-band spectrum. For example, a grid point located at a National Park trail site traversing through a deciduous forest may have an average ambient noise level of 28.5 dB(A) in the summer; but the level may decrease to 23.3 dB(A) in the winter due to loss of foliage and change in wind conditions. Similarly, since wind speeds tend to increase later in the day, a time-of-day bias for both the average ambient noise level and the one-third octave-band spectrum may be appropriate. Presumably all ambient noise level data will be stored in an electronic format for easy use in later analysis.

It is possible that a particular study area may maintain permanent meteorological instrumentation and an associated long-term data base, with wind speed information available for very specific locations. If so, this information may be used to supplement the limited amount of wind data measured during the course of a low-level ambient noise measurement study. Specifically, assume that the average ambient noise level measured for a National Park trail site traversing through a deciduous forest was 33.2 dB(A), with a corresponding average wind speed of 4.5 mph. If a specific regular grid point classified identically (trail/deciduous forest) was located in the vicinity of a park meteorological station, the wind speed data from that station should be used along with the ambient/wind speed relationship developed for that classification (see Section 5.5) to determine a more accurate average ambient noise level for that grid point.

Also, grid points in the vicinity of localized noise sources such as waterfalls and river rapids should be assigned ambient noise data which reflects a continuous decrease in sound level as a function of increasing distance from the source. The information collected regarding sound level drop-off rate (see Section 4.5) should be used for this purpose. In the case of roadways, the FHWA Traffic Noise Model (FHWA TNM®) is suggested for establishing the drop-off rates.[20]

6.0 Testing the Ambient Noise Measurement and Assessment Guidelines

This document is based on the combined acoustic measurement and analysis experience of the authors, as well as substantial input from the FAA and its contractors, and from the NPS and its contractors. However, by no means is it suggested to be complete. It is recommended that the protocol be considered a working document at least until it has been field tested.

6.1 Measurement Repeatability

An area of justified concern is the repeatability of an ambient noise data measurement program in a dynamic outdoor environment. This is a special concern when in many instances the study area can span tens and sometimes close to hundreds of square miles in the case of several of the National Parks in the western portion of the U.S. If a field measurement program cannot be considered repeatable it has virtually no lasting value. Recognizing this fact, a major goal of the protocol was to provide a procedure which offered a repeatable method for collecting low-level ambient noise data in the field -- the procedure had to be not only repeatable by those individuals performing the study, but also by a similarly-trained independent group. The next logical step in the evolution of this document would be for two independent groups to implement the procedures contained herein in the same study area so that a measure of repeatability can be obtained.

6.2 Candidate Study Areas

Low-level ambient noise measurements have been tentatively scheduled to take place in support of several FAA and NPS studies this year. It is essential that the ambient noise measurement protocol be reviewed and updated, as appropriate, based on experience gained through the measurements in these and other studies.

7.0 References

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4: Noise Assessment and Prediction of Long-Term community Response." American National Standard, ANSI Standard S12.9-1996/Part 4. New York: American National Standards Institute, 1996.

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[15] Instruction Manual, Battery Driven Power Supply Type 2804. Nærum, Denmark: Brüel &

Kjær, March 1988.

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APPENDIX A

Manufacturers and Vendors

The following is a list of sources for the types of instrumentation discussed in Section 3.

A.1 Microphone, Preamplifier and Windscreen

- 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.
- CEL Instruments, 1 Westchester Drive, Milford, NH 03055, (800) 366-2966.
- Cirrus Research p/c, Acoustic House, Bridlington Road, Hunmanby, Y014 OPH UK, 44-1723-891655.
- Diagnostic Instruments, 124 South 7th St., Terre Haute, IN 47801, (812) 234-0836.
- Dytran Instruments, Inc., 21592 Marilla St., Chatsworth, CA 91311, (818) 700-7818.
- Entran Devices, Inc., 10 Washington Ave., Fairfield, NJ, 07004, (201) 227-1002.
- Hewlett-Packard Company, P.O. Box 95052-8059, Santa Clara, CA 95052, (800) 333-1917.
- Harbinger Studios, P.O. Box 208, Bellingham, MA 02019, (508) 966-3329.
- 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.
- Metrosonics, Inc., P.O. Box 23075, Rochester, NY 14692, (716) 334-7300.
- The Modal Shop, Inc., 1776 Mentor Ave., Suite 170, Cincinnati, OH 45212, (513) 351-9919.
- Ono Sokki Technology, Inc., 2171 ExecutI’ve Drive, Suite 400, Addison, IL 60101, (708) 627-9700.
- PCB Piezotronics, Inc., 3425 Walden Ave., Depew, NY 104043, (716) 634-0001
- Quest Technologies, 510 South Worthington Street, Oconomowoc, WI 53066, (414) 567-9157.
- Scantek, Inc., 916 Gist Avenue, Silver Spring, MD 20910, (301) 495-7738.
- Schenck Trebel, 535 Acorn St., Deer Park, NY 11729, (516) 242-4010.
- Scientific Atlanta, Inc., 13112 Evening Creek Drive, San Diego, CA 92128, (619) 679-6379.
- Vibration Consultants, Inc., 5733 S. Dale Mabry Hwy., Tampa, FL 33611, (813) 839-2826.
- Ziegler-Instruments GmbH, P.O. Box 500280, 41172 Moenchengladbach, Germany, 492166 355-58.

A.2 Sound Level Meter (SLM)

- Brüel & Kjær Instruments, Inc., 2364 Park Central Blvd., Decatur, GA 30035, (800) 332-2040.
- CEL Instruments, 1 Westchester Drive, Milford, NH 03055, (800) 366-2966.
- Cirrus Research p/c, Acoustic House, Bridlington Road, Hunmanby, Y014 OPH UK, 44-1723-891655.
- Harbinger Studios, P.O. Box 208, Bellingham, MA 02019, (508) 966-3329.
- 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.

- 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.

A.3 Spectrum Analyzer

- Brüel & Kjær Instruments, Inc., 2364 Park Central Blvd., Decatur, GA 30035, (800) 332-2040.
- CEL Instruments, 1 Westchester Drive, Milford, NH 03055, (800) 366-2966.
- Harbinger Studios, P.O. Box 208, Bellingham, MA 02019, (508) 966-3329.
- 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.
- 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 DrI've, Milford, OH 45150, (513) 248-1911.

A.4 Tape Recorder

- Brüel & Kjær Instruments, Inc., 2364 Park Central Blvd., Decatur, GA 30035, (800) 332-2040.
- CEL Instruments, 1 Westchester Drive, Milford, NH 03055, (800) 366-2966.
- Harbinger Studios, P.O. Box 208, Bellingham, MA 02019, (508) 966-3329.
- 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.
- 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.

A.5 Meteorological Instrumentation

- Climatronics Corp., 1324 Motor Parkway, Hauppauge, NY 11787, (516) 567-7300.
- Edmund Scientific, Order Dept., Edscorp Bldg., Barrington, NJ 08007-1380, (609) 573-6250.
- Industrial Instruments & Supplies, P.O. Box 416, County Line Industrial Park, Southampton, PA 18966, (215) 396-0822.
- Larson Davis Laboratories, 1681 West 820 North, Provo, UT 84601, (801) 375-0177.
- Qualimetrics, Inc., 1165 National Drive, Sacramento, CA 95834, 1-800-824-5873.
- R.M Young Company, 2801 Aero-Park Drive, Traverse City, MI 49686, (616) 946-3980.
- Robert E. White Instruments, 34 Commercial Wharf, Boston, MA 02110, (617) 742-3045.
- Viking Instruments, 525 Main Street, S. Weymouth, MA 02190, (800) 325-0360.

A.6 Other Instrumentation

A.6.1 Sound Calibrator

- Brüel & Kjær Instruments, Inc., 2364 Park Central Blvd., Decatur, GA 30035, (800) 332-2040.
- Harbinger Studios, P.O. Box 208, Bellingham, MA 02019, (508) 966-3329.
- 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.

A.6.2 Microphone Simulator

- Brüel & Kjær Instruments, Inc., 2364 Park Central Blvd., Decatur, GA 30035, (800) 332-2040.
- Harbinger Studios, P.O. Box 208, Bellingham, MA 02019, (508) 966-3329.
- Larson Davis Laboratories, 1681 West 820 North, Provo, UT 84601, (801) 375-0177.

A.6.3 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.
- Harbinger Studios, P.O. Box 208, Bellingham, MA 02019, (508) 966-3329.

A.6.4 Windscreen

- Brüel & Kjær Instruments, Inc., 2364 Park Central Blvd., Decatur, GA 30035, (800) 332-2040.
- Harbinger Studios, P.O. Box 208, Bellingham, MA 02019, (508) 966-3329.
- Larson Davis Laboratories, 1681 West 820 North, Provo, UT 84601, (801) 375-0177.

APPENDIX B

Volpe Low-Amplitude Recording Equipment (VOLARE)

System Reference

B.1 Instrumentation List

A. B&K Very Low Level Microphone System, VLLMS (see Figure 6):

Model 4179 One-Inch Microphone.

Model 2660 Preamplifier.

Model 2804 Power Supply (modified).

B. Sound Level Meter (SLM) :

LDL Model 820 SLM with LDL Model 827 Preamplifier.

C. Spectrum Analyzer or Tape Recorder :

LDL Model 2900 Spectrum Analyzer.

or

Sony Model PC208Ax DAT.

D. Ancillary :

NPS Two-Stage Windscreen and Mount including B&K Model UA0207 Foam Windscreen (see Figure 7).

2 - B&K Model AO 0029 100 ft (30 m) Microphone Cables.

B&K Model 4231 Sound Calibrator.

Half-inch Microphone Simulator (Dummy Microphone).

Ivie Model IE-20B Pink Noise Generator.

40 Ah Gel-Cell Battery.

Tripod.

B.2 Configuration

A. B&K Model 2660 Preamplifier : The user-selectable preamplifier switch should be set to “4179 + 20 dB”

B. LDL Model 820 SLM :

1. **25 dB Offset Calibration** - Calibrate using 94 dB SPL signal, but set “Cal Level” on LDL Model 820 to “119.0” dB. For any SLM readings, subtract 25 dB from the indicated value, whether displayed or stored.

2. **Output Gain / Weighting** - During calibration, set the “AC Output Weighting” to “Flat”. Note: Changing the output gain does not affect the SLM indications.

3. **Special Calibration** - Proper firmware calibration of the LDL Model 820 is dependent on a special calibration procedure using an approved ½-inch microphone and calibrator, or a 0.5 Vrms 1 kHz sine wave. Follow the procedure included in Section B6 of this Appendix entitled “LDL Model 820 SLM Special Calibration”. This calibration need not be repeated unless the LDL Model 820 has a power failure during which setup information is lost. Normal calibration of the LDL Model 820 should include capturing a short duration of the calibration signal, in SLM mode, and notation of the indicated level.

4. **Modified A-Weight for SLM** - The A-weight filter in the Volpe Center’s Model 820 SLM has been modified to meet Type 1 SLM response using a B&K Model 4155 microphone at grazing incidence. Though the B&K

Model 4179 has differing response characteristics from the B&K Model 4155, the modified A-weight curve still improves the B&K Model 4179's grazing and random incidence response.

5. **LDL Model 827 Preamplifier for Impedance Matching** - Although the LDL Model 827 preamplifier does not add any gain to the signal, it *must* be connected between the B&K Model 2804 and the LDL Model 820 for impedance matching. Use of the LDL-to-BNC adapter alone will cause the LDL Model 820 input to overload and behave unpredictably.

C. LDL Model 2900 Spectrum Analyzer :

1. **LDL Model 827 Preamplifier not required** - Will accept output directly from the B&K Model 2804 without an LDL Model 827 preamplifier. Use the LDL-to-BNC adapter.
2. **Range settings** - Normal calibration will automatically set the input range to 90 dB. Change the input range to 70 dB for data collection. Any changes in range will also affect the gain applied to recorded data if the recorder is fed from the LDL Model 2900 AC output. All such changes must be logged.

D. SONY Model PC208Ax DAT Recorder :

1. **Mode** - Operate at 20 kHz bandwidth (10 kHz is sufficient if necessary). Configure as 2-channel@1X speed, or 4-channel@2X speed. Note: 27.5 ft (90 m) tape provides 3 hours recording time at 1X speed.

2. **Range** - Input voltage range: Calibrate at 2 V. Range changes made after calibration provide the following gain values:

Range	Gain

0.5 V	+12 dB	(Suggested setting for measurement in most environments.)
1 V	+6 dB	
2 V	0 dB	
5 V	-8 dB	
10 V	-14 dB	

Note: If IRIG B Time Code is being recorded, set corresponding DAT input channel to 5 V range.

B.3 Operation

A. Setup :

1. Install NPS Two-Stage windscreen and mount in accordance with Section B7 of this appendix entitled “NPS Two-Stage Windscreen and Mount Instructions”.

2. Run microphone cable and connect between B&K Model 2660 preamplifier and B&K Model 2804 power supply. Note: When using older cables, connector extensions are required.

3. Interconnect equipment per Figure 8.

4. Connect power leads for LDL Model 2900 or Sony Model PC208Ax, Time Code Generator (If used), and LDL Model 820 to 40 Ah gel-cell battery. Connect power leads to equipment. Turn on all equipment.

5. Set time and date on LDL Model 2900 or Sony Model PC208Ax, and SLM per universal time base.

6. Check instrument settings, especially recorder speed, channel configuration and input range.

B. Calibration :

[NOTE: The B&K Model 4179 Microphone obtains its low-level sensitivity by means of an under-damped diaphragm. Due to this lack of damping, the diaphragm can easily short against the backplate. This causes no permanent damage but requires recovery time. If this occurs, the microphone can take several minutes to stabilize. The B&K Model 2660 Preamplifier may also take time to stabilize its output current as a result of being powered by 28 V instead of the specified 120 V. Finally, the polarization voltage (200 V @ 40 kHz,) from the B&K Model 2804 power supply requires time to stabilize as well. For all these reasons, extreme caution must be exercised when handling the microphone capsule, and when applying the calibration signal.]

1. Remove fabric cover, rotate windscreen frame assembly out of the way (see Section B7) and remove foam windscreen from microphone.

2. Carefully apply calibrator to microphone.

3. Carefully apply power to calibrator (94 dB setting).

4. Wait at least three minutes for system to stabilize.

5. Perform normal calibration of LDL Model 820 or LDL Model 2900. Keep in mind that the LDL Model 820 calibration level must be set to 119.00 in order to properly set its dynamic range. If calibrator output

level is unsteady after a three-minute wait, this is an indication that the calibration is unreliable, and the entire system must be allowed to rest for at least three minutes before re-trying. Such instability is indicative of an error in sensitivity of approximately 3 to 4 dB.

6. Once the front-end has been calibrated and a steady calibration signal is observed, record the calibration signal on the Sony Model PC208Ax for one minute. The one-minute duration is required to ensure that the Sony Model PC208Ax event ID system does not get “scrambled”. A 30 second duration is sufficient when in 2X speed model. Ensure that no gain or weighting is being applied at the front end by checking the setup parameters of the LDL Model 820 or LDL Model 2900. A normal calibration will illuminate 4 segments on the Sony Model PC208Ax LCD display.

7. After recording the calibration signal, very carefully turn off the calibrator and remove it from the microphone.

8. Very carefully remove the microphone capsule and the one-inch adapter sleeve from the B&K Model 2660 preamplifier. Feed a short length of preamplifier cable into the mast through the cable slot so that the preamplifier end does not slide down into the mast tube.

9. Attach the Ivie Model IE-20B Pink Noise Generator to the B&K Model 2660.

10. Set output level of the Ivie Model IE-20B to within 10 dB of the normal calibration level. Wait three minutes.

11. Capture and record one minute of pink noise data (Recording of a 30-second duration should be sufficient when operating at 2X speed mode).

12. Remove the Ivie Model IE-20B.

13. Attach the half-inch microphone simulator to the B&K Model 2660.

14. Apply gain at the level intended for use during the noise measurements (+20 dB available at the LDL Model 820 AC Output, 10 dB increments available at the LDL Model 2900 AC output by switching its input range, and +6, +12, -8 and -14 dB available at the Sony Model PC208Ax by changing its input range. For measurement in most environments use +12 dB gain by switching the Sony Model PC208Ax input range from 2 V to 0.5 V). Wait three minutes.

15. Capture and record one minute of microphone simulator floor (Recording of a 30-second duration should be sufficient when operating at 2X speed mode). The LDL Model 820 SLM should indicate approximately 25 dB(A) (which equals approximately 0 dB(A) in actuality) in the SLM mode. The Model 2900 should indicate approximately 6 dB(A) in the SUM display, and should indicate approximately -5 dB in the 1 kHz band.

16. Remove the microphone simulator.

17. Carefully, reinstall the one-inch adapter sleeve and the B&K Model 4179 microphone. Use a lens brush to clean any dust or debris from the back of the microphone capsule and the end of the preamplifier. Due to the sensitivity of the VLLMS, small particles can adversely affect performance.

18. Carefully attach the calibrator to the microphone.

19. Set system gain back to 0 dB for final calibration.

20. Carefully apply power to calibrator (94 dB setting).

21. Wait three minutes for calibrator signal to stabilize.

22. Perform normal calibration of the LDL Model 820 and/or the LDL Model 2900.

23. Once the front-end has been calibrated and a steady calibration signal is observed, record the calibration signal on the Sony Model PC208Ax for one minute (minimum 30 seconds at 2X speed).

24. After recording the calibration signal, very carefully turn off the calibrator and remove it from the microphone. Attach the foam windscreen and re-deploy the NPS Two-Stage windscreen (see Section B7).

25. Re-apply system gain to be used during measurements.

26. Let the system rest for three minutes before starting measurements.

B.4 Performance Limits

Component	Mode	Overload Point	Floor (Half-Inch Mic Simulator)		
			A-Weight	1kHz	10kHz
B&K VLLMS		104dB@1kHz	~-2.5dBA	~-16dBSPL	~-11dBSPL
LD820 & 827 SLM Indication	(Cal indicates 119.0dB)	103dBA (128 Indic.)	~0dBA (~25 Indic.)	n/a	n/a
AC Output	0dB Gain	102dB @1kHz	~1dBA	~-11dBSPL	~-9dBSPL
	+20dB Gain	82dB @ 1kHz	~1dBA	~-11dBSPL	~-9dBSPL
LD2900 Analyzer Display	90dB Range	97dB @1kHz	~17dB (linearity floor, FS-80dB) (~26dBA; ~14dB@1kHz; ~14dB@10kHz)		
	70dB range	78dB @1kHz	~-2dB (linearity floor, FS-80dB) (~6dB floor visible in display)		
AC Output	0dB Gain (90dB range)	103dB@1kHz	~0dBA	~-12dBSPL	~-11dBSPL (dip in filter)
	+20dB Gain (70dB range)	87dB@1kHz	~1dBA	~-12dBSPL	~-18dBSPL (dip in filter)
SONY PC208Ax DAT Recorder	2V Input range (0db input gain)	100dB@1kHz	15dB (linearity floor, FS -85dB)		
	1V (after cal @ 2V) (+6dB DAT gain)	94dB@1kHz	9dB (linearity floor, FS -85dB)		
	0.5V (after cal @ 2V) (+12dB DAT gain)	88dB@1kHz	3dB (linearity floor, FS -85dB)		
	2V Input range (+20dB input gain at LD820 or 2900)	80dB@1kHz	-5dB (linearity floor, FS -85dB)		
	5V (after cal @ 2V) (-8dB DAT gain & +20dB input gain at LD820 or 2900 / System gain = +12dB)	88dB@1kHz	3dB (linearity floor, FS-85dB)		

B.5 Power Requirements and Considerations

A. Effect of powering devices from same supply :

There is an apparent grounding problem when the LDL Model 820 SLM is powered from the same battery as the B&K Model 2804, which degrades the noise floor by about 2 to 3 dB.

There is a lesser problem when powering the True Time GPS Time Code generator from the same battery as the B&K Model 2804, which results in a bump in the noise floor in the 630 Hz band.

There is also a grounding problem when powering the LDL Model 820 from the same battery as the LDL Model 2900, if the output from the B&K Model 2804 is split between them.

Due to these potential problems, it is recommended that the B&K Model 2804 be powered from a 12 V lantern battery. Since the current draw is very low (~15 mA), a 1 Ah battery would last over 65 hours. It is also recommended that the LDL Model 820 be powered only from the internal battery, or from one or two external 9 V batteries.

B. Power requirements :

B&K Model 2804 Power Supply: 3 x D cells plus external 12 V lantern battery (15 mA)

Typical "life": D cells - **40 hours** (per manual)

12 V - unknown, assume > **60 hours** if battery = 1 Ah

LDL Model 820: 1 x 9 V or external 6 to 12 V (23 mA @ 9V)

Typical "life": 9V - 250 mAh ~ **10 hours**
Duracell 9V: 500 mAh ~ **20 hours**
Radio Shack Ultralife lithium 9V: 1 Ah ~**40 hours**

LDL Model 2900: 12 V (~1 A)

Typical "life": **40 hours** if powered by separate gel-cell battery
11 to 16 hours if same gel-cell powers Sony Model PC208Ax

SONY Model PC208Ax: 11 to 30 V (~1.5 to 2.4 A @ 12V)

Typical "life": **16 to 25 hours** if powered by separate gel-cell battery
11 to 16 hours if same gel-cell battery powers LDL Model 2900

B&K Model 4231 Calibrator: 4 x AA cells

TAMS Met System: 12 x AA cells or 12 V

Typical "life": AA cells > **24 hours**

Notebook PC (on inverter): ~1.25 A (Internal battery fully charged)

Typical "life": **16 hours** (2 PCs on 1-40 Ah gel cell battery)

B.6 LDL Model 820 SLM Special Calibration

It is fairly well documented that the LDL Model 820 can provide conflicting sound level readings for the same input signal when comparing readings taken with the unit in calibration mode versus SLM mode. Without proper adjustment, these differences can be as large as several tenths of a decibel. The following procedure was recommended by the manufacturer, LDL, to improve agreement between the calibrated level and the SLM indication on their Model 820 SLM. This is a procedure which should be performed in the laboratory prior to any field measurements. Experience has shown that this procedure generally reduces differences to one tenth of a decibel or less.

1. Apply a 1 kHz sine wave at calibration level through the LDL Model 827 preamplifier (NOTE: LDL's calibration level in their laboratory is equivalent to 0.5 Vrms, however they have indicated that the procedure will work fine with the B&K Model 4155 microphone and a 114 dB SPL calibrator, e.g., the B&K Model 4231; but it will not work properly with the B&K Model 4179 Microphone System).

2. Apply power to the LDL Model 820 and perform a full RESET:

[SHIFT] [RESET] -> "Reset ALL Data? [Yes]"
[R/S]

3. Set the LDL Model 820's calibrator level to 225.48 dB (Note: This is a *"Back Door"* into the manufacturer's special calibration procedure):

[SETUP] [SHIFT] [CAL] -> "CAL Level"...

[⇨] -> blinking cursor

[2][2][5][.][4][8][R/S] -> "CAL Level (225.48)"

[OFF] -> main greeting screen

4. Calibrate the instrument:

[SHIFT] [CAL] -> "CAL-a"... If a different letter appears after "CAL", press **[SHIFT][CAL]** repeatedly until the "CAL-a"... screen appears.

[⇩] -> "CAL S="... The unit will go through an extended calibration procedure. The value for 'S' will increment from '1' through '3'. The display will briefly indicate "Done", which will be replaced by "Offset".

NOTE: The above calibration procedure resets the LDL Model 820's detector time-weighting to "Slow" regardless of the current setting. If desired, change Time-weighting as follows:

[SETUP][SLM] -> "Detector [Slow]"

[⇨] (press repeatedly until desired setting appears.)

[R/S]

`[OFF]`

5. The calibration data may be saved to EEPROM, effectively replacing the factory default as follows:

`[SHIFT][STR]` -> "STORE EEPROM"
`[R/S]` -> "Storing SETUP to EEPROM"...
`[OFF]`

B.7 NPS Two-Stage Windscreen and Mount Instructions

A. Introduction:

The NPS Two-Stage Windscreen and Microphone Mount described herein is a modification of a design originally developed by the acoustic consulting firm of Harris Miller Miller and Hanson, Inc. (HMMH) for the NPS LONOMS system. It performs two primary functions:

1. It minimizes wind-induced noise enough to allow for the measurement of very low-level acoustic data, effectively improving the signal-to-noise ratio of the measured sound.
2. It acts as a mounting system for B&K's VLLMS.

The unit has standard camera-mount (1/4-inch-20) screw threads, that can be attached to any standard camera tripod.

B. Components (see Figure 8):

The windscreen frame is comprised of the *Top Disc* (which holds the top ends of the *Ribs* in place via an elastic loop, and is attached to the *Mast* by four *Suspension Cords*), 32 steel wire *Ribs* (which form the shape of the windscreen frame.), and the *Sliding Ring* (which, like the *Top Disk*, has an elastic loop to hold the bottom ends of the *Ribs* in place, and which can be fixed into position via three slotted-head setscrews). The *Rib-Spacing Cord* is used to insure uniform spacing between the Ribs when the unit is fully deployed. The Retractable Suspension Fingers help the windscreen frame to form a spherical shape by limiting the vertical travel of the Top Disc.

The Microphone Mount is basically the *Mast* (which features a funnel-shaped Microphone Cradle opening at the top end, and a *Cable Slot* at the bottom for insertion and removal of the B&K Model 2660 Preamplifier while the unit is attached to a tripod.

Not shown is the Fabric Cover*,* which forms the outer stage of the windscreen. It features a drawstring closure at the bottom, which is used to tighten the fabric around the base of the windscreen frame.

C. Installation Instructions:

1. Set up the tripod for a 5 ft (1.5 m) microphone height: set the top of the tripod to 33.5” (85 cm) above the local ground level.
2. Carefully remove the Two-Stage Mount from its packing container.
3. Attach the Mast to the Tripod. Tighten all Tripod fittings.
4. Raise the *Sliding Ring* to a position just above the *Cable Slot* and tighten the slotted-head setscrews. Remove the foam from the *cable slot* and set aside. Make sure that the *Suspension Cords* are properly aligned by ensuring that the setscrew with the black ring around it is aligned with the vertical groove in the mast.

5. Using the attached string, lower the B&K Model JJ2217 ½-inch adapter into the funnel-shaped microphone cradle opening at the top of the mast. Continue lowering the adapter until it appears at the bottom of the mast, visible through the *Cable Slot*.

6. While holding the string at the top of the mast, attach the B&K Model JJ2217 adapter to the front end of the B&K Model 2660 Preamplifier. Do not misplace the black plastic cap which protects the threaded end of the Model 2660.

7. Use the string to pull the B&K Model 2660 up through the *Mast* until it appears at the top. While pulling the string, feed the Model 2660 cable in through the *Cable Slot* at the bottom of the *Mast*.

8. Place the large end of the B&K Model 2660 Preamplifier in a protective container (e.g., fanny pack, plastic bag, etc.) and place at the base of the tripod. This container should also include a fabric windscreen cover, slotted screwdriver, microphone case, lens brush, and microphone simulator.

9. Loosen the setscrews on the *Sliding Ring*. Lower it, and rotate the windscreen frame assembly to one side. It may help to slide the *Rib Spacing Cord* downward a bit on the ribs. Gently spread the *Rib*s apart to clear the *Mast*, *Retractable Suspension Fingers*, etc. Be careful to avoid disengaging the ends of the *Ribs* from the retaining elastics at either end.

10. Remove the B&K Model JJ2217 adapter from the B&K Model 2660 Preamplifier and attach the 1-inch adapter in its place.

11. Gently pull back on the B&K Model 2660 cable to snugly fit the 1-inch adapter into the Microphone Cradle.

12. Attach the B&K Model 4179 Microphone to the 1-inch adapter / Model 2660 Preamplifier. Before attaching, use the lens brush to clean any dust/debris from the back of the microphone capsule and the threaded end of the preamplifier. Keep the clear plastic cap on the microphone

until it can be covered by the foam windscreen or until a calibrator is applied. The presence of particles on the diaphragm or between the electrical contacts can degrade the system's performance.

13. Attach the B&K Model UA 0207 Foam Windscreen to the B&K Model 4179 Microphone.

The remaining steps should be followed after the Calibration Procedure has been completed:

14. Carefully rotate the windscreen frame assembly back into position.

15. Loosen the setscrews on the *Sliding Ring*. Make sure that the *Rib-Spacing Cord* is positioned approximately halfway up the length of each *Rib*.
16. Place the Fabric Cover over the top of the windscreen frame. The "X-seam" of the cover should be located directly over the *Top Disc*.
17. Slowly move the *Sliding Ring* upward until it is even with the lowest of the four *Vertical Alignment Grooves* on the *Mast*. Make sure that the setscrew with the black ring around it is aligned with the long vertical groove on the mast. Tighten the three setscrews.
18. Pull the fabric cover down evenly over the windscreen frame and pull the drawstring tight. Secure it with the string lock.
19. Dress the cable, securing it to the tripod. Tighten all tripod fittings. Replace the foam in the *Cable Slot*.

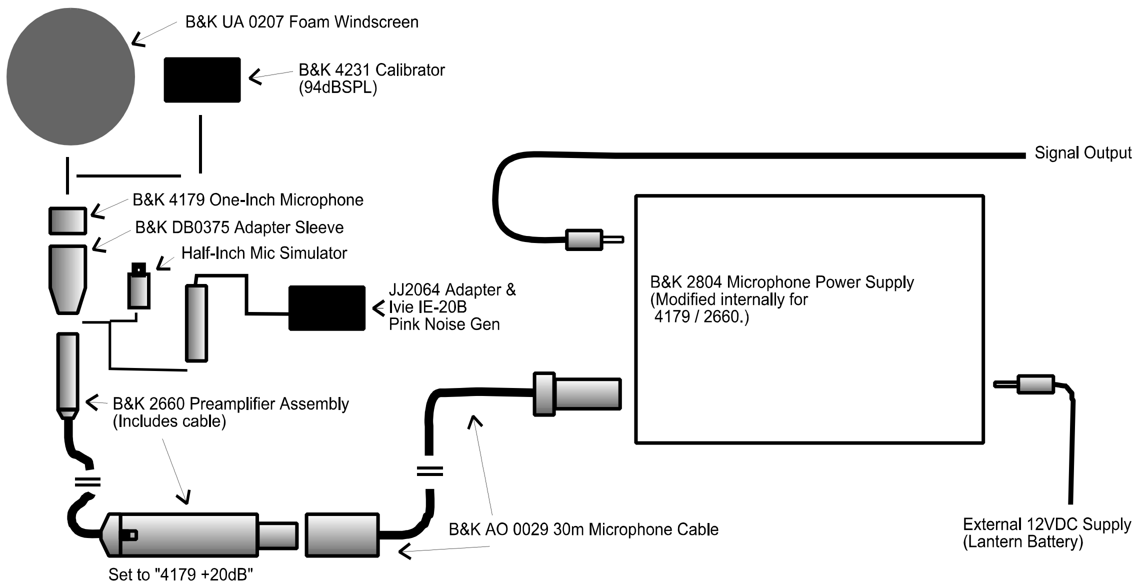

Figure 6 - B&K Very Low Level Microphone System (VLLMS)

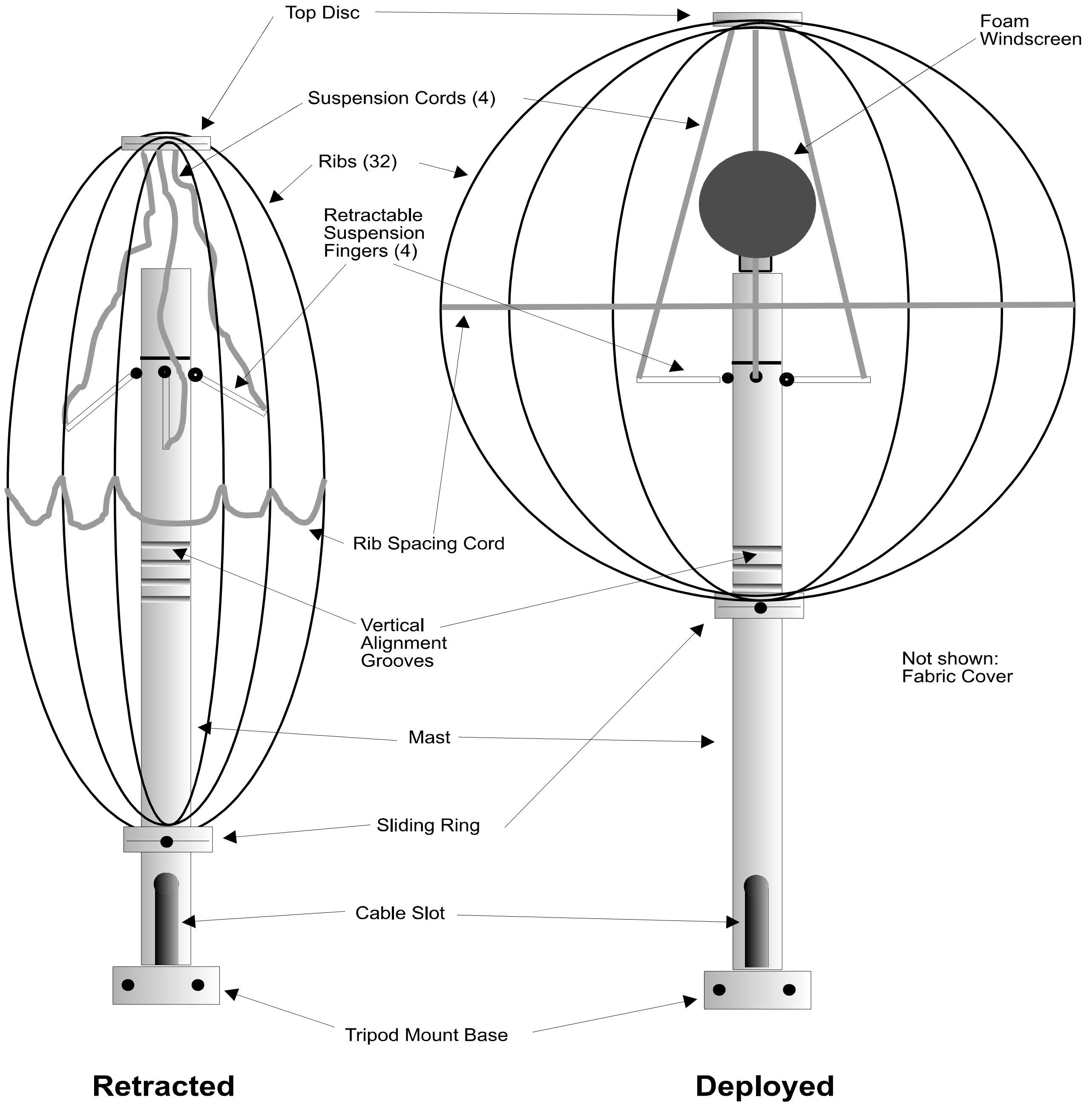

Figure 7: NPS Two-Stage Windscreen and Microphone Mount

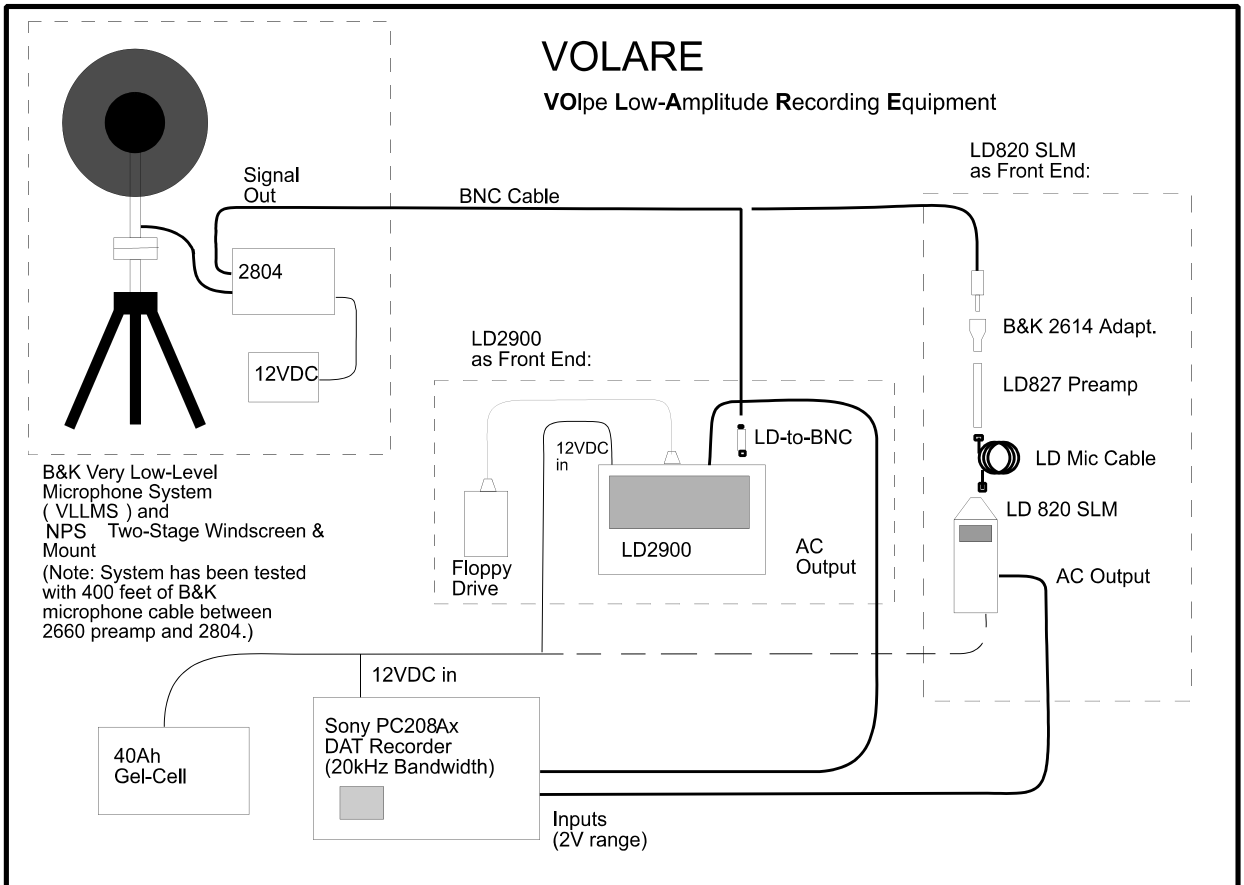

Figure 8: VOLARE Instrumentation Block Diagram

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