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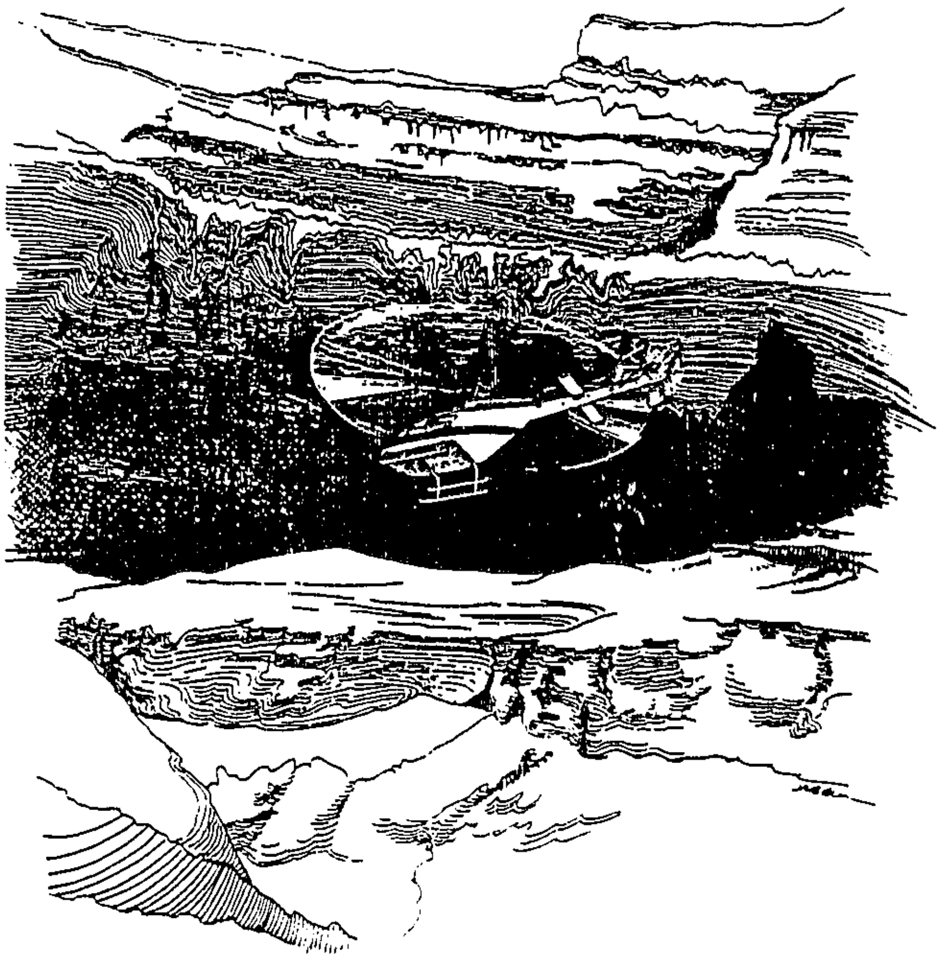
National Park Service

Final Report
March 1989



METHODOLOGY FOR THE MEASUREMENT AND ANALYSIS OF AIRCRAFT SOUND LEVELS WITHIN NATIONAL PARKS

NATIONAL PARK SERVICE
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Final Report

March 1989

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EXECUTIVE SUMMARY

Purpose. Aircraft overflights affecting park visitors and resources have been identified as a significant problem at a number of National Parks and Wilderness Areas throughout the United States. In recognition of these concerns, Congress passed the National Park Overflights Act of 1987 (Public Law 100-91). This law requires the National Park Service and the United States Forest Service to determine any adverse effects of these overflights on park/wilderness visitor safety and enjoyment. The effects of these overflights on the natural, cultural, and historical resources of the park/wilderness are to be studied. The benefits of the aircraft overflights, in terms of visitor enjoyment, protection, and search and rescue, are also to be considered.

The types of aircraft overflights identified in the legislation for review include nearly all sectors of aviation, such as "*...sightseeing aircraft, military aircraft, commercial aviation, general aviation, and other forms of aircraft which affect such units.*" The law specifically excludes aircraft operations associated with landing fields within, or adjacent to, such park units.

This report contains the results of an initial study with the National Park Service to address various technical issues relating to the assessment of sound from aircraft overflights within parks. These technical issues include techniques for measuring aircraft sounds within park/wilderness settings and determining the acoustic parameters that are important in describing aircraft sound within these settings. As part of future studies, sociological surveys of park/wilderness users will be used to quantify the visitor response from these aircraft operations. A goal of these studies is to develop policies to manage aircraft noise within various park/wilderness areas.

The first element of the research was a review of current or potential methods for assessing aircraft overflight sounds in wilderness settings. Noise measurements were then completed at two park units and at a remote location of an air force base. The purpose of these initial measurements was to develop and test methodologies for conducting ambient and aircraft measurements in a park/wilderness environment.

Literature Review. A detailed literature review was completed on the subject of quantifying aircraft sound in a park/wilderness setting. While extensive research has been completed on the effects of aircraft overflights on urban populations in the vicinity of airports, this search revealed a shortage of information on the subjects of en route aircraft sound, aircraft sound in wilderness settings, or the acoustic effects on a park visitor population. However, there are a number of studies that address issues important to the park service study. These studies include research into signal detection of low-level sounds and an assessment of sounds from Military Training Route (MTR) operations.

Most aircraft operations affecting parks are characterized by low-level sounds in quiet background settings. Studies demonstrate that the detection of low-level sounds may be predicted by a descriptor known as detectability. This concept of signal detection and nondetection has evolved into an analytical tool through interest in military, industrial and environmental concerns for detecting sounds in the environment. In addition to these low-level signal detection applications, research suggests that detectability can also be used to rate different levels of intrusiveness of a sound.

The concept of detectability and its relation to annoyance appears to be applicable to low-level sound situations within the park. However, it should be noted that the research on detectability has been completed primarily under constrained laboratory conditions. Detectability has not been tested to predict annoyance in an outdoor setting where both the background and source vary with respect to amplitude, frequency, and temporal domains. More evidence should be collected and analyzed before using it for quantifying effects from aircraft flyovers in the park/wilderness setting.

Currently, the Air Force is conducting a major study to analyze the acoustic effects of low-altitude MTR flights. The metric evolving from the Air Force study is based on the Day Night Noise Level (DNL), with an integration period used equal to the average day of the peak month of aircraft activity. The metric is further adjusted by an onset rate factor to account for the surprise or startle element from high-speed aircraft operations.

While many aspects of the Air Force study have applications to the park/wilderness setting, there are some significant differences. The first important distinction is that the Air Force study addresses a permanent rural residential population that has prior experience with MTR operations. In the park setting, the population changes daily. Therefore, the startle effect of high onset rates may be different for a visitor population than for a population with prior experience. While research shows that onset rates are an important element in describing noise from MTR operations, it is not clear what weighting factor appropriately represents this disturbance to a park visitor population.

The use of a metric averaged over some time period to describe MTR operations also has limited applications in the park setting. A visitor population changes daily and the noise from MTR operations show significant daily variation. In addition, visitors are not fixed at one location, but move throughout the park during the course of their stay. Visitors are never exposed to the average level, only to the aircraft sound levels that occur at each individual's particular location on that visitor's day in the park. This means that the probability of a park visitor being acoustically affected by MTR operations is very slight. However, when a visitor is impacted, the level is very high. It will be very difficult to know precisely the sound exposure that each individual surveyed has experienced. The MTR type of noise presents a difficult sampling problem for both the acoustic and sociological portions of the study.

Measurement Results. The first noise survey was conducted at Grand Canyon National Park. The operations at Grand Canyon are predominantly tour helicopters or fixed-wing aircraft with some en route high-altitude jets and sightseeing general aviation aircraft. The survey showed that there are a large number of aircraft operating over the park, with each site averaging 145 aircraft overflights per twenty-four hour period. The ambient sound levels in Grand Canyon can be extremely quiet (below 20 dBA).

The maximum sound levels from the aircraft flyovers were generally less than 50 dBA. However, with the low background levels, these events were 10 to 40 dBA above the background. Because of these low background levels, the aircraft events were characterized by long durations and very slow onset rates. A typical overflight would be audible to the field engineer for 2 to 6 minutes. Aircraft were audible for an average of more than 4-1/2 hours per day, with 90% of these operations during an 8-hour time period. (And this survey was taken during the off-peak tourist season.)

On the basis of the results from the Grand Canyon survey, the measurement program was refined and updated for subsequent tests at Hawaii Volcanoes National Park. Aircraft operations at this park unit are primarily tour helicopters viewing the volcano craters and lava flows. Occasional fixed-wing tour aircraft and transient military aircraft also overfly the park. The ambient sound levels at Hawaii Volcanos were not as quiet as Grand Canyon. The prevailing tradewinds, the surf and the vegetation noise were important contributors to the ambient environment. However, the number of aircraft operations at this park were less. The park does have a number of unique "points of interest" that attract tour aircraft for extended passes, with some aircraft audible for up to 20 minutes.

The purpose of the Edwards Air Force Base noise measurements was to test the methodology for measurements of low-altitude military jet training operations. These measurements were also used as a final test of the proposed measurement methodology using the digital audio tape (DAT) recording system. Edwards Air Force Base was selected for these tests because the large number of low-altitude operations that occur over the expansive base allowed for the measurement of a large sample of aircraft events in a relatively short period of time.

Conclusions and Recommendations. Many factors influence how a sound is perceived and whether or not it is considered annoying to a listener. These include not only physical characteristics of the sound but also nonacoustic factors. Important acoustic factors in describing these aircraft sounds in park/wilderness settings were found to include:

Background Sound Level
Aircraft Sound Level (Relative to Background and Absolute Level)
Spectral Characteristics of the Sound
Duration of the Aircraft Sound
Onset Rate of the Aircraft Sound

A number of observations and conclusions concerning the measurement and description of the ambient and aircraft sound in park/wilderness settings are discussed in the following paragraphs. These are presented relative to these acoustic factors. Predictors used to describe the aircraft sound in these settings should include the effects from these acoustic factors.

Background Sound Level. The measurements showed that background sound played a significant role in determining the relative loudness of an aircraft event and the duration for which the aircraft signal was audible. In these quiet park/wilderness settings, even low-levels of aircraft sound were clearly audible for extended durations.

Often the background sound levels were below the level commonly considered the threshold of hearing. The measurement instrumentation used for wilderness measurements must be capable of measuring sound levels as low as the Minimum Audible Field (MAF) curve.

Accurate information relative to the background sound levels is the most critical and variable element in quantifying the detection of the aircraft events. The background level is the level above which the aircraft event becomes intrusive. The influence of temporal variations in the ambient sound levels are minimized by using the L90 descriptor to represent the background sound level. This study recommends that L90 in each 1/3 octave band and the A-weighted L90 be used to define the background sound level. To minimize the longer-term temporal variations, the background sound is to measured in close proximity to the time of each aircraft overflight.

The most important variable that effects the background sound level is wind speed. Determining the contribution of the wind noise to the ambient sound environment and the role of this noise in the masking of aircraft events is an important element of the ambient sound level analysis. The noise measurements should include simultaneous wind speed measurements as well as the sampling of other traditional meteorological information. The study recommends that long-term meteorological data be determined for each study area.

Aircraft Sound Level and Spectral Characteristics. Various rating scales have been devised to approximate the human subjective assessment to the loudness or noisiness of a sound. Potential noise predictors were examined for use in describing both the absolute sound level and the level relative to the background sound. Among the predictors reviewed were: A-weighted Maximum level, C-weighted, SEL, calculated Loudness Levels, PNLT, EPNL, and Detectability.

It is necessary to determine the absolute sound levels of the aircraft, and the sound level relative to the background. This is especially important when the aircraft sound levels are significantly greater than the background. Sound with the same relative loudness can be perceived differently in different background sounds. The primary acoustic effect of the low background sound levels is not that otherwise quiet sounds appear loud, but that sounds that would normally not be audible are now clearly audible, and are audible for extended durations. Detectability is favored for describing relative sound level of the aircraft overflights. Given the temporal variations in the aircraft sound, detectability is best expressed in terms of time durations above different levels of intrusiveness. (The use of detectability to define the time duration of the sound is presented later in this summary.)

Once the sociological surveys are completed, the aircraft sound level predictor that best correlates with park visitor response can be selected. However, until these surveys are completed, no one predictor is recommended. The proposed methodology is designed to measure the acoustic data necessary to calculate any of these potential metrics. This requires the measurement of 1/3 octave band sound levels for both ambient and aircraft environments. The sound data can be transferred to a computer, and any or all of these metrics can be calculated without additional analysis time.

With respect to low-level aircraft sounds (operations other than MTRs), preliminary measurements did not favor any one rating scale in terms of describing the relative loudness of aircraft in the wilderness setting. In these low sound level settings, the loudness of the sound may play a less prominent role in predicting annoyance. In low-level sound applications, signal detection or audibility appears to be the most important factor in predicting annoyance.

The noise from MTR operations is very different than that of other types of aircraft operations affecting parks. Research into determining which rating scale most accurately reflects annoyance from MTR operations is probably beyond the scope of the park service study and does not appear to be as important as the onset rate or the time average. Measuring A-weighted sound levels, as recommended by the Air Force methodology (with potentially different onset rate penalties and time averages), is recommended.

Duration of the Aircraft Sound. The following discussion pertains to en route aircraft operations other than low-altitude MTR operations. The audible duration of the aircraft events is very important in the park setting. The total time that aircraft were audible in the Grand Canyon measurements (more than 4 hours per day) is higher than found around most major airports. This is not to say that the aircraft sound levels at Grand Canyon are more severe than at major airports, but it illustrates that the audible duration is a very important acoustic factor in describing aircraft sound in the park/wilderness setting.

Detectability may be useful in quantitatively describing when a signal is detectable in various background settings. It can also be used to describe different levels of intrusiveness of a sound. Research with detectability has shown that detection can occur with very low detectability values for individuals specifically listening for a signal. However, this is most likely below the detection level which will disturb or be noticeable to a casual park visitor and is very difficult to measure in the field. The use of higher detection values, while not necessarily accounting for the total time an aircraft event may be audible, reflect practical detection in the wilderness setting where users are hiking, viewing points of interest, or doing something other than looking for aircraft. The sociological surveys may determine the detectability levels that most accurately reflect visitor response. Preliminary findings do indicate that the detectability metric is a good indicator for defining the time duration of low-level sound events at various levels of intrusiveness.

Onset Rate of the Aircraft Sound. The onset rate is an important acoustic factor for aircraft operations within park/wilderness areas. Many of the operations affecting parks are characterized by either very slow or very fast onset rates. The onset rate, or rise time, is the rate of change of the sound until it reaches its maximum. Very fast onset rates are often a characteristic of low-altitude MTR operations. Sounds with very fast onset rates have been found to be more disturbing because of the surprise or startle element of the sound.

In the same manner, sounds with very slow onset rates have also been found to be disturbing, but to a much lower degree. This is a characteristic of most other operations in parks. In quiet backgrounds the aircraft are audible over large distances. For these far-off aircraft, the rate of change of the distance between source and receiver is slow, resulting in slow changes in the sound level. Research has shown that sounds with very slow onset rates are more disturbing as a result of uncertainty as to the eventual maximum.

This study recommends that the onset rate be determined for all types of aircraft operations within the parks. Penalty factors associated for aircraft overflights with very slow and very fast onset rates should be investigated.

Summary. The proposed sound-monitoring program must take into consideration the many unique and difficult problems associated with measurements within National Parks and Wilderness Areas. The program requires the use of specialized measurement instrumentation and a specific methodology for data collection. This is intended to ensure the highest level of accuracy and standardization of the measurement results. Elements of the sound monitoring program are: specific instrumentation requirements; site selection methodology; measurement procedures; acoustic data analysis; meteorological and aircraft data collection; and statistical sampling requirements.

This study recommends the use of DAT recorders to continuously record the sound data in the field. Continuous measurement is necessary in order to determine the time duration of an event and the background sound levels both before and after the event. The DAT's acoustic performance, light weight, and portability make it ideal for use in all types of park/wilderness settings. Field measurement of detectability requires attended measurements with the field engineer taking detailed notes of aircraft and ambient conditions.

different approach than ours — it is not necessary to have a human on-site for ambient monitoring

An important element of the study is an accurate assessment of the number and type of aircraft operating over the parks. Although the number of overflight incidents over some park units are thought to be extensive, the actual number has not been documented. A standardized methodology for determining the number of aircraft operations within each park has been developed.

Given a fixed measurement resource, the sampling program should represent a balance between statistical confidence at any site and spatial coverage of the park. In general, more measurements at fewer sites will provide more meaningful information than less measurement time at more sites. This study recommends that measurements be conducted for four separate trips per year at three to eight sites per park. The duration of each trip depends upon the level of operations and the desired confidence interval. It is estimated that each site will need to be monitored for one to two weeks per trip. MTR operations may need to be measured even longer.

thus continuous monitoring should also be acceptable

The sound-monitoring portion of the overall study must be well coordinated with the sociological surveys of park visitors. One of the most difficult tasks of the study will be to determine the actual sound exposure level for each visitor that is surveyed. The sociological survey must provide information concerning each visitor's itinerary. The sound measurement site selections and visitor survey locations must be developed with knowledge of park visitor use patterns. It is necessary to have knowledge of the aircraft sound exposure levels for each day of the visitor surveys. The survey can not be correlated with averaged sound level data because that may not be that particular individuals exposure. The sociological survey must be completed simultaneously with the sound level measurements.

Section 1.0
INTRODUCTION

1.1 Purpose

National Parks have been set aside throughout the United States for the public's enjoyment and the protection of natural, cultural or historic resources. In recent years, an increase in the number of aircraft overflights in certain park units has become a source of disturbance to visitors. A 1987 survey of threats to park resources identified aircraft sound as one of the twenty most significant threats to parks.

This report is submitted as part of the implementation of Congressional Legislation PL100-91, entitled The National Park Overflights Act of 1987 (U.S. Congress, 1987), which requires the Director of the National Park Service to "*...conduct a study to determine the proper minimum altitude which should be maintained by aircraft when flying over units of the National Park System.*" The United States Forest Service is also a participant in this study (Section 5 of PL100-91) and is required to conduct an assessment of any adverse effects on wilderness resources that may be caused by overflights.

The purpose of the study is to identify problems associated with overflights and to determine the types of operations causing the problems. Parks (and portions thereof) most seriously affected by overflights are to be identified. Issues to be examined include determining any adverse effects on park/wilderness visitor safety and enjoyment. The effects of aircraft overflights on the natural, cultural, and historical resources of the park/wilderness are to be studied. The benefits of the aircraft overflights, in terms of visitor enjoyment, protection, and search and rescue, must also be considered.

The research specified in PL100-91 also calls for an evaluation of the differences in sound levels (within the parks) associated with commonly used aircraft at different altitudes. The types of aircraft operations identified for review include nearly all sectors of aviation, including "*...sightseeing aircraft, military aircraft, commercial aviation, general aviation, and other forms of aircraft which affect such units.*" The law specifically excludes aircraft operations associated with landing fields within, or adjacent to, such park units. The aircraft overflights from each of these categories of operations are summarized in the following paragraphs.

> _Sightseeing Aircraft_. Sightseeing aircraft are commercial tour flights over park units for the purpose of observing park scenery. These aircraft are primarily helicopters and small fixed-wing propeller-driven aircraft. Currently, over 30 park units are overflown by commercial air tour operators. The majority of these tour operations are at altitudes of less than 2,000 feet above ground level (agl).
>
> _Military Aircraft_. Military operations consist of helicopters, fighters, bombers, and transport aircraft. These overflights include aircraft in designated operational airspace over or near park units. These operational airspaces, known as Military Training Routes (MTRs) and Military Operations Areas (MOAs), are set aside for the military to conduct training activities. Activities in these airspaces range from low-altitude radar avoidance flights to aerial combat maneuvers. In addition, military overflights include transient aircraft such as aircraft on high-altitude jet routes over park units and cross-country flights.
>
> _Commercial Aircraft_. Jet routes for high-altitude commercial aircraft cross over or near a number of park units. Aircraft on these routes are at altitudes as high as 35,000 feet mean sea level (msl). A number of parks are also affected by overflights by commercial aircraft in transition altitudes of 5,000 to 15,000 feet msl. These aircraft are vectored over park units when entering or leaving a local airport's airspace.
>
> _General Aviation_. General aviation aircraft overflying park units are primarily single-engine and small twin-engine propeller-driven aircraft. Overflight activities include: sightseeing, incidental traffic associated with a nearby airport, and aircraft using physiographic features within the park for navigational aids.
>
> _Other Forms of Aviation_. Other sources of aircraft activities include aircraft used by: the Park Service, various law enforcement agencies, and contractors/researchers. Aircraft used for these flights are primarily helicopters and small fixed-wing aircraft. NPS aircraft use includes: search and rescue, construction, maintenance work, service of facilities, or access to remote locations. The Coast Guard also operates within coastal park units. Many park units have ongoing research studies of park resources that use aircraft for gathering of data for accessing remote areas.

The purpose of this initial study is to address various technical issues relating the assessment of the sounds from aircraft overflights within parks. These technical issues include techniques for the measurement of aircraft sounds within park/wilderness settings and determining the acoustic parameters that are important in describing aircraft sound within these settings. A methodology is to be developed that is capable of assessing all types of aircraft sounds in all types of park settings on a system-wide basis. Ultimately, the study is to include research at no less than eleven units of the National Park system and an unspecified number of Forest Service Wilderness Areas. As part of the future studies, sociological surveys of park/wilderness users will be used to determine visitor response to these aircraft operations. From this research, assessment criteria for the determination of the effects of aircraft overflight on park visitors is to be developed. A goal of these studies is to develop policies to manage aircraft noise within various park/wilderness areas.

1.2 Contents of the Report

This report contains the results of the initial study to develop a sound measurement methodology to be used for the assessment of aircraft overflight sound levels within the National Park system. Measurements were conducted at two park units and at a remote location of an Air Force Base. The parks studied were Grand Canyon National Park in November 1987, and Hawaii Volcanoes National Park, in January 1988. Measurements of low-altitude military operations were conducted at Edwards Air Force Base (AFB) in June 1988.

This report is divided into five sections and a section of Appendices. The content of each of these sections is briefly discussed below:

<u>Section 1.0 - Introduction.</u> Summarizes the purpose and content of the study.

<u>Section 2.0 - Literature Review.</u> This section summarizes the state of the art in aircraft noise assessment through a review of potential sound-rating scales used in aircraft noise analyses and a literature search that addresses the assessment of en route aircraft sounds within wilderness environments. A more detailed summary of sound-rating scales is contained in Appendix B.

<u>Section 3.0 - Sound Measurement Program Development.</u> The measurement methodology and data collection procedures that were followed at the three measurement site visits are examined. Among the issues discussed in this section are equipment specifications, site selection criteria, measurement methodology, monitoring procedures, noise metric evaluation, and acoustic and nonacoustic data collection requirements. Results from these site visits are reported and discussed, thereby leading to specific recommendations for sound-rating metrics and methods for acoustic impact determination.

Section 4.0 - Special Issues. Special issues of concern to the study are presented in this section. These issues include: statistical sampling requirements, special monitoring requirements for cultural or historic parks, and a program to document the actual number and type of aircraft overflights within each park unit.

Section 5.0 - Ambient and Aircraft Sound Measurement Program. The results of the preliminary measurements were used to develop a methodology for the measurement of ambient and aircraft sounds in the park/wilderness setting. This proposed measurement program is presented in this section.

Appendices. The Appendices contain background information on characteristics of sound as it relates to its description in the park/wilderness setting and a more detailed summary of sound-rating metrics. A list of references, equipment used for each survey, noise measurement results, and an example of measurement sites for three park units are also included.

Section 2.0
LITERATURE REVIEW

2.1 Introduction

This section of the report presents a review of the literature on current and potential methods for assessing aircraft overflight sounds in wilderness settings. These methodologies include sound-rating scales used by the Federal Aviation Administration (FAA) for aircraft noise and land-use compatibility analysis as well as other less established metrics that are used in various types of acoustic analyses. This section is intended to give the readers a greater understanding of methodologies used to assess aircraft noise.

The literature search focused on information relative to: existing data on aircraft and/or ambient sound levels within National Parks or wilderness settings; existing methods of assessing the impact of aircraft noise in wilderness or quiet background settings; data describing the response of a nonpermanent population, such as park visitors, to aircraft noise; protion of the "natural quiet" as a resource; and the protection of solitude as a natural resource.

A comprehensive literature search was conducted using the computer search facilities DIALOG and BRS. Data bases accessed included TRIS, NTIS, Pollution Abstract, and SCI Search. While sound measurement studies have been conducted within national parks (Dunholter, 1986; Foch & Oliver, 1980; Harnapp, 1988) the search revealed a shortage of information on the subjects of en route aircraft sound, aircraft sound in wilderness settings, or the acoustic effects of aircraft overflights on a park visitor population.

One Canadian researcher (Kariel, 1980) has studied the response of visitors to all types of sounds found in Canadian national parks. The survey showed that annoyance to sound was related to the source of the sound, with natural sounds found to be less annoying than technology-related sounds (i.e., auto, aircraft, chain saw). Nonacoustic factors (i.e., listener expectations, necessity of the noise, and prior experience) were also very important in determining annoyance. Aircraft noise was not a major issue at the parks studied in that research.

An extensive amount of data is available on the effects of aircraft overflights on urban populations in the vicinity of airports. Most research on the effects of noise was completed around airports and highways. A very extensive report was prepared by the Environmental Protection Agency that summarized the effects of noise on people (EPA, 1974). A number of studies of populations around airports and highways are listed in the references of this report (TRACOR, 1970; Galloway, 1973; Taylor & Hall, 1977; Schultz, 1978; Kryter, 1982), but none of these studies specifically addressed the issue of the effects of noise in a park or wilderness setting. The Air Force has specifically studied the noise effects from Military Training Route operations.

The following subsections present a review potential sound-rating metrics and various studies that address issues relating to the park service research. Subsections include: (1) Factors Influencing Human Response to Sound; (2) Review of Sound Rating Scales; (3) Detectability; (4)High-Altitude En Route Aircraft Sound; (5) Aircraft Noise from Low-Altitude Training Flights; (6) Helicopter Noise; and (6) Aircraft Noise Models and Emission Data.

2.2 Factors Influencing Human Response to Sound

Many factors influence how a sound is perceived and whether or not it is considered annoying to the listener. This includes not only physical characteristics of the sound but also secondary influences such as sociological and external factors. Molino, in the Handbook of Noise Control (Harris, 1979) describes human response to sound in terms of both acoustic and nonacoustic factors. These factors are presented in Table 2-1.

Sound rating scales are developed to account for the factors that affect human response to sound. Nearly all of these factors are relevant in describing how aircraft sounds are perceived in the park/wilderness settings. It is necessary that the acoustic data-gathering portion of the study adequately addresses each of these parameters that are found to be important. This table also illustrates how the acoustic and sociological aspects of the National Park study are interrelated. Many of the nonacoustic parameters play a prominent role in affecting park user response to aircraft noise. Background sound, an additional acoustic factor not specifically listed, is very important in describing aircraft sound in the park/wilderness setting.

Table 2-1
Factors that Affect Individual Annoyance to Noise

Primary Acoustic Factors
Sound Level
Frequency
Duration
Secondary Acoustic Factors
Spectral Complexity
Fluctuations in Sound Level
Fluctuations in Frequency
Rise-time of the Noise
Localization of Noise Source
Nonacoustic Factors
Physiology
Adaptation and Past Experience
How the Listener's Activity Affects Annoyance
Predictability of When a Noise will Occur
Is the Noise Necessary?
Individual Differences and Personality

Source: C. Harris, 1979

2.3 Review of Sound Rating Scales

The description, analysis, and reporting of community sound levels from aircraft is made difficult by the complexity of human response to sound and the myriad of sound-rating scales and metrics that have been developed for describing acoustic effects. Various rating scales have been devised to approximate the human subjective assessment to the "loudness" or "noisiness" of a sound. Noise metrics have been developed to account for additional parameters such as duration and cumulative effect of multiple events.

The most prominent of these rating scales and metrics include: Loudness Level, Frequency Weighted Contours, Perceived Noise Level, Sound Exposure Level, Effective Perceived Noise Level, Time Above, Equivalent Noise Level, Noise Exposure Forecast and the Day Night Noise Level. All of these scales are discussed in greater detail in Appendix B. The Handbook of Noise Rating (Pearsons & Bennett, 1974) provides a summary of calculation procedures for each of these scales. The purpose of this subsection is to summarize the most common scales used by the FAA and other agencies in assessing community noise impacts from aircraft.

The Loudness Level rating scale is the subjective judgment of an individual on how loud or quiet a particular sound is perceived. The human ear is not equally sensitive to all frequencies; some frequencies are judged to be louder for a given signal than others. Calculated Loudness Levels (Stevens, Zwicker) are single number ratings of full spectrum sound signals that are determined from specific formulas. They are designed to provide an acoustic measurement of an individual's judgment of loudness. The loudness level is determined by converting 1/3 octave spectral levels to loudness, correct for interband masking, and adding the contribution of sound from each spectral band. There are no specific community noise standards that use calculated loudness levels.

As a way of simplifying the measurement and computation of sound loudness levels, frequency-weighted contours have obtained wide acceptance. The equal loudness level contours (all points on the contour are judged to be equally as loud) for 40 dB, 70 dB and 100 dB were selected to represent human frequency response to low, medium, and loud sound levels. By inverting these equal loudness level contours, the A-weighted, B-weighted and C-weighted frequency weighting networks were developed. D-weighted is another frequency weighted network that has some limited use in aircraft measurements.

The metric used in describing the noise environment involving humans is usually in terms of A-weighted decibels. A-weighted sound pressure is filtered or weighted to reduce the influence of the low- and high-frequency extremes. Many past studies reveal that when people make relative judgments of the "loudness" or "annoyance" of a noise, their judgments correlate quite well with the A-weighted sound levels of those noises. Most community sound-rating indices are based upon the A-weighted decibel.

Perceived Noise Level (PNL) and Tone Corrected Perceived Noise Level (PNLT) are other methods of rating sound. Originally developed for the assessment of aircraft noise, PNL and PNLT differ from loudness in that they were developed to rate noisiness or annoyance of a sound as opposed to loudness of a sound. The Effective Perceived Noise Level (EPNL) metric is based on the PNLT level, and takes into account an individual's response to the "noisiness" of the aircraft, the disturbing effect of any pure tones, and the duration of the event. The FAA's FAR Part 36 aircraft certification noise standards are based upon the EPNL metric. This regulation certifies new subsonic civilian aircraft for arrival, departure, and sideline noise levels.

The FAA, in response to the 1979 Aviation Safety and Noise Abatement Act, established a single system of metrics for measuring and evaluating aviation noise for environmental impact assessment. These metrics may generally be grouped as either single event or cumulative levels and were developed to address the sound from aircraft at urban areas in the vicinity of airports.

The Day Night Noise Level (DNL) is used by the FAA as a single number to measure community noise exposure. DNL is a cumulative 24-hour metric based upon the A-weighted decibel. DNL was introduced as a simple method for predicting the effects on a population of the average long-term exposure to environmental noise. A 10 dB correction is applied to nighttime (10 p.m. to 7 a.m.) sound levels to account for the increased annoyance of noise during those hours. The specified time integration period for DNL is 24 hours, and there is no stipulation of a minimum noise sampling threshold. DNL is the specified metric in the FAA FAR Part 150 noise compatibility planning process.

Applying the DNL metric to en route aircraft sound environments found in sample parks does not adequately describe current levels of adverse visitor response within these parks. Again, it should be noted that noise assessment criteria in terms of DNL have evolved from the study of urban land uses in the vicinity of airports, not remote areas affected by en route aircraft. In addition, DNL does not consider background sound, or more simply stated, the relative difference in ambient sound levels and the levels generated by aircraft activity.

One other metric that may be of interest in this study is the 24-hour Time Above (TA). TA provides the duration, in minutes, for which the combined aircraft event throughout the day exceeds a specified A-weighted sound level. Although there are no assessment criteria in terms of TA, it can be directly related to some threshold of physiological or activity interference. There is no evidence that suggests any correlation between TA and community response to noise, but it may provide a means of illustrating intrusion of the aircraft sounds above the background sound levels.

2.4 Detectability

Cumulative measures of community noise (such as DNL) are generally insensitive to low-level sounds that may occur infrequently and thereby do not materially affect integrated energy averages. This situation is predominant in the National Park System, in which otherwise quiet areas are intermittently disturbed by low-level sounds from aircraft overflights. For this reason, a metric that considers both background sound and the relative level from the aircraft overflights is desirable.

Researchers (Fidell & Teffeteller, 1978) have demonstrated that the annoyance of low-level sounds may be predicted through a descriptor known as detectability. The research showed that in low-level sound settings, signal detection or audibility can be the most important factor in predicting annoyance. Detectability provides a method of measuring this level of intrusion.

Detectability, as it is known today, began with the development of a formal psycho-acoustic theory of detectability in the mid-1960s (Green & Swets, 1966). This concept evolved into an analytical tool through interest in military, industrial, and environmental applications. Emphasis has also been placed on establishing criteria for nondetectability as well. For example, predicting the audibility of acoustic signals from military vehicles in the field is a prime application area (Fidell, Pearsons & Bennett, 1972; Fidell & Bishop, 1974).

Detectability (d') is a function of the differential between the 1/3 octave band noise level of the source and the background in the same frequency band. Other factors include the band width in that same frequency band and the efficiency of the listener. It can be expressed as the maximum detection value or a composite level of all of the detectability values in each band. Detectability (d') can also be expressed as a level using the log scale. For the purposes of this study, detectability will be presented as the 10log(d') level using the nomenclature D'.

Detectability is useful in describing when a signal is detectable in various background settings. The Fidell research demonstrated that detection can occur with D' values below 4 for individuals specifically listening for a signal. In addition to these low-level sound applications, more recent work by Fidell, et al. (Fidell & Teffeteller, 1981) suggests that the detectability concept may also be applicable to more complex noise environments. These studies report that with a D' of 22, virtually everyone exposed to the noise will notice it, and approximately 50% of those people will be annoyed. Further, a D' of 40 indicates that most of the exposed population will be highly annoyed by the intruding sound.

A modification of the detectability method described above is used by the United States Forest Service (Harrison, 1980). This method relates detectability to the amount of intrusive noise a person is willing to endure. Intrusive noise is classified into four broad areas, ranging from very quiet (primitive) to noisy (modern). Using the methodology described in this work, a maximum D' of 0 is considered appropriate for primitive areas whereas a maximum D' level of 16 is acceptable for modern sites. This methodology accounts for the fact that the perception of annoyance depends upon a person's expectations for a particular setting. In other words, most people desire even lower sound levels from external sources when these individuals are located in a primitive setting. This method is used by the Forest Service in recreational siting decisions. This methodology has been used successfully to site off-road vehicle trails (Harrison, 1988, personal communication). Detectability has also been applied in the siting of power plants (Leibich & Cristoforo, 1988).

In summary, the concept of detectability and its relation to annoyance appears to be applicable to low-level sound situations within the park. However, it should be noted that the research on detectability was completed primarily under constrained laboratory conditions. Detectability has not been tested to predict annoyance in an outdoor setting where both the background and source vary with respect to amplitude, frequency and temporal domains. More evidence should be collected and analyzed before using it for quantifying the effects from aircraft flyovers in a quiet background setting, and it may not be found to be as useful in higher sound level situations. In addition, detectability does not consider self-masking by adjacent bands nor does it take into consideration recruitment of loudness. As part of the future sociological surveys, the use of detectability to predict annoyance in these settings should be investigated.

2.5 High-Altitude En Route Aircraft Sound

Existing jet routes for high-altitude aircraft cross over or near a number of National Parks and Forest Service Wilderness Areas. Aircraft on these routes are at altitudes as high as 35,000 feet msl. In the past, these aircraft have occasionally deviated from published routes to provide a better view of the park scenery. There was little information in the literature on high-altitude en route aircraft sound as a source of annoyance.

The FAA is currently addressing the potential of acoustic effects from en route commercial jet operations in transition altitudes for a community in New Jersey. Modifications to flight procedures at Newark International Airport resulted in aircraft flying over an affluent rural residential area that did not have any overflights before these changes. These aircraft are at altitudes of greater than 7,000 feet. The FAA study is designed to assess why adverse community response is taking place in an area that, based on the DNL criteria, should not be considered to have a noise problem. Specific methods for addressing the noise impacts from these types of operations has not yet been developed.

A number of researchers in Scandinavian countries are also addressing the problem of aircraft operations in transition altitudes (Linde & Meijer, 1986) . Linde et al., have completed a number of noise surveys on en route aircraft operations. Their analysis is based upon a metric called the Flight Noise Level. This is similar to the DNL in that it considers the number and duration of flights, and it applies a penalty for nighttime operations. It differs in that it uses the maximum noise level from an aircraft event as the basis for further calculations. A value of 55 has been established as the threshold of acoustic impact. This metric has the same limitations as DNL in that is does not consider background levels.

A potential concern for future sound levels in National Parks is a new generation of commercial aircraft engine that is now being developed and tested. Preliminary indications are that the new unducted fan technology may result in higher en route sound levels than the current jet engine technology.

Unducted fans are unique because the turbine blades are not contained in any form of engine cowling but are exposed to the open atmosphere. Concerns have been raised about whether or not these unducted fans will result in a sound problem. Unducted fan engines have no cowling with sound absorbent material to stop sound at the source. Also, the counter rotating blades have noise characteristics not yet seen in jet engines. The air flow around the blades is quite complex with velocities at the tips reaching supersonic speeds. Engineering changes between now and the time of production should produce reductions in the projected noise levels. In summary, it is too early to draw any firm conclusions about the unducted fan noise levels. However, it would not be unreasonable to assume that high-altitude en route noise from unducted fan engines will be at least as loud as current technology. Research by NASA (McCurdy, May 1988) has found the annoyance factor to be similar to current jet engined aircraft.

NASA (McCurdy, 1988) has studied the annoyance caused by sounds from advanced turboprop aircraft engines. These engines will be used on new generation commercial, commuter and larger general aviation aircraft. Advanced turboprop, or "propfan", engines are a single rotation propeller turbofan with different propeller shapes and number of blades. This engine technology has unique spectral characteristics. The study showed that A-weighted sound pressure level with a modified tone correction was the best descriptor for predicted annoyance. The research concluded that sounds from these engines were found to be slightly less annoying then conventional jet and turboprop engined aircraft.

2.6 Aircraft Noise from Low-Altitude Training Flights

One category of aircraft operation that affects park units has been the subject of extensive research. Currently, the Air Force is conducting a major study to analyze acoustic effects of low-altitude military training flights. These flights are usually on fixed routes called Military Training Routes (MTRs). These routes may be a number of miles wide. Aircraft using these routes are typically high-performance jets, flying fast and low. As a result, these incidents occur rapidly and are of short duration. The Air Force is in the process of developing a method of quantifying the acoustic effects from these flights (Plotkin, Sutherland & Molino, 1987). MTR operations are a unique noise problem that is very different than other types of aircraft operations affecting parks.

The metric evolving from this Air Force study is based on DNL, except that the integration period is equal to the average day of the peak month of aircraft activity and not the annual average level of operations. Further, the metric is adjusted by an onset rate factor to account for the surprise or startle element from high-speed aircraft operations.

Surprise or startle element can be a major factor in the noise effect of MTR overflight. The onset rate (see Table 2-1) is a measure of this surprise factor and has potential application to those parks located in the vicinity of MTRs. The Air Force study defines onset rate as the rate of change, in decibels per second, of the A-weighted "fast" sound level of the overflight signal between the time the signal first exceeds the ambient level by 5 decibels and the time the signal first exceeds a level 5 decibels below its maximum value. Individual flyovers along these routes are usually at an altitude of 400 to 600 feet above ground level (agl) and produce maximum noise levels in the range of 100 to 110 dBA (Plotkin et al., 1987). Other flights operate at lower altitudes (100 to 200 agl); thus, they produce higher noise levels and higher onset rates. The width of the corridor affected by the aircraft sound is narrower at lower altitudes.

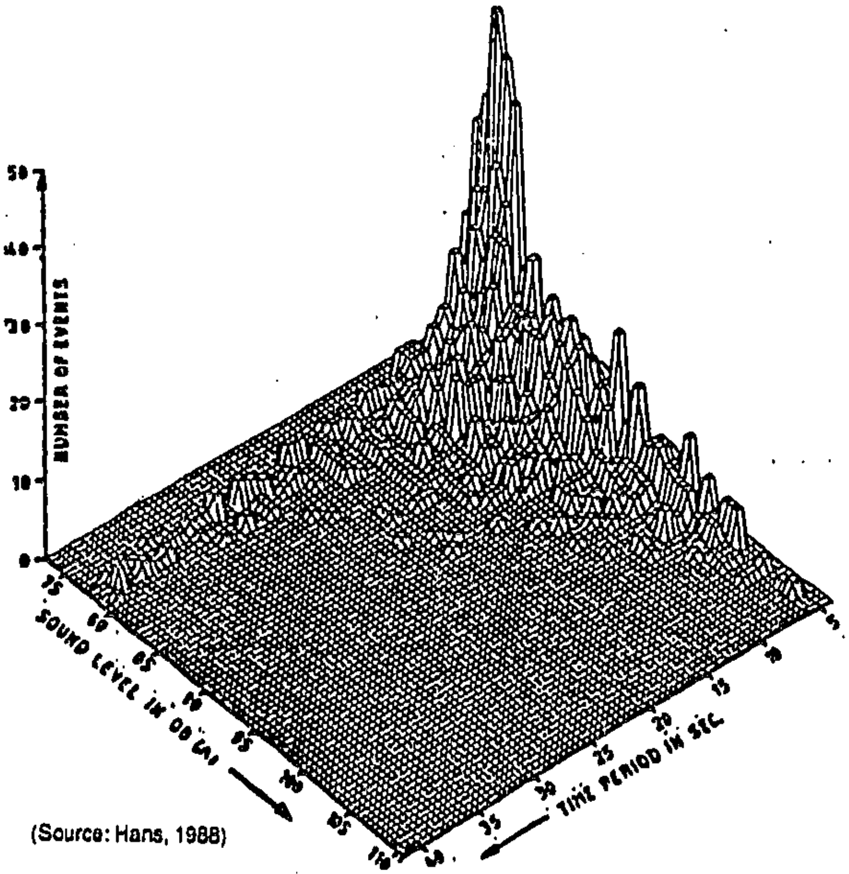
It has also been suggested that a given noise would be more intrusive in a quiet environment than a noisy one (Plotkin et al., 1987). Laboratory experiments indicated that decreasing the difference between the aircraft noise and the background sound by approximately 20 dB made the aircraft noise about 5 dB less intrusive. This same study also showed a linear relationship between subjective response to individual aircraft events and the maximum noise level generated by that event. These experiments showed that background sound should be considered in the development of a metric to assess these aircraft overflights.

In accounting for a single military aircraft overflight along an MTR, the Sound Exposure Level (SEL) provides a convenient method of measuring the contribution of each flight to the surrounding noise environment. Plotkin, et al., devised a method of quantifying the intrusiveness of military aircraft overflights along MTRs using the SEL. This method places a penalty on the SEL for events that exceed an onset rate of 15 dB per second, with a maximum penalty of 5 dB occurring at an onset rate of 30 dB per second. This study further recommends that no adjustment should be applied if the maximum A-weighted sound level of the overflight, measured by a system with the time response set to "fast", does not exceed the ambient sound by at least 15 dB.

While many aspects of the Air Force study have applications to the park/wilderness setting, there are some major differences. An important distinction is that the Air Force study addresses a permanent residential population, that has prior experience to MTR overflights. In the park setting, the population is not permanent; a complete change in individuals occurs every few days. As a result, most people have no prior experience to noise from MTR operations. For many park visitors; any MTR overflight will be a first time experience. Therefore, the startle effect of high onset rates on a visitor population may result in a higher level of disturbance than is reflected in recommendations in the Air Force study.

The use of a metric averaged over some time period to describe MTR operations has limited use in the park/wilderness situation. MTR operations generate high noise levels and high onset rates directly under the flight path, but the width of the high noise exposure zone is narrow. MTR routes are not fixed paths, but operate within specified corridors. Because the width of the noise exposure for each overflight is narrow, at any given fixed location, most of the MTR operations on that route will not generate the very high sound levels. The high sound levels only occur when the aircraft happens to be on a path that is close to overhead. An example of the distribution of the sound level and the time period of the event for one location is presented in Exhibit 2-1 (Hans, 1988). This exhibit illustrates how, for a given location, the noise level and the duration of the event vary significantly. (The duration can be directly related to onset rate.)

Exhibit 2-1
Distribution of Sound Levels and Time Periods for MTR's



(Source: Hans, 1988)

Averaging the noise exposure over some period of time de-emphasizes these peak levels and spreads the sound over the width of the flight corridor. Given the fact that a visitor population may be different every day, visitors are never exposed to the average, but only to the aircraft sound levels that occur at each individual's particular location on that individual's day in the park. The result is that the majority of visitors are exposed to little or no aircraft sound at all. However, a visitor who happens to be at a location at which the aircraft is directly overhead, would be exposed to very high noise levels. This illustrates a problem for the sociological surveys. It will be very difficult to know precisely the sound exposure that each individual surveyed has experienced. A visitor population changes daily, so the sound level must be known on a daily basis. In addition, visitors are not fixed at one location, but move throughout the park during the course of their stay.

MTR operations are also a significant problem in Europe. The operations in Europe affect areas with higher population densities than those in the United States. Extensive measurement studies have been completed on European MTR flights. One researcher (Hans, 1985 & 1988) measured over 8,000 operations at one measurement point. This researcher concludes that an equivalent continuous sound level metric (LEQ or DNL) is not adequate for addressing the noise effects from low-altitude military training flights. (Note: Sociological studies were not included as part of these studies.) The research concluded that the distribution of the sound levels and the rise time of the noise are important factors in describing the acoustic environment. The study presents no recommendations as to a specific methodology for rating noise levels from these operations.

In conclusion, while research shows that onset rates are an important element in describing noise from MTR operations, it is not clear which weighting factor appropriately represents this disturbance in a park/wilderness setting. This should be investigated as part of the NPS study. In order to develop a correlation between the sound level data and the sociological surveys, these surveys must be completed simultaneously. Sound levels from MTR operations will need to be known on a daily basis and not averaged over some time period. Even with simultaneous acoustical and social sampling, it will be very difficult to determine the actual sound exposure of each visitor being surveyed.

2.7 Helicopter Noise

Concern has been expressed on whether current methodology of measuring and predicting community response to helicopter noise is adequate. Current methods generally are based upon A-weighted DNL noise level. Some researchers suggest that methods may need to be supplemented by other noise metrics or include penalties specific to helicopter noise to better correlate community response with the noise environment.

NASA conducted a detailed review of 34 studies concerning the measurement of helicopter noise (Molino, 1982). A number of psychoacoustic studies reviewed by the NASA research team have proposed alternative methods of prediction of helicopter noise. These proposed methods are designed to more adequately account for the unique perception of helicopter blade slap noise. The studies involved laboratory and field analysis of human response to noisiness or annoyance caused by various levels and types of helicopter noise. Some authors suggested new methods of predicting helicopter noise or the addition of a constant penalty number to current methods of analysis. Many of these studies yielded conflicting conclusions. The conclusion of the NASA study was that for the present state of scientific knowledge, the current method of measuring perceived helicopter noise levels is adequate; there is no need to measure helicopter noise any differently from other aircraft noise. Note that this conclusion was drawn from often conflicting results. There is no consensus of opinion among acousticians on this subject.

2.8 Aircraft Noise Models and Emission Data

An extensive amount of acoustic data has been developed relative to measured sound levels for various aircraft types. This data has been gathered primarily by the Air Force and the FAA, and covers nearly all types of aircraft that operate in and around park units and wilderness areas. The Air Force Aerospace Medical Research Laboratory (AMRL) at Wright Patterson Air Force Base has generated noise emission data for nearly all of the military aircraft in operation today. This sound level data is in terms of A-weighted noise level as well as spectral noise level for standard temperature and pressure. Civilian aircraft manufacturers have sound emission data available for most recent production aircraft as a requirement of FAR 36 regulations. The FAA has sound emission data for nearly all types of aircraft and helicopters. This data is in terms of both A-weighted and EPNL noise levels versus distance.

Computer models have been developed by various governmental agencies for the analysis of noise generated by aircraft. In general, these models were developed to assess the potential noise levels around airports. The Air Force has developed noise models to assess sonic boom and MTR noise. These programs have mapping capability for developing noise contours.

The FAA recommends use of their Integrated Noise Model (INM) Version 3.9 for noise and land use studies for civilian airports. The original version was released in 1977, and the present data base Version 3.9 was released in 1987 (Flythe, 1982). The INM is a large computer program developed to plot noise contours for airports. The program is provided with standard aircraft noise and performance data for over 60 aircraft types that can be tailored to the characteristics of the airport in question. Aircraft sound level data that can be determined from this model include: DNL, NEF, SEL and Time Above. The FAA has recently developed the Helicopter Noise Model (HNM) to address the noise generated from helicopter operations (Keast, Eldred & Purdum, 1988). This model provides similar acoustic information concerning helicopter noise as the INM model.

The Department of Defense requires the use of the NOISEMAP model for the analysis of aircraft noise around military airports. The latest version of the model is Version 5.1 (Air Force, 1983) with Version 6.0 expected for release in mid 1989. The aircraft noise data base is contained within the NOISEFILE program. Acoustic information that can be determined from the model are DNL, LMAX, and SEL.

Although these airport models are different, from a mathematical and programming perspective the programs are similar. These airport noise models require the input of the physical and operational characteristics of the airport. Physical characteristics include runway coordinates, airport altitude, and temperature. Operational characteristics include aircraft mix, flight tracks, approach profiles, departure profiles, approach parameters, and aircraft noise curves.

The Air Force is developing a new computer model called ROUTEMAP to predict the noise from MTR operations. Version 1.0 is to be released in early 1989. This model is based upon the methodology developed by the Air Force that was reviewed in this section. Inputs to the model include: number of operations, aircraft type, flight track routes, flight track dispersion, altitude, and speed, among others. Acoustic information that can be determined from the model are DNL, SEL and onset rate.

To analyze the effects from sonic booms, the Air Force has developed a model called BOOMMAP2 (Day, Reilly, & Seidman, 1988). This model analyzes the sound generated by supersonic aircraft. The model can calculate the intensity and location of sonic booms resulting from aircraft overflights. Contours can be plotted for the average peak overpressure or C-weighted DNL noise levels.

Section 3.0

SOUND MEASUREMENT PROGRAM DEVELOPMENT

This section provides a description of the measurement and data collection procedures that were used at Grand Canyon National Park, Hawaii Volcanoes National Park, and at Edwards Air Force Base. This details the development history of the methodology recommended for use in measuring ambient and aircraft sound levels, and in documenting the resulting acoustic effects of these overflights in the park/wilderness setting. The methodology was refined, updated, and tested at each subsequent park site.

On the basis of these measurements, procedures for the proposed noise measurement program were fully developed and are presented in Section 5.0. Note that the purpose of these measurements was not to quantify the noise environment of these park units, but to test and develop a program that can be applied for future noise monitoring requirements throughout the National Park system. These measurement results did provide preliminary information relative to the level of aircraft sound in each of these parks.

This section is divided into four subsections. Subsections 3.1 to 3.4 present the results of the measurement surveys and the evolution into the final program based on the measurement results from Grand Canyon, Hawaii Volcanoes and Edwards AFB. The measurement surveys are discussed relative to: (1) site selection methodology, (2) measurement instrumentation, (3) measurement procedures, (4) measurement results including a review of potential sound rating descriptor and (5) conclusions and recommendations.

Section 3.1
GRAND CANYON NATIONAL PARK MEASUREMENTS

3.1.1 Site Selection

Grand Canyon National Park (GCNP) was selected for the first phase of the sound measurements. The park has a history of noise problems from aircraft overflights and the high number of aircraft operations provides a large sample of test data of aircraft operating within a wilderness setting. The types of aircraft over the park are predominantly tour aircraft, both helicopters and fixed wing, with some en route high altitude jet operations and transient general aviation aircraft. The purpose of these measurements was to identify acoustic factors that are important for describing aircraft sounds in these settings and testing methods for describing these factors.

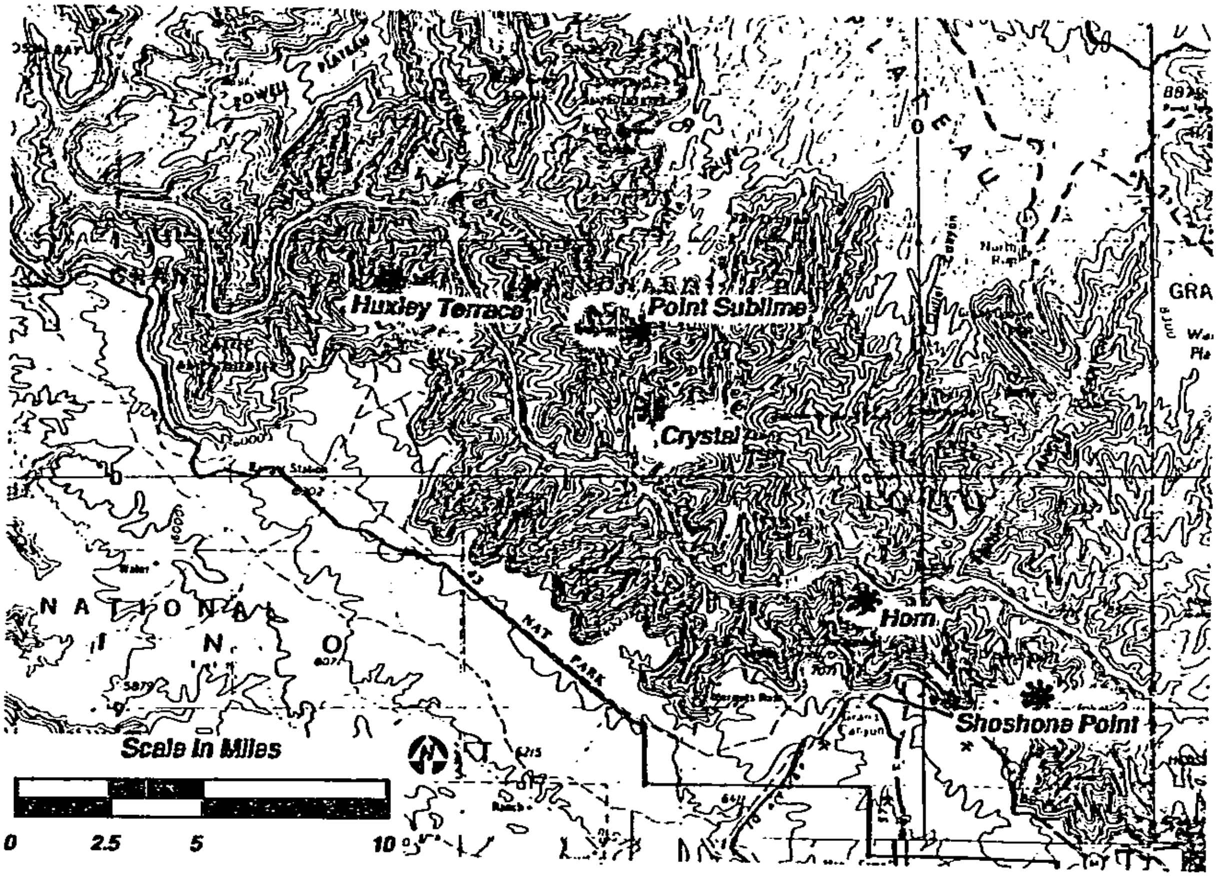
The noise measurement survey was conducted from the 9th to the 13th of November 1987 at five locations in the park. These locations are presented in Exhibit 3-1. The Shoshone Point site was used primarily for equipment testing prior to the measurements at the remaining sites. The four remaining sites are located in areas with varying degrees of aircraft exposure to all of the types of aircraft that operate in the park. Each site would be considered a day hiking area or overnight backcountry location. These four primary sites were each measured for a 24-hour period.

Aircraft and ambient sound levels were measured at each site. The variety of sites were selected to determine aircraft sound levels under various ambient and operational conditions. The measurement sites were selected on the basis of the following preliminary criteria:

n/a to our study

- These sites must be exposed to a variety of aircraft sources and altitudes. They should include all categories of aircraft identified for review by the legislation.
- Each site should have vegetation and terrain representative of the immediate area being studied.
- The sites should be in areas that have some level of recreational use; either hiking, camping or sight seeing.
- The site must have access for up to 100 lbs. of equipment, which must be accessible and operable with minimal detection of the local aviation operators.

Exhibit 3-1
Noise Measurement Locations (GCNP)



3.1.2 Measurement Equipment

A listing of the equipment by model and serial number used in the measurements is contained in Appendix C - Noise Measurement Equipment. These measurement systems comply with the American National Standards Institute (ANSI) Standards 1.4 1983 for Type 1 precision noise measurement instrumentation. This class is the most stringent ANSI standard for outdoor noise measurement systems.

DH equip also meets this std - as does Larson Davis

Two separate types of noise monitoring systems were used in the Grand Canyon survey. One system was designed to tape record the data in the field for later frequency analysis in the laboratory. The second system automatically measured the A-weighted sound levels and provided a continuous strip chart recording of the data. Exhibit 3-2 graphically illustrates the instrumentation used for this survey and the sound rating metrics derived from each system. exactly what we're doing

The frequency analysis system consisted of Bruel & Kjær (B&K) 2230 or B&K 2204 sound level meters as input to Nagra instrument tape recorders (III & SJ-SJS). The recorded data was analyzed in the laboratory with a Hewlett Packard 3561A Dynamic Signal Analyzer. This analyzer performed the 1/3 octave band analysis on the measurement data. The 1/3 octave information was determined for both ambient and aircraft sound. Various potential sound rating metrics were calculated from this data. The A-weighted measurements used a B&K 4427 automated digital noise data acquisition system. This instrument has the capability of operating unattended while calculating specific A-weighted descriptors and strip chart recordings of the sound levels. This data was primarily used as a verification of the results from the tape recorded data.

we are not doing 1/3 octave band analysis at this time*

*we are collecting some calibrated tapes for use at a later date.

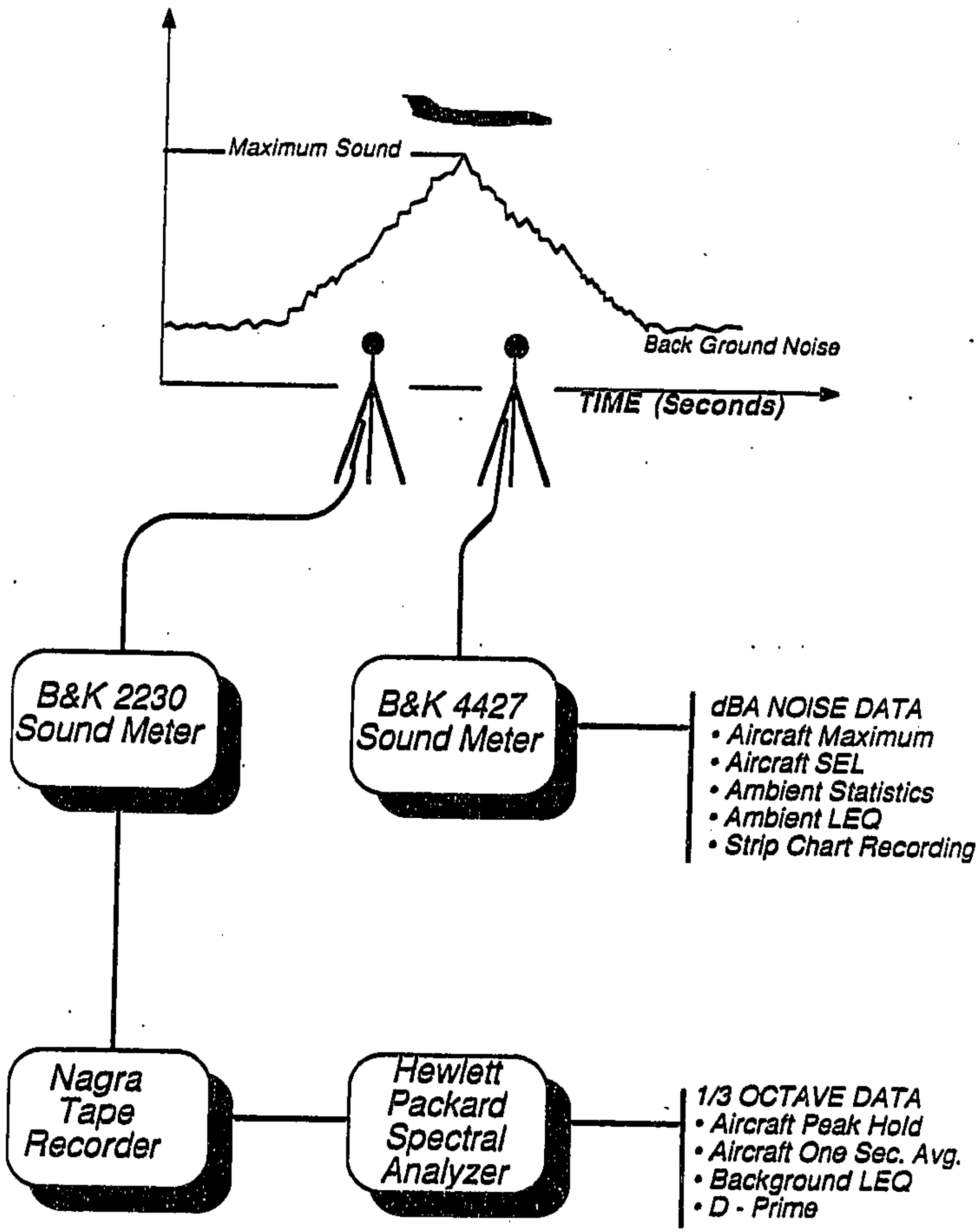
These noise monitors were equipped with B&K Model 4155 1/2 inch electret microphones (the B&K 2204 meter was equipped with a B&K 4131 1- inch microphone). The microphones were all equipped with foam wind screens (B&K UA0237).

3.1.3 Measurement Procedures

Ambient and aircraft sound levels were determined for each site using the following procedures. At all measurement sites, the microphone was located at an elevation of five feet above the ground. The sound levels were analyzed with time response set to ANSI "slow". Pertinent meteorological data, such as wind speed and direction, temperature,

we're at 10 ft.

Exhibit 3-2
Aircraft Measurement Systems (GCNP)



humidity, and atmospheric cloud conditions was measured during the noise survey.

The systems were calibrated with a B&K Model 4230 calibrator with calibration traceable to the National Bureau of Standards. The calibrators were certified accurate throughout the duration of the measurements by Bruel & Kjær. The tape recorded systems were recalibrated for every new tape, or at least every two hours. The B&K 4427 system was calibrated at the beginning and at the end of the 24-hour measurement sequence and at two additional times during the day.

Ambient sound levels were determined during periods when aircraft were not visible or audible to the field engineer. These measurements were of limited duration, typically five minutes. (At times it was difficult to have even this short period of time without interference from aircraft events). The ambient measurements were conducted on the average of every two hours or when changing meteorological conditions dictated an additional sample.

Aircraft sound levels were determined from the same measurement systems described above. The field engineer started the tape recording either when an aircraft event became audible, was visible, or when its arrival was noted on an aircraft radio. The recorder was stopped when the aircraft was no longer audible to the field engineer. Often, many aircraft events were grouped, so the beginning or end of these events could not be individually determined. During each event, the type of aircraft, the flight track and an estimate of altitude was noted by the field engineer.

The tape recorded data was returned to the laboratory for frequency analysis. The sound level for each 1/3 octave band between 20 and 8,000 Hz was determined. The analyzer calculated the 1/3 octave band levels at what is equivalent to 0.8 second LEQs. The ambient sound levels were determined in terms of the LEQ sound level during the periods without aircraft overflights.

For these preliminary measurements, detectability was determined from the "Peak-Hold" level for each 1/3 octave band. (Note, this methodology was revised during the subsequent measurements). This is the highest level reached in each 1/3 octave band during the flyover. The detectability level was calculated relative to this peak-hold level and the ambient level in the corresponding frequency. For these first phase measurements, detectability was calculated for the maximum D' value in any frequency. It should be noted that the highest level in each band will not necessarily coincide with the maximum sound during the flyover. For some frequencies, the peak level may occur before the aircraft is at is closest point from the microphone. Therefore, this peak-hold value will numerically be higher than the maximum sound level during the event. The spectral levels was also determined for any time period of interest.

The A-weighted ambient and aircraft sound levels were determined from the continuous operation of the B&K 4427 sound level meter. This instrument was programmed to calculate the LEQ sound level and the L(n) sound levels for each hour as well as displaying a printed strip chart recording of the sound. Note that the hourly LEQ sound levels and the L(n) data is calculated from all of the noise sources that occur during that hour, including aircraft events.

we will be gathering LEQ as well as max & mins on an hourly basis

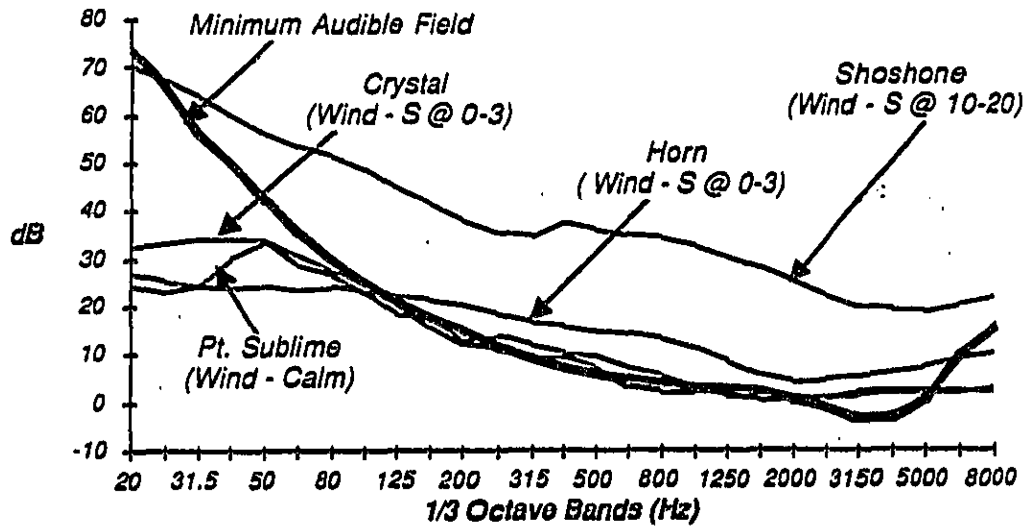
The continuous strip chart recording from the B&K 4427 was used to determine the maximum A-weighted sound level and the effective duration for each aircraft overflight. The effective duration is the time between when a sound rises above the background sound level until it drops back below the background level. For these preliminary measurements, the effective duration was roughly defined as the time above the ambient L90 sound level plus 3 dBA. This approximates the time which the aircraft would generally be considered audible. SEL levels were also calculated for those events exceeding 45 dBA.

3.1.4 Ambient Measurements

Results. The results of the preliminary measurements at GCNP showed that the ambient sound levels can be extremely quiet. Generally, during the meteorological conditions that were present during the survey (absence of wind), the ambient sound levels were consistently below 20 dBA. In the mid-range and higher frequencies, the 1/3 octave band levels were below 10 dB. An example of 1/3 octave sound level results from four of the sites is shown in Exhibit 3-3. (The ambient 1/3 octave measurement data for all of the sites is summarized in Appendix D - Measurement Results.)

This exhibit presents the 1/3 octave sound level in terms of the LEQ metric for the four different locations measured at Grand Canyon. Each curve is an example of one sample period under varying ambient conditions and the wind speeds that were presented during the monitoring survey. Note: The data for Point Shoshone shows higher sound levels because of the higher wind speeds that were present during that measurement. The samples at Horn showed slightly higher sound levels in the mid-frequencies. This is a measure of the sound from the Colorado River that is just measurable at this location.

Exhibit 3-3
Sample Ambient Noise Levels (GCNP)



Most of the measured ambient sound levels were at or below the threshold of hearing. The threshold of hearing is often defined by the Minimum Audible Field (MAF) curve (also shown in Exhibit 3-3). The MAF curve represents the sound pressure level of the threshold of hearing for young adults (discussed in detail in Section B.2 of Appendix B). The threshold of hearing is defined as the minimum sound that is able to generate an auditory response. Note that at many of the frequencies the ambient levels are below the MAF curve. This was especially true in the lower frequencies. In the frequency range that was found to be most critical in the detectability calculation (100 to 500 Hz), the MAF curve and the measured sound levels were similar. Under higher wind speeds, the measured sound levels where generally higher than the MAF curve.

The B&K 4427 sound level instrument displayed a continuous strip chart recording of the A-weighted sound levels throughout the measurement survey. A sample of one of the hours for the Point Sublime measurement site is shown in Exhibit 3-4. This exhibit shows the continuous A-weighted sound level for that hour including aircraft events and the calculated L1, L10, L50, L90, & L99 and the LEQ sound level for that hour. Note: The large number of aircraft events for that hour was typical for the conditions experienced during the measurements.

Conclusions and Recommendations. A number of observations can be drawn from this ambient measurement data as it applies to developing the NPS measurement program. These observations are listed below and described in detail in the following paragraphs.

Instrumentation Requirements
Incorporation of the Threshold of Hearing
Descriptor for Ambient Sound Measurements
Meteorological Considerations

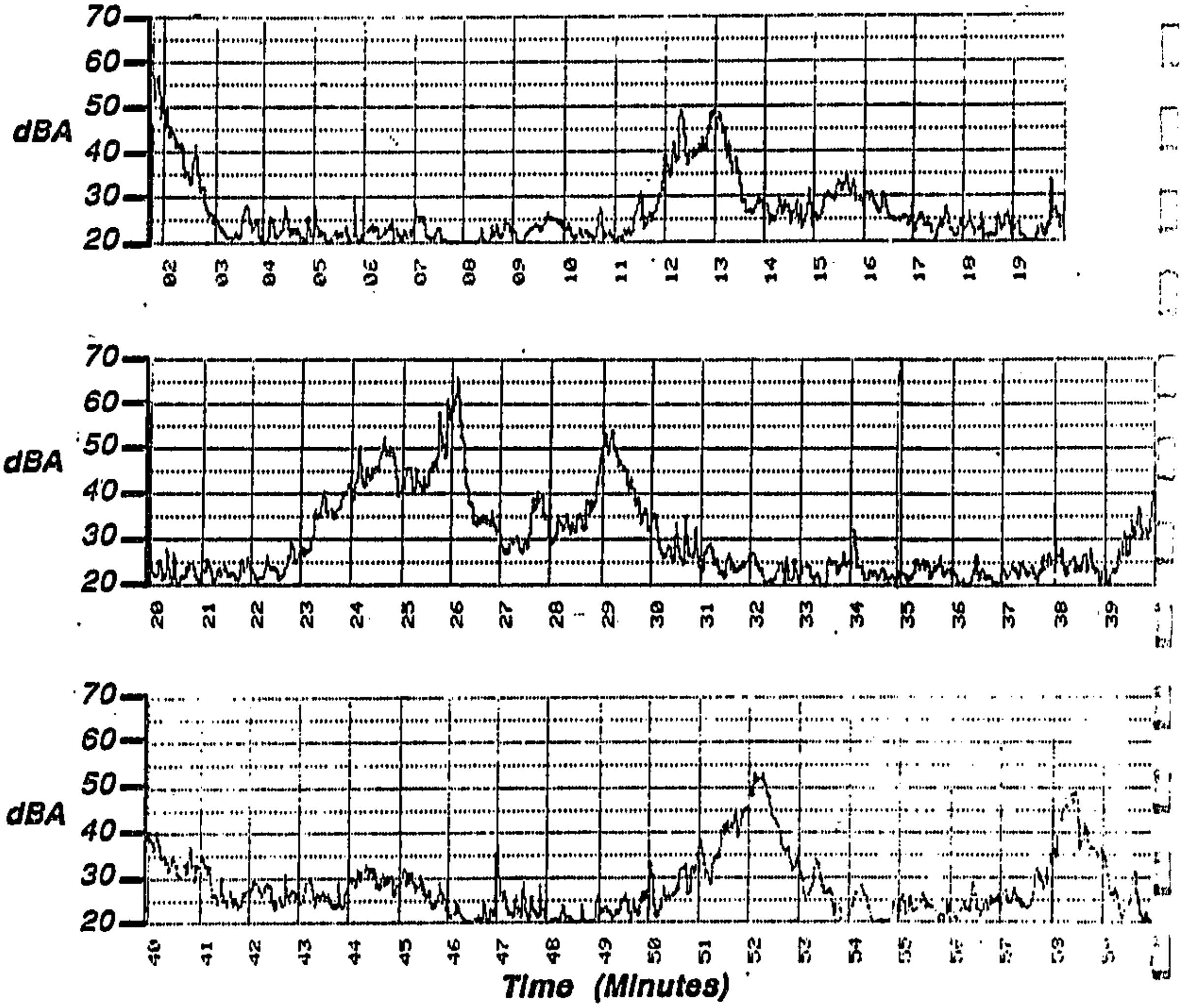
Instrumentation Requirements. The ambient sound levels experienced at Grand Canyon were often below the noise floor for many analyzers and microphone systems used for outdoor community noise assessment. The primary microphone/preamplifiers used for these measurements generally have a lower limit of 22 dBA (with a minimum signal to the noise floor greater than 5 decibels). The noise floor for each 1/3 octave band ranges from 1 to 11 dB depending upon the frequency, with the lower and higher frequencies having the highest noise floor. Therefore, the background sound levels at Grand Canyon were so low, that most of the measurements were a measure of the noise floor of the instrumentation and not the background sound. For the late night conditions without wind, the environment was essentially without sound.

our equip has a lower limit to 20dB

Exhibit 3-4
Sample Point Sublime Strip Chart (GCNP)

LEQ	41.8 dBA
L 0.1	64.0 dBA
L 10.0	40.6 dBA
L 50.0	25.2 dBA
L90.0	21.0 dBA
L99.0	20.8 dBA

November 10,1987
Start Time 4:00 p.m.
End Time 5:00 p.m.



A second instrumentation concern is the ability to measure large dynamic ranges. With the need to continuously measure both ambient and aircraft sounds in 1/3 octave bands, the dynamic range requirements can be greater than 80 dB. The dynamic range requirements for the MTR operations will be even higher. Analog tape recorders do not meet this dynamic range requirement. Only digital audio tape (DAT) recorders or in field use of real time analyzers with digital filters can achieve this dynamic range requirement.

we are not doing 1/3 bands

Not all park units would be expected to have sound levels as low as at Grand Canyon. This high desert setting (low humidity) is essentially void of any vegetation, wildlife noise or other natural sources that are more prevalent at other parks. However, instrumentation specified for the final program should have capabilities of measuring in these very quiet environments and meet the dynamic range requirements. There are special microphone/preamplifier systems available to measure very low sound levels.

Incorporation of the Threshold of Hearing. A second important consideration is that these sound levels measured at Grand Canyon were often below the level that most individuals are capable of hearing. Therefore, the detectability of an aircraft sound may not necessarily be relative to the background sound levels but to that particular listener's threshold of hearing. Detectability calculations should be relative to not only the background sound, but also the hearing threshold, whichever is greater. ?

dangerous strict [illegible] this

Defining the threshold of hearing is not an exacting proposition. Threshold of hearing varies with the population. The Minimum Audible Field (MAF) curve was presented in Exhibit 3-3 and in Exhibit B-2 of Appendix B. The MAF curve represents the sound pressure level of the threshold of hearing for young adults with normal hearing measured in a free field. It was determined for pure tones with the listener facing the source and listening with both ears. The threshold of hearing is not a sharp boundary, but is defined in terms of the probability of a sound being heard. The threshold of hearing is not equal in all frequencies with reduced sensitivity in the lower and higher frequencies. This curve is similar in shape to the A-weighted curve.

Note hearing sensitivity will vary between individuals and generally declines with age. Other curves have been developed that represent the average hearing threshold for the population or for defining normal hearing threshold for audiometry testing. These curves specify threshold of hearing levels higher than the MAF curve. The MAF curve is recommended for use in the NPS study because it is a measurement in the free field, as with the park settings, and it is a well established definition of minimum audibility.

Descriptor for Ambient and Background Sound Measurements. The ambient or background sounds are not steady state but vary with time. Because of these temporal variations, statistical metrics must be used to define these sound level conditions.

For the purposes of this study the ambient sound and background sound have specific meanings. The ambient sound environment is a measure of all sounds in the park, both natural and man made, except the sound from aircraft operations. The ambient sound levels are to be determined for representative time periods throughout the day. The background sound represents the residual sound environment, or the level from which all sounds, both aircraft and non-aircraft intrude. The background sound level is to be determined close to the time of each aircraft event.

Ambient Measurements. The ambient sound environment is to be determined for sample periods throughout the day. The sources of sounds effecting the ambient environment is to be documented. The purpose of these measurements are to document the ambient conditions that currently existing in the park system. The ambient measurement data to be reported is in terms of the LEQ noise level and the statistical L(n) levels. For each ambient sample period, the LEQ, Lmax, L10, L50, L90 and the L99 are to be determined for each 1/3 octave band level and the A-weighted level. The ambient sound levels should be recorded during extended periods when there is no aircraft activity.

agree

Background Measurements. Accurate information relative to the background sound levels is the most critical and variable element in quantifying the detectability of the aircraft events. Measuring the energy mean (LEQ) sound level for each 1/3 octave band for a limited duration is <u>not</u> sufficiently precise for defining the background sound levels.

The LEQ sound level is the energy mean sound level during the sample measurement period. The LEQ level would be highly sensitive to events such as vehicle pass-bys, wind gusts and even events caused by the individual making the measurements. These short duration events are part of the ambient sound environment, but will not mask the noise of the aircraft event unless these events have the identical temporal variability.

agree

A statistical metric that is less sensitive to short duration event sounds is more appropriate for defining the background sound environment in the park settings. The influence of temporal variations in the ambient sound levels are minimized by using the L90 descriptor (measured near the time period of the overflight) to represent the background sound level. In community noise analysis, the L90 A-weighted sound level has historically been used as representative of the background sound level. The L90 sound level is the sound level exceeded 90 percent of the time. It is representative of the residual noise environment. The background sound environment is illustrated in Exhibit 3-5. This exhibit shows that different events that take place during the sample period do not materially affect the background sound level. This background level is the level from which the aircraft event becomes intrusive.

An example of the L90 metric was presented in Exhibit 3-4 for the sample hour of measurement at Point Sublime. The results show that the L90 sound level is still 21 dBA, the level that the strip chart shows when no aircraft events occur, even though during the sample period there were many aircraft events. (In order to determine the background LEQ level, the level would need to be calculated only when aircraft are not present). Proper measurement of the LEQ metric for ambient levels in the park setting is highly sensitive to discretionary actions by the individual making the measurements (i.e., site location; time and duration of measurements; or sound caused by the field engineer). The L90 statistical metric is less sensitive to these variables that could influence the results.

This study recommends that the L90 sound level in each 1/3 octave band and the A-weighted L90 level be used to define the background sound level. This should be determined from a minimum sample period that was measured within a specified period of time from the aircraft overflight for which detectability will be calculated. (For example a ten minute sample that was measured within 15 minutes of the aircraft event. These limits are to be specified in the proposed measurement program.) The L90 descriptor best represents the background sound from which the intrusive levels of the aircraft event can be calculated. Intrusive sounds, both natural and un-natural will be audible when their sounds intrude into and above this background level.

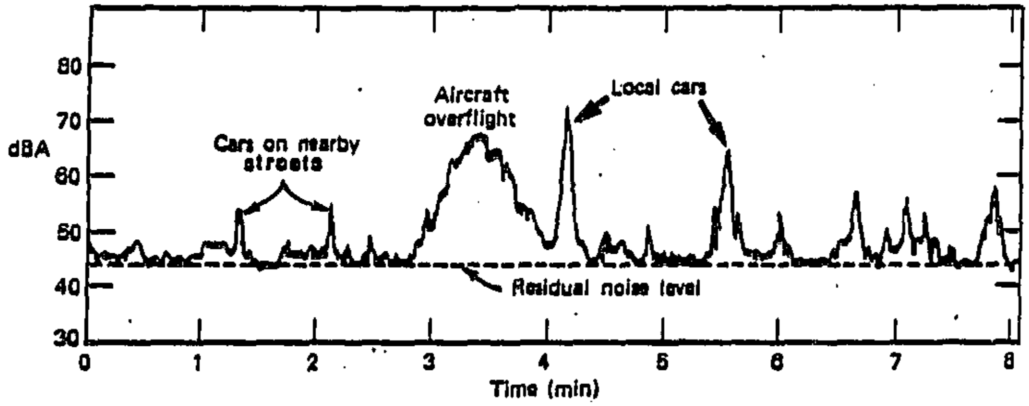
I still think these samp period are too short

Meteorological Considerations. The ambient sound environment (as well as aircraft sound) will be affected by meteorological conditions that are present during the time of the survey. Pertinent meteorological data was recorded during the noise survey and should be collected as part of all future surveys. This data includes wind speed, direction, temperature and humidity. The wind data is determined because in quiet sound environments, the wind can play a prominent role in the sound levels. The wind speed is the most important variable in determining the ambient sound level. For example, in Exhibit 3-3, the ambient levels at Shoshone are higher because of the higher wind levels.

* am not sure Dou would agree w/ mic readings at 5'.

Jakobsen (1983) in an effort to determine ambient wind noise categorized the wind noise measured by the microphones as : (1) natural wind noise, (2) vegetation noise, and (3) "microphone noise". Natural wind noise is the noise of the wind itself originating from

Exhibit 3-5
Illustration of Background Noise Levels



(Source: "Community Noise," NTID 300.3 EPA, December 1971) turbulence in the air. Vegetation noise results from the rattling of leaves and other vegetation excited by the wind. The microphone noise or "pseudo-noise" is the noise perceived by the microphone and originating from the air flow turbulence around the diaphragm of the microphone. An example of the effects of wind speed on the measured sound levels is presented in Exhibit 3-6.

Determining the contribution of the wind noise to the ambient sound environment and the role of this noise in the masking of the aircraft events is an important element of the ambient sound level analysis. The elimination of pseudo-noise from measurement results is highly desirable. If proper precautions are not taken to control pseudo-noise the measurement results may be much higher than actually existed.

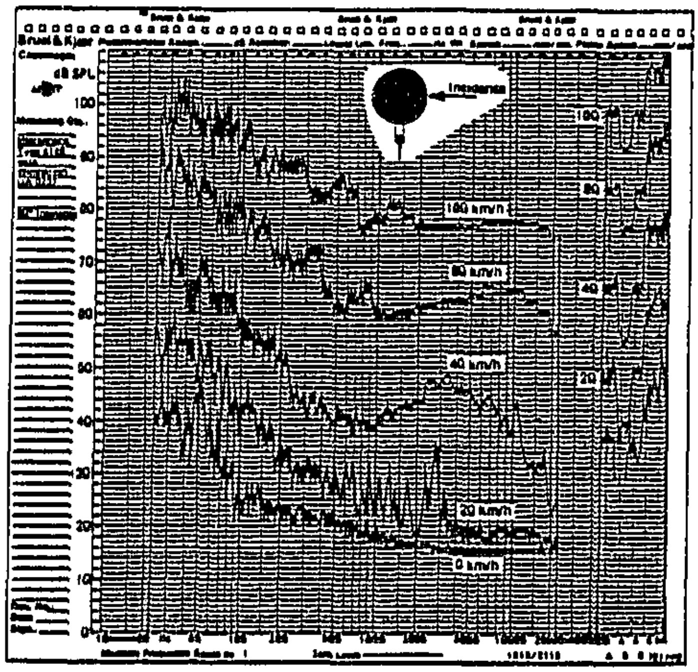
The first step in eliminating pseudo-noise is through the use of a proper windscreen. This usually consists of an open cell foam ball which is placed over the end of the microphone. The B&K wind screen (Model #UA0237) are recommended windscreens for use on this study.

The number of measurement days necessary to adequately describe the ambient sound environment will vary with the variability of the meteorological conditions. National Parks with a variety of meteorological conditions may require multiple days of measurements to quantify the ambient environment. Long term meteorological data from each study area can be correlated with the ambient measurements to facilitate the determination of the statistical distribution of the ambient environment. Statistical sample requirements to determine the ambient sound levels were analyzed from a large sample of sound data collected over a five year period at Grand Tetons National Park. This analysis is presented in Section 4.1.

3.1.5 Aircraft Noise

Results. The measurement survey showed that there are a large number of aircraft operating in and around Grand Canyon. The measurement sites averaged 145 aircraft events per twenty-four hour period. The maximum sound level from these events typically ranged from 30 to 50 dBA. Given the low background sound levels, these events were 10 to 40 dBA above the background level. As a result of these low background levels, these aircraft operations were clearly audible for extended durations and had very slow onset rates. Most aircraft events were audible for 2 to 6 minutes.

Exhibit 3-6
Effects of Wind on Measured Sound Levels



Source: Bruel & Kjaer, Data Handbook for Condenser Microphones

The results of sample aircraft measurements at Grand Canyon are presented in Appendix D. For illustrative purposes, five events are presented within the text (Exhibits 3-7 through 3-11), with one sample measurement for each site. The data contained in these exhibits is discussed in the following paragraphs.

The top section of these exhibits describes the site location, the type of aircraft, flight track of the aircraft, date and time of the event, and meteorological conditions. The middle section of these exhibits summarizes both the spectral and A-weighted results. The spectral information presented includes: the critical frequency (i.e., the frequency for the highest detectability level), the delta value in the frequency (i.e., the difference between the aircraft peak hold level and the background sound level/Minimum Audible Field), and the detectability value for the critical frequency. For these preliminary measurements, detectability was calculated for the maximum D' value in any frequency. The use of different methods of calculating D' was investigated in the Hawaii Volcanoes measurements.

The A-weighted information presented includes: the aircraft maximum sound level, the ambient L90 level during the hour of that particular aircraft event, the difference between the aircraft and ambient level, and the effective duration of the event (defined for these preliminary measurements as the time above the L90 sound level plus 3 dBA). The A-weighted strip chart recording for that event is also shown.

The bottom section of these exhibits presents the 1/3 octave spectral data. The top graph presents the peak hold spectral levels for the aircraft event, the ambient levels and the MAF curve. The middle graph shows the difference between the aircraft peak hold level and the ambient or MAF level, which ever is greater. The bottom graph presents the aircraft peak hold and ambient level with the A-weighted correction. This is presented to illustrate which frequencies are most important in terms of human response to noise.

Exhibit 3-12 presents spectral data for different time periods of the overflight for the Point Sublime helicopter event (Exhibit 3-11). This exhibit shows the spectral data for the peak hold level as well as the spectral data as the helicopter approaches the site from the east (52 seconds before the maximum), the spectral levels at the A-weighted maximum sound level, and the spectral levels as the helicopter departs to the south (104 seconds after the maximum). In addition, the SEL level for each frequency band is also shown.

A number of observations can be drawn from these exhibits. For example, the critical frequency in terms of the detectability calculation is not necessarily constant

Exhibit 3-7
Sample Horn Aircraft Data (GCNP)

General Aviation - Single Engine
Over River to East @ 8500' (est)

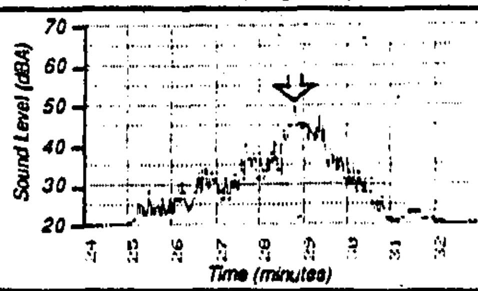
11/12/87 3:30 p.m.

Weather:
S @ 0-3 Clear
64°F 45% Humidity

Measurement Results:-

Critical f = 250 Hz
Delta (Max vs. Amb/MAF) = 34 dB
D' = 39

Aircraft (Max) = 50 dBA
Ambient (L90) = 20 dBA
Delta (Max vs. Amb) = 30 dBA
Duration (L90 +3) = 267 Seconds



1/3 Octave Spectral Data:

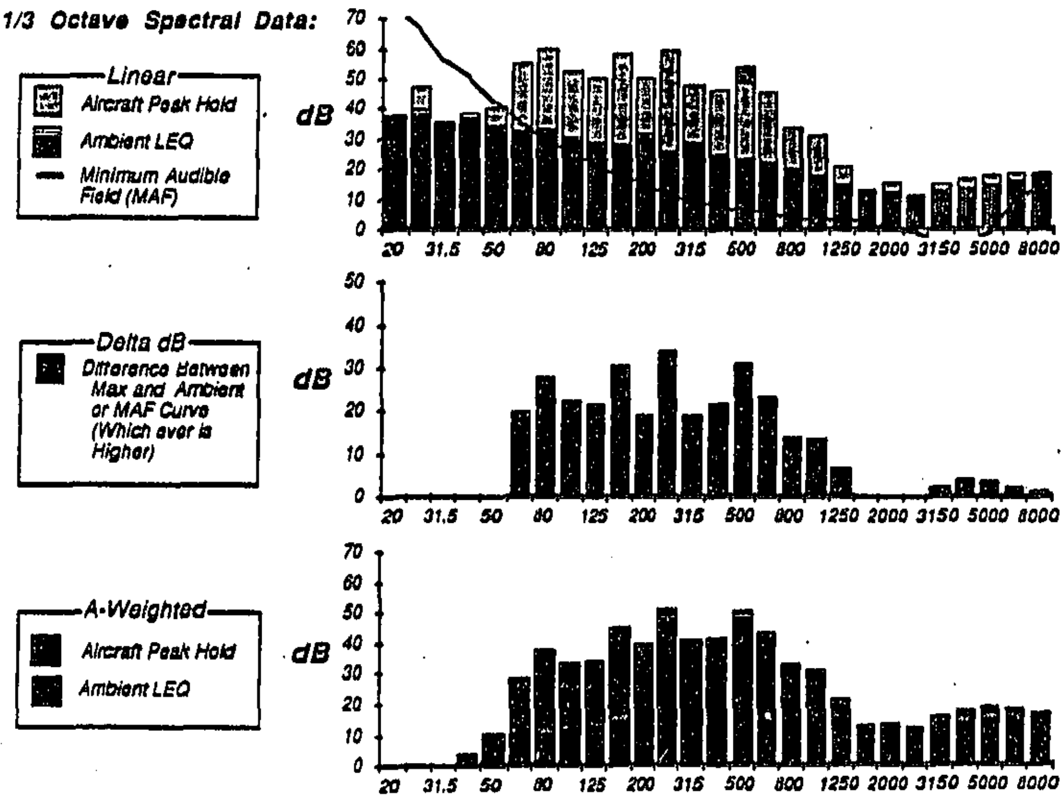
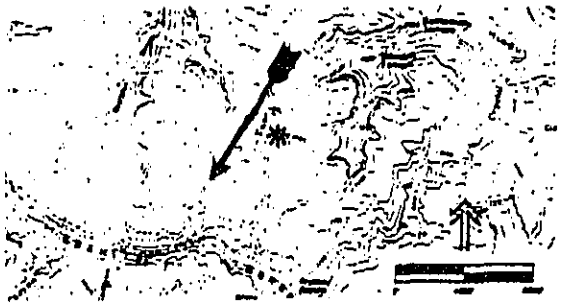


Exhibit 3-8
Sample Crystal Aircraft Data (GCNP)

Enroute Jet
High Altitude to South

11/12/87 8:16 p.m.

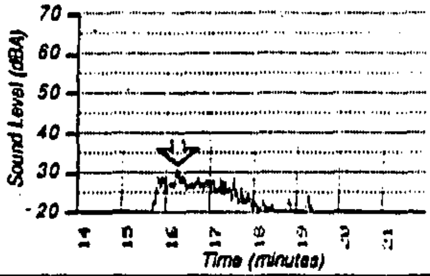
Weather:
S @ 0-3 Clear
56°F 49% Humidity



Measurement Results:

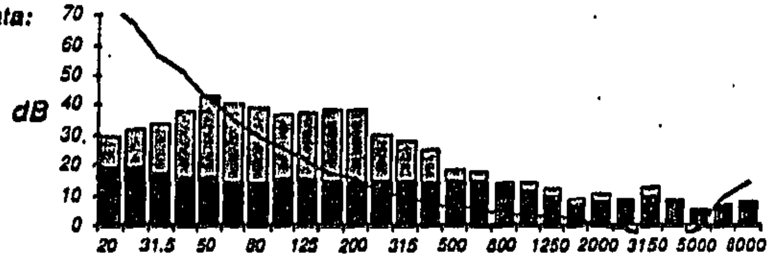
Critical f = 200 Hz
Delta (Max.vs. Amb/MAF) = 24 dB
D' = 28

Aircraft (Max) = 31 dBA
Ambient (L90) = 20 dBA
Delta (Max vs. Amb.) = 11 dBA
Duration (L90 +3) = 130 Seconds

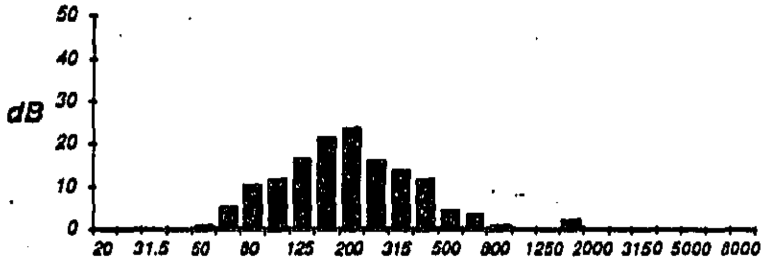


1/3 Octave Spectral Data:

Linear
- Aircraft Peak Hold
- Ambient LEQ
- Minimum Audible Field (MAF)



Delta dB
- Difference Between Max and Ambient or MAF Curve (Which ever is Higher)



A-Weighted
- Aircraft Peak Hold
- Ambient LEQ

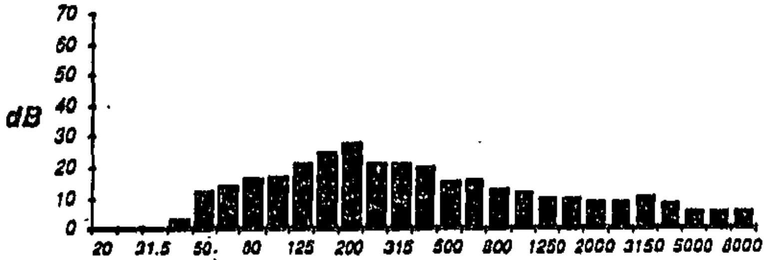
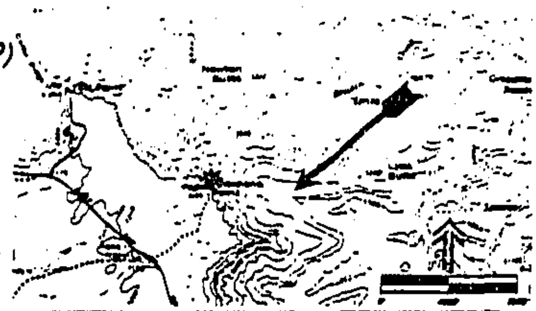


Exhibit 3-9
Sample Shoshone Pt. Aircraft Data (GCNP)



Fixed Wing Tour - Twin Otter
Approach To Grand Canyon Airport

11/13/87 4:55 p.m.

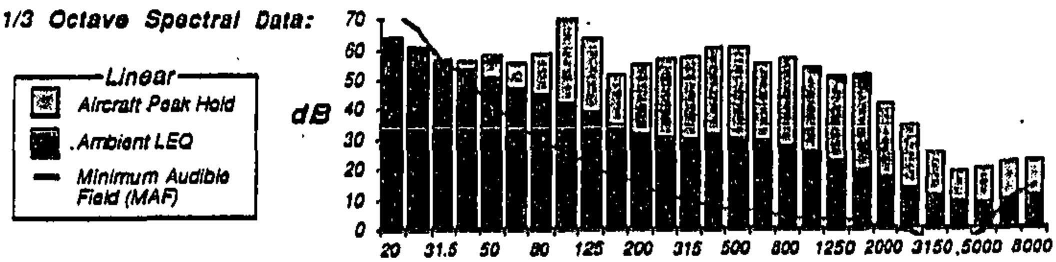
Weather:
S @ 10 to 20 E120 -OVC
45°F 66% Humidity

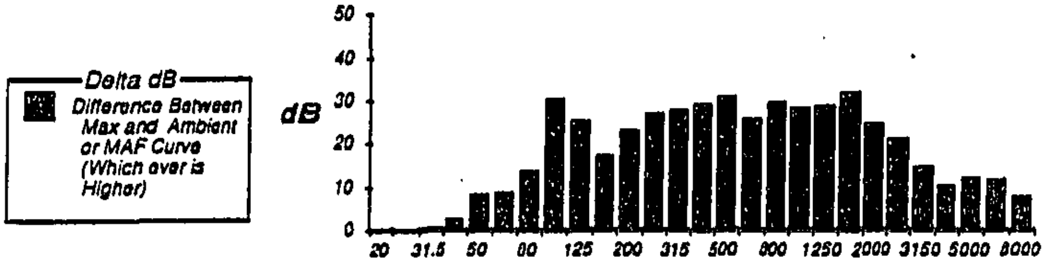
Measurement Results:

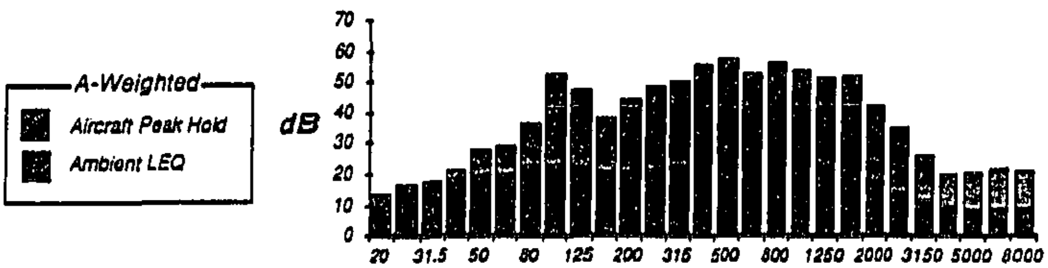
Critical f = 1600 Hz
Delta (Max vs. Amb/MAF) = 32 dB
D' = 41

Aircraft (Max) = 59 dBA
Ambient (L90) = 36 dBA
Delta (Max vs. Amb.) = 23 dBA
Duration (L90 +3) = 90 Seconds (est)

1/3 Octave Spectral Data:







1/3 Octave Bands

Exhibit 3-10
Sample Huxley Terrace Aircraft Data (GCNP)

Fixed Wing Tour
Over Site to East @ 7500'

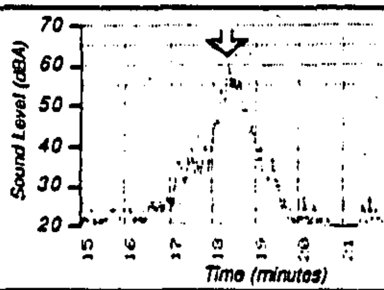
11/11/87 11:16 a.m.

Weather:
E @ 0-3 Clear
50°F 60% Humidity

Measurement Results:

Critical f = 400 Hz
Delta (Max vs. Amb/MAF) = 48 dB
D' = 54

Aircraft (Max) = 61 dBA
Ambient (L90) = 21 dBA
Delta (Max vs. Amb) = 40 dBA
Duration (L90 +3) = 180 Seconds



1/3 Octave Spectral Data:

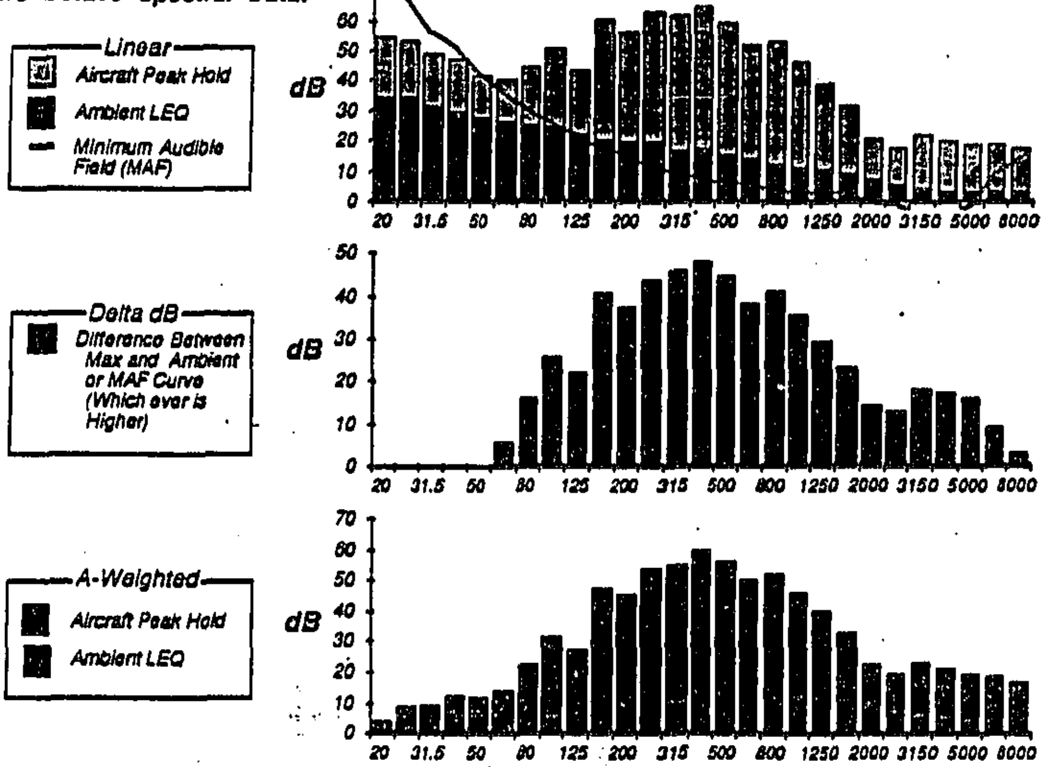


Exhibit 3-11
Sample Point Sublime Aircraft Data
(GCNP)

Tour Helicopter- Bell 206
Point Sublime Tour

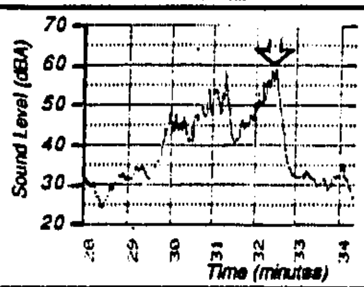
11/11/87 10:29 p.m.

Weather:
W @ 3-5 Clear
42°F 75% Humidity

Measurement Results:

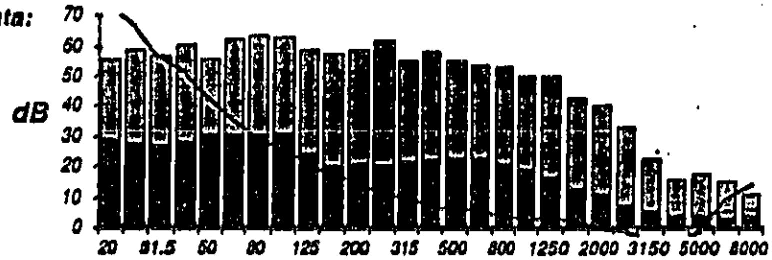
Critical f = 250 Hz
Delta (Max vs. Amb/MAF) = 42 dB
D' = 47

Aircraft (Max) = 59 dBA
Ambient (L90) = 25 dBA
Delta (Max vs. Amb.) = 34 dBA
Duration (L90 +3) = 193 Seconds

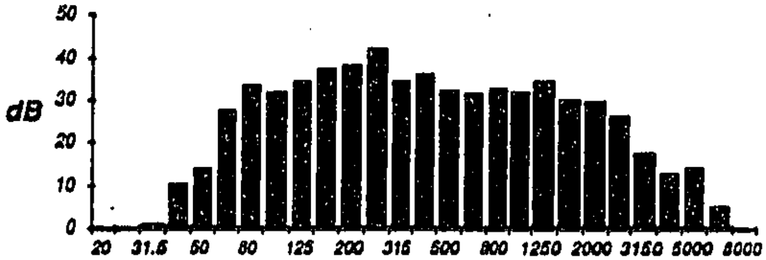


1/3 Octave Spectral Data:

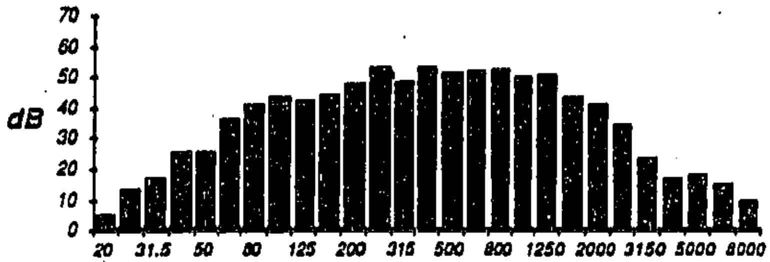
Linear
- Aircraft Peak Hold
- Ambient LEQ
- Minimum Audible Field (MAF)



Delta dB
- Difference Between Max and Ambient or MAF Curve (Which ever is Higher)



A-Weighted
- Aircraft Peak Hold
- Ambient LEQ

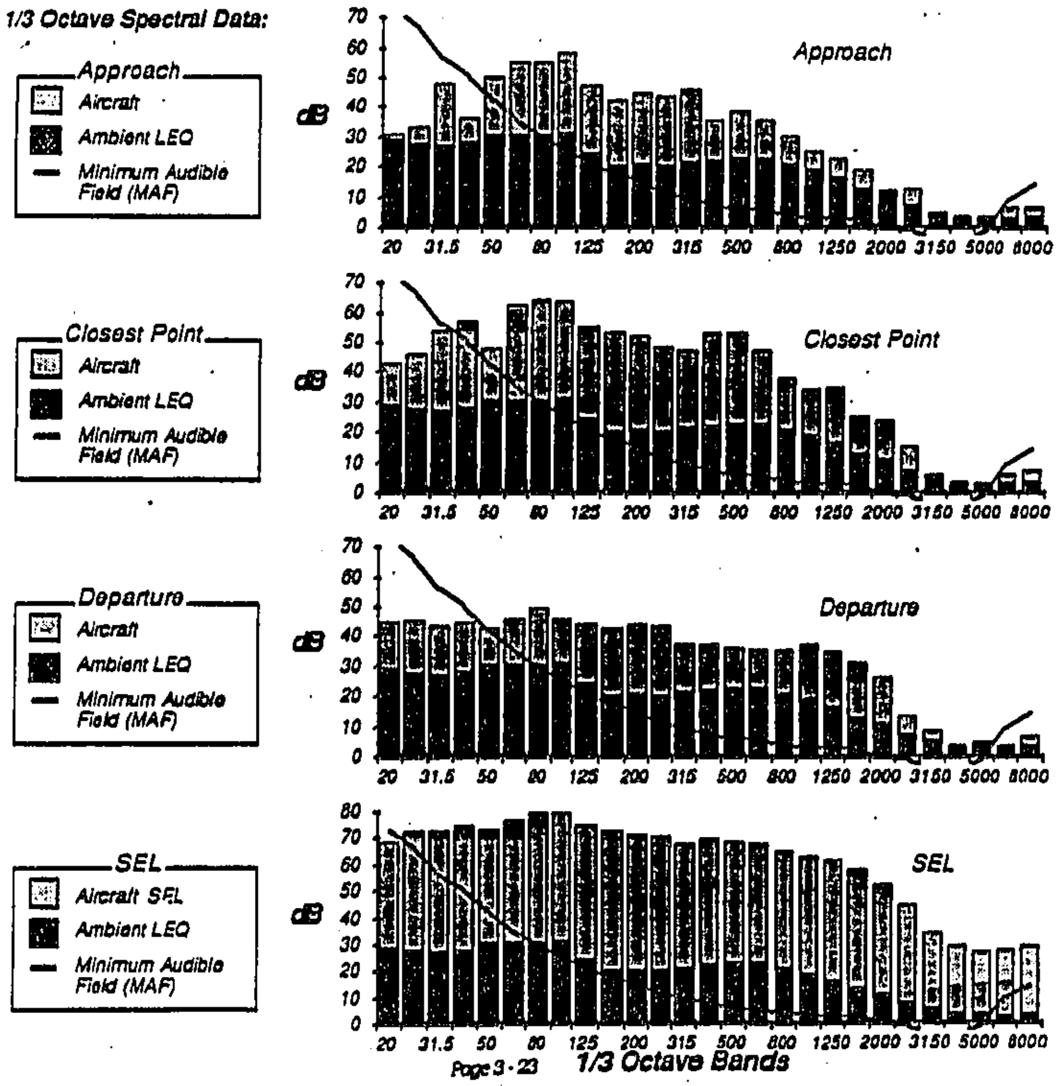


1/3 Octave Bands

Exhibit 3-12
Point Sublime Helicopter Example Frequency Data (GCNP)

Tour Helicopter- Bell 206
Point Sublime Tour

11/11/87 10:29 p.m.



throughout the event. Note that the dominate helicopter frequency is different toward the front of the helicopter (approaching the site) than the rear of the craft (departing the site). Also note that the critical SEL sound level frequency is shifted towards the lower frequencies. The audibility will begin and end with the lower frequencies, while the peak detectability sound occurs at a higher frequency. Note also that the critical frequency is higher in higher wind conditions (Exhibit 3-9).

The effective duration of the events was found to be an important acoustic factor in describing the aircraft sound. Effective duration information was also calculated for each of the four 24-hour sites. For these preliminary measurements, the effective duration was defined as the time above the L90 A-weighted sound level plus 3 dBA. Note that this is a conservation definition with the actual duration that the aircraft was audible being somewhat longer. These results were determined from the strip chart recordings from the B&K 4427. A sample of these recordings was presented in Exhibit 3-4. The total number of aircraft events and the duration of these events for the Crystal site is presented in Appendix D, Table D-1. This table also presents the type of aircraft, flight track, maximum A-weighted sound level, and the level above the ambient for each of these flights.

At the Crystal site a total of 134 aircraft were observed during a twenty-four hour period. These aircraft were audible to the field engineer for over 5 hours, of which over 90% of these operations were during the eight hour time period of an hour after sunrise and an hour before sunset; and this survey was completed during the off-peak tourism season. The effective durations for each of the measurement sites is summarized in Table 3-1.

Table 3-1
Summary of Aircraft Effective Durations
(Time Above L90 + 3 dBA)

Location	Duration Aircraft Audible (Hours/Day)
Pt. Sublime	5.1
Huxley Terrace	4.0
Crystal	5.0
Horn	4.2

For comparative purposes, the duration above the ambient sound environment was estimated for locations around two sample airports. The example locations are (1) under the approach pattern to Los Angeles International, a major commercial airport, and (2) under the departure pattern for Santa Monica Municipal Airport, a busy general aviation airport. The audible duration for these airports was estimated using the Time Above subroutine from the FAA's Integrated Noise Model.

The results of these estimations are presented in Table 3-2. This table also presents the DNL sound level at these representative locations. The results show the effective duration of aircraft noise at Grand Canyon is higher than around these sample airports. This analysis is not intended to infer that the sound levels at Grand Canyon are more severe than around major airports, but to illustrate that audible duration is an important acoustic factor in describing aircraft sound in the wilderness setting.

Table 3-2
Time Above for Sample Airports

AIRPORT	DNL NOISE LEVEL*	TIME ABOVE 50dBA
Los Angeles International Airport	65	3.8 hrs.
Santa Monica Municipal Airport	57	2.0 hrs.

* - Shows DNL level at representative location selected to illustrate Time Above.

An additional important observation from the measurements was that the aircraft operations were characterized by very slow onset rates. The onset rate, or rise time, is the rate of change of the sound until it reaches its maximum. Sounds with very slow onset rates have been found to be more disturbing. In quiet backgrounds the aircraft are audible over large distances. For these far off aircraft, the rate of change of the distance between source and receiver is slow, resulting in slow changes in the sound level. Research has shown that sounds with slow onset rates are more disturbing as a result of uncertainty as to the eventual maximum of the sound.

Conclusions and Recommendations. Many factors influence how a sound is perceived and whether or not it is considered annoying to a listener. Acoustic factors found to be important in describing these aircraft sounds in park/wilderness settings are listed below. All of these factors vary in different background sound level. Each of these elements are discussed in greater detail in the next paragraphs.

Audible Duration of the Aircraft Sound
Aircraft Sound Level (Relative and Absolute)
Onset Rate of the Aircraft Sound
Number of Aircraft Overflights per Day

Audible Duration of the Aircraft Sound. An important acoustic factor in describing the acoustic impact from aircraft operations in a park setting is determining when a particular aircraft becomes audible and for what duration. Studies have shown that in low-level sound settings, signal detection or audibility can be the most important factor in predicting annoyance. Duration of aircraft events in the Grand Canyon was determined from a simple estimation based on the A-weighted data. This method proved adequate for the unusually quiet and stable setting in the Grand Canyon measurements, but is not sufficiently exacting or precise for all park applications or settings.

A more precise method of defining duration can be obtained from detectability. The total time that an aircraft event exceeds a specific detectability value could be determined. The advantages to using this definition of duration include: (1) it is a mathematical relationship that is repeatable, and can be included in a computer program that calculates both detectability and duration, (2) detectability has some support from existing acoustic research in describing annoyance in low-level sound settings, and (3) this method would be applicable to more varied park conditions.

An important factor is the level of detectability to be used to define audibility. The Fidell research has shown that a detectability (D') of 3.8 will result in a 50 percent correct detection of an aircraft event. *(Note the numerical values derived from d' can be misleading for this application, and are better presented on the logarithmic scale. For this study all detectability levels are presented as 10log(d') or D').* It is important to note that this low signal detection level is for a military observer actively listening for an aircraft and whose life may depend on correctly identifying that aircraft. The research has shown that a D' of 13 is a detectable sound to individuals performing another task other than solely identifying a sound; but the observer was still actively listening for that sound. These studies have shown that, D' values of 16 or greater are generally intrusive. These higher values more appropriately reflect the park setting, where users will be hiking, sight seeing, or participating in some other activity other than looking for aircraft.

It is therefore proposed that a D' of 13 to 16 be used to define minimum audibility and to determine the effective duration of a given aircraft event. This value is reasonable in light of the fact that people using a national park are not usually actively listening for an aircraft. In addition, lower levels of D' are difficult to measure with reliability, and these values do not accurately represent those people using the park for recreational purposes.

D' exceeding other levels of intrusiveness should also be calculated. The sociological surveys may determine that one of these other detectability levels more accurately reflects visitor response to the aircraft sound. This information may ultimately be used to develop a "Time Above" descriptor to rate different levels of intrusiveness for the total durations for all the operations for the day. Measuring duration requires the ability to continuously sample so that the start of an event can be measured. This was not practical with the portable analog tape recorders used in Grand Canyon. The measurement system for future measurements must be capable of continuous sampling.

Aircraft Sound Level. Various sound rating scales are available for describing the "loudness" or "noisiness" of the aircraft sounds and were reviewed for their suitability in these wilderness settings. The results of the Grand Canyon measurements showed that the background sound level influenced the perception of these aircraft sounds and these rating scales should be determined relative to the background level. The important criteria for selecting the rating scales are: (1) correlation to park user response to the noise, (2) applicability to all park settings, (3) support for metric with psychoacoustic research, and (4) simplicity of determination. Three preliminary rating scales were reviewed at Grand Canyon and are presented below. All of these rating scales are determined relative to the background sound level.

Highest Detectability Level
A-weighted Level above Background
SEL sound level for the audible duration of the event

Sample aircraft events from the Grand Canyon measurements were used to calculate the relative sound level based upon each of these metrics. Table 3-3 presents the sound level for these sample aircraft and the sound level for each metric. This table also shows the measurement location, the aircraft type, A-weighted maximum and the duration

Table 3-3
SUMMARY NOISE LEVEL DATA FOR SAMPLE AIRCRAFT EVENTS

Location	Aircraft	Duration (sec) L90 + 3 dBA	Max Level dBA	D' '10logd'	A-wt. Diff Lmax-L90	Δ	SEL over max 1/3 Octave A-wt.
Pt. Sublime	Twin Piston	220	37	40	17	23	44
	Helicopter	205	50	37	29	11	46
	ENR Jet	115	45	37	21	16	38
	ENR Jet	- -	46	40	22	18	48
	Twin Piston	175	50	47	28	19	49
	Helicopter	193	59	47	34	13	47
Crystal	Twin Otter	150	49	49	27	22	51
	ENR Jet	185	41	36	21	15	41
	Single Engine	250	48	48	28	20	51
	Twin Piston	85	52	52	32	20	54
	ENR Jet	130	31	28	11	17	36
	Helicopter	355	55	52	35	17	54
Huxley Terr.	Twin Piston	180	61	54	40	16	54
	Single Engine	164	55	48	35	13	52
Shoshone Pt.	ENR Jet	230	51	32	15	14	39
	Twin Otter	90	59	41	23	14	39
Horn	Single Engine	267	50	39	30	9	43
	Twin Piston	190	54	44	33	11	48
	ENR Jet	140	40	32	20	12	44
	Helicopter	340	31	29	11	18	41

avg = 16.3

σ = 3.73

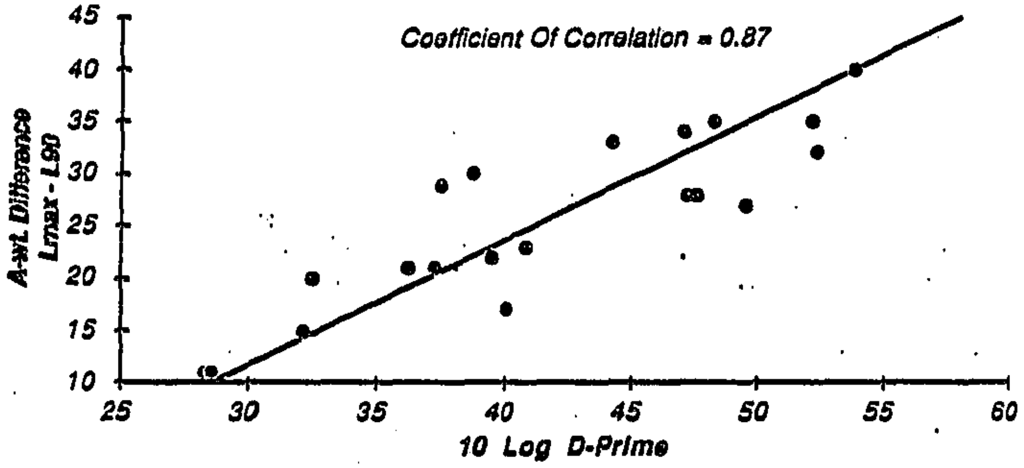
based upon the L90 + 3 dBA formula. Each of these metrics and their strengths and weakness relative to their application to this study are presented in the following paragraphs.

> *Highest Detectability Level.* This is the metric proposed for use in the study. Research has demonstrated that annoyance of low-level sounds may be predicted with detectability. However, D' has not yet been tested to predict annoyance in an outdoor setting where both the source and background vary with respect to amplitude, frequency and temporal domains. Detectability also does not account for differences in how sounds are perceived in different background settings.
>
> *A-weighted Level Above Background.* This metric is the simplest and most understandable of all the possible metrics. It can be simply calculated by subtracting the maximum A-weighted aircraft sound level from the ambient L90 sound level. It adequately presented the relative sound level of the aircraft operations during the Grand Canyon measurements. Its limitations are that it may not be adequate in all park settings, especially at locations with higher background sound levels. Because of its simplicity, no matter what other metric is selected, the A-weighted levels should also be reported.
>
> *SEL sound level for the audible duration of the event.* The SEL level is useful because it takes into account not only the loudness of an event but the duration of the event. SEL is commonly used in aircraft noise modeling, however, there is very little community response research relative to the SEL level alone. In addition, SEL is based upon the equivalent energy principal that may not hold true in low level sound applications. The SEL value can be calculated for each frequency band or a summation of all of the frequencies.

The relationship between the highest detectability and the relative A-weighted level above the background is shown graphically in Exhibit 3-13. These results show good correlation between each of these potential metrics. In essence, each metric tended to describe similar levels of relative sound. However, these results were determined under ideal measurement conditions with little or no background sounds. The signal to noise ratios ranged from 11 to 40 dBA. In other settings, one of these metric may be found to be more useful. However, a correlation may be developed that allows for some A-weighted measurements to supplement the more costly spectral measurements.

It is necessary to also determine the absolute sound levels of the aircraft, not just relative to the background level. This is especially important with the higher sound levels. Sound with the same relative loudness can be perceived differently in different background

Exhibit 3-13
Comparison of Noise Measurement Descriptors (GCNP)



sounds. The primary acoustic effect of the low background sound levels is not that otherwise quiet sounds appear loud, but that sounds that would normally not be audible are now clearly audible, and are audible for extended durations.

These potential sound rating scales, in addition to Loudness Level and Perceived Noise Level, were reviewed in the Hawaii Volcanoes measurements (Section 3.2) for suitability in describing the aircraft sounds within the park setting. The selection of a sound rating scale is to be completed in concert with the sociological surveys. The proposed measurement program is to be capable of determining any of these possible descriptors.

Onset Rate of the Aircraft Sound. Sounds with slow onset rates (long rise times) have been found to be more disturbing than sounds that reach their maximum in less than 3 seconds. The aircraft overflights at Grand Canyon where characterized by very slow onset rates, where the maximum sound level was not reached for many minutes. These onset rates averaged less than 0.2 dBA per second. There is little research to suggest an appropriate penalty to apply to sounds with very slow onset rates. However, the effects of this acoustic factor should be examined as part of the sociological surveys. It is recommended that the onset rate be determined for sample aircraft operations to document the slow onset rates. Determining the onset rate for all aircraft is not necessary, because the relative difference between these rates appears to be insignificant.

Number of Aircraft Overflights Per Day. An important element in addressing the acoustic impacts of aircraft operations in National Parks is an accurate assessment of the number and type of aircraft operating over the parks. Although the number of overflight incidents over some park units are thought to be extensive, the actual number has not been clearly determined. The measurement sites at Grand Canyon averaged 145 aircraft overflights in a 24-hour period.

A standardized methodology for the identification of the levels of aircraft operating over park units has been developed. This methodology is presented in Section 4.3. This program is designed to determined not only the total number of operations, but also the type, time of day, flight patterns and seasonal variations. The number of operations is to be used during the sound measurement survey, the sociological survey, and a sufficient number of additional days that may be necessary in order to gain a confident level of knowledge of the total number of operations.

Section 3.2
HAWAII VOLCANOES NATIONAL PARK MEASUREMENTS

3.2.1 Site Selection

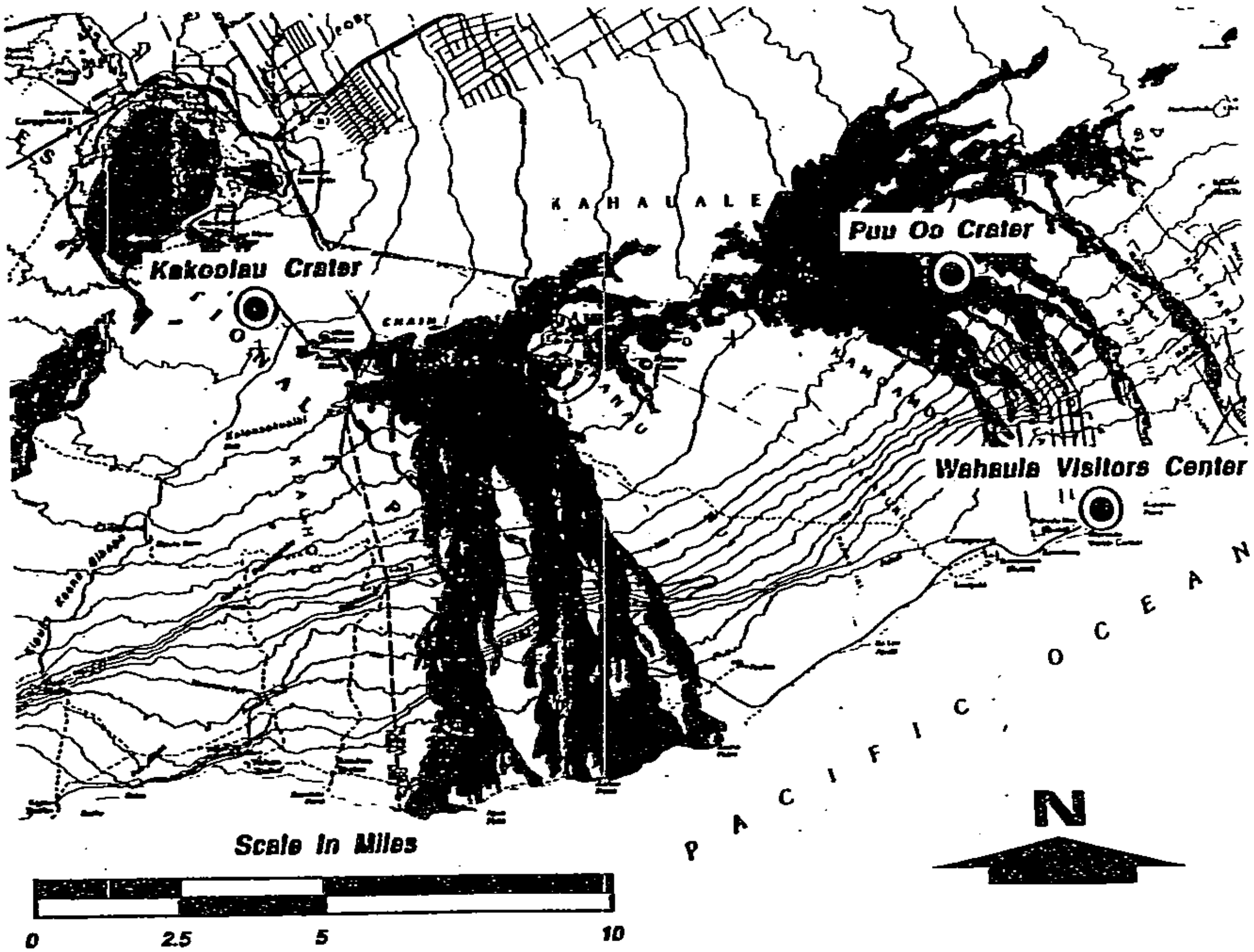
Hawaii Volcanoes National Park (HVNP) was selected for the second phase sound measurements. Aircraft operations at this park are predominantly tour helicopter flights. The helicopters ferry tourists and scientists who desire to view or study current and previous lava flows in the rugged park. Other types of operations include tour and general aviation fixed wing aircraft overflights and transient military helicopter operations.

The noise measurements were conducted from January 24th to January 28th 1988, at three locations in the Park (Exhibit 3-14). These sites were chosen to represent various ambient and aircraft conditions along active flight corridors. The methodology for selection of these sites were the same as those used in Grand Canyon (Section 3.1.1). The Wahaula Visitors Center site is located near an area where lava is actively flowing into the ocean. This attracts most of the island's sightseeing tour helicopter flights as well as fixed wing aircraft flying along the coast. The tour helicopters would generally remain in the area for a number of minutes viewing the lava. The Kokoolau Crater and the Puu Oo Crater sites are inland park areas and are located along common helicopter flight corridors. Both the Wahaula Visitors Center and Kokoolau Crater sites are accessible front country locations, while the Puu Oo Crater site is a remote backcountry location.

3.2.2 Measurement Equipment

The Grand Canyon measurement survey identified acoustic factors that are important for describing aircraft sounds in the wilderness setting and recommends instrumentation requirements necessary to determine this information. The results showed that specialized spectral measurement instrumentation is required in order to adequately measure the ambient and aircraft sounds in these settings. DAT tape recorders or in field use of real time analyzers (RTA) with digital filters were recommended for the future measurements. The Hawaii Volcanoes sound measurements utilized a real time analyzer. DAT tape recorders were not yet available at the time of this survey.

Exhibit 3-14
Noise Measurement Locations (HVNP)



The noise monitoring system used in Hawaii Volcanoes was a programmable real time frequency analyzer (RTA), Model 830, manufactured by Norwegian Electronics, Inc. The instrument performs real time 1/3 octave analysis of the sound using digital filters. Signal input to the system was provided by either a 1 inch B&K Model 4161 microphone with a Model 2639 preamplifier or a B&K 2230 sound level meter with a 1/2 inch B&K 4155 microphone. A listing of the equipment by model and serial number used in the measurements is contained in Appendix C. This measurement system complies with the ANSI Standards 1.4-1983 for Type 1 precision noise measurement instrumentation and ANSI Standard S1.11 1986 Class III for 1/3 octave filters. This type and class are the most stringent ANSI standard for outdoor noise measurement systems.

The concept of a portable RTA was used in order to evaluate the potential for gathering and analyzing all data in the field, thus eliminating the need for costly and time consuming follow-up laboratory analysis. The system was programmed to capture the relevant data needed to determine ambient and aircraft sound levels. This instrumentation setup was invaluable, in that it enabled real time in-the-field illustration of detectability as the aircraft event was taking place.

3.2.3 Measurement Procedures

The Grand Canyon measurements identified the importance of determining the time duration of the aircraft event and the background sound levels at the time of the event. In order to determine the total duration of an overflight, it is necessary to have a continuous measurement of the sound environment. Tape recording the sound using the analog tape recorders used in Grand Canyon was not practical, because it is difficult to measure the start of the event. The procedures utilized for these measurements were designed for continuous real time measurement of spectral noise data in the field using the real time analyzer. Specific time periods of interest were later analyzed by computer to determine specific sound metrics of interest. Microphone height, calibration, wind screens and meteorological data collection procedures were the same as described for the Grand Canyon measurements.

The Norwegian Electronics 830 real time analyzer was set up for continuous measurement of ambient and aircraft sound levels. The instrument was programmed to continuously calculate 1-second LEQ values for each 1/3 octave band (20 Hz to 10,000 Hz) and the A-weighted sound level. The systems internal memory continuously stores each

1-second spectra for the prior 12 minutes of sampled data. This data can be manually stored to disk for later analysis by a computer.

Ambient sound levels were determined during periods when aircraft were not visible or audible to the field engineer. These measurements were conducted on the average of every two hours or when changing meteorological conditions dictated an additional sample. These ambient samples were 12 minutes in duration.

Aircraft sound levels were measured in the same manner. At the end of an aircraft event, this 12 minutes of data was manually stored to disk. The field engineer noted the beginning and ending time of each aircraft event, as well as the type of aircraft which caused the event, and its approximate flight track and altitude. This 12 minute sample of spectral data would generally include the total duration of the sound from the aircraft overflight as well as background sound levels that were present both before and after the event.

The 12 minute sample of spectral data was transferred to a computer that was programmed to calculate a number of potential sound descriptors. This included sound rating scales for both ambient and aircraft data. The detectability level for the complete time history of the aircraft overflight was determined from the data.

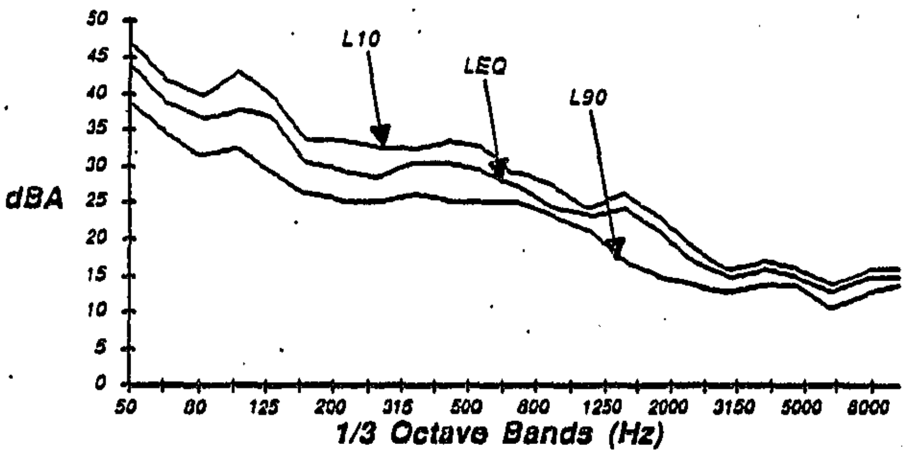
An advantage to this measurement procedure was the ability to instantaneously observe detectability. The background sound level spectrum was overlayed over the time history of the overflight to illustrate the spectral characteristics of the aircraft event relative to the background levels. This allowed for the field engineer and park service personnel to correlate real time detectability levels with actual field experience.

3.2.4 Results

The ambient sound levels measured at Hawaii Volcanoes were not as quiet as were measured at Grand Canyon. The ambient sound levels were influenced by the prevailing tradewinds, the surf, animal, and vegetation noise that were not found at Grand Canyon. Vehicular traffic on park roadways was also a contributor to the ambient environment.

An example of ambient sound measurement results for the Kokoolau Crater site is presented in Exhibit 3-15. This exhibit shows the L10, L90 and LEQ sound level in each 1/3 octave bands for a sample time period. Note the spike in the results at 1250 Hz. This was a

Exhibit 3-15
Sample Kakoolau Crater Ambient Noise Levels (HVNP)



result of noise from occasional vehicles passing over a cattle crossing in a roadway approximately 500 feet away. This occasional short duration sound did not materially affect the L90 descriptor while the LEQ value shows an increase. This very short duration sound would not influence the ability of an individual to hear an approaching aircraft. The temporal characteristics of this sound is much shorter than the aircraft sounds. This illustrates how the L90 descriptor minimizes the influence of sounds with shorter temporal characteristics in describing the background sound level..

The total number of aircraft operations over this park was less than at Grand Canyon. Ninety percent of these operations were tour helicopters. The maximum sound levels from these operations were generally higher and the durations were shorter than at Grand Canyon. This is a result of the aircraft operating at lower altitudes (less than 1,000 feet agl). The higher background sound levels also played a role in reducing the total time that these aircraft were audible. Maximum detectability also took place at a higher frequency.

At the Kokoolau Crater site, typical maximum sound levels were 50 to 75 dBA with effective durations of less than 1 minute (The effective duration was defined for these measurements as the time above a D' of 13). The maximum noise levels measured at the Wahaula Visitors Center site were lower, however the durations were much longer. The lower noise levels and longer durations was a result of these aircraft not directly flying overhead, but circling around the lava flows for a number of different passes. Many of these aircraft remained in the area for up to 20 minutes.

Sample measurement results data for Kokoolau Crater and Wahaula Visitors Center sites are presented in Exhibits 3-16 and 3-17 respectively. Additional data is presented in Appendix D - Noise Measurement Results. These exhibits present the calculated noise data for each event, including A-weighted, Loudness Level, Perceived Noise Level, Detectability, and the time durations above specific Detectability levels. The bottom portion of the exhibits present the time history of the events in terms of both the A-weighted sound level and the D' level.

A potential sound metric of interest is the total time throughout the day that the sound levels from aircraft overflights exceed specific levels of detectability. Based upon the measurement results and an estimate of the average number of daily operations, the total average daily Time Above specific detectability levels (TAD') were estimated. Rough estimates of operations at the Kokoolau Crater site were 25 overflights per day, at the Puu

Exhibit 3-16
Sample Kakoolau Crater Aircraft Data (HVNP)

1/27/93 2:44 p.m.

Weather:
S @ 5 kts E18 BKN E40 OVC
67 °F 75 % Humidity

Bell 206 Helicopter
East of Site to South @ 800' AGL (est.)

D-Prime
Critical f = 200 Hz
Delta (Max vs. Amb/MAF) = 35 dB
D-Prime = 10,800 10logd' = 40

A-Weighted
Aircraft (Max) = 59 dBA
Ambient (L90) = 34 dBA
Delta (Max vs. Amb.) = 25 dBA

Loudness Level (ISO 532B)
Aircraft (Max) = 78 Phons
Ambient = 52 Phons

Perceived Noise Level (Tone Corrected)
Aircraft (Max) = 72 PNdB
Ambient = 41 PNdB

MD 500 Helicopter
West of Site to North @ 500' AGL (est.)

D-Prime
Critical f = 400 Hz
Delta (Max vs. Amb/MAF) = 48 dB
D-Prime = 242,077 10logd' = 54

A-Weighted
Aircraft (Max) = 74 dBA
Ambient (L90) = 34 dBA
Delta (Max vs. Amb.) = 40 dBA

Loudness Level (ISO 532B)
Aircraft (Max) = 94 Phons
Ambient = 52 Phons

Perceived Noise Level (Tone Corrected)
Aircraft (Max) = 89 PNdB
Ambient = 41 PNdB

Duration Above d' for both events

d' 20	10logd' 13	140 sec.
d' 40	10logd' 16	123 Sec.
d' 63	10logd' 18	98 sec.
d' 100	10logd' 20	94 sec.
d' 200	10logd' 23	91 sec.
d' 630	10logd' 28	64 sec.
d' 2000	10logd' 33	47 sec.
d' 6300	10logd' 38	23 sec.
d' 20000	10logd' 43	13 sec.
d' 63000	10logd' 48	10 sec.

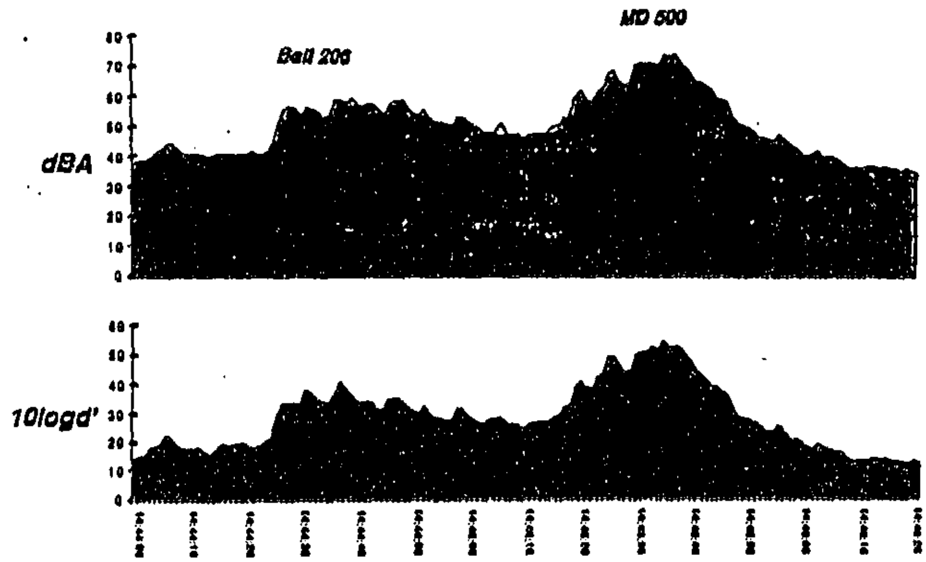


Exhibit 3-17
Sample Wahaula Center Aircraft Data (HVNP)

1/27/88 10:20 a.m.

Weather:
S @ 5 to 10 kts E20 BKN
60 °F 75 % Humidity

Twin Cessna
Circling over Ocean Lava Flows

D-Prime
Critical f = 80 Hz
D-Prime = 2711 10logd' = 34

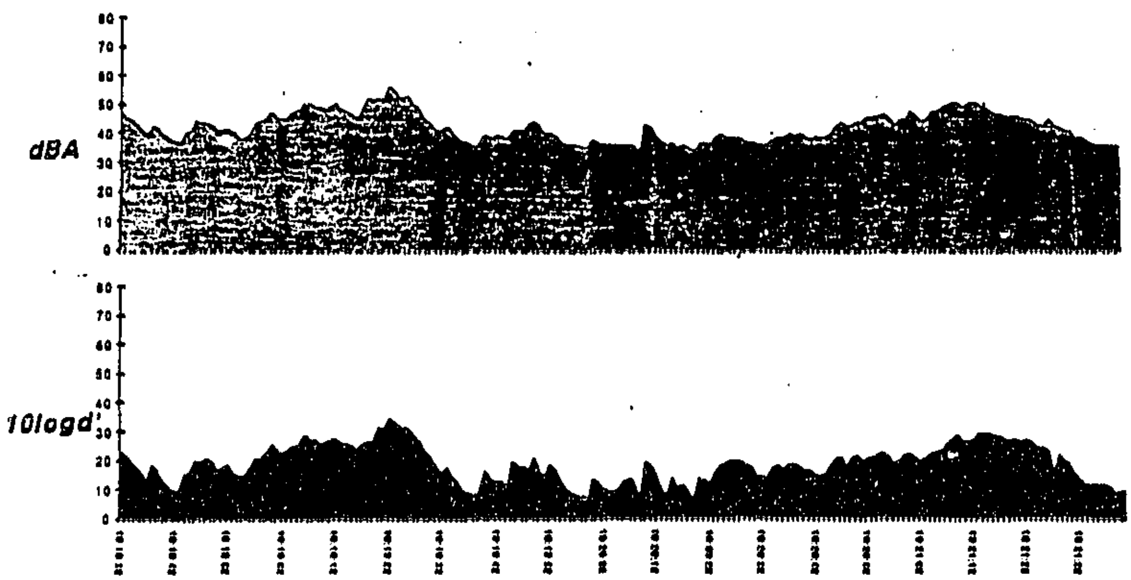
A-weighted
Aircraft (Max) = 56 dBA
Ambient (L90) = 36 dBA
Delta (Max vs. Amb.) = 20 dBA

Loudness Level (ISO 532B)
Aircraft (Max) =
Ambient =

Perceived Noise Level (Tone Corrected)
Aircraft (Max) =
Ambient =

Duration Above d' Values

d'20	10logd'13	157 sec.
d'40	10logd'16	131 sec.
d'63	10logd'18	78 sec.
d'100	10logd'20	72 sec.
d'200	10logd'23	48 sec.
d'630	10logd'28	8 sec.
d'2000	10logd'33	0 sec.



Oo Crater site 25 overflights per day, and at the Wahaula Visitors Center site 45 overflights per day. These results are presented in Table 3-4.

Table 3-4
Summary of Average Daily Aircraft Durations

LOCATION	TIME ABOVE (Minutes/Day)			
	TAD' 13	TAD' 23	TAD' 33	TAD' 43
Kokoolau Crater	35	23	16	7
Wahaula Center	144	20	8	5

TAD' - Time Above Detectability (D') Level

3.2.5 Conclusions and Recommendations

A number of issues for the measurement of aircraft sound in the park/wilderness setting were addressed during this survey. These issues include: background sound measurement, detectability, absolute and relative aircraft sound level, A-weighted measurements, and instrumentation requirements.

Background Sound Measurement. The results of the measurements again illustrated the importance of the background sound in studying aircraft sound in park/wilderness settings. In these low-level sound settings, background sound influences the intrusive level of the aircraft sound and the total time duration that an aircraft is audible. The influence of temporal variations in the ambient sound levels are minimized by using the L90 descriptor to represent the background sound level.

The fluctuations in the ambient sound levels generally have different duration characteristics than the aircraft signal. Measurement of the L90 sound level in close proximity to the time of the aircraft event minimizes the influence of these fluctuations. Measuring the background sound within 30 minutes of an aircraft event is usually adequate for characterizing the background conditions that are presented at the time of the aircraft overflight. The background measurements should have a minimum duration of 5 minutes.

Detectability. The results of these measurements showed that detectability is useful in quantitatively describing when a signal is detectable in various background settings. It can also be used to describe different levels of intrusiveness of a sound. Detectability provides a precise calculation of the time duration of the aircraft overflight. This methodology is capable of describing lower levels of intrusiveness of aircraft sound that is not possible with a simple A-weighted descriptor.

It is recommended that D' of 15 be used as a preliminary definition of audibility and to determine the effective duration of a given aircraft event. Laboratory research has shown that for detection levels between D' of 13 to 16 people would first notice a sound when performing other tasks (Fidell et al., 1978). This method does not account for all of the time that an aircraft may be audible, but is a good indicator of the lowest detection level when an aircraft may first be noticeable to park visitors. It is also approaches the lowest detectability level that can be reasonably measured in the field.

D' exceeding other levels of intrusiveness should also be calculated. Time Above D' levels of 10, 20, 25, 35, and 45 are recommended to present a range in D' values. (Note the proposed methodology is designed to be capable of calculating time durations above a D' level). The sociological surveys may determine that one of these other detectability levels more accurately reflects visitor response to the aircraft sound. This information may ultimately be used to develop a "Time Above" descriptor to rate different levels of intrusiveness for the total durations for the day.

Detectability can be calculated from the measured 1/3 octave sound data using a computer program. Using a computer, the time durations above any number of detectability level can easily be calculated. To minimize false events, the duration should have a minimum duration time of five seconds to be considered an event. Events of less then three seconds apart should be merged. Note: Measuring detectability requires attended measurements with the field engineer taking detailed notes of aircraft and ambient conditions.

Detectability can be expressed as a function of the maximum detectability value in any 1/3 octave band or the integration of all of the detectability levels in each 1/3 octave band to give a composite value of detectability. No one method has been demonstrated to more accurately predict annoyance. The detectability calculations presented in this report are based upon the highest detectability level in any band (D' maximum) and is recommended for use in this study. The measurement of a composite D' would be very difficult to complete in the field and could not be used to accurately field measure as low of detectability levels as can be done using the maximum D' methodology. (Most research with detectability has been done in controlled laboratory settings.)

Absolute and Relative Aircraft Sound Level. A number of sound rating scales are available to describe the "loudness" or "noisiness" of the aircraft sound. The aircraft sound level is to be determined for its absolute level and relative to the background level. Potential sound rating scales reviewed in this study include: A-Weighted Level, Detectability, Loudness Levels, and Tone Corrected Perceived Noise Level.

Detectability is recommended for describing the relative sound level of the aircraft overflights. It is the only currently developed relative sound level metric with some research to support its use. Detectability can be used to field measure low-level sound environments that is not possible with the other metrics. Given the temporal variations in the aircraft sound, detectability is best expressed in terms of time durations above different levels of intrusiveness. This was described in the previous paragraphs.

The results of the preliminary measurements did not favor one sound rating scale over another in terms of describing the absolute sound level of aircraft in these settings. In these low sound level settings; the absolute loudness of the sound may play a less prominent role in predicting annoyance. Research has shown that in low-level sound applications signal detection or audibility is the most important factor in predicting annoyance (Fidell et al., 1978). Note that in applications with higher sound levels (i.e., MTR operations) the absolute sound level becomes more important than relative sound level.

Once the sociological surveys are completed, the metric that best correlates with park visitor response can be selected. Until these surveys are completed, no one metric is recommended for describing absolute sound level. The proposed methodology is capable of measuring all of the acoustic data necessary to calculate any of these potential metrics. Once the data has been transferred to a computer, all of these metrics can be calculated without any additional analysis time.

In these low sound level applications, the results suggest that the absolute sound level from the aircraft overflight can be described using the A-weighted rating scale. The low sound levels and frequency range (50 to 1000 Hz) of the aircraft sound are adequately described using A-weighting. Some types of aircraft operations do have unique tonal characteristics, however, detectability is sensitive to these characteristics and the value reflects their presence.

A-Weighted Measurements. Determining spectral sound level information requires the use of more sophisticated instrumentation and substantially more data collection and analysis time. One of the goals of this study is to investigate less costly means of assessing the aircraft sound environment. As with the Grand Canyon measurements, the D' and the A-weighted relative sound level showed good correlation. This is for events that were clearly above the background (i.e., greater than 10 to 20 dBA above the background L90). This means that both metrics are predicting similar sound level information.

In situations of limited resources (equipment and labor), A-weighted only measurements may be used to supplement the more complete spectral measurements. For conditions at a particular park, a relationship may be developed between the more complex D' descriptor and the A-weighted relative sound level. Subsequent measurements may then be completed in A-weighted to provide more long-term acoustic information.

Instrumentation Requirements. Real time measurement analysis in the field is feasible, and was useful in analyzing the ambient and aircraft sound; however there were some limitations. The primary constraint to this method is its limited portability. Real time analyzers that meet the more stringent ANSI Class III requirements weigh a minimum of forty pounds, are very power intensive and the internal memory storage capability of these machines is limited. An additional constraint with real time measurements is that at locations with multiple sources of noise other than the aircraft, it can be difficult to differentiate between the different events. The field engineer must take very detailed notes beyond which would be necessary for tape recorded data. Recording of the sound data, using DAT tape recorders is recommended for future measurements.

Section 3.3
EDWARDS AIR FORCE BASE MEASUREMENTS

3.4.1 Site Selection

The purpose of the third and final phase of noise measurements was to test the methodology for measurements of low-altitude military training route (MTR) operations. This survey was also used to test the measurement methodology using the digital audio tape (DAT) tape recording system. Edwards Air Force Base (AFB) was selected for these measurements because of the large number of low-altitude operations that occur over the base. The expansive base had many remote areas used for training runs that allowed for the measurement of a large sample of aircraft events in a relatively short period of time. In addition, the Air Force was conducting air speed calibration tests on a T-38 tjat enabled us to precisely measure acoustic and aircraft operational data in a controlled setting. The remoteness of the facility simulated the ambient sound levels of a park/wilderness area in a high desert setting.

Noise measurements were performed at two locations on the base. The first site was along the fly-by line on Rogers Lake Bed. This site is near the airport at a location on the dry lake bed that is used for low-altitude high speed indicator tests that simulates MTR operations and altitude. The second site was at a remote location at the base along the old south sled track (also referred to as the Hay Stack) that is used for low-altitude training flights. The measurements were conducted on June 13th through June 16th, 1988.

3.4.2 Measurement Equipment

The primary measurement system to be tested during this survey was tape recording the sound data using a DAT tape recorder. The tape recorded data was then analyzed in the laboratory to determine the desired noise metrics. Input to the system was provided by either a B&K 2204 Sound Level Meter with a 1-inch B&K Model 4161 Microphone or a B&K 2230 Sound Level Meter with a 1/2 inch B&K 4155 Microphone. The digital tape recorder used in the measurements was a Sony TCD-D10. The recorded data was analyzed in the laboratory with a B&K 2231 Real Time Frequency Analyzer. This analyzer performed the 1/3 octave band analysis on the measurement data. This data was directly transferred to a computer program that calculated all of the aircraft and ambient sound descriptors of interest.

Simultaneous to these measurements, A-weighted noise levels were also determined from a B&K 4427 automated digital noise data acquisition system described in the Grand Canyon measurements. The purpose of the A-weighted measurements were for verification of the digital recorded results. A listing of the equipment by model and serial number used in the measurements is contained in Appendix C. These measurement systems comply with the ANSI Standards 1.4-1983 for Type 1 precision noise measurement instrumentation and ANSI Standard S1.11 1986 Class III for 1/3 octave filters. This type and class are the most stringent ANSI standard for outdoor noise measurement systems.

The key to the system is the digital audio tape recorder that has greatly enhanced performance capabilities over conventional analog recorders. The Grand Canyon measurements demonstrated the importance in measuring the total duration of the aircraft event as well as the background sound level at the time of the event. In order to measure the start of an event and the background sound before the event, it is necessary to continuously measure the sound. This is not practical with an instrumentation analog recorder because of the amount of magnetic tape that would be needed. In addition, analog recorders do not achieve the dynamic range requirements for this study. The measurements in Hawaii Volcanoes showed that the measurements could be achieved with a real time analyzer in the field, however, the weight and power requirements constrained the use of this system in the wilderness setting.

DAT recorders are a relatively recent development that records and plays back sound in digital form. These digital audio recordings have superior dynamic range and frequency response characteristics. DAT recorders are only recently became available in the United States because of concern by the recording industry over copywrite problems. A portable version was used for the Edwards AFB measurements. This recorder weights less than four pounds and records sound onto small cassette tapes of up to two hours in length.

The DAT recorder's dynamic range and frequency response characteristics were tested in the laboratory. With a B&K 2230 sound level meter as input, the overall system demonstrated a dynamic range of greater than 80 dB. Between 50 and 10000 Hz, the frequency range of concern for this study, the frequency response of the DAT was measured at better than +/- 1 dB. (The results of these tests are presented in Appendix C). This is far superior than could be achieved with an analog recorder. The DATs light weight, portability, length of recording time, and superior performance characteristics make it an ideal candidate for use on the NPS study.

3.4.3 Measurement Procedures

The results of the sound measurements at Grand Canyon and Hawaii Volcanoes were used to develop a measurement methodology. This methodology was tested during the Edwards AFB measurements. In addition, since noise from low altitude military training operations had not been monitored during the two previous surveys, the methodology for measuring these operations was also tested. Microphone height, calibration, wind screens and meteorological data collection procedures were the same as described for the Grand Canyon measurements.

Ambient and aircraft sound levels were determined from continuous digital tape recorded noise data. The digital tape recorder allows for continuous recordings for up to 2 hours of data. The continuous recording of sound level data allows for the measurement of the ambient sound levels just before and after an aircraft event as well as the full duration of the event. Field engineers noted the beginning and ending time of each aircraft event as well as other available aircraft operational information. From this digital tape, the relevant ambient and aircraft acoustic metrics were calculated.

This recorded data was then analyzed in the laboratory using the B&K 2123 Spectrum Analyzer. The 1/3 octave band noise level from 50 to 10000 Hz as well as the A-weighted data was determined with time response set to ANSI "fast" at a sample rate of 125 milliseconds or higher. This spectral data was transferred to a computer program that automatically calculates the ambient and aircraft noise descriptors.

3.4.3 Results

The results of the measurements showed that the ambient sound levels at Edwards AFB were relatively quiet during the morning time periods. The base is located in the high desert were strong afternoon winds affect the afternoon ambient sound environment. While there is minimal vegetation, sound from insects and birds were common. The Rogers Lake Bed measurement site was very close to the airport, so at that location, taxiing aircraft were audible for much of the measurements.

Sample ambient sound measurement results for the South Sled Track site are presented in Exhibit 3-18. The exhibit presents the L10, LEQ and L90 sound level in each 1/3 octave band. This is an example of the ambient sound levels during a period of calm wind conditions. Note the spike in the sound level at 630 Hz. The site was located near a number of trees, and this spike reflects bird sounds. Again note how these short duration sounds affect the LEQ but do not materially affect the L90 sound levels.

During the time of the noise measurement survey, the Air Force was conducting an air speed calibration test for a T-38 jet aircraft. The test consisted of a number of low altitude passes along a precise fly-by line on Rogers Lake Bed at different air speeds. Exact air speed and altitude information were determined in order to calibrate the air speed indicator of the aircraft. Noise measurements were conducted during this test, with the monitor located at a distance of 325 feet from the fly-by line. Precise aircraft air speed, altitude and position are determined during these tests.

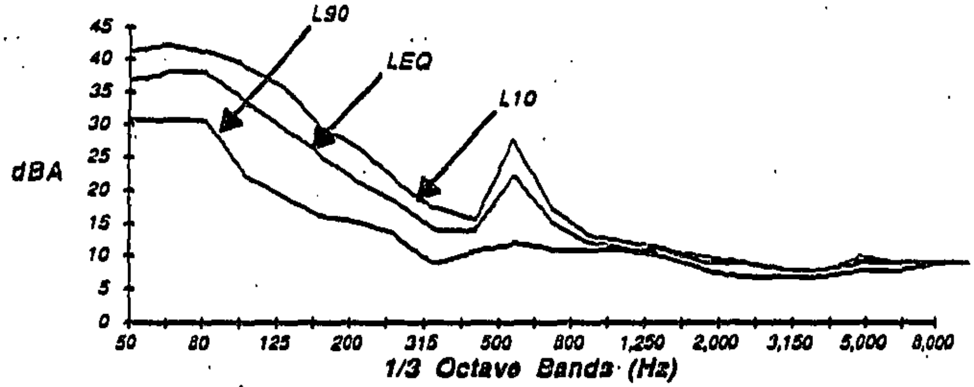
The results of these noise measurements for eleven passes is presented in Table 3-5. This table shows the aircraft air speed, altitude, onset rate and various acoustic rating scales. These rating scales include: the SEL level; maximum A-weighted, C-weighted, Loudness Level, Detectability (D') Level; and the Effective Perceived Noise Level. The onset rate is a measure of the rate of change in noise in dBA per second. Note that the noise level and onset rate both increase with an increase in air speed.

Table 3-5
LOW ALTITUDE T38 NOISE LEVELS

TIME	SPEED (kts)	ALTITUDE (agl)	ONSET (dBA/sec)	SEL (dBA)	MAXIMUM AIRCRAFT LEVEL (dBA)	(dBC)	D'	LL	EPNL
0631	342 kts	91 ft	28	96	92	92	72	98	104
0636	394 kts	89 ft	26	97	93	93	73	98	106
0640	428 kts	136 ft	37	99	96	97	77	103	109
0644	471 kts	122 ft	50	100	98	98	80	103	112
0647	497 kts	111 ft	63	110	107	106	88	111	120
0651	586 kts	71 ft	124	112	110	109	89	116	121
0655	593 kts	67 ft	93	113	111	110	91	113	122
0703	214 kts	75 ft	14	93	89	90	72	97	103
0708	168 kts	63 ft	9	91	88	89	69	96	101
0713	170 kts	115 ft	8	92	88	89	71	97	102
0718	525 kts	120 ft	58	112	109	108	90	113	121

LL - Loudness Level (ISO 532B)

Exhibit 3-18
Sample Ambient Noise Levels (Edwards)



An example of the spectral sound level data from two of these fly-bys is presented in Exhibits 3-19 and 3-20 for the 0631 and 0651 events. Note that the noise levels from these operations were 60 to 80 dBA above the background levels. Typical D' levels were 70 to 90. The spectral noise characteristics of these operations have a higher frequency component than with the aircraft measured in the previous studies. This would be expected, given the smaller slant range distances between source and receiver. Generally the most prominent frequencies were between 800 and 2000 Hz. The higher the air speed, the higher the thrust, the higher the sound level, and in general the higher the dominant frequency.

These operations were also characterized by very high onset rates. Onset rate is a measure of the rate of change of the sound level. Sounds with high onset rate result in a surprise or startle factor that can be major factor in the noise impacts of these operations.

3.4.5 Conclusions and Recommendations

Instrumentation Requirements. The results of these measurements showed that the DAT recording system was capable of obtaining the necessary acoustic information for describing the ambient and aircraft noise within park settings. This was achieved within the specified tolerances for the measurement system. This system was capable of measuring the very large dynamic ranges that are part of MTR events. Its lightweight and portability make it ideal for use in all types of park/wilderness settings.

MTR Measurement Requirements. Aircraft noise from MTR operations have unique acoustic characteristics that are very different than other types of aircraft operations over parks. The sound from most of the other types of aircraft operations over parks are characterized by low-level sounds in quite background settings. MTR operations are characterized by potentially very high sound levels with high onset rates. This requires different methodologies for the measurement of the sounds from MTR operations.

Many researchers are addressing this issue of MTR noise with often conflicting recommendations (Section 2.6). Based upon conclusions in these studies and the results of these preliminary measurements, the important acoustic factors can be identified. The important acoustic factors in describing noise from MTR operations are the absolute sound level, onset rate and number of overflights. The background sound level becomes a factor in conditions where the maximum sound level from the aircraft is not significantly greater than the background.

Exhibit 3-19
Sample T-38 Low Altitude Operation (342 kts - Edwards)

Edwards AFB -- Rogers Lake Bed
Sideline Distance = 325 ft.

T-38
342 kts 95 ft. agl

6/14/88 6:31 a.m.

Weather:
Calm Clear
20 °C 45 % Humidity

RESULTS:

Critical *f* = 3150 Hz
Delta (Max vs. Amb/MAF) = 62 dB
D-Prime = 17,128,000
C-Weighted Level = 92
EPNdB Level = 104
Loudness Level (ISO 532B) = 98

Aircraft (Max) = 92 dBA
Ambient (L90) = 39 dBA
Delta (Max vs. Amb.) = 53 dBA
On-set Rate = 28 dBA/second

1/3 Octave Spectral Data:

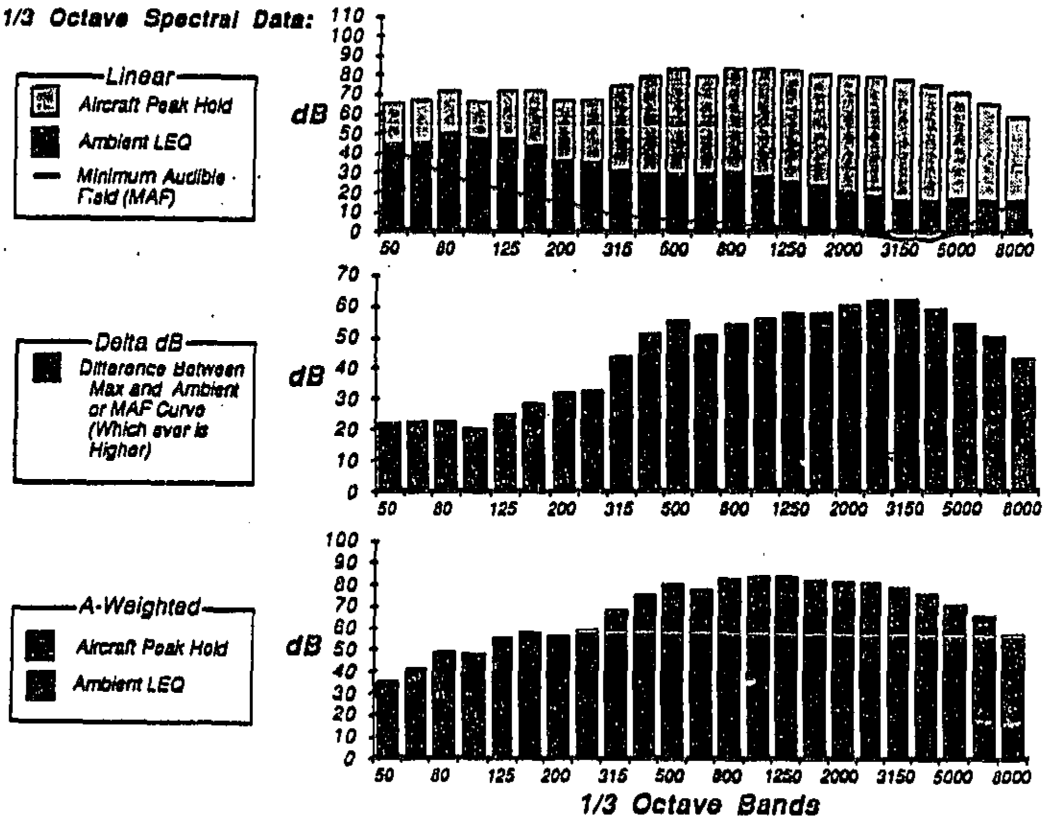


Exhibit 3-20
Sample T-38 Low Altitude Operation (586 kts - Edwards)

Edwards AFB -- Rogers Lake Bed
Sideline Distance = 325 ft.

T-38
586 kts *71 ft. agl*

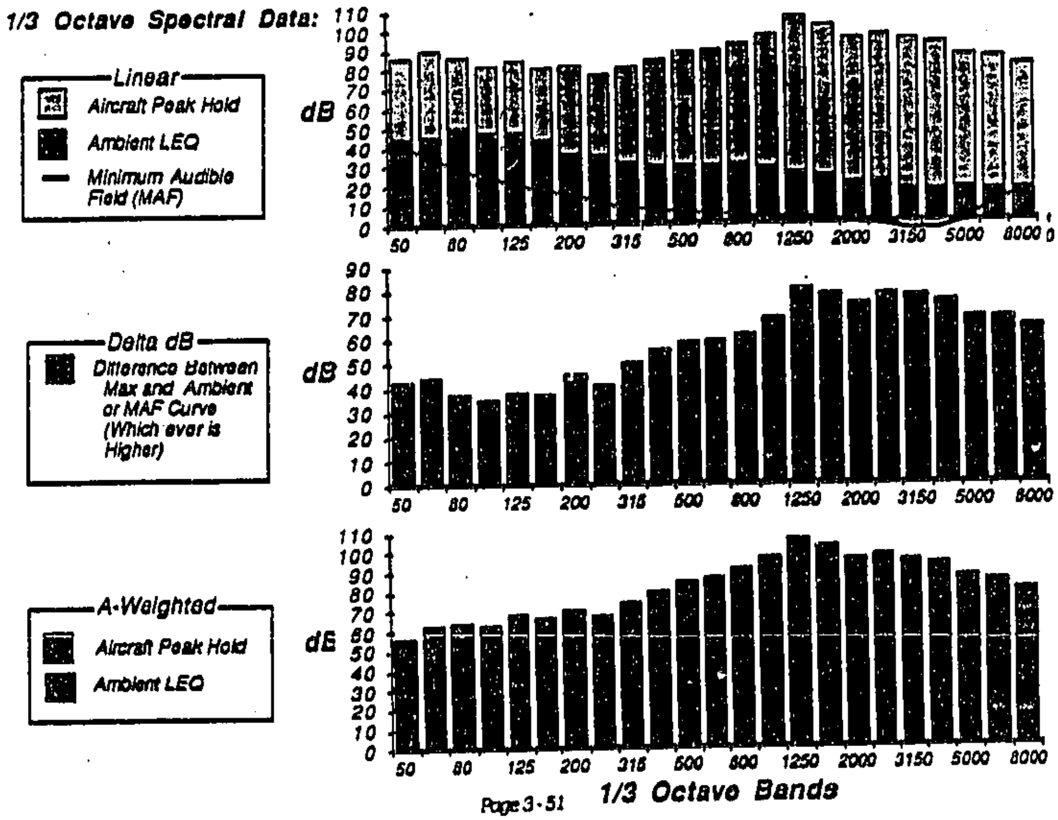
6/14/88 *6:51 a.m.*

Weather:
Calm *Clear*
20 °C *45 % Humidity*

RESULTS:

Critical f = 1250 Hz
Delta (Max vs. Amb/MAF) = 81 dB
D-Prime = 859,026,000
C-Weighted Level = 109
EPNdB Level = 121
Loudness Level (ISO 532B) = 116

Aircraft (Max) = 110 dBA
Ambient (L90) = 39 dBA
Delta (Max vs. Amb.) = 71 dBA
On-set Rate = 124 dBA/second



The Air Force recommends the use of the A-weighted sound level to measure the absolute noise from MTR operations. The SEL descriptor is used as a convenient method of measuring the A-weighted sound from each flight. A penalty of up to 5 dBA is added to the SEL level to account for high onset rates. When the maximum sound level from the aircraft is within 20 dBA of the background level, then any penalty associated with the onset rate is not to be included. The cumulative noise from these operations is determined for the daily DNL averaged over the peak month of operational activity. The distribution of the actual flight track for aircraft on an MTR route are assumed to be normally distributed within a corridor. While many aspects of the Air Force study have applications to a park/wilderness setting, there are some significant differences. These similarities and differences are discussed in the following paragraphs in the development of a recommended methodology for use in the NPS study.

Sound rating scales other than A-weighted have been suggested to describe the absolute sound level for MTR overflight. These potential rating scales include: C-weighted levels to calculate SEL, EPNL, and calculated Loudness Level. Most researchers currently use A-weighted levels, in part do to its simplicity and to maintain consistency with current methods used to assess other types of aircraft operations. While the A-weighted level may not be the most accurate predictor of annoyance from MTR operations, it has been shown to be a reasonably good predictor.

Research into determining which rating scales most accurately reflects annoyance is probably beyond the scope of the NPS study. The relatively small differences that might be shown from the use of a different rating scale will still not adequately describe the sound problems of MTR operations in the park/wilderness setting. Other acoustic factors such as onset rate penalty and time averaging are more important. Therefore, the A-weighted sound pressure level is recommended for use in the NPS study for describing the sounds from MTR operations.

Directly under the aircraft flight path, the background sound level is not a major factor because in most settings, the aircraft noise is significantly above the background. In these situations, detectability does not provide any additional useful information concerning MTR noise. Detectability was developed for low-level sound applications and give misleading results in higher sound level settings. For example, a sound of 110 dBA in a background of 50 dBA will be more disturbing than a sound of 80 dBA in a background of 20 dBA, however, the detectability levels for these two examples would be the same. For less extreme differences, the relative sound level is still an important acoustic factor. At locations sideline to the aircraft overflight, the background sound level is useful in defining the width of the area that the aircraft will be audible.

Ambient sound levels should be determined at all MTR measurement sites. This measurement methodology should be the same as recommended for all sound measurements within the parks. For long-term sampling, A-weighted data can be used to supplement the spectral measurements.

The onset rate is a very important acoustic factor in describing the annoyance from MTR operations. It is very possible that in the park/wilderness setting, the surprise or startle effect is the most important factor in determining annoyance. The Air Force recommends a penalty for onset rates above 15 dBA/second with a maximum penalty of 5 dBA for rates above 30 dBA/second.

The Air Force study addresses a permanent residential population, that has prior experience to MTR overflights. In the park setting, the population is not permanent and may have little or no exposure to the very unique experience of an MTR overflight. Therefore, the startle effect of high onset rates may result in a greater level of disturbance for a park visitor than a permanent population. The appropriate penalty factor to be applied to MTR overflights with high onset rates should be investigated. Onset rates should be determined for all MTR operations.

The use of a metric averaged over some time period to describe MTR operations is not applicable to the park/wilderness situation. MTR operations generate high noise levels and high onset rates directly under the flight path, but the width of the high noise exposure zone is narrow. MTR routes are not fixed paths, but operate within specified corridors. Averaging the noise exposure over some period of time de-emphasizes these peak levels and spreads the sound over the width of the flight corridor. Given the fact that a visitor population may be different every day, visitors are never exposed to the average, but only to the aircraft sound levels that occur at each individuals particular location on that individuals day in the park. The result is that the majority of visitors are exposed to little or no aircraft sound at all. However, a visitor who happens to be at a location that the aircraft is directly overhead would be exposed to very high noise levels.

The sound monitoring portion of the overall study must be well coordinated with the park visitor surveys. One of the most difficult tasks of the study will be to determine the actual sound exposure level for each visitor that is being surveyed. In the park setting, the visitor population is not a permanent population and changes day to day. In addition, a park visitor is not fixed at one location, but moves throughout the park where the aircraft sound exposure levels can be significantly different. For these reasons it is necessary to have knowledge of the aircraft sound exposure levels for each day of the visitor surveys. The sociological survey must be completed simultaneously with the sound level measurements; with the sociological survey providing information concerning each visitor's itinerary.

It is recommended that sampling resources at parks with MTR operations be oriented towards larger measurement samples at fewer measurement sites. Measurement of spectral data for all of the measurements is not necessary. Measurement of the A-weighted noise levels and the onset rate may be a more efficient use of resources. Supplemental unattended measurements can also be a useful method of increasing the sample size at certain park units. The actual number of MTR overflights in each park needs to be documented. This methodology is presented in Section 4.3.

Section 4.0
SPECIAL ISSUES

This section presents the results of a number of individual areas of study to be addressed as part of the overall aircraft sound study. Three issues are addressed within this section. The first section presents the development of a statistical sampling methodology for analyzing the ambient and aircraft sound measurement data. This includes a review of current statistical methods and an application of this methodology to actual measurement data from a National Park. The second section reviews the monitoring needs for the assessment of aircraft noise on cultural or historic park units that may be different than those required for natural or wilderness parks. The third section describes a program for the identification of the number and type of aircraft operations over park units. This aircraft overflights documentation program is to be completed by NPS personnel.

Section 4.1

DEVELOPMENT OF STATISTICAL MEASUREMENT REQUIREMENTS

4.1.1 Overview

The issue of measurement statistics is a complex one. This discussion is not intended to be a technical discussion of the intricate mathematics of the theories of sampling and statistical procedures. It is meant to provide an overview of historical procedures used in noise control engineering and to present some engineering observations about the technical problem that is being discussed. It is likely that statisticians and engineers are not going to agree on the best methods of evaluating the adequacy of a noise measurement sample. In this analysis we will discuss the purely statistical approach and the engineering approach. In the statistical approach you will see that little or no knowledge of the phenomena being measured is used to develop an analysis of the adequacy of a measurement sample. Because of the somewhat unique nature of sound measurement in decibels, a logarithmic scale, some very difficult problems are encountered using a purely statistical approach. You shall see that the more information you can provide about the noise being measured, the better able you will be to determine adequacy of the sample size. Two methods of evaluating the measurement sample will be discussed including: (1) using auto-correlation to evaluate sample adequacy and (2) computing confidence intervals using the Students-t distribution. Technical references for each method are presented in the following paragraphs. First, a good problem definition is needed.

The problem at hand is how to determine the duration of a noise measurement program in order to adequately describe the noise environment at a given location. In this case the noise source of concern is aircraft flyover noise. In other words, how long must you measure at a given location in order to know the impact of aircraft noise at that site? This topic is discussed below for the general case of aircraft flyover noise. The problem of defining background sound levels in a National Park is presented in Section 4.1.4.

4.1.2 Measurement Strategy Alternatives

There is one option for measurement that eliminates the need to analyze the adequacy of the measurement sample. That option is permanent noise monitoring. The

State of California, in its Airport Noise Regulations (State of California, 1970) requires permanent noise monitoring systems for certain commercial airports with incompatible land uses within the high noise areas around the airport. All major air carrier airports in California have permanent noise monitoring systems. A number of airports outside California also have permanent systems.

Permanent noise monitoring is expensive. A typical system of 4 permanent stations connected to a central computer can cost close to $200,000. Some airports have nearly 30 stations as part of their systems (San Francisco International, for example).

The FAA and the 49 states other than California have not required permanent noise monitoring because of the high cost and the opinion that short-term measurements, which are much less expensive, can be used to adequately measure the noise environment. Permanent noise monitoring is used primarily for noise ordinance enforcement and documentation of long-term trends.

In a situation where financial resources available for monitoring are limited, short-term measurements allow many more areas to be measured and are a more cost effective method of environmental noise monitoring. Therefore, a goal of short-term monitoring is to determine the shortest period of monitoring that is needed to adequately define the sound environment.

4.1.3 Noise Measurement Statistics

Four Week Seasonal Measurements. The State of California Airport Noise Regulations provides airports with guidelines on short-term sampling. The State requires 1 week of noise monitoring in each of the four seasons. This was selected intuitively as well as empirically based on available permanent noise monitoring data. The goal was to ensure that measurements included the range of aircraft operating conditions that occur over the year, including the effects of temperature, wind speed and direction, and seasonal variation in aircraft traffic. It should be noted that effects of temperature and wind are important effects relative to sound propagation as well as aircraft performance, runway utilization, flight tracks, and flight routes.

Auto Correlation Analysis. This discussion is presented based on the work of Schomer (Schomer, 1981). One of the critical assumptions made in selecting the mathematical method to be used to evaluate measurement sample adequacy is the independence of the measurement events. As we shall see later, if each aircraft flyover is an independent event, and normally distributed (gaussian distribution), then the job of describing measurement adequacy is somewhat simpler. Auto-correlation can be thought of as a measure of event independence. Independent events show values of very low auto-correlation while dependent events are highly auto-correlated. A good example of an independent event is the flipping of a coin or a roll of the dice. Each event is unique and not dependent on any previous events, nor are subsequent events dependent on the current event. Auto correlation is computed by calculating the correlation coefficient between the noise levels in a time series with noise levels earlier in the time series. In other words, it is the correlation of a variable with itself, but taken over different time periods.

Schomer et al., examined long-term DNL at several airports including CNEL levels at Los Angeles International Airport (LAX) where there are numerous permanent noise monitoring stations. (CNEL is California's version of DNL but includes an evening weighting period.) Schomer concluded that there tended to be a high degree of auto-correlation among day to day CNEL levels and hence produced a result that indicated very long measurement periods were needed. Schomer does conclude that, even though some of the LAX measurement points indicated a need for long sampling times, in general 4 weeks of monitoring should be sufficient to describe long-term noise levels.

This result has proven to be counter-intuitive to many engineers who observed that at LAX the day to day variation in CNEL was quite small and therefore the needed sample should be much smaller. In trying to interpret Schomer's results it is clear that the auto-correlation computation numerically described the consistency of Southern California weather near the coast. The Southern California coastal area experiences only 2 wind conditions during the day; on shore or off shore. Off shore winds occur only 10% of the time and because of the logarithmic averaging used to compute CNEL, have no significant effects on long-term noise levels. It appears that Schomer's data says that in order to measure all the variation in noise levels at LAX, one must measure over a very long period of time and that is due to the fact that the weather is so consistent. However, the long-term measurements are not necessary if the nondominant mode is not important in describing the overall sound exposure. Most park/wilderness settings are not expected to show high auto-correlation.

Confidence Interval Based on the Students T Distribution. It is common in science and engineering testing and research to describe the confidence intervals for measurement results. These confidence intervals are based on the probability that the true answer lies within a certain range. For example, take the simple case of making a very precise measurement of an Olympic sized swimming pool. By taking many measurements there will be a variety of results as each precise measurement will produce some small variations. Such a series of measurements could for example, produce an average result of 100 meters with a 90% confidence interval of plus or minus 0.2 meters. This is interpreted as meaning that the there is a 90 percent probability that the true value lies between 99.8 and 100.2 meters. A more correct definition of the confidence interval is that if the measurements were repeated many times, the measured average result would lie between 99.8 and 100.2 meters 90 percent of the time. The confidence interval provides a quantitative means of describing the adequacy of the size of the measurement sample. As more measurements are made the confidence interval becomes smaller as will be described in later paragraphs.

The confidence interval can be stated in terms of many percentiles although 90, 95, and 99 percent confidence intervals are the most common. In airport acoustics work, the 90 percent confidence interval is the most commonly used method of specifying the accuracy of a measurement sample. A detailed description of Students-t method of computing confidence intervals is presented by the U.S. Air Force (AMRL, 1980).

The confidence intervals are computed by making the following computations. For a measurement sample the sample mean is computed. The confidence interval about the mean is computed from the equation 1, in Table 4-1.

There are two conditions that should be met for use of the above equation. One is that the distribution of the measurement sample be normal or nearly normal which means that the sample should not be skewed or biased, and the other condition is that each sample be an independent event. The independence of events was discussed as part of the discussion on auto-correlation. While daily DNL appears highly auto-correlated (dependent), individual flyover noise events are not dependent on any previous or subsequent noise events. Therefore, for computing confidence intervals for single event noise metrics, the condition of independence is assumed to be met. The type of distribution of the sample is discussed below.

An important question to be dealt with is whether or not aircraft noise data is normally or near normally distributed. A histogram plot of aircraft single event data or daily DNL data clearly shows that the data is essentially normally distributed. Example plots of aircraft data are shown in Exhibits 4-1 and 4-2. The causes in variation in noise levels measured lead one to suspect aircraft noise data should be normally distributed. Noise is dependent on aircraft power, speed, altitude, control surface configuration, type of aircraft, wind speed, wind direction, temperature gradient, and relative position of the

Table 4-1
Sample Statistical Equations

Confidence Interval = $CI = \bar{L} \pm \frac{t\,S}{(n)^{1/2}}$ (1)

where:

- $\bar{L}$ is the sample mean value,
- t is the Students t value for sample size n
- n is the sample size, and
- S is the sample standard deviation.

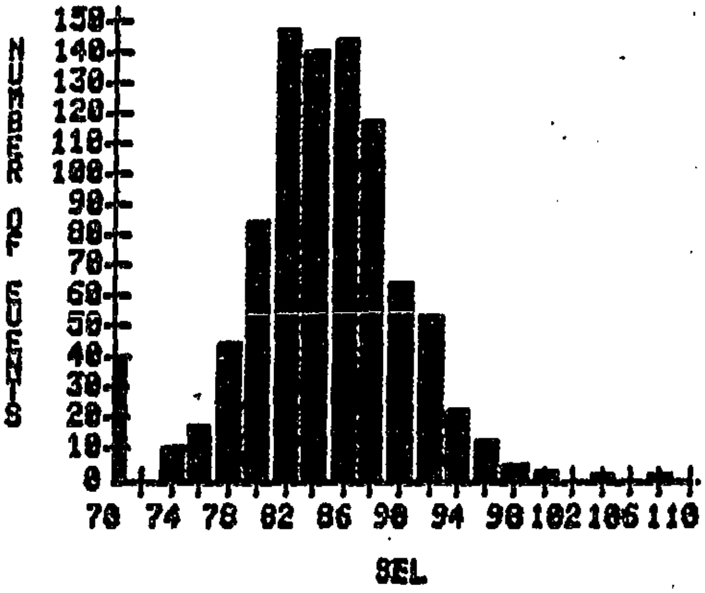
Linear Average = $\bar{L} = \frac{1}{n} \sum L_i$ (2)

Standard Deviation = $S = \left[\frac{\sum (L_i - \bar{L})^2}{}\right]^{1/2}$ (3)

Logarithmic Average = $L^{*} = 10 \operatorname{Log}_{10} \left(\frac{1}{n}\right) \left[\sum 10^{(L_i/10)}\right]$ (4)

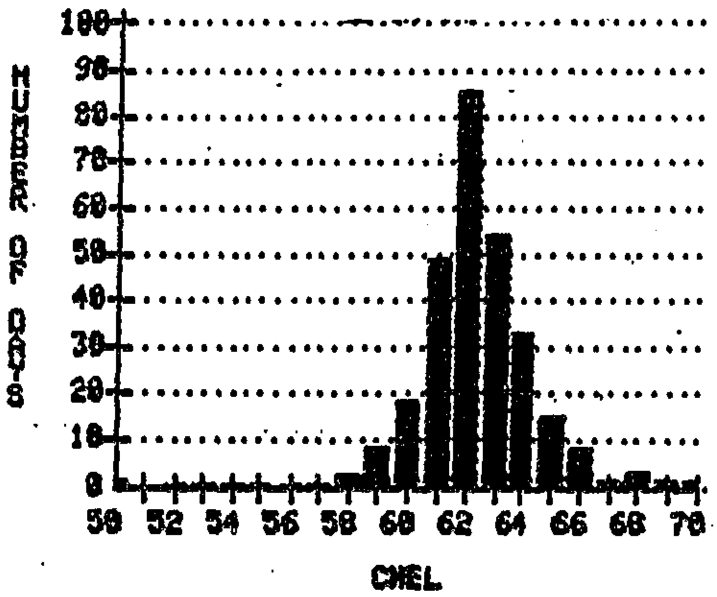
Standard Deviation (log) = $S^{*} = \left[\frac{\sum (10^{L_i} - 10^{\bar{L}})^2}{n}\right]^{1/2}$ (5)

Exhibit 4-1
Sample Plot of SEL Data
1 Year of Data



Source: City of Santa Monica Airport Master Plan Update, 1983 for Noise Monitoring Site 1.

Exhibit 4-2
Sample Plot of CNEL Data
1 Year of Data



Source: City of Santa Monica Airport Master Plan Update, 1983 for Noise Monitoring Site 2.

aircraft to the observer. Given the number of variables that affect aircraft noise and the independent nature of most of the variables, i.e., type of aircraft is not dependent on wind speed, one would expect a normal distribution of noise levels.

The complicating factor to this analysis is that in noise control engineering, the linear average of a sample is rarely the method used to compute the result that is desired. The average noise level of a sample, whether the measurement is of daily DNL or aircraft single event levels or hourly equivalent noise levels, is always based on the logarithmic average. The equations for these two forms of averaging are as presented in Table 4-1, equations 2 through 4.

It is important to note that when computing the logarithmic average, it includes a non-linear transformation on the data. Such a non-linear transformation does not preserve the normal (gaussian) characteristics of the distribution. The Air Force documents referenced earlier recommend doing the confidence interval analysis using the logarithmic average and logarithmic standard deviation. Such a technique has its problems including the fundamental fact that in the logarithmic domain (actually the anti-logarithmic domain) the data distribution is highly skewed. This means the technique is questionable and will occasionally result in undefined answers (in the anti-logarithm domain, the standard deviation can sometimes exceed the mean value and the lower limit calculation will result in trying to take the logarithm of a negative number).

It is recommended that to compute the confidence interval for logarithmic averaged noise data, the confidence interval should be computed based on the linear domain (the "dB domain"). And that these confidence intervals be applied to the logarithmic average. This technique will tend to overestimate the confidence interval, particularly the lower limit. The logarithmic average is more heavily influenced by data above the mean than data below the mean. Therefore, uncertainty on the low side of the mean is overestimated.

4.1.4 Estimating the Necessary Sample Size, Background Noise: A Case Study

Now that the basic issues of computing the noise measurement statistic has been presented, it is important to evaluate how this procedure works when computing background sound levels. Background sound or residual sound is defined as the ambient sound level in the absence of any noise intrusions. For purposes of defining background sound levels, the 90th percentile (L90) sound level is used. That is the sound level that is exceeded 90 percent of the time. This exercise in evaluating the sample size requirements for measuring background sound levels is important because previous studies of noise sampling requirements have dealt with predicting some form of average noise level such as CNEL, DNL, or average SEL. Therefore, establishing the requirements for an L90 measurement may be unique.

The design of this evaluation was to take an existing large database of L90 data and divide it up into many small samples. The evaluation consisted of computing the statistics on each of these small samples and determining how the sample statistic compares with the statistic for the whole population, as a function of sample size. This exercise is made possible by using a series of computer programs that systematically goes through the database dividing it up into small samples and performing the computations for a very large number of possible sampling schemes. This is a computer simulation of what would happen if the larger database had not been collected and only a small sample had been collected. The advantage of the computer simulation is that many combinations of possible small samples can be evaluated and compared with the result obtained from the whole population.

A very unique data base exists for performing this evaluation. Over the past five years a series of aircraft sound measurements have been conducted in Grand Teton National Park. These measurements are done as part of Jackson Hole Airport's requirement to demonstrate compliance with a lease agreement establishing maximum permitted noise levels in the park. These measurements are during both a spring and summer season. The 'spring' measurement was done in March and was used to represent winter measurements as snow was still on the ground, temperatures were in the 0 to 20° F range and ski season was still going strong. Measurements were not made in the earlier winter months because of measurement equipment problems at temperatures as low as 30°F below zero which are not uncommon in Grand Teton. Also, the most popular ski time in Jackson (busiest airport period) is for the later part of the winter season.

The measurements consist of 24 hour continuous noise monitoring in the park, and include DNL, SEL, LEQ and the statistical measures of L10, L50, and L90 dBA sound level. The data used for testing was taken from measurements made in August of 1983 and March of 1984. Continuous hourly L90 noise levels from 6:00 p.m. August 12, 1983 to 11:00 a.m. August 19, 1983 and 8:00 p.m. March 11, 1984 to 6:00 p.m. March 18, 1984 were utilized. The measurements were taken at the "Barker" measurement site which is located within the National Park along Moose-Wilson Road. The annual average DNL at this site is less than 45 DNL.

The computer programs tested various combinations of measurement periods and sizes to determine the percentage of combinations whose predicted 90% confidence interval contained the true average. Recall that the definition of Students-t confidence intervals is that if the measurement were repeated many times, 90% of the results would fall within the 90% confidence interval. The computer program would systematically select a sample size and series of data of that sample size and compute, for each unique sample, the 90% confidence interval. Then, for that sample size and sampling scheme, determine the percentage of trials where the true average L90 for the entire population lies within the sample confidence interval. If indeed 90% of the samples had a confidence interval that included the true average L90, the Students-t confidence interval is a valid method of determining the adequacy of the sample size.

Random Sampling. This sampling method randomly chooses the times and sizes of noise levels, and the group of readings are lumped together to form a unique combination of samples. To simulate this random sampling process on a computer, a program was created to pick random L90 values from the test data given and generate its own unique combinations of samplings. The results are shown in Table 4-2. This table shows that 21 tests were run on the data. The first column shows the sample size used, the second column identifies the total number of combinations that were tested, the third column identifies whether the sample included one or two seasons of monitoring, the third column shows the average confidence interval (to show how the typical size of the interval changes with sample size) and the last column shows the percentage of samples whose confidence interval included the true average L90 computed from the entire population of data.

The results presented in Table 4-2 indicated that the Students-t method very accurately predicted the correct confidence interval. That is, for all sample sizes, approximately 90% of the tested small samples had 90% confidence intervals that included the true average L90 of the entire population.

In an actual noise monitoring program this would relate to randomly monitoring hourly data throughout the year to find the ambient sound level. This is not practical since it is much more likely that once a measurement setup is made, many hours of consecutive data would be collected at that site before moving to another site. The same analysis was completed for various series of consecutive data in the following section.

Consecutive Sampling. The goal here is to identify the best utilization of measurement resources by defining the shortest noise measurement period necessary to obtain an accurate background sound level. The simplest way to accomplish this is to

Table 4-2
Random Sample Results

Test No.	Sample Size	No. of Combinations Tested	No. of Seasons	Average C.I.	% Within Student-t Predicted 90% C.I.
1	100	200	2	0.6	98%
2	50	200	2	0.9	94%
3	20	200	2	1.4	89%
4	15	200	2	1.7	90%
5	10	200	2	2.1	93%
6	5	200	2	3.3	91%
7	2	200	2	6.5	79%
8	100	200	1	0.4	100%
9	50	200	1	0.5	94%
10	20	200	1	0.8	90%
11	15	200	1	1.0	94%
12	10	200	1	1.3	92%
13	5	200	1	1.9	86%
14	2	200	1	3.3	67%
15	100	200	1	0.5	99%
16	50	200	1	0.8	97%
17	20	200	1	1.2	92%
18	15	200	1	1.5	93%
19	10	200	1	1.9	93%
20	5	200	1	2.6	88%
21	2	200	1	5.2	79%

make one continuous measurement of hourly noise levels over the shortest possible length of time. To find the shortest noise measurement period required, a computer program was written to simulate this consecutive sampling. For example, let us assume that L90 values were monitored continuously for a period of 8 days. The first test would show results for treating this measurement period as one continuous sample (which in this first case would be 8 days long). Then the program divided the measurement period by two which produced two separate 4-day periods. The computer runs were repeated dividing the measurement data into 4 and then 6 consecutive sequences.

Table 4-3 gives the results of these tests. The first column gives a unique test number for referencing. In the second column the total number of samples for each combination is given. For example in Test 1, 100 consecutive samples were tested in each combination. The number of series of consecutive samples is given in the third column. In Test 1, 1 series of 100 consecutive samples were used. In Test 34, 6 series of 17 consecutive samples were chosen out of the array of values resulting in 102 total samples per combination. This was done for 36 different combinations. In a measurement situation the number of series relates to the number of times per year measurements would be taken, and the total number of samples relates to the total number of hours of measurements made during each series. The fourth column gives number of combinations in each test. For tests with one series (Tests 1 through 21) the maximum number of unique combinations were tested. In tests with more than 1 series (Tests 22 through 39) the program divided each season into subseries and took multiple combinations of these subseries. A sufficient number of unique combinations were selected to represent a portion of the extremely large number of possible combinations. This is discussed more in a later section.

In the fifth column the number of seasons used in the test is presented. The sixth column shows the average confidence interval for all the combinations. That is, each combination had a unique confidence interval and for Test 1, for example, this is the average for all 219 combinations (this is shown to give the reader an idea of typical confidence intervals for this sample size). The seventh column shows the percentage of combinations whose 90% confidence interval included the true average L90 for the entire population. Tests 1 through 7 used 1 period of consecutive samples that included 2 seasons of data. Such a series could only be collected at the end of one season and the beginning of another. Tests 8 through 14 used 1 period of consecutive samples taken from the summer data and tests 15 through 21 used 1 period of consecutive samples taken from the spring data. Tests 1 through 21 show that for a case using one measurement series, the percentage of samples that successfully compute a 90% confidence interval that includes the true

Table 4-3
Conservative Sample Results

Test #	Total # of Samples	# of Measurement Series	Combinations	# of Seasons	Average C.I.	% Within Student-t Predicted 90% C.I.
1	100	1	219	2	0.4	10%
2	50	1	269	2	0.5	28%
3	20	1	299	2	0.8	9%
4	15	1	304	2	0.9	8%
5	10	1	309	2	1.0	10%
6	5	1	314	2	1.3	20%
7	2	1	317	2	1.8	29%
8	100	1	58	1	0.3	48%
9	50	1	108	1	0.5	31%
10	20	1	138	1	0.7	54%
11	15	1	143	1	0.8	55%
12	10	1	148	1	0.1	48%
13	5	1	153	1	1.3	50%
14	2	1	156	1	1.8	46%
15	100	1	62	1	0.5	26%
16	50	1	112	1	0.6	8%
17	20	1	142	1	0.9	21%
18	15	1	147	1	1.0	24%
19	10	1	152	1	1.1	30%
20	5	1	157	1	1.3	39%
21	2	1	160	1	1.8	36%
22	100	2	108	2	0.6	19%
23	50	2	133	2	0.8	31%
24	20	2	148	2	1.3	49%
25	16	2	150	2	1.4	55%
26	10	2	153	2	1.9	73%
27	6	2	155	2	2.6	87%
28	100	4	54	2	0.6	63%
29	60	4	64	2	0.8	67%
30	20	4	74	2	1.4	80%
31	16	4	75	2	1.6	83%
32	12	4	76	2	1.9	87%
33	8	4	77	2	2.4	99%
34	102	6	36	2	0.6	100%
35	60	6	43	2	0.8	100%
36	24	6	49	2	1.3	98%
37	18	6	50	2	1.5	100%
38	12	6	51	2	2.0	100%
39	6	6	52	2	3.1	100%
40	100	4	324	2	0.6	73%
41	60	4	384	2	0.8	87%
42	20	4	444	2	1.4	96%
43	16	4	450	2	1.6	96%
44	12	4	456	2	1.9	96%
45	8	4	462	2	2.4	97%
46	100	4	336	2	0.7	79%
47	60	4	396	2	0.9	80%
48	20	4	456	2	1.5	83%
49	16	4	462	2	1.7	89%
50	12	4	468	2	1.9	93%
51	8	4	474	2	2.5	97%
52	100	4	378	2	0.6	100%
53	60	4	448	2	0.7	100%
54	20	4	518	2	1.2	92%
55	16	4	525	2	1.4	91%
56	12	4	532	2	1.6	94%
57	8	4	539	2	2.1	96%
58	100	4	2970	2	0.6	77%
59	60	4	4160	2	0.8	77%
60	20	4	5550	2	1.4	89%
61	16	4	5700	2	1.6	85%
62	12	4	5852	2	1.9	90%
63	8	4	6006	2	1.4	94%

average L90 for the total population is much less than 90%. One immediate observation about these data is that the predicted 90% confidence intervals are much smaller for these consecutive data than for similarly sized random samples. This indicates much more consistency in the data producing smaller standard deviations.

Clearly, this sampling methodology does not meet the requirements needed to use Students-t methods of predicting confidence intervals. Such data is not sufficiently independent. In such a series the data shows small day to day variation most likely due to consistent weather patterns. This is similar to the high degree of autocorrelation found by Schomer, et al in the LAX data.

In order to make the monitoring program closer to random monitoring, instead of using a single consecutive sample of time, a scheme using multiple periods of consecutive measurements was investigated. Tests 22 through 27 used 2 sample periods with half of the total number of samples for each combination taken from the spring data and half from the summer data. Tests 28 through 33 used 4 sample periods with 1/4 of the samples taken from the first half and 1/4 of the samples taken from the second half of the spring and summer data. Tests 33 through 39 used 6 sample periods splitting the spring and summer data in a similar manner. Examining the results of tests 22 through 39, it is clear that as you increase the number of measurement series the Students-t methodology works better. These data show that somewhere between 4 and 6 measurement series are needed to use Students-t methods for assessing sample size requirements.

There are some inconsistencies in Table 4-3 that are troublesome. One is that at 6 series the Students-t method achieves a near 100% performance rather than 90%. With a series of 4 measurements the results vary a large amount in the 60 to 100% range rather than being consistent. One of the concerns is with the number of combinations evaluated by the computer program. For this series of tests a rather simple means of selecting the number of combinations was used that tended to reduce the number of combinations evaluated as a function of the number of series used. Another series of tests were run in which the number of combinations was varied and is discussed below.

Tests 40 through 63, shown in Table 4-3, tested increasing numbers of combinations with 4 sample periods to find the number of combinations needed to adequately represent the extremely large number of possible combinations. Some of the tests have a similar number of combinations, albeit much larger numbers of combinations than used for the 4 series in Table 4-4, but significantly different results because the samples were taken from different parts of the whole database. What is quite interesting is

Table 4-4
Additional Conservative Sample Results

Test #	Total # of Samples	# of Measurement Series	Combinations	# of Seasons	Average C.I.	% Within Student-t Predicted 90% C.I.
1	100	4	270	2	0.6	100%
2	60	4	320	2	0.7	100%
3	20	4	370	2	1.2	91%
4	16	4	375	2	1.4	90%
5	12	4	380	2	1.6	94%
6	8	4	385	2	2.0	96%
7	100	4	280	2	0.7	80%
8	60	4	330	2	0.9	73%
9	20	4	380	2	1.6	82%
10	16	4	385	2	1.8	85%
11	12	4	390	2	2.0	89%
12	8	4	395	2	2.5	94%

that increasing the number of combinations shows that the sampling 4 times a year produces results very close to the expected 90% success rate.

4.1.5 Summary

The results of these experiments indicate that for measuring background levels using the L90 metric should be made 4 times a year. This is in agreement with the State of California guidelines for airport noise measurement and with Schomer's, et al., recommendations for airport noise measurements.

The duration of each of the 4 measurement trips should be based on the desired confidence interval. The results show that for a 90% confidence interval of ± 1 dB, data from 15 different hour samples would be needed to determine the average L90. For a confidence interval of ± 1.5 dB, data from 5 hours would be needed. And for a confidence interval of ± 2.0 dB, data from 5 hours would also be required.

These measurement times are for measuring background sound only. Describing aircraft noise levels adequately would require longer measurement periods for each of the 4 annual trips. The required sample size would depend upon the number of aircraft operations measured at each park. The methodology for calculating the number of aircraft sample is presented in Section 5.5. It is based upon the same methodology presented in this section.

Section 4.2

MEASUREMENT REQUIREMENTS FOR CULTURAL PARKS

A number of park units are considered cultural or historic resources that may have different sound measurement requirements than natural or wilderness parks. The focus of this subsection is to review any unique issues to these settings that should be addressed by the measurement program. These issues include differences in park visitor expectations of the sound environment and structural vibration effects on historical structures.

4.2.1 Visitor Expectations

Some of the historic or cultural park units are located near or within urban areas. The ambient sound levels as well as other urban sources of noise are generally higher than those found in wilderness areas. These higher ambient sound levels will help mask the noise from aircraft overflights. In addition, park visitors may not have the same expectations of a quiet environment in a more developed setting than in a wilderness setting. Visitors who hike for two days to reach a remote location will have different expectations of a quiet environment then one who drives to a cultural building.

A cultural or historic park, by its nature, has some man made development associated with it. Generally either a building, fortress or monument. Therefore, it would not be completely unexpected to have some by-product of cultural, i.e., aircraft noise, affecting the environment. This is not to say that aircraft noise would be acceptable in these settings, but that the threshold of significance may be different than in a wilderness setting.

Some of the historic or cultural parks were established to honor events from American history. Visitors to these areas often experience moments of quiet thoughts over the historic significance of what the park is honoring. Extraneous events such as aircraft flyovers can interrupt this train of thought and thereby alter the visitor experience of the park. The detectability analysis, presented in the measurement program, can be used to describe when a sound may result in disturbances of this type. This can be expressed in terms of the time above or the number of times per day this disturbance is likely to occur.

The noise measurement program proposed for wilderness parks is also applicable to historic or cultural parks. The potential disturbances from aircraft overflights in these settings can be adequately described by this program. Sociological surveys of park visitors to historic or cultural parks may not correlate with the results from surveys at wilderness sites, and vice versa. In addition, the type of individual that visits historic parks may also have different sensitivity to technology-related sounds than a visitor to a wilderness park. Therefore, it is recommended that sociological surveys also be completed for at least one cultural park. Those cultural or historic park units that are located in remote area would be expected to have the same concerns as with wilderness parks.

4.2.2 Structural Vibration

A number of historic or cultural parks have very old buildings or Native American Indian structures located within the park. These structures are often fragile and concern has been expressed over the potential for damage from vibration caused by aircraft overflights. In order for aircraft overflights to result in structural vibration, the aircraft must generate noise levels that are sufficiently loud or cause sonic booms. The noise levels from aircraft at most park settings are not of sufficient intensity to result in structural vibration, either noticeable vibration or levels that would result in structural damage. In general, only those historic buildings affected by low-altitude military overflights (MTRs) or sonic boom would be potentially affected. In order to assess the degree of impact due to vibration it is necessary to first estimate the amount of structural vibration due to these operations and then to determine the potential significance of these vibrations on the historic structure.

Vibration is measured in terms of acceleration. The two most common terms of scaling acceleration are in terms of meters per second squared or in multiples of the acceleration of gravity, commonly referred to as "g". When an element is excited it will vibrate at its own natural frequency. Similar to a string on a guitar; no matter how fast or how hard you pluck the string it will still vibrate at the same frequency. How hard you pluck the string will affect the amplitude or the loudness of the note. One has to change the physical properties of the guitar string, such the length, tension, or weight, to change the natural frequency of the string. Different building elements will have different natural frequencies. Typical natural frequencies for building elements are less than 70 Hz.

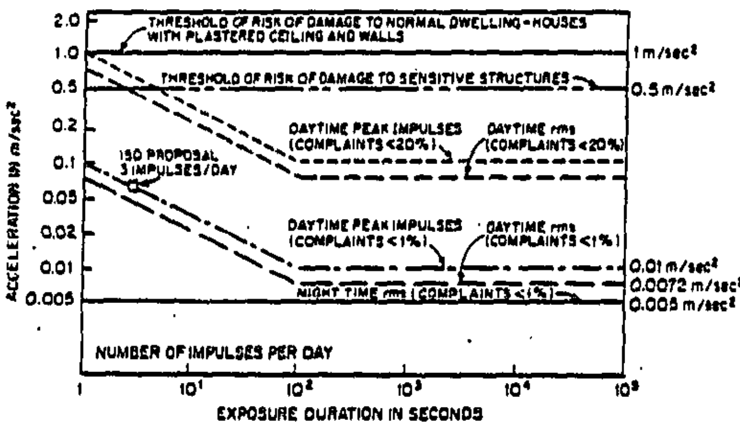
Researchers (Stephens et al., 1982) have compiled data for helicopters, aircraft, and wind turbines which show a correlation between wall, window, and floor vibration for various noise levels. To obtain acceleration levels of 0.001g in floors, walls, and windows, peak noise levels of approximately 95, 80, and 75 dB respectively are required.

Published guidelines suggest accelerations of 0.1g be used as a safe limit for structural damage, although minor damage may occasionally occur. More recently, a commonly accepted conservative threshold for vibration to structures is 0.05g. Generally accepted vibration levels for structural buildings in presented in Exhibit 4-3. For extremely sensitive structures, such as is the case with historic structures within some park units, a lower threshold is recommended. The threshold of vibration that may result in potential damage to these historic structures should be investigated.

The Air Force Noise and Sonic Boom Impact Technology Project (NSBIT) and the Oakridge National Laboratories are studying the vibration effects from sonic booms and MTR operations respectively. Included as part of these studies are the effects to unique and sensitive structures. For example, the results have shown no adverse effects of sonic booms on Indian pithigraphs. The Park Service should request that certain sensitive structures of concern be included as part of this research.

Historic structures located near sonic boom areas or military training routes should be considered for measurement for structural vibration. These measurements can be completed using long term unattended sampling instrumentation. Correlation with aircraft overflights would still be necessary.

Exhibit 4-3
Criteria for Building Vibration Exposure



(Source: C. Harris, 1979):

Section 4.3
DOCUMENTATION OF AIRCRAFT OVERFLIGHT INCIDENTS

An important element in addressing the acoustic impacts of aircraft overflights in National Parks is an accurate assessment of the number and type of aircraft operating over the parks. Although the number of overflight incidents over some park units are thought to be extensive, the actual number has not been clearly determined. The purpose of this section is to devise a standardized methodology for the identification of the levels of aircraft operating over park units. This program is to be capable of determining the baseline level of overflights presently occurring, and to provide a means to assess change in the number of flights or flight patterns over time.

Public Law 100-91 requires that the study "*...distinguish between the impacts caused by sightseeing aircraft, military aircraft, commercial aviation, general aviation and other forms of aircraft which affect such units*". The impacts from overflights by both fixed wing and helicopters are to be determined. Therefore, the levels of operations are also to be determined for each of these categories of operation. The program is organized such that the operational levels for different modes such as seasonal variations can also be determined.

Overview

The purpose of the program is to determine the level of aircraft operations by category. This level needs to be determined on a daily basis or averaged over some time period. The criteria for developing the aircraft identification program include:

- Statistical confidence
- Simplicity
- Minimum manpower requirements
- Application to all park settings

There are two possible methods for determining the number and type of aircraft operations within a park unit. The first method is to determine aircraft operations from field observation by park service employees. This sampling program could involve:

continuous year long sampling, informal non-random sampling, or formal random sampling.

The second method is to obtain the data directly from operators of aircraft that overfly the park and when applicable, Air Traffic Control. Sources of aircraft operations include: commercial airlines schedules, Air Traffic Control personnel, the local military base, tour operator reports, and scientific research flight schedules. At some park units, it may also be possible to observe operations on jet routes over the park from the local Air Traffic Control TRACON. The pros and cons of each of these methods are discussed in the following paragraphs.

Continuous sampling for a year would, of course, result in the most complete data, however, the costs for such a program could be very high. Another method of gathering the required data would be to have all park employees that are in the field to be on a constant lookout for aircraft overflights, and noting information relative to that aircraft. This method of non random sampling has had limited success in past studies. An informal sampling program by all park employees would be subject to a higher level of variability. The results would vary depending upon the time each employee was able to commit to the program. There would be no basis for statistical confidence in the results.

A carefully devised formal random sampling program provides the optimum balance between statistical confidence and available resources. It is recommended that sampling be completed by an individual or staff specifically assigned to a formal program. These individual could also be performing their normal job only if this job did not interfere with the aircraft data collection. For example, a ranger at the entrance gate at a park that has a large number of operations would miss many events. However, a ranger assigned to the backcountry could also be used to observe occasional loud MTRs operations.

Operational information obtained from aircraft operators can provide useful information relative to the frequency of occurrence of overflights. Not all operations can be determined from this method, nor can information relative to the path of the aircraft be determined. Therefore, it is recommended that this data be obtained to supplement the formal field random sampling program. This source of information may be especially useful for aircraft operations that are found to occur non-randomly. This data can also be used to develop the preliminary sampling requirements and to test the reasonableness of the results.

This program is developed for application on the dBASE computer program on an IBM compatible system. It is devised to be flexible and to be applied to all park settings and changing conditions. It is assumed that the aircraft observers used for this program will have some knowledge of aircraft types and aircraft operations. It is assumed that the manager of the study will have working knowledge of the dBASE program and of basic statistics. Each of the elements for the development of this program are discussed in the following paragraphs.

ELEMENT 1 - Identify operational information to be determined

An important first step is to identify the type of operational data to be determined from the sampling program. This is to ensure that the sampling is organized in a manner that desired information can be determined. Typical operational data to be determined from this program is listed below.

- Operations on a daily basis
- Average daily operations throughout the year
- Average daily operations for peak month of activity
- Average daily operations for each season

This data is to be determined in terms of total operations, operations by category of aircraft, and operations by flight corridor. In order to estimate peak levels of activity, the probability distribution of these operations will be determined when the distribution of the data allows for such determinations.

ELEMENT 2 - Estimate current operational levels

Prior to the start of the sampling program, the number, type, frequency and time of aircraft operations over the park unit should be estimated. This information can be used in the formation of the sampling requirements and to help validate the results. The sampling program can then be organized so that it is capable of determining the operations for all of the aircraft overflights of concern. For example, if the operations have significant seasonal variations, then the sampling program should include seasonal measurements.

The first step is to identify the types of operations within the park. These operations will generally fall into the categories of commercial operations, sightseeing tour flights, general aviation, military operations and other flights (NPS, research, law enforcement, search & rescue). Additional information to be determined when possible includes: estimating the number of average daily operations; any seasonal variations in operations; frequency variations in which the operations occur (i.e., weekdays only; a two week period once per year) and the time of day the operations are likely to occur (i.e., daytime only).

These estimates can be determined from a number of sources. Any previous studies of aircraft overflights within the park should first be reviewed. Park employees with long term experience are also a good source of information concerning types of operations and any unique features in terms of when these operations occur.

Aircraft operators and the local Air Traffic Control should be contacted to determine operational information. The aircraft operators to be contacted may include the local military bases, sightseeing operators, and commuter airlines. For example, the local military bases that send aircraft over the MOAs and MTRs near the park can be contacted to obtain training schedules. Most training operations are scheduled at least a week in advance. The base can provide information as to when major training exercises will occur. Information on sightseeing aircraft can be obtained from the tour operators. They can provide information on number of operations, time of day, differences in the seasons, and generalized flight patterns.

At park units located near jet routes, or near airport approach or departure patterns, the local Air Traffic Control (ATC) can be contacted to determine estimates on number of commercial operations on these routes. It may even be possible to observe aircraft operations over the TRACON radar. Knowledge of the origin/destination of aircraft on these routes would also be useful in estimating operational levels. The number of operations could then be estimated from the schedules of airlines that serve these routes.

The information from these sources will not be complete data, but should provide an good initial estimate on the aircraft operations. This data can be used to incorporate current knowledge of the characteristics of the aircraft operations into the development of the aircraft overflights sampling program. This information can be used to direct the sampling resources to collect the information that is most important.

ELEMENT 3 - Identify Major Modes and Categories of Operation

Aircraft overflights need to be defined relative to the different modes or categories of operation. For the purposes of this section, a mode of operation refers to groups of operations that display independent statistical characteristics. For these different modes, the operational data are to be determined independently in order to: (1) determine statistical confidence or (2) provides information that is desired to be known separately. The amount of sampling may vary for each of these modes. Only these modes with significant differences, or those that are desired to be known independently, need to be calculated separately. This information will be used for the statistical calculations as part of the dBASE program.

These modes of operations are variables relative to: (1) types of aircraft operations, (2) variations relative to changing weather patterns, (3) seasonal variations, and (4) variations relative to time of day. These variables are discussed in the next paragraphs.

Different sampling requirements will be necessary for different types of aircraft operations. For example, the commercial air carrier operations over Everglades National Park are relatively constant and do not vary significantly on a day to day basis. The required sampling days to achieve a statistically acceptable results will not be large. However, the low altitude military training operations occur on a more sporadic basis and these operations tend to occur in groups. Therefore, the number of required sampling days for these types of operations is going to be much greater; in fact, they may not even be normally distributed. It is expected that only MTR operations will have sufficient differences in sampling requirements that they may need to be analyzed independently from other aircraft.

Most parks would not be expected to have significant differences in aircraft operations as a result in changes in weather patterns (except of course, the operations are less during inclement weather). Aircraft operations and runway use at an airport are dependent on wind direction and speed. Parks that are located near major airports (i.e., 50 miles or less) may experience some variations in overflights as Air Traffic Control may have different approach and departure routes to and from the airport. In most park applications, these changes in weather patterns occur randomly, and will not need to be considered.

A number of parks, especially those with sightseeing tour operations would be expected to have a large variation in the number of aircraft operations in different seasons. This may require that the sampling be completed in more than one season, and the level of operations determined for each season.

Most parks are not expected to have a significant sound problem from nighttime operations. It may be cost effective to divide the day into daytime and nighttime mode. If nighttime operations are not of concern at a particular park unit, then they will require little or no measurements. The available resources can be directed toward the daytime mode.

In summary, for most park applications the only type of aircraft operations that may need to be analyzed independently from other operations are MTRs. Seasonal differences in the operations and the daytime versus nighttime operations should also be analyzed separately. For illustrative purposes, the preliminary modes of operations for a typical park are presented below:

- Aircraft type modes
  MTR aircraft operations
  Other aircraft operations
- Weather modes
  Good Weather Mode
  Bad Weather Mode
- Seasonal modes
  Winter/Fall
  Spring/Summer
- Time of day modes
  Daytime
  Nighttime

The results from the initial samples may show that additional modes may need to be analyzed independently. For example, the measurements may show distinct differences in the operations on good weather days versus bad weather days. Therefore, it may be desirable to calculate the statistical confidence for these operational modes separately.

ELEMENT 4 - Identify primary flight corridor or patterns

Generally, aircraft overflights in parks are not on specific flight tracks. At a first glance, these aircraft appear to fly in all directions without any pattern. However, most operations over parks can be categorized into a limited number of defined flight corridors or grouped as patterns of operations. These corridors represent groups of operations of aircraft that are on similar flight paths. The corridors can be as specific as a flight track or as wide as a zone of operations.

The aircraft operations at each park unit should be categorized into 10 to 20 preliminary flight corridors. This should be completed by an individual familiar with the operations at that park. These corridors or zones can be refined or added to during the surveys. Note that not all operations need to have a precise corridor that defines this operation. For example, general aviation aircraft that randomly overfly the park. To account for these operations, a park wide zone such as "Eastbound over Park" is an acceptable description for grouping of operations.

ELEMENT 5 - Identify Sampling Locations

Ground locations to observe and identify the aircraft operations must be selected. These locations should be situated in open areas that provide for the most advantageous view of the overflights. The sampling sites do not need to be one precise location, but can be representative of an area for which the operations are to be determined. Large parks may require multiple sampling locations.

The number of locations should be minimized. Generally even at the very large parks, the operations can be determined from three to five carefully selected locations. At these parks, the multiple locations should be sampled simultaneously. During simultaneous data collection, overflights of the same aircraft recorded at different sites should be entered into the data base program as one overflight on one flight corridor. They can usually be correlated using the time, flight corridor and aircraft description data. *Note, when sampling for one specific type of operation (i.e., MTR operations) in one area, it is not necessary to sample at all of the other locations if sufficient data on the operations in those areas has already been determined.*

ELEMENT 6 - Devise Random Sampling Program

The sampling of aircraft overflights needs to be conducted on a random basis. This is a very important element of the program. This random sampling scheme needs to be strictly followed. If the randomly selected day falls on a weekend or a day with poor weather, it must still be sampled. In order to be a true random sample, the sampling days must be determined randomly for each time period for analysis.

The day may be divided into the daytime hours and the nighttime hours. For this NPS study, the daytime is defined as the hours between sunrise and sunset. Note of course, that the daytime hours will vary depending upon the season and the latitude of each park unit. This is different than with the DNL metric, which defines nighttime as the hours between 10 p.m. and 7 a.m.

The daytime and nighttime operations can be determined separately. It is expected that at most park units, nighttime operations are minimal and not of major concern.

Therefore, a limited sampling of the nighttime operations that may not be statistically sufficient, is still an adequate sample. Simply stated, a couple of days of nighttime samples are adequate if the nighttime operations are known to be small in comparison with the daytime. (Note: It is possible to extend this assumption to other hours of the day if the operations during these hours are not significant relative to the total operations).

Various methods are available for selecting the random sample. These include the use of a random number generator, random number tables, or simply selecting the sample days out of a hat. It is recommended that initially the sampling be determined for each month. The number of days to be sampled depends on the desired statistical confidence, available resources and variability in the number of operations. The actual number of required sample days can not be determined until some preliminary sampling has been completed.

For the purposes of this study the sample size will be determined for a 90 percent confidence interval of plus or minus 20 percent of the average number of operations. In order to estimate the number of sample days, statistical calculations were completed of the operations at an airport that is assumed to have similar characteristics as many park units. Based upon these results, approximately 5 days should be sampled per month for most types of aircraft operations. For MTR operations, the number of days was estimated to be 10 days per month.

ELEMENT 7 - Conduct Aircraft Sampling

An example aircraft identification form has been devised that illustrates the type of information to be determined for each aircraft overflight. This sample form is presented in Exhibit 4-4. The form is organized so that most of the information is divided into categories or sub-categories that can be checked off The form includes information relative to the time of the aircraft overflight, the type of aircraft, the category of aircraft, the corridor of operation, and subjective judgments as to the altitude and loudness of the aircraft. Spaces are provided for more detailed information if it can be determined.

Exhibit 4-4
Sample Aircraft Identification Log

NPS AIRCRAFT LOG SHEET

PARK ______ SITE ______________ DATE ______ TIME ______ INITIALS ______

AIRCRAFT TYPE

______JET
____Commercial AC
____Military Fighter
____Military Other
____Corporate (small)

______PROPELLER
____Single-Engine
____Multi-Engine
____Multi-Engine(+10 pass.)
____Sea Plane

______HELICOPTER
____Civilian
____Military

______UNKNOWN

______OTHER

COMMENTS______________________________ VISIBLE ___Yes ___No

AIRCRAFT CATEGORY

______COMMERCIAL
____Confirmed ____Probable

______GEN. AVIATION

______TOUR

______UNKNOWN

______MILITARY
____mtr
____moa
____Other

______OTHER
____Park Service
____Research
____Law Enf/S&R
____Other

COMMENTS______________________________

FLIGHT ZONE OR PATH

____Flight Zone Number
____Other

Comments ______________
____
____

ALTITUDE (agl)

____Very Low Level (<500 ft)
____Low Level (500 to 2,000 ft)
____Transition (2,000 to 10,000 ft)
____High Altitude (>10,000 ft)

Comments______________

SOUND LEVEL

____ Inaudible or Barely Audible
____ Clearly Audible (No Speech Interference)
____ Loud (Speech Interference)

Comments ______________
____

Alternatives to this log form is a data sheet with columns for each of these data. Codes for the different types and categories of operations is entered into each column. The information to be determined for each overflight is to be presented in the following paragraphs.

- SITE - Identifies the location of the observer
- DATE - Date of the observation
- TIME - Time in military time of the aircraft overflight
- INITIALS - Identification of the observer
- AIRCRAFT TYPE - The type of aircraft should be marked as either jet engine, propeller or helicopter. Spaces are also available if the type of aircraft can not be determined or for other types of aircraft that do not fall under these descriptions. Sub-types of each of these aircraft types should marked when this additional data is known. If this additional information can not be determined, than this sub-category should be left blank. Space is provided in the comment section if the exact type of aircraft is known including N number identification. Visual siting of the aircraft should be noted. The types of aircraft and the available sub-types are listed below.
  - Jet Aircraft
    - Commercial air carrier jet
    - Military Fighter jet
    - Military Other jet
    - Small Corporate business jet
  - Propeller Aircraft
    - Single Engine propeller
    - Multi Engine piston or turboprop
    - Large Multi-Engine piston or turboprop (10 passenger or greater)
    - Sea Plane
  - Helicopter
    - Civilian
    - Military
  - Unknown
  - Other

  To facilitate the identification of aircraft, a number of handbooks are available. Sample sources include "A Field Guide to Airplanes" (M.R. Montgomery, Houghton Mifflin Company, Boston 1984) and "Jane's Book of Aircraft" (Macmillan Publishing Co., New York). Occasionally, the use of an aircraft radio will provide additional information on the aircraft type.
- AIRCRAFT CATEGORY - These operations are to be divided into the categories of operations specified in the legislation. These categories are listed below:
  - Commercial Aviation - Air carrier commercial airlines and scheduled commuter aircraft.
  - General Aviation - Predominantly the smaller propeller single engine or twin engine aircraft and occasionally the small corporate jet aircraft. Air taxi operations that are not on a sightseeing flight are included in this category.

Sightseeing Tour - Aircraft for hire that is performing sightseeing flights within the park. These aircraft are most commonly helicopters or small twin engine piston aircraft. Air taxi aircraft with the purpose of sightseeing are also included in this category.

Military - All military aircraft including fighter jets, military transport aircraft, military surveillance aircraft and helicopters. Subcategories to be noted when possible include low altitude military training operations (MTRs), aircraft in designated Military Operating Areas (MOAs) and all other military aircraft including transient aircraft.

Other - All other categories of operations. Subcategories include: NPS maintenance, service of facilities or access to backcountry locations; aircraft operations used for in research studies approved by the park; aircraft used for search and rescue, law enforcement or drug enforcement patrols; and other operations including the Coast Guard.

Note that it is not always possible to identify the specific category of aircraft. However, knowledge of the types of aircraft and operational procedures around the park allows for a high level of confidence in determining the category. The degree of confidence in identify the category of aircraft is to be noted as confirmed, probable and when it is not possible, then listed as unknown. An optional comments section is also provided.

- CORRIDOR OF OPERATION - The flight path of the aircraft should be identified with one of the corridors or patterns that have been developed for each park. If the operation does not fit into any of these listed, then the 'Other' space should be check and the flight path should be listed in the comments section. If enough similar operation occur, then it may be necessary to add another flight corridor to reflect this group of operation.
- ALTITUDE - A subjective estimate of the altitude of the aircraft should be completed. No more than three to four categories should be used. This is not intended to provide precise information in terms of altitude, but is for presenting generalized categories of operations relative to altitude. Each individual park may need to develop their own unique categories. These categories should fall under the headings of low level, transition, and high altitude. Estimates of altitude can be determined from a number of sources. This includes use of aircraft radio, comparison with known cloud altitudes, and with distance measuring instruments.
- SOUND LEVEL - A subjective estimate of the sound level of the aircraft is provided to facilitate the categorizing of the operations. Again this is not intended to be precise information. The actual sound level data is to be collected from a noise measurement surveys. These three general categories of sound level description include: inaudible or barely audible to reflect aircraft that are generally not noticeable unless one is specifically looking for aircraft. The second category, clearly audible, reflects sound levels that can clearly be heard, however, these levels would not result in speech interference of normal communication. The third category is sound levels that are sufficiently loud so that speech communication would be interrupted or altered. An approximate sound level would be above 60 dBA.

Meteorological data is to be determined in conjunction with the operational data collection. The data should be collected on the average of every two hours, or when changing meteorological conditions dictate an additional reading. The pertinent meteorological to be determined includes:

- Average wind speed and direction
- Temperature
- Humidity
- Atmospheric cloud conditions and precipitation

Sources of this meteorological data include: actual field measurements; a meteorological station at the park unit; and the local airport or military base. Atmospheric data should be reported using standard weather report terminology. The source of the meteorological data should also be noted.

ELEMENT 8 - Enter Data into dBASE Program

A standardized data base file has been developed on the dBASE program that can be used to enter the data. This information can then be tabularized in a report form, with summarizes and statistical results. The information to be entered into the dBASE file is presented in Table 4-5. This data also includes codes for use in grouping of the data and performing calculations. These codes are shown in Exhibit 4-5.

Once the data has been entered into the dBASE file, a number of options are available for calculating and displaying the results. These options include:

- Listing of daily results
- Daily operational summaries
- Operational averages with statistical calculations

The operational averages and statistical data is calculated for any of the modes of operations that have been identified. The modes are identified be defining the different categories or codes that are to be grouped together for calculation. For example, the summary of operations for MTR aircraft can be determined.

The statistical information that can be determined includes: (1) average number of operations, (2) standard deviation, (3) 90 percent confidence band, (4) and additional samples necessary to achieve the desired limits of the 90 percent confidence band.

Table 4-5
Data Base Input

- SITE - Identifies observer's location.
- DAY (XX) - Day of Month of observation.
- MONTH (XX) - Month of observation.
- YEAR (XX) - Year of observation.
- DAY OF WEEK (1234567) - Day of the week with 1 for Monday and 7 for Sunday.
- TIME (Military) - Time of the Aircraft overflight (Military time in hours and minutes).
- TIME OF DAY CODE - Enter 1 for daytime and 0 for nighttime.
- INITIALS - Identification of the observer.
- AIRCRAFT TYPE - Enter Code in Exhibit 4-5 for type of aircraft.
- AIRCRAFT CATEGORY - Enter Code in Exhibit 4-5 for category of aircraft .
- FLIGHT CORRIDOR - Enter flight corridor number.
- ALTITUDE - Enter altitude code from Exhibit 4-5.
- SOUND LEVEL - Enter sound level code from Exhibit 4-5.
- COMMENTS - Enter all comments from the log sheet including any of the following information. Twenty five spaces are available.
  - Specific Aircraft type when observed.
  - Aircraft N number when observed.
  - When the aircraft operation was not visible (note as not visible).
  - If the category of aircraft was: confirmed (C) or probable (P).
  - Flight corridor comments.
  - Altitude comments.
  - Sound level comments.
  - Any other comments.
- WIND SPEED - Average wind speed in Knots.
- WIND DIRECTION - Wind direction in terms of compass heading (000).
- CLOUD COVER - Cloud cover and precipitation data.
- TEMPERATURE - Temperature in degrees F.
- HUMIDITY - Relative Humidity in percent or dew point.
- WEATHER MODE1 - Optional code for defining different weather modes that effect operational levels. For example, leave blank for when weather is good. Enter the number 1 when severe weather affects the number of operations.
- BLANK1 - Available for grouping different modes of operations or for future use.
- BLANK2 - Available for grouping different modes of operations or for future use.

Exhibit 4-5
Sample Log Sheet with dBase Codes

NPS AIRCRAFT LOG SHEET

PARK ____ SITE ____ DATE ____ TIME ____ INITIALS ____

AIRCRAFT TYPE

10 JET
11 Commercial AC
12 Military Fighter
13 Military Other
14 Corporate (small)

20 PROPELLER
21 Single-Engine
22 Multi-Engine
23 Multi-Engine(+10 pass.)
24 Sea Plane

30 HELICOPTER
31 Civilian
32 Military

40 UNKNOWN

50 OTHER

COMMENTS ____ VISIBLE ___Yes ___No

AIRCRAFT CATEGORY

10 COMMERCIAL

20 GEN. AVIATION

30 TOUR

40 MILITARY
41 mtr
42 moa
43 Other

50 OTHER
51 Park Service
52 Research
53 Law Enf/S&R
54 Other

60 UNKNOWN

___Confirmed ___Probable

COMMENTS ____

FLIGHT ZONE OR PATH

___Flight Zone Number
___Other
Comments ____

ALTITUDE (agl)

1 Very Low Level (<500 ft)
2 Low Level (500 to 2,000 ft)
3 Transition (2,000 to 10,000 ft)
4 High Altitude (>10,000 ft)
Comments ____

SOUND LEVEL

1 Inaudible or Barely Audible
2 Clearly Audible (No Speech Interference)
3 Loud (Speech Interference)
Comments ____

Section 5.0

AMBIENT AND AIRCRAFT SOUND MEASUREMENT PROGRAM

The proposed sound monitoring program for the National Park Service is a carefully designed program that takes into consideration the many unique and difficult problems associated with sound measurements in National Parks. The program requires the use of specialized measurement instrumentation and a specific methodology for data collection. The program is intended to ensure the highest level of accuracy and standardization of the measurement results.

In order to determine complex sound-rating metrics, the methodology includes the measurement of spectral sound level data. The measurement of spectral sound level data requires the use of more sophisticated instrumentation and substantially more data collection and analysis time than with A-weighted measurements. Under conditions of limited resources (equipment and labor), there are situations where simple A-weighted sound level measurements may be used as a substitute for the more complete spectral measurements. Where applicable, this option of measuring only A-weighted levels is presented.

A-weighted measurements can be used for the measurement of MTR operations and when conditions dictate the need for longer-term sampling than can be completed with available resources. For conditions at a particular park, a relationship may be developed between the more complex descriptors requiring spectral information and the A-weighted descriptor. Subsequent measurements may then be done in A-weighting to provide the long-term acoustic information.

This section of the report outlines the procedures to be used in the measurement program. The program is divided as follows:

5.1 Equipment Specifications
5.2 Measurement Site Selection
5.3 Measurement Procedure
5.4 Acoustic Data Analysis
5.5 Statistical Sampling Requirements

5.1 Equipment Specifications

The measurement equipment to be used for this study must comply with exacting instrumentation standards and specifications. These specifications are for the complete measurement system, including any audio recording equipment and apply to all types of aircraft measurements. These requirements are listed below.

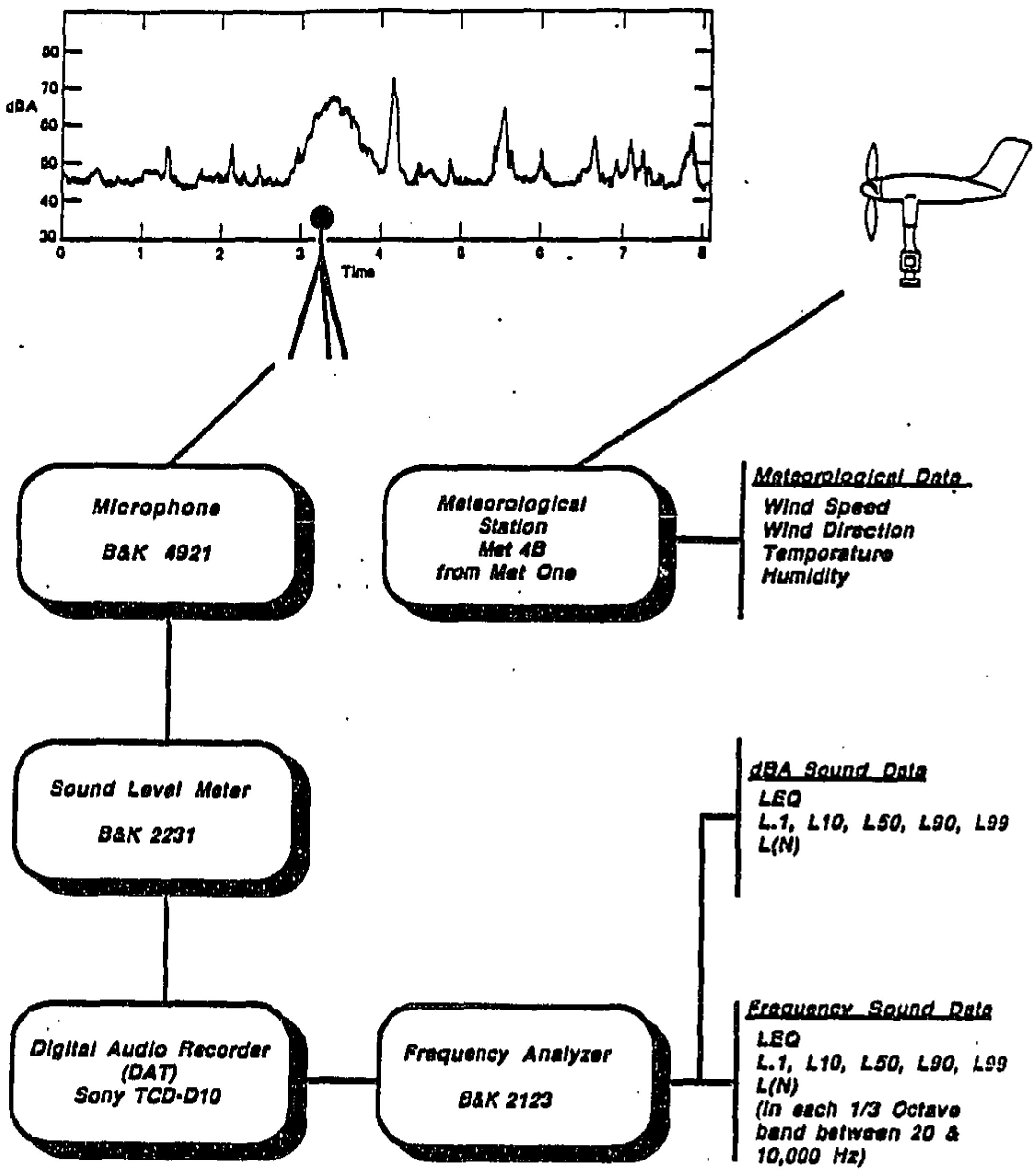
- Sound level measurements must conform with ANSI S1.4 1983 and IEC 651/DIN Type 1.
- Measure A-weighted sound level and 1/3 octave band levels between 50 Hz and 10,000 Hz. Frequency response of +/- 3 dB from 50 to 10,000 Hz.
- 1/3 Octave Bandwidths must meet ANSI S1.11 1986, ICE 225, and DIN 45652 for Class III filters.
- Minimum dynamic range of 80 dB (+/- 2 dB with less than 1% harmonic distortion) not including crest factor.
- Lower limit noise level of 5 dB from 50 to 200 Hz and 0 dB from 250 to 10,000 Hz. Microphones/preamplifiers with higher limits may be used when approved by the NPS or USFS.

Proper care should be taken to ensure all auxiliary equipment is correctly used with the sound level meter. For example, filters, recorders, and cables should have an input impedance appropriate for the sound level meter output impedance. To ensure measurement integrity, actual demonstration of the capabilities of the complete measurement system must be documented before beginning the measurement program. This requirement is for the complete system including all connection cables. This demonstration requirement is for the frequency response, dynamic range and lower limit noise level specifications.

Various measurement systems are available that meet these requirements. The final measurement system used for this survey used a digital audio tape (DAT) recorder to record the ambient and aircraft sound levels in the field. The recorded data can then analyzed in the laboratory. The use of DAT recorders is recommended for this study.

A sample sound measurement system that meets the above requirements is presented in Exhibit 5-1. Note that this equipment is presented for illustrative purposes

Exhibit 5-1
Example Measurement Instrumentation



only. Other manufacturers produce similar types of equipment that also meets these specifications. It is extremely important that only instruments manufactured by companies with long-standing reputations in the acoustic instrumentation field, with the ability to support such equipment, be considered. Measurement instrumentation used in this program should have a demonstrated history of operating under harsh environments.

The cost for the complete sound measurement system may range from $8,000 to $20,000. Note that this does not include the cost of the frequency analyzer that is necessary to analyze the tape-recorded results. The cost for the frequency analyzer may range from $20,000 to $35,000. The costs for a meteorological station is less than $2,000. Special weather protection equipment for long-term measurements in high-moisture or low-temperature environments can add $3,000 to $5,000 to the unit cost of the measurement system.

This sound measurement system is recommended for use in all types of ambient and aircraft settings. MTR operations and supplemental measurements may be done in A-weighted sound levels only. The A-weighted system should have automated digital noise data acquisition capabilities and provide a strip-chart recording of the measurement data. The system must also meet the above standards that apply to A-weighted measurements. The cost for this system may range from $8,000 to $15,000. An example sound level instrument that meets these requirements is the Bruel & Kjær 4427.

5.2 Measurement Site Selection

The proper selection of representative measurement locations is a critical element in describing the ambient and aircraft acoustic environment within the National Park setting. Many of the parks encompass thousands of acres with varied aircraft environments, and it is not feasible to measure at all areas within a park. Given the very large areas of these park units, it is necessary to develop and apply criteria for selecting representative measurement locations. It is particularly important to make certain that background sound levels are representative of actual conditions in the park and that sites are representative of the aircraft activity.

The selection of measurement locations must also be consistent with the needs of the sociological portion of the study. The following criteria are to be used for selection of these measurement locations.

- These sites must be exposed to a variety of aircraft types and operations. They should include all categories of aircraft identified for analysis by the law. This includes any tour aircraft, en route high-altitude jets, military aircraft, and general aviation aircraft that may operate at that particular park unit.

- The vegetation and terrain of the sites must be representative of that sites area of the park. The ambient sound exposure for each site must also be representative of that area. Although site should not be located directly adjacent to major sources of sound these sources should not to be excluded. For example, a site directly adjacent to a roadway or river is not acceptable. However selecting a site in the environs of these sources is acceptable as they are part of the ambient environment. WHAT ?

- The sites should be in areas that have a high level of recreational use (i.e., hiking, camping, or sightseeing). The sites should include areas that represent a range of activity levels including remote back country dispersed recreation and accessible front country developed area use. In the larger parks, at least one site for each type of park use should be selected to represent the acoustic environment for each of these areas. Forest Service sites are to be measured at remote backcountry locations only.

- The park use patterns of visitors should also be incorporated into the site selection process. Measurement sites should be grouped to defined areas of use. This is intended to facilitate the correlation between and acoustical and sociological portion of the study. For example, a site that represents a popular overnight hiking trail would be an excellent site.

- At park units with a "point-of-interest", a measurement site should be selected that is representative of that location. A point-of-interest is defined as an attraction point in the park that generates activities from both sightseeing tour flights and as well as park visitors on the ground (e.g., Mount Rushmore National Monument or Wahaula Visitors Center at Hawaii Volcanoes National Park).

- The measurement site should not be located near any structures, large trees, or severe topographic variations that will alter the sound exposure. An exception can be made if the site is designed to measure this type of environment. For example, measuring in the forest or a canyon is appropriate if that is representative of the park area; measuring under the only tree in the area is not appropriate.

- The law specifically excludes operations associated with landing fields within, or adjacent to such units. Therefore, the measurement sites should not be located local to any airport approach or departure patterns or within the airport traffic area. En route aircraft operations are only considered by this legislation.

- The sites must be accessible for the field technician and the monitoring equipment. Access and operation must be achieved with minimal detection by the local aviation operators. The use of helicopters for site access is acceptable when necessary, but its use is to be minimal and discouraged.

- The site should be marked in some manner so that it can again be relocated for monitoring at some future date. This could be a detailed description of the site or a stake.

The NPS or USFS staff should make a preliminary recommendation on the number of measurement locations for each park unit or wilderness area under consideration for study. Given a fixed funding resource, the number of measurement sites will always represent a tradeoff between spatial coverage of the park area and statistical confidence in the results. In general, more measurements at fewer sites will provide more meaningful information on the aircraft sound environment than less measurement time at more sites.

For most park units and wilderness areas, approximately five representative locations should provide sufficient information concerning the ambient and aircraft environment. For very large units with varied levels of aircraft operations, as many as eight sites may be necessary. For smaller units one to three locations may be adequate. Sample measurement sites are presented for three park units in Appendix E.

5.3 Measurement Procedure

The program requires specific standardized measurement procedures that must be followed. This is designed to ensure uniformity for all of the measurements. These measurement procedures have been developed for both acoustic and nonacoustic data acquisition. These specifications are summarized in the following paragraphs.

Acoustic

- Microphone is to be mounted on a tripod at an elevation of five feet above the ground.

- The microphone is to be covered with a foam wind screen. This wind screen should have comparable wind induced noise characteristics to the Bruel & Kjær UA0207 screen.

- Sound level data is to be recorded in the field using DAT tape recorders. The tape recorders should operate continuously. Continuous recordings are necessary in order to record the time history of an aircraft overflight and the background sound levels before and after the event. Input signal to the recorder must be linear between the frequencies of 50 and 10,000 Hz.

- When measuring with instrumentation that only determines the A-weighted sound level, the measurements must include a continuous stripchart recording of the sound environment.

- The equipment is to be calibrated at regular intervals with calibration traceable to the National Bureau of Standards. This calibration certification is to be completed by the calibrator manufacturer and must be current for the duration of the measurements.. Regular intervals are defined as a minimum of every four hours for all sites that the field engineer is in attendance and bi-weekly for any long-term unattended measurements. Tape recording of data must have at least one calibration signal on all tapes.

- A hard copy of the measurement data must be stored on tape, printout, or disk by the contractor, and be available for review for at least one year after the completion of the contract. This requirement is designed to allow for modifications to the metric used to describe the actual aircraft noise settings.

Nonacoustic

- Meteorological data is to be collected in conjunction with the acoustic data. The data should be reported hourly during the daytime hours and at least twice during any nighttime sampling. For measurement sites where the field engineer is in attendance, this data should be reported for each measurement site. For long-term unattended sampling, the data should be correlated with meteorological data from other measurement locations. The meteorological data to be collected includes:

- Wind speed and direction measured at an elevation of five feet at a location at or near the recording microphone. The data is to be reported in terms of average and maximum speed.
- Temperature, humidity and atmospheric pressure.
- Atmospheric cloud conditions.
- Lapse rate data. NPS may occasionally request lapse rate information be determined for a number of samples at one location in the park using radiosondes.

- In order to provide long-term information on the meteorological conditions in a park unit, it is recommended that a permanent meteorological station be installed prior to the start of the measurement program. Site specific meteorological data can be correlated with the permanent site.

- Each aircraft overflight must be identified in terms of a category of aircraft and the flight procedure. The aircraft are to be identified by the specific type where possible and at least by category. This identification procedure must be the same as the aircraft identification program specified in Section 4.3 of this report.

  The aircraft flight corridor relative to the measurement site is to be reported. This flight corridor classification should be consistent with the corridors defined within the aircraft identification program (Section 4.3). The program is designed to determine the number of overflights in each park. The altitude of the aircraft should also be estimated as well as any specific procedure, such as climbing or descending, that the aircraft performs during the measurements.

- The measurement sites are to be characterized relative to the type of vegetation, recreational use, and level of park visitor activity. All sources of sound affecting the ambient sound levels at that location should be reported. This includes both natural sources (i.e., rustling of trees, rivers, and wildlife such as birds, insects etc.) and man made (i.e., traffic noise, park visitors, generators, power lines etc.).

5.4 Acoustic Data Analysis

The measurement program requires the collection of both ambient and aircraft sound level data. Ambient sound levels are to be determined in order to characterize ambient sound level conditions within the park and to provide information concerning the background sound level during the time of each aircraft overflight. Accurate information relative to the background sound levels is the most critical and variable element in quantifying the detection of the aircraft events. Therefore, the background sound level is to be determined close to the time period of each aircraft overflight.

Currently there is no single number rating system recommended to describe the aircraft sound levels. Potential rating systems will be reviewed and developed in concert with the sociological surveys. At this time a number of sound-rating scales and acoustic factors are being considered to describe the aircraft sound levels. These potential descriptors are based upon both A-weighted sound level data and on more complex information that require collection of 1/3 octave band noise levels. This measurement program is established in a manner that allows for collection of all the necessary acoustic information so that computer calculations of all of these potential descriptors can be completed.

The noise levels are to be analyzed using time constant ANSI "slow" response. The acoustic data to be determined from the measurements is the A-weighted sound level and the 1/3 octave sound levels from 50 to 10,000 Hz. The data should be processed at a minimum sample rate of once per second for all aircraft operations other than MTR overflights. For MTR operations, the sample rate during the overflight should be a minimum of 125 milliseconds or at a minimum rate necessary to determine the maximum sound level and the onset rate.

Ambient Measurements

For the purposes of this study the ambient sound and background sound have specific meanings. The ambient sound environment is a measure of all sounds in the park, both natural and man made, except the sound from aircraft operations. The sources of sounds affecting the ambient environment is to be documented (e.g. wind, wildlife, roadway, campground). The ambient sound levels are to be determined for representative time periods throughout the day. The purpose of these measurements are to document the ambient conditions that currently existing in the park system. The background sound represents the residual sound environment, or the lowest levels of sound from which all sounds, both aircraft and non-aircraft intrude into. The background sound level is represented by the L90 level. The background sound level is to be determined during the time of each aircraft event.

The ambient sound environment is to be determined for sample periods throughout the day. The ambient measurement data to be reported is in terms of the LEQ sound level and the statistical L(n) levels. For each ambient sample period, the LEQ, Lmax, L10, L50, L90 and the L99 are to be determined for each 1/3 octave band level and the A-weighted level. The data reported should be rounded to the nearest whole number after all calculations are made. Sources of noise affecting these measurements, including natural and man made sources should be described as discussed in Subsection 5.3 (Measurement Procedures).

The ambient sound levels should be recorded during extended periods when there is no aircraft activity. During the measurements, at least one sample is to be collected every two hours. More specifically, for describing the ambient sound environment, the measurements should include one sample every two hour during the daytime hours and at least two samples during any nighttime measurements. The duration of these measurements can be from 15 to 60 minutes.

At least one measurement site within a park unit should include sampling during the nighttime and other off hours. The amount of sampling necessary should be correlated with the type and level of nighttime aircraft activity at a particular park unit. Parks with only tour aircraft would not have significant nighttime activity. Other parks, located near jetways, may have more nighttime operations that make knowledge of nighttime sound levels more of a concern.

The background sound environment is to be determined during the time period whenever there is an aircraft event or series of aircraft events. The L90 sound level in each band and the A-weighted level is to be used to define the background sound environment. Every aircraft event should have an associated background sound level that is indicative of the background sound levels during the time period of the event. This background sound level should be determined for a time period as close to the time of the event as possible. The period of time used to characterize the background sound environment is defined below.

The 1/3 octave and dBA L90 values used to represent the background sound level for a particular event must include data measured within five minutes before or after the event occurred. (For these calculations, the beginning or end of an event is defined as when the field observer no longer considers the aircraft audible, or 10 seconds before or after D' exceeds fifteen for a preliminary calculation.) Data measured more than 30 minutes before or after an event is not to be included in these calculations. The minimum duration of measurement is 5 minutes. The maximum duration is 30 minutes.

(Note: This is not an absolute requirement, but should be adhered to as often as possible. There will be some measurements in which aircraft will be affecting the noise environment for extended durations and ambient conditions may change substantially during that time period. When necessary, the contractor is to use judgment to define an appropriate measurement period to determine the background sound level. The contractor is to document any deviation from this standard procedure.)

Aircraft Measurements

The noise levels from individual aircraft events are to be analyzed. Often, a number of aircraft operations will occur simultaneously and these aircraft will be grouped as one event. The A-weighted and 1/3 octave band sound levels during aircraft events, the two minutes prior to the start of the event, and the two minutes after the end of the event are to be used in the calculations. A number of different acoustic metrics used to describe the aircraft noise levels are to be determined from this data.

Many of these metrics are based on detectability. Detectability (d') is a function of the differential between the 1/3 octave band noise level of the source and the background in the same frequency band. The band width and the efficiency of the listener are also factors in the d' calculation. For this study, the detectability value reported is the maximum detectability value in any 1/3 octave band. Detectability (d') is to be reported in terms of the 10log(d') level, or D'. The equation is presented below:

$$D' = 10\log(d') = 10\log(\mu(w)^{1/2}(S/N))$$

where: S - Signal level in a 1/3 octave band
N - Background level in same band
w - Band width in same 1/3 octave
μ - Efficiency of observer relative to an ideal energy detector. For this study, μ =.4

CORRECTION!

THE PREVIOUS DOCUMENT(S) MAY HAVE BEEN FILMED INCORRECTLY . . .

RESHOOT FOLLOWS!

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Upper Marlboro, Maryland 20772
(301) 249-0110

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- w - Band width in same 1/3 octave
- μ - Efficiency of observer relative to an ideal energy detector. For this study, μ =.4

the maximum level and the background is the L90 level. The relative Loudness Level is also to be determined (difference between maximum level and L90 level).

- PNLT. The tone corrected Perceived Noise Level (PNLT) is to be determined for the aircraft and background conditions. The PNLT of the aircraft is the maximum level and the background is the L90 value. The relative PNLT level is also to be determined (difference between maximum level and L90 level).

- Time Above L90 dBA levels (TAL90+ 5, 10, 20, 30, 40). The duration of the event above the background sound level is to be determined for various levels of intrusion. The background sound level is the L90 dBA value. These durations are defined as time above the L90 value plus 5, 10, 20, 30, 40 dBA. The event must have a minimum duration of three seconds. For fluctuating events, the total durations of the event are summed. This information is determined in order to provide a correlation between determining duration using the more precise detectability and using simpler A-weighted data.

A number of park units are located in areas with MTRs. The aircraft sound levels from these MTRs are often associated with low-altitude aircraft that potentially have high sound levels and onset rates. The following acoustic data is to be determined for MTR operations.

Primary Data

- SEL Level. The Sound Exposure Level (SEL) from the A-weighted measurement data is to be determined.

- dBA Sound Level. The maximum dBA sound level from the aircraft overflight and the background L90 dBA level are to be reported. The maximum value represents the highest dBA noise level measured for this aircraft event. The relative A-weighted sound level is also to be reported (A-weighted difference between the maximum level and the background L90).

- Onset Rate. The onset rate of the aircraft event in terms of the rate of change in dBA per second is to be determined for each aircraft overflight. Onset is to be determined between the time the signal is 5 dBA above the background and 5 dBA below the maximum dBA value.

Secondary Data

- EPNL. The Effective Perceived Noise Level (EPNL) from the event is to be calculated.

- Loudness Level. The Loudness Level (ISO 532B) is to be determined for the aircraft and background conditions. The Loudness Level of the aircraft is the maximum level and the background is the L90 level. The relative

CORRECTION!

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Many of these metrics are based on detectability. Detectability (d') is a function of the differential between the 1/3 octave band noise level of the source and the background in the same frequency band. The band width and the efficiency of the listener are also factors in the d' calculation. For this study, the detectability value reported is the maximum detectability value in any 1/3 octave band. Detectability (d') is to be reported in terms of the 10log(d') level, or D'. The equation is presented below:

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where: S - Signal level in a 1/3 octave band
N - Background level in same band
w - Band width in same 1/3 octave
μ - Efficiency of observer relative to an ideal energy detector. For this study, $\mu = .4$

For example, a measured signal of 60 dB in the 500 Hz 1/3 octave band (the signal also includes the background sound level) in a background sound of 50 dB in the same frequency band results in a D' of 16.

The acoustic information to be determined from these aircraft measurements varies for different types of aircraft operations. These operations can be divided into two categories. One category is the low-altitude MTR operations. These operations are characterized by potentially high maximum sound levels and high onset rates. All of the remaining types of aircraft operations affecting parks are included in the second category. These operations are generally characterized by relative low-level sounds with long duration and very slow onset rates.

The following paragraphs describe the acoustic information that is to be reported for all aircraft operations other than MTR aircraft. A computer program has been written that will automatically calculate this information from the measurement data. Once again, an aircraft event may include a number of grouped aircraft that operated simultaneously.

Primary Data

- dBA Sound Level. The maximum dBA sound level from the aircraft overflight and the background L90 dBA level are to be reported. The maximum value represents the highest dBA noise level measured for this aircraft event. The relative A-weighted sound level is also to be reported (A-weighted difference between the maximum level and the background L90).

- Time Above D' Levels (TA D' 10,15, 20, 25, 35, 45). The time duration of the event above various detectability levels is to be determined. These durations are defined as time above D' of 10,15, 20, 25, 35, 45. In the D' calculation, the signal (S) is the event sound levels and the Noise (N) is the larger of the ambient L90 or the MAF curve in the same band. The event must have a minimum duration of three seconds. For fluctuating events, the total durations of the event are summed.

Secondary Data

- Onset Rate. The onset rate of the aircraft event in terms rate of change in dBA per second is to be determined for a representative sample of aircraft overflights. Onset is to be determined between the time signal exceeds D' of 15 and the maximum dBA value.

- Loudness Level. The Loudness Level (ISO 532B) is to be determined for the aircraft and background conditions. The Loudness Level of the aircraft is the maximum level and the background is the L90 level. The relative Loudness Level is also to be determined (difference between maximum level and L90 level).

- PNLT. The tone corrected Perceived Noise Level (PNLT) is to be determined for the aircraft and background conditions. The PNLT of the aircraft is the maximum level and the background is the L90 value. The relative PNLT level is also to be determined (difference between maximum level and L90 level).

- Time Above L90 dBA levels (TAL90+ 5, 10, 20, 30, 40). The duration of the event above the background sound level is to be determined for various levels of intrusion. The background sound level is the L90 dBA value. These durations are defined as time above the L90 value plus 5, 10, 20, 30, 40 dBA. The event must have a minimum duration of three seconds. For fluctuating events, the total durations of the event are summed. This information is determined in order to provide a correlation between determining duration using the more precise detectability and using simpler A-weighted data.

A number of park units are located in areas with MTRs. The aircraft sound levels from these MTRs are often associated with low-altitude aircraft that potentially have high sound levels and onset rates. The following acoustic data is to be determined for MTR operations.

Primary Data

- SEL Level. The Sound Exposure Level (SEL) from the A-weighted measurement data is to be determined.

- dBA Sound Level. The maximum dBA sound level from the aircraft overflight and the background L90 dBA level are to be reported. The maximum value represents the highest dBA noise level measured for this aircraft event. The relative A-weighted sound level is also to be reported (A-weighted difference between the maximum level and the background L90).

- Onset Rate. The onset rate of the aircraft event in terms of the rate of change in dBA per second is to be determined for each aircraft overflight. Onset is to be determined between the time the signal is 5 dBA above the background and 5 dBA below the maximum dBA value.

Secondary Data

- EPNL. The Effective Perceived Noise Level (EPNL) from the event is to be calculated.

- Loudness Level. The Loudness Level (ISO 532B) is to be determined for the aircraft and background conditions. The Loudness Level of the aircraft is the maximum level and the background is the L90 level. The relative

Loudness Level is also to be determined (difference between maximum level and L90 level).

- dBC Sound Level. The maximum dBC sound level from the aircraft overflight and the background L90 dBC level are to be reported. The maximum value represents the highest dBC noise level measured for this aircraft event. The relative C-weighted sound level is also to be reported (C-weighted difference between the maximum level and the background L90).

- Time Above D' Levels (TA D' 10,15, 20, 25, 35, 45). The time duration of the event above various detectability levels is to be determined. These durations are defined as time above D' of 10,15, 20, 25, 35, 45. In the D' calculation, the signal (S) is the event sound levels and the Noise (N) is the larger of the ambient L90 or the MAF curve in the same band. The event must have a minimum duration of three seconds. For fluctuating events, the total durations of the event are summed.

The above acoustic data is intended to provide the most complete information concerning the ambient and aircraft sound environment. In situations where available resources limit the ability to conduct a more complete study, limited acoustic data concerning the sound environment can still be useful in describing the sound levels of operations within a particular park. This data would be in terms of A-weighted sound level measurements. This program may also be used to supplement the more completed measurements in order to provide long-term information. The descriptors to be determined from this modified program are presented in the following paragraphs. The ambient and background sound level is determined in the same manner as presented in the completed program, except that A-weighted only sound levels are measured.

Operations other than MTR

- dBA Sound Level. The maximum dBA sound level from the aircraft overflight and the background L90 dBA level are to be reported. The maximum value represents the highest dBA noise level measured for this aircraft event. The relative A-weighted sound level is also to be reported (A-weighted difference between the maximum level and the background L90).

- Time Above L90 dBA levels (TAL90+ 5, 10, 20, 30, 40). The duration of the event above the background sound level is to be determined for various levels of intrusion. The background sound level is the L90 dBA value. These durations are defined as time above the L90 value plus 5, 10, 20, 30, 40 dBA. The event must have a minimum duration of three seconds. For fluctuating events, the total durations of the event are summed. This data should be correlation with detectability results.

MTR Operations

- SEL Level. The Sound Exposure Level (SEL) from the A-weighted measurement data is to be determined.

- dBA Sound Level. The maximum dBA sound level from the aircraft overflight and the background L90 dBA level are to be reported. The maximum value represents the highest dBA noise level measured for this aircraft event. The relative A-weighted sound level is also to be reported (A-weighted difference between the maximum and the background L90).

- Onset Rate. The onset rate of the aircraft event in terms of the rate of change in dBA per second is to be determined for each aircraft overflight. Onset is to be determined between the time the signal is 5 dBA above the background and 5 dBA below the maximum dBA value.

A number of park units have historical or cultural resources that are affected by MOA and MTR operations. These operations can result in very high sound levels or sonic booms. The potential effects of vibration caused by these overflights on these sensitive structures is not known. At historical or cultural structures affected by these overflights, sound and vibration measurements should be completed. These measurements should be done using automated equipment that can operate unattended for long periods of sampling time. During the measurements, park personnel should note the time of any sonic booms or very loud overflights to correlate the measured values with the aircraft operations.

The information to be determined from these measurements is the maximum dBC sound level from the aircraft overflight and any structural vibration measured in Gs. The instrument measuring the C-weighted sound level should be located on or near the structure of concern. A convenient location is a roof top. The vibration transducer should be attached to a critical location of the building. In general, this should be located on the building structure itself, and not windows, in that it is the integrity of the building structure is of concern.

The measurement instrumentation to be used for these measurements is the same automated sound instrumentation specified for the long-term A-weighted measurements. The vibration measurements use the same instrumentation, except that the microphone/preamplifier is replaced with a transducer. Note: This methodology provides information concerning the vibration levels caused by these operations and the number of times vibrations occur, but does not research into what the effects are to the structure and what levels would be acceptable.

5.5 *Statistical Sampling Requirements*

The following paragraphs present the recommended methodology for determining the measurement sampling period for both aircraft overflight sound levels and ambient sound level measurements. The key elements in determining the sample size include identifying the major "modes" affecting aircraft operations, estimating the measurement statistics and, finally, estimating the needed measurement sample sizes and the duration of time needed to achieve that sample size.

The statistical confidence recommended for this study is the 90% confidence level for plus or minus 3 dB. For duration data, a 90% confidence level for plus or minus 10% of the mean. The sample size needed for the measurements will be determined for this confidence level. The methodology could be used for other confidence intervals or levels of confidence, but actual experience in the field and limits on measurement resources will probably determine the best level of confidence that can be achieved.

There will always be a tradeoff between statistical confidence and number of sites measured. Longer measurement periods at each site will result in higher statistical confidence in the measured results. However, given a fixed amount of measurement resources (measurement equipment and labor), the more time spent at any given site will result in fewer sites being measured. Therefore, the sampling program selected should represent a balance between statistical confidence at any site and spatial coverage of a large park system.

This section is not intended to provide complete information in terms statistical analysis requirements. Its purpose is to present the general methodology used to develop statistical sampling requirements. A general guideline to use in estimating the number of sampling days is also presented.

5.6.1 Determine Major Modes and Categories of Aircraft Operations

In order to define sample size it is important to recognize the different and unique "modes" or "categories" that may affect aircraft noise. For the purposes of this section, a mode or category of operation refers to groups of operations that display independent statistical characteristics. The amount of sampling may vary for each of these modes. These modes of operations are variables relative to: (1) types of aircraft operations, (2) variations relative to changing weather patterns, and (3) seasonal variations. One must determine these modes and determine if it is necessary to measure during all modes of operation or just certain dominant modes. The aircraft identification program to determine levels of aircraft operations (Section 4.3) can be used to help establish modes and categories of operations. Modes of operations are discussed in detail in Element 3 of that section.

A wind rose or historical operations data can also be used to help determine dominant modes of operations. Note that there may be seasonal variations in demand, i.e., tourist seasons versus off-seasons. In general there will be a need to treat different aircraft noise exposure situations with care. At or near an airport, runway utilization and seasonal variations will be important. When sampling near en route traffic corridors, the wind direction will be an important factor primarily because of the effect of wind direction on sound propagation over long distances. Upwind of a corridor the noise may be highly attenuated while downwind at the same distance the noise may be significantly higher. Under or near areas of sightseeing aircraft the winds may determine direction of flight and the season may have a significant effect on tourist demand and subsequent number of operations.

Noise measurements should be made during each major seasonal mode of operation that is identified. In general, measurements should be conducted for at least 4 different times during the year, or once for each season. For park units with only one season, two trips are recommend with each measurement trip at least two weeks in duration.

5.6.2 Determine Sample Size for Aircraft Noise Events

Once the dominant seasonal modes and the time period that they occur have been identified, there is a need to know how long to measure during each of the seasons. The required sample size can be estimated from accompanying equations for the Students-t confidence interval (Exhibits 5-2 and 5-3). For a given confidence interval, i.e., plus or minus 3 dB, the sample size, n, can be computed if the standard deviation is known. Therefore, preliminary measurements be made to estimate the standard deviation. These calculations are necessary for each type of aircraft that as been identified for each aircraft rating scale being analyzed.

An alternative to preliminary measurements is to estimate the standard deviation based on previous measurement experience. In general there are substantial data provided by the FAA that show that in the vicinity of the 65 DNL contour at civilian air carrier airports the standard deviation for air carrier aircraft is about 2 dB. At military airports, the Air Force has published a curve for military aircraft that shows the expected standard

Exhibit 5-2
Student-t Equations

The following equations are used for the computation of confidence intervals for samples of size n. The value for t is found in the attached based on the magnitude of of *n*.

$$\text{Confidence Interval} = CI = \overline{L} \pm \frac{t\ s}{(n)^{1/2}}$$

If the desired confidence interval is plus or minus 1.5 dB the following equations can be used to estimate the required sample size, n.

$$\text{Sample Size} = n = \left[\frac{t\ s}{1.5}\right]^2$$

In the above equations the symbols are defined as:

- t is the Students-t value from the attached table for 90%, 95%, or other confidence level desired.
- s is the sample standard deviation
- $\overline{L}$ is the sample mean value

Exhibit 5-3
Students-t Distribution

STUDENTS-t DISTRIBUTION

Sample Size, n	CONFIDENCE LEVEL 90%	95%	98%	99%
1	6.314	12.706	31.821	63.657
2	2.920	4.303	6.965	9.925
3	2.353	3.182	4.541	5.841
4	2.132	2.776	3.747	4.604
5	2.015	2.571	3.365	4.032
6	1.943	2.447	3.143	3.707
7	1.895	2.365	2.998	3.499
8	1.860	2.306	2.896	3.355
9	1.833	2.262	2.821	3.250
10	1.812	2.228	2.764	3.169
11	1.796	2.201	2.718	3.106
12	1.782	2.179	2.681	3.055
13	1.771	2.160	2.650	3.012
14	1.761	2.145	2.624	2.977
15	1.753	2.131	2.602	2.947
16	1.746	2.120	2.583	2.921
17	1.740	2.110	2.567	2.898
18	1.734	2.101	2.552	2.878
19	1.729	2.093	2.539	2.861
20	1.725	2.086	2.528	2.845
21	1.721	2.080	2.518	2.831
22	1.717	2.074	2.508	2.819
23	1.714	2.069	2.500	2.807
24	1.711	2.064	2.492	2.797
25	1.708	2.060	2.485	2.787
26	1.706	2.056	2.479	2.779
27	1.703	2.052	2.473	2.771
28	1.701	2.048	2.467	2.763
29	1.699	2.045	2.462	2.756
30	1.697	2.042	2.457	2.750
35	1.690	2.030	2.438	2.724
40	1.684	2.021	2.423	2.704
45	1.679	2.014	2.412	2.690
50	1.676	2.009	2.403	2.678
55	1.673	2.004	2.396	2.668
60	1.671	2.000	2.390	2.660
70	1.667	1.994	2.381	2.648
80	1.664	1.990	2.374	2.639
90	1.662	1.987	2.368	2.632
100	1.660	1.984	2.364	2.626
200	1.653	1.972	2.345	2.601
400	1.649	1.966	2.336	2.588
1,000	1.646	1.962	2.330	2.581
2,000	1.646	1.961	2.328	2.578
10,000	1.645	1.960	2.327	2.576

deviation based on distance from the flight tracks and angle of elevation to the ground. This is presented in Exhibit 5-4. These types of data have not been published for general aviation aircraft or commuter aircraft or helicopters. It would be of benefit to this program to develop curves of estimated standard deviation based on elevation angle and distance for general aviation and rotorcraft aircraft similar to the data developed by the Air Force for military aircraft.

Once the standard deviation is known either by preliminary measurement or estimated, the needed sample size can be estimated from the equation in Exhibit 5-2. This sample size will apply for each mode or category of aircraft operation. For example, if it is determined that there are 2 types of aircraft operations, and the needed sample size for statistical confidence is 20 aircraft noise events, then 20 aircraft flyover measurements should be made for each type of aircraft.

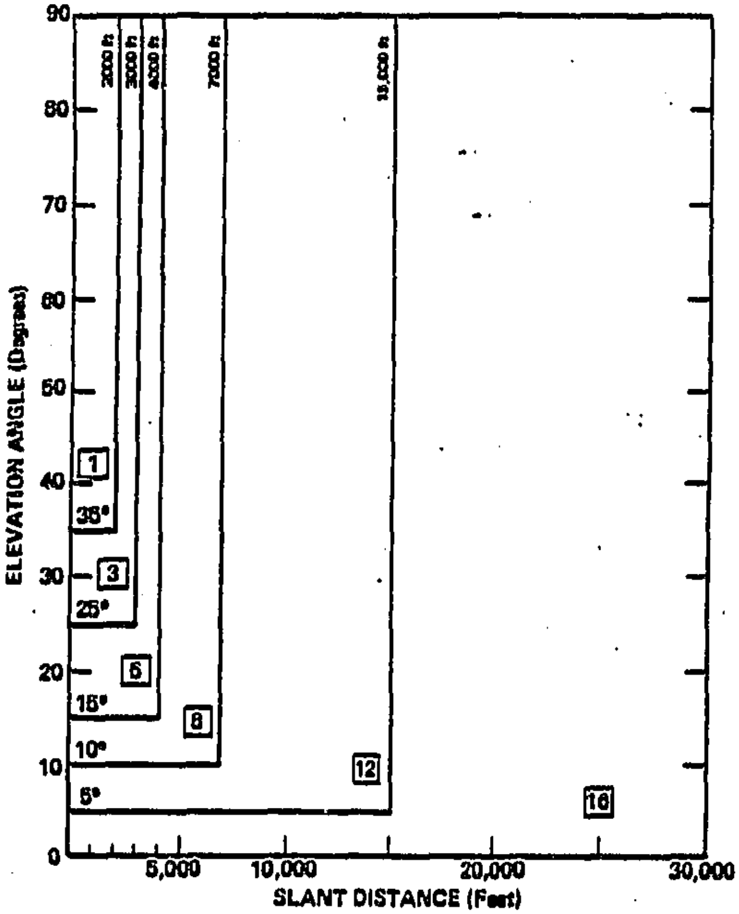
In general, it can be assumed that 10 to 30 samples of aircraft overflights are required for each mode or category of operation. These measurement samples should be determined from a minimum of seven different days per measurement trip.

5.6.3 Determine Sample Size for Ambient Non-Aircraft Noise

The ambient sound level shall be defined by measuring the L(n) and LEQ sound levels. The measurements should be made during each major mode of operation affecting aircraft noise, and in fact should be completed as part of the aircraft noise measurement sequence. Weather has a major effect on ambient levels as well as aircraft noise patterns. Therefore, ambient sound measurements need to cover periods which represent the range of wind conditions.

The 90 percent confidence intervals for the average L(n) computed from the sample L(n)s can be determined using the same Student-t methodology. Again the needed sample size of ambient measurement periods needed for estimating the average L(n) with a plus or minus 3 dB confidence interval can be determined from the Students-t equation based on the sample standard deviation of the L(n)s. The study recommends that ambients sound levels be determined from four seperate measurement trips. A minimum of 10 ambient measurements randomly selected over a one week period should be completed for each trip.

Exhibit 5-4
Sigma vs. Distance and Angle
for Military Aircraft



Air Force Estimates of Variance
(as a function of elevation angle and slant distance)

APPENDICES

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Appendix A

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Appendix B

BACKGROUND INFORMATION ON ACOUSTICS

Appendix B

BACKGROUND INFORMATION ON ACOUSTICS

B.1 Introduction

The description, analysis and reporting of community sound levels from aircraft is made difficult by the complexity of human response to sound and the myriad of noise metrics that have been developed for describing acoustic impacts. The purpose of this chapter is to present background information on the characteristics of sound as it relates to the National Park setting, and present various rating scales that are available to describe the sound. This is intended to give the reader a greater understanding on sound and the current methodologies used to assess potential impacts from noise.

This chapter is divided into four sections. The first section presents properties of sound that are important for technically describing sound in the park/wilderness setting and factors in human subjective response to a sound that affects its perception. The second section describes potential human disturbances and health effects to sound and factors that affect individuals response to that sound. The third section presents various sound rating scales and how they may be applied to addressing aircraft operations within parks. The fourth section presents a summary of current noise assessment criteria that is used for quantifying the effects of aircraft noise.

B.2 Properties of Sound

Sound Level and Frequency. Sound can be technically described in terms of the sound pressure (amplitude) of the sound and frequency (similar to pitch) of the sound. The sound pressure is a direct measure of the magnitude of a sound without consideration for other factors that may influence its perception.

A standard unit of measurement of the sound is the Decibel (dB). The range of sound pressures that occur in the environment is so large that it is convenient to express these pressures as sound pressure levels on a logarithmic scale. The sound pressure level in decibels is the pressure of a sound relative to a reference pressure of 20 micropascals. The logarithmic scale compresses the wide range in sound pressures to a more usable range of number in a manner similar to the Richter scale for earthquakes.

The frequency of a sound is expressed as Hertz (Hz) or cycles per second. The normal audible frequency for young adults is 2 Hz to 16,000 Hz. The prominent frequency range for aircraft noise in the park setting is between 50 Hz and 5,000 Hz. The human ear is not equally sensitive to all frequencies with some frequencies judged to be louder for a given signal than another. As a result of this, various methods of frequency weighting have been developed.

Sound levels decrease as a function of distance from the source as a result of wave divergence atmospheric absorption and ground attenuation. If sound is radiated from a source in a homogenious and undisturbed manner, the sound travels as spherical waves. The sound wave form travels away from the source, the sound energy is dispersed over a greater area dispersing the sound power of the wave. Spherical spreading of the sound wave reduces the noise level at a rate of 6 dB per doubling of the distance.

Atmospheric absorption also influences the levels that are received by the observer. The greater the distance traveled, the greater the influence and the resultant fluctuations. Atmospheric absorption becomes important at distances of greater than 1000 feet. The degree of absorption is a function of the frequency of the sound as well as the humidity and temperature of the air. For example, atmospheric absorption is lowest at high humidity and higher temperatures. Sample atmospheric attenuation graphs are presented in Exhibit B-1. Turbulence and gradients of wind, temperature and humidity also play a significant role in determining the degree of attenuation. Certain conditions can also result in higher noise levels than would result from spherical spreading as a result of channeling the sound waves.

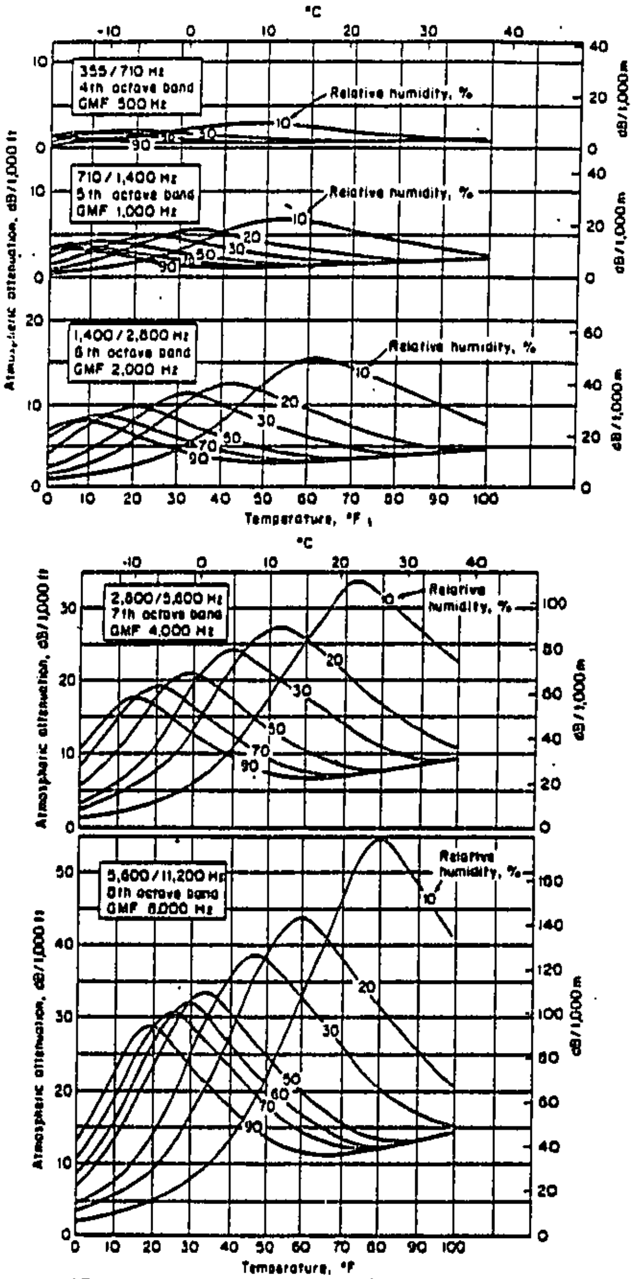
Absorption effects in the atmosphere vary with frequency. The higher frequencies are more readily absorbed than the lower frequencies. Over large distances, the lower frequencies become the dominate frequency as the higher frequencies have been attenuated. For example, the sound at ground level from the high altitude en route jets has a very strong low frequency component.

These factors are an important consideration for assessing altitude and flight track restrictions over park units. Given the large distances between the noise source and receiver in many of the park settings, atmospheric conditions will play a significant role in affecting the sound levels on a day to day basis and how these sounds are perceived.

Duration of Sound. The annoyance from a sound rises with increased durations. The "*effective duration*" of a sound is the time between when a sound rises above the background sound level until it drops back below the background level. Psychoacoustic studies have determined a relationship between duration and annoyance. Exhibit B-2 presents the results from one such study (Kryter, 1968) that determined the amount a sound must be reduced to be judged equally annoying for increased duration. Duration is an important factor in describing the aircraft sound in the park/wilderness setting.

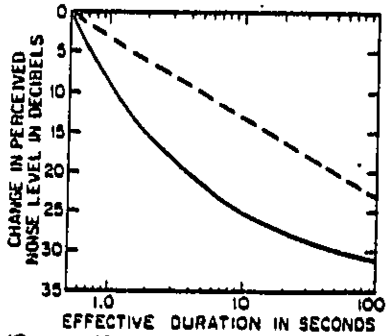
This exhibit also illustrates the equivalent energy principal of sound exposure. The dashed line corresponds to a reduction of 3 dB per doubling of duration. Reducing the acoustic energy of a sound by one half results in a 3 dB reduction. Doubling the duration of the sound increases the total energy of the event by 3 dB. This equivalent energy principal is based upon the premise that the potential for a noise to impact a person is dependent on the total acoustical energy content of the noise (EPA, 1974). DNL, LEQ and SEL are all based upon the equal energy principle.

Exhibit B-1
Atmospheric Attenuation Graphs



(Source: Beranek, 1981)

Exhibit B-2
Changes in perceived noise level as a function of effective duration



(Source: Kryter, 1968)

Rise Time. The rise time or onset rate of a sound can also affect its perception. The rise time or onset rate of a sound is the time until the sound reaches its maximum sound level. Very quick and very slow onset rates have been found to have an increased level of disturbance. Rise time rates between 0.5 and 3 seconds are found to be the least disturbing. Impulsive noises with quick rise times and short durations can result in a startle effect that is judged to be more annoying.

Both quick and slow rise time rates are of concern to the park setting. Low-altitude military operations are characterized by rise times of less than 0.5 seconds. Measurements of high altitude aircraft resulted in very slow rise time rates of many seconds.

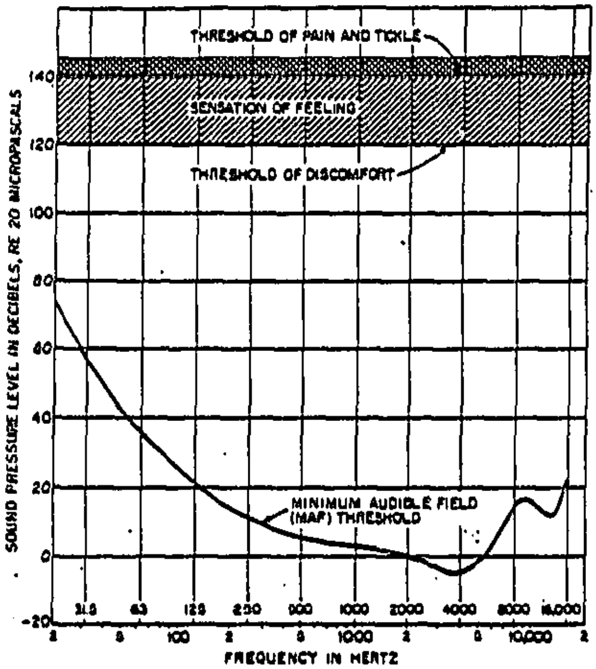
Threshold of Hearing. The threshold of hearing is the minimum sound pressure level that will result in an auditory response. This threshold is not an exact level, and therefore is expressed as a probability of an individual hearing a sound (typically defined as 50 percent). The threshold of hearing varies with the population. The Minimum Audible Field (MAF) curve is reproduced in Exhibit B-3. This MAF curve represents the sound pressure level of the threshold of hearing for young adults with normal hearing measured in a free field. It is determined for pure tones with the listener facing the source and listening with both ears. The threshold of hearing is not equal in all frequencies with reduced sensitivity in the lower and higher frequencies.

Note hearing sensitivity will vary between individuals and generally reduces with age. Other curves have been developed that represent the average hearing threshold for the population or for defining normal hearing thresholds for audiometry testing. These curves specify threshold of hearing levels higher than the MAF curve.

Change in Noise. This concept of change in ambient sound levels can be better understood with an explanation of the hearing mechanism's reaction to sound. The human ear is a far better detector of relative differences in sound levels than absolute values of levels. Under controlled laboratory conditions, listening to a steady unwavering pure tone sound that can be changed to slightly different sound levels, a person can just barely detect a sound level change of approximately one decibel for sounds in the mid-frequency region. When ordinary noises are heard, a young healthy ear can detect changes of two to three decibels. A five decibel change is readily noticeable while a 10 decibel change is judged by most people as a doubling or a halving of the loudness of the sound.

Recruitment of loudness. Recruitment describes the perception of loudness in situations where the threshold of hearing of a sound is elevated by masking from a background sound. A listener's judgement of the loudness of a sound will vary with different levels of background noise. In low level background situations that are near the threshold of hearing, the loudness level of a sound increases gradually. In these situations, a desired sound, such as music that is a level of 40 to 60 dB above the background, would be judged as comfortable. In loud background settings, a sound that is approximately 20 dB above the masking threshold will be perceived as the same loudness as the sound would have if no masking sound was present.

Exhibit B-3
Minimum Audible Field (MAF Curve)



(Source: Harris, 1979)

Masking Effect. A characteristic of sound that is critical in the National Park setting is the ability of a sound to interfere with the ability of a listener to hear another sound. This is defined as the masking affect. The presence of one sound effectively raises the threshold of audibility for the hearing of a second sound. For a signal to be heard, it must exceed the threshold of hearing for that particular individual and exceed the masking threshold for the background noise.

The masking characteristics of sound is dependent upon many factors, including the spectral characteristics of the two sounds, the sound pressure levels and the relative start time of the sounds. The masking affect is greatest when the masking frequency is closest to the frequency of the signal. Low frequency sounds can mask higher frequency sounds, however, the reverse is not true.

B.3 Health Effects of Noise

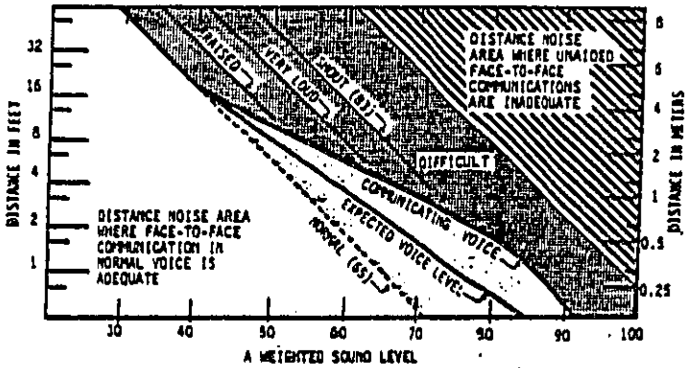
Noise has often been described as unwanted sound and it is known to have several adverse effects on people. From these known effects of noise, criteria have been established to help protect the public health and safety and prevent disruption of certain human activities. This criteria is based on such known effects of noise on people as hearing loss (not a factor with community noise), communication interference, sleep interference, physiological responses and annoyance. Each of these potential noise impacts on people are briefly discussed in the following narratives:

HEARING LOSS is, in general, not a concern in community airport noise problems. The potential for noise induced hearing loss is more commonly associated with occupational noise exposures in heavy industry or very noisy work environments with long term exposure. The Occupational Safety and Health Administration (OSHA) identifies a noise exposure limit of 90 dBA for 8 hours per day to protect from hearing loss. Noise levels in neighborhoods, even in very noisy airport environs near major international airports, is not sufficiently loud to cause hearing loss.

COMMUNICATION INTERFERENCE is one of the primary concerns in environmental noise problems. Communication interference includes speech interference and activities such as watching television. Normal conversational speech is in the range of 60 to 65 dBA and any noise in this range or louder may interfere with speech. There are specific methods of describing speech interference as a function of distance between speaker and listener and voice level. Exhibit B-4 shows the percent of sentence intelligibility with respect to various noise levels.

SLEEP INTERFERENCE is a major noise concern in aircraft noise assessment and, of course, is most critical during nighttime hours. Sleep disturbance is one of the major causes of annoyance due to community noise. Noise can make it difficult to fall asleep, create momentary

Exhibit B-4
Speech Interference Levels



(Source: EPA, 1974)

disturbances of natural sleep patterns by causing shifts from deep to lighter stages and cause awakening. Noise may even cause awakening which a person may or may not be able to recall.

Extensive research has been conducted on the effect of noise on sleep disturbance. Recommended values for desired sound levels in residential bedroom space range from 25 to 45 dBA with 35 to 40 dBA being the norm. The National Association of Noise Control Officials have published data on the probability of sleep disturbance with various single event noise levels. Based on experimental sleep data as related to noise exposure, a 75 dBA interior noise level event will cause noise induced awakening in 30 percent of the cases. A summary of this data is presented in Exhibit B-5.

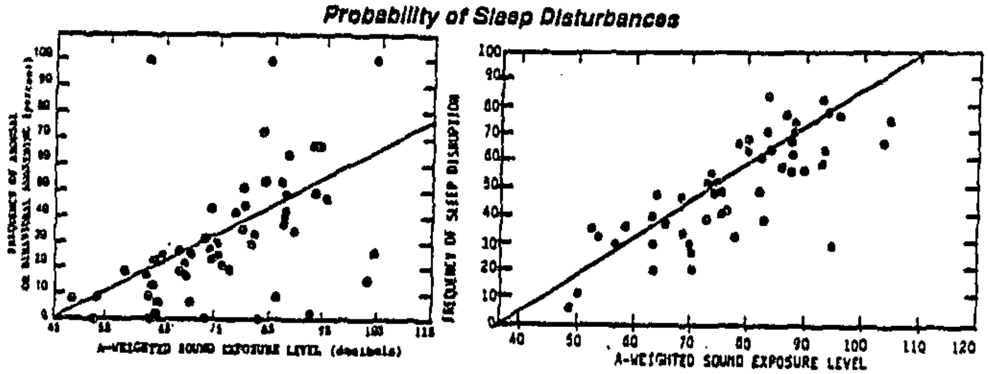
PHYSIOLOGICAL RESPONSES are those measurable effects of noise on people which are realized as changes in pulse rate, blood pressure, etc. While such effects can be induced and observed, the extent is not known to which these physiological responses cause harm or are a sign of harm. Generally, physiological responses are a reaction to a loud short term noise such as a rifle shot or a very loud jet overflight.

ANNOYANCE is the most difficult of all noise responses to describe. Annoyance is a very individual characteristic and can vary widely from person to person. What one person considers tolerable can be quite unbearable to another of equal hearing capability. The level of annoyance, of course, depends on the characteristics of the noise (i.e.; loudness, frequency spectra, time, and duration), and how much activity interference (e.g. speech interference and sleep interference) results from the noise. However, the level of annoyance is also a function of the attitude of the receiver. Personal sensitivity to noise varies widely. It has been estimated that 2 to 10 percent of the population is highly susceptible to noise not of their own making, while approximately 20 percent are unaffected by noise. Attitudes are affected by the relationship between the person and the noise source. (Is it our dog barking or the neighbor's dog?) Whether we believe that someone is trying to abate the noise will also affect our level of annoyance.

B.4 Sound Rating Scales

Loudness Level. Various rating scales have be devised to approximate the human subjective assessment to the "loudness" of a sound. Loudness is the subjective judgement of an individual as to how loud or quiet a particular sound is perceived. The human ear is not equally sensitive to all frequencies with some frequencies judged to be louder for a given signal than another. This sensitivity difference also varies for different sound pressure levels.

Exhibit B-5
Probability of Sleep Disturbances



(Source: NANCO, 1981)

Exhibit B-6 presents equal loudness level contours for pure tone signals. These equal loudness level contours are expressed as Phones. All points on a contour represent a sound level that is judged to be equally as loud as another point on the same contour. The bottom of this exhibit also shows the Minimum Audible Field (MAF) curve that forms the threshold of audibility.

This data is obtained through group laboratory studies of human response to noise. Generally a pure tone signal of 1000 hertz is played and then after an elapsed interval a second tone of a different frequency is played. The listener must adjust the signal until the two tones are judged to be the same.

The Phone scale for equal loudness level curves is a decibel scale. In the decibel scale, increases in sound pressure levels of 10 dB is roughly equivalent to a judgement of the sound being perceived as twice as loud. Loudness differs from loudness level, but they are related logarithmically. Loudness is expressed in the Sones scale, a subjective scale that gives a ratioed scale of loudness. The Sones scale establishes that a sound of 2 Sones is twice as loud as a sound of 1 Sone. One Sone is defined as the loudness of a 1000 Hz tone having the sound pressure level of 40 dB.

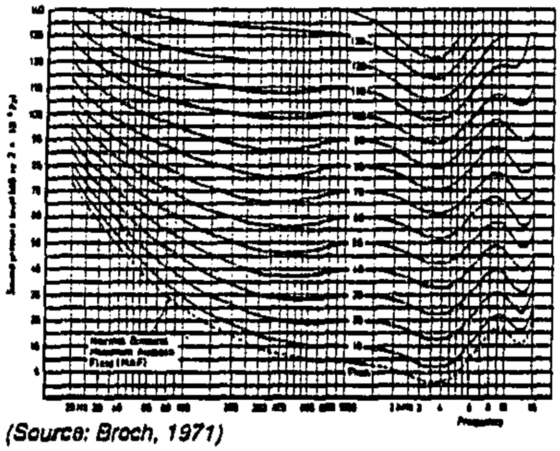
Calculated loudness levels are single number ratings of a full spectrum sound signal that is determined from specific formulas. They have been designed to provide an acoustic measurement that correlates with an individual's judgement of loudness. There are two accepted methods for calculating loudness level: ISO Method A (Stevens) and ISO Method B (Zwicker). Both require acoustic data measured in one or 1/3 octave. The loudness level is determined by converting 1/3 octave spectral levels to loudness, correct for interband masking and add the contribution of sound from each spectral band.

There are no specific noise standards that use calculated loudness levels. Loudness calculations are most useful in showing relative differences in changes in steady state sound levels as opposed to absolute fluctuating levels.

Frequency Weighted Contours (dBA, dBB, dBC and dBD). In order to simplify the measurement and computation of sound loudness levels, frequency weighted networks have obtained wide acceptance. The equal loudness levels contours for 40 dB, 70 dB and 100 dB have been selected to represent human frequency response to low, medium, and loud sound levels. By inverting these equal loudness level contours, the A-weighted, B-weighted and C-weighted frequency weightings were developed. D-weighted is another frequency weighted network that has found some limited use in aircraft measurements. These contours are presented in Exhibit B-7.

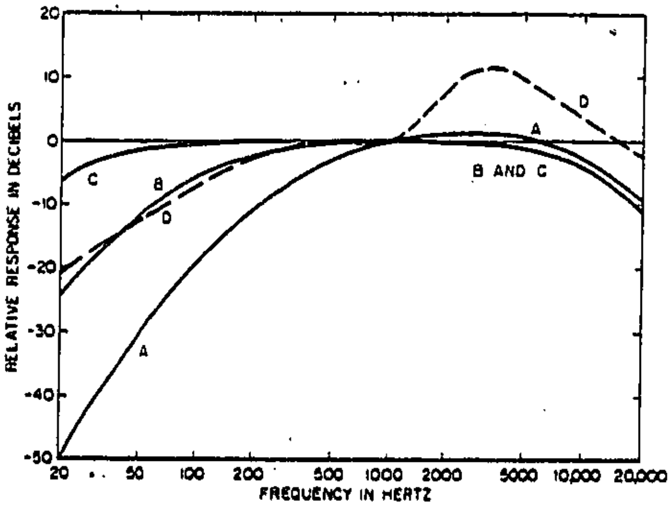
The A-weighting (dBA) scale has become the most prominent of these scales and is widely used in community noise analysis. Its advantages are that it has shown good correlation with other rating scales and is easily measured. In the A-weighted decibel, every day sounds normally range from 30 dBA (very quiet) to 100 dBA (very loud). Most community noise metrics, such as DNL or LEQ and SEL are based upon the dBA scale. The C-weighted scale has some limited industrial and military uses.

Exhibit B-6
Equal Loudness Contours



(Source: Broch, 1971)

Exhibit B-7
Frequency Weighted Networks



(Source: C. Harris, 1979)

Perceived Noise Level. Perceived noisiness is another method of rating sound. It was originally developed for the assessment of aircraft noise. Perceived noisiness is defined as "*the subjective impression of the unwantedness of a not unexpected, nonpain or fear-provoking sound as part of one's environment*" (Kryter, 1970). "Noisiness" curves differ from "loudness curves" in that they have been developed to rate the noisiness or annoyance of a sound as opposed to the loudness of a sound.

Equal perceived noisiness curves (noys) are presented in Exhibit B-8. As with loudness curves, noisiness curves have been developed from laboratory psychoacoustic surveys of individuals. However, in noisiness surveys, individuals are asked to judge in a laboratory setting when two sounds are equally noisy or disturbing if heard regularly in ones own environment. These surveys are more complex and therefore subject to greater variability.

Rating scales have been developed to combine the contributions of each of the spectra of a complex sound to give an overall perceived noise level rating. These scales include the Perceived Noise Level (PNL) and the tone corrected Perceived Noise Level (PNLT). PNLT differs from PNL in that it also takes into account discrete frequency components. These metrics, by themselves are not widely used, however, the time domain metric EPNL, used by the FAA, is based upon the measured PNLT level.

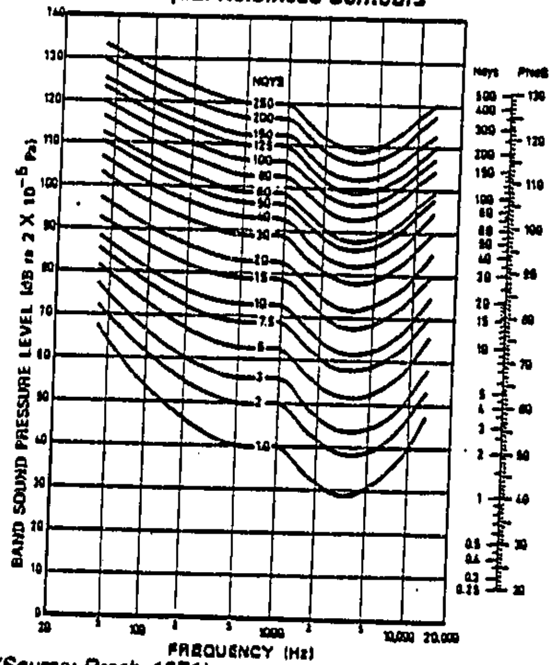
Maximum Noise Level. The highest noise level reached during the flyover is, not surprisingly, called the "Maximum Noise Level," or Lmax. Lmax is usually measured in dBA. As an aircraft approaches, the sound of the aircraft begins to rise above ambient noise levels. The closer the aircraft gets the louder it is until the aircraft is at its closest point directly overhead. Then as the aircraft passes, the noise level decreases until the sound level again settles to ambient levels. Such a history of a flyover is plotted in Exhibit B-9. It is this metric to which people generally instantaneously respond when an aircraft flyover occurs. Speech and sleep interference research can be assessed relative to maximum noise level data.

Sound Exposure Level (SEL). Another metric that is reported for aircraft flyovers is the Sound Exposure Level (SEL). It is computed from dBA sound levels. Referring again to Exhibit B-9 the shaded area, or the area within 10 dB of the maximum noise level, is the area from which the Sound Exposure Level is computed. The SEL value is the integration of all the acoustic energy contained within the event.

This metric takes into account the maximum noise level of the event and the duration of the event. Single event metrics are a convenient method for describing noise from individual aircraft events. This metric is useful in that airport noise models contain aircraft noise curve data based upon the SEL metric. In addition, cumulative noise metrics such as LEQ and DNL can be computed from SEL data.

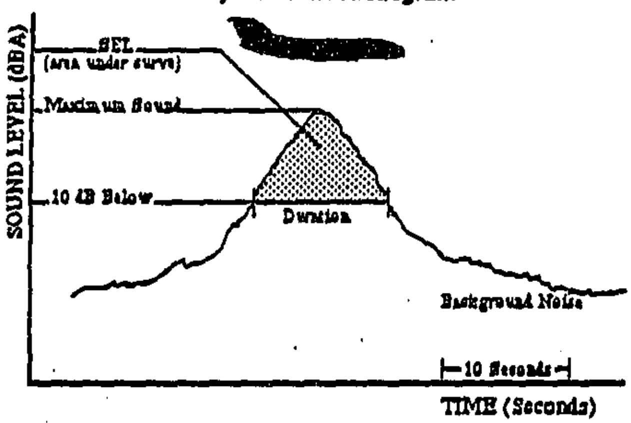
Effective Perceived Noise Level (EPNL). The EPNL sound level is similar to SEL except that it is based upon the tone corrected Perceived noise level data (PNLT) as opposed to dBA sound level data. It takes into account an individual's response to the "noisiness" of the aircraft, the disturbing effect of any pure tones such as whines or screeches, and the duration of the event. (It is calculated for 1/2 second 1/3 octave

Exhibit B-8
Equal Noisiness Contours



(Source: Broch, 1971)

Exhibit B-9
Flyover Time Histogram



spectral data of an aircraft flyover.) Being derived from noisiness curves, EPNL will have the same limitations as the perceived Noise level. The FAA's FAR Part 36 aircraft certification noise standards are based upon the EPNL metric. This regulations certifies new subsonic commercial aircraft for arrival, departure and sideline noise levels.

Equivalent Noise Level (LEQ). LEQ is the sound level corresponding to a steady-state A-weighted sound level containing the same total energy as a time-varying signal over a given sample period. LEQ is the "energy" average noise level during the time period of the sample. It is based on the observation that the potential for a noise to impact people is dependent on the total acoustical energy content of the noise. It is the energy sum of all the sound that occurs during that time period. This is graphically illustrated in Exhibit B-10.

LEQ can be measured for any time period, but is typically measured for 15 minutes, 1 hour or 24-hours. The one hour LEQ is also referred to as the Hourly Noise Level (HNL). A number of agencies have developed noise standards in terms of the LEQ index. This includes a 24 hour LEQ by the FAA to assess the impact of helicopter noise and a peak hour LEQ by the Federal Highway Administration for the assessment of highway traffic noise impacts.

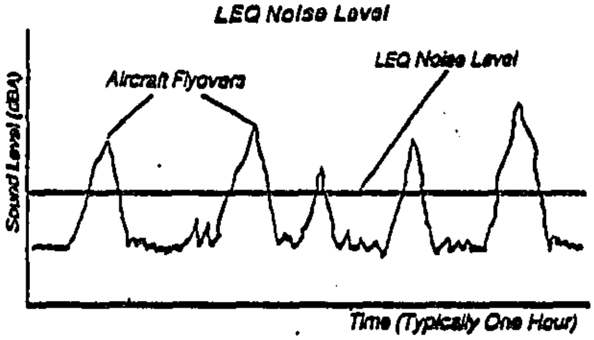
Percent Noise Level (Ln). To account for intermittent or fluctuating noise, another method to characterize noise is the Percent Noise Level (Ln). The Percent Noise Level is the level exceeded n% of the time during the measurement period. It is usually measured in the A-weighted decibel, but can be an expression of any noise rating scale. Percent Noise Levels are another method of characterizing ambient noise where, for example, L90 is the noise level exceeded 90 percent of the time, L50 is the level exceeded 50 percent, and L10 is the level exceeded 10 percent of the time. L90 represents the background or minimum noise level, L50 represents the average noise level, and L10 the peak or intrusive noise levels.

This descriptor can be used to account for the fact that some time histories may be more annoying than others. For example, a nearly constant background noise of a given frequency spectrum, such as found in many national parks, is likely to be much less annoying than a noise which fluctuates rapidly with time. Such a situation exists when an aircraft intrudes on an otherwise natural setting. In this case, an L90 noise could provide a good description of the background sound level in a park setting.

Community Noise Ordinances are commonly specified in terms of the percent noise levels. Ordinances are designed to protect people from non-transportation related noise sources such as music, machinery and vehicular traffic on private property.

Day Night Noise Level (DNL). Cumulative noise metrics have been developed to assess community response to noise. They are useful because these scales attempt to include the loudness of each event, the duration of these events, the total number of events and the time of day these events occur into one single number rating scale. They are designed to account for the known health effects of noise on people described in

Exhibit B-10
LEQ Noise Level



Time Axis Not Drawn To Scale
Noise Events Are Much Shorter Duration Than Shown Here

Section B.3. DNL does not take into consideration background sound levels.

DNL is a 24-hour, time-weighted energy average noise level based on the A-weighted decibel. It is a measure of the overall noise experienced during an entire day. The time-weighted refers to the fact that noise that occurs during certain sensitive time periods is penalized for occurring at these times. In the DNL scale, those events that take place during the night (10 p.m. to 7 a.m.) are penalized by 10 dB. This penalty was selected to attempt to account for the higher sensitivity to noise in the nighttime and the expected decrease in background noise levels that typically occur in the nighttime. The DNL index is specified by the FAA and the Environmental Protection Agency (EPA) for airport noise assessment. It is also specified by many other agencies to assess all types of transportation noise.

The public reaction to different noise levels varies from community to community. Extensive research using the DNL index has been conducted on human responses to exposure of different levels of aircraft noise. Exhibit B-11 relates DNL noise levels to community response from one of these surveys. Community noise standards are derived from tradeoffs between community response surveys, such as this, and economic considerations for achieving these levels.

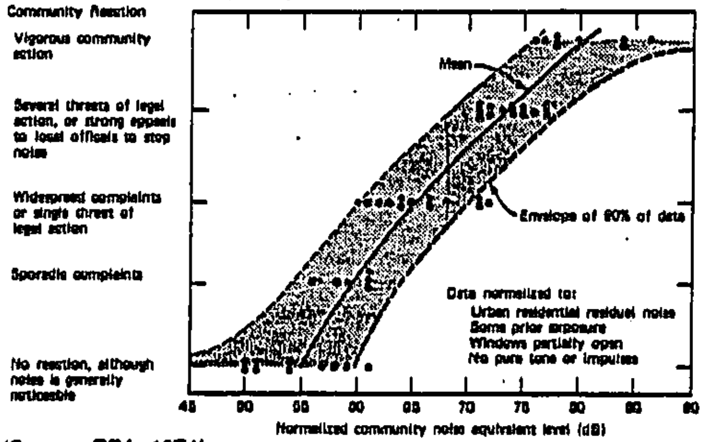
Community Noise Equivalent Level (CNEL). CNEL is a energy average 24-hour, time weighted noise level based on the A-weighted decibel. It is similar to DNL, except that CNEL also has an evening time period penalty. Sounds that occur between the hours of 7 p.m. and 10 p.m. are considered more intrusive and are weighted by 5 dB. CNEL has been used by the State of California to assess community noise levels around airports. Recently, the State of California has changed to DNL in the updated airport noise regulations.

Noise Exposure Forecast (NEF). NEF is the total summation of all the noise that takes place in a 24-hour period based on the Effective Perceived Noise Level (EPNL). NEF has been used to assess noise levels around airports. As with DNL, events that take place at night (10 p.m. to 7 a.m.) are weighted by 10 dB.

Flight Noise Level. The Swedish government has also developed a metric for quantifying impacts from aircraft noise (Linde, 1986). This metric, called the Flight Noise Level, is similar to the DNL in that it considers the number and duration of flights, and it applies a penalty for nighttime operations. It differs in that it uses the maximum noise level from an aircraft event as the basis for further calculations. A value of 55 has been established as the threshold of impact. This metric would have the same limitations as DNL, in that it does not consider background levels.

Time Above (TA). The FAA has developed the Time Above metric as a second metric for assessing impacts of aircraft noise around airports. The Time Above index refers to the total time in seconds or minutes that aircraft noise exceeds certain dBA noise levels in a 24-hour period. It is typically expressed as Time Above 75 and 85 dBA sound levels. While this index is not widely used, it is required by the FAA in environmental assessments of airport projects that show an increase in noise levels. There are no noise and land use standards in terms of the Time Above index. Modifying

Exhibit - B-11
Community Response to Environmental Noise



(Source: EPA, 1971)

Time Above to determine the Time Above the background sound level may have applications in the wilderness/park setting.

Noise and Number Index (NNI) The Noise and Number Index is an older index that was developed in England after extensive surveys around London's Heathrow Airport. It takes into account the maximum PNL noise level (based on noisiness curves) and the number of operations to compute a composite noise rating for any specified time period. The NNI index uses a factor that shows a doubling of the number of operations will increase the composite noise by 4.5 dB (DNL and LEQ gives a 3 dB increase).

B.5 Noise/Land Use Compatibility Standards and Guidelines

The above presented noise metrics have attempted to quantify community response with various noise exposure levels. Based upon these metrics, noise standards have been developed. These standards generally are in terms of 24-hour averaging scales that are based upon the A-weighted decibel. Extensive research has been conducted on human responses to exposure of different levels of community noise. Utilizing these metrics and surveys, agencies have developed standards for assessing the compatibility of various land uses with the noise environment. As would be expected, these metrics and standards do not always adequately predict community response to all particular noise levels. For example, this has occurred with helicopter noise, where adverse community response has existed in areas that, based upon DNL assessment criteria, would not be considered to have an acoustic problem.

The purpose of this section is to present information regarding the compatibility of various land uses with environmental noise. Noise/Land use guidelines have been produced by a number of Federal and State agencies including the Federal Aviation Administration, the Environmental Protection Agency, the American National Standards Institute and State and Local agencies. There are other agencies that have published noise guidelines including the Federal Highway Administration, the Department of Housing and Urban Development and the Department of Defense. The FHWA guidelines are specifically for highway noise sources and not airports. The other agencies' guidelines are essentially the same as either the FAA or ANSI guidelines. A summary of number of these regulations and guidelines are presented in the following paragraphs (MGA, 1986).

With respect to airports, most of the administrative actions are taken by the Federal Aviation Administration. These laws and regulations provide the basis for local development of airport plans, analyses of airport impacts, and enaction of compatibility policies.

- *Airport and Airway Development Act of 1970, as amended (Public Laws 91-258 and 94-353).*

  This act establishes the Federal requirements for funding of airport planning under the Planning Grant Program (PGP) and airport development under Airport Development Aid Program (ADAP). An Airport and Airway Trust Fund is created to pay for these programs and operations of the Federal Aviation system. The general types of projects eligible for Federal funding are indicated. Additionally, the Act directs the preparation of a National Airport System Plan (NASP) which lists the location of airports in the national system of airports and the recommended development of each.

  Among the conditions for Federal funding are two requirements involving airport/land use compatibility. As a condition to the receipt of ADAP funds, the airport sponsor (owner) must, among other things, give assurances regarding land uses in the airport environs that:

  > *"The aerial approaches to the airport will be adequately cleared and protected by removing, lowering, relocating, marking, lighting or otherwise mitigating existing airport hazards and by preventing the establishment or creation of future airport hazards";*
  >
  > *and that: "Appropriate action, including the adoption of zoning laws, has been or will be taken to the extent reasonable, to restrict the use of land adjacent to or in the immediate vicinity of the airport to activities and purposes compatible with normal airport operations, including landing and takeoff of aircraft."*

  (The authorization for funding under PGP and ADAP expired in October 1980 and as of early 1982 Congress has not enacted new legislation. Previous funding was provided at a rate of 90% Federal to 10% local. There is great uncertainty as to future sharing ratios; historically, Federal aid to airports has been available in various forms since 1946 with local matching requirements ranging from 10 to 50%).

- *Federal Aviation Regulations, Part 36, "Noise Standards: Aircraft Type and Airworthiness Certification".*

  Originally adopted in 1960, FAR Part 36 prescribes noise standards for issuance of new aircraft type certificates. Part 36 prescribes limiting noise levels for certification of new types of propeller-driven, small airplanes as well as for transport category, large airplanes. Subsequent amendments extended the standards to certain newly produced aircraft of older type designs. Other amendments have at various times extended the required compliance dates. Although aircraft meeting Part 36 standards are noticeably quieter than many of the aircraft then and now flying, the regulations make no determination that such aircraft are acceptably quiet for operation at any given airport.

The FAA has considered adopting certification noise standards for helicopters. These standards would be similar to the FAR Part 36 standards now in place for fixed wing commercial and general aviation aircraft. While a similar standard is under consideration for helicopters, it is not expected to be adopted in the near future.

- *U.S. Department of Defense Air Installations Compatible Use Zones (AICUZ) Program SECNAVINST 11010.11.*

  The Department of Defense initiated the AICUZ program to protect the public's health, safety, and welfare and to prevent civilian encroachment from degrading the operational capability of military air installations. The AICUZ program recommends land uses which will be compatible with noise levels, accident potential and flight clearance requirements associated with military airfield operations.

- *U.S. Department of Transportation Aviation Noise Abatement Policy.*

  This policy, adopted in 1976, sets forth the noise abatement authorities and responsibilities of the Federal Government, airport proprietors, State and Local governments, the air carriers, air travelers and shippers, and airport area residents and prospective residents. The basic thrust of the policy is that the FAA's role is primarily one of regulating noise at its source (the aircraft) plus supporting local efforts to develop airport noise abatement plans. The FAA will give high priority in the allocation of ADAP funds to projects designed to ensure compatible use of land near airports, but it is the role of State and Local governments and airport proprietors to undertake the land use and operational actions necessary to promote compatibility.

- *Aviation Safety and Noise Abatement Act of 1979.*

  Further weight was given to the FAA's supporting role in noise compatibility planning by congressional enaction of this legislation. Among the stated purposes of this act is "To provide assistance to airport operators to prepare and carry out noise compatibility programs". The law establishes funding for noise compatibility planning and sets the requirements by which airport operators can apply for funding. The law does not require any airport to develop a noise compatibility program.

- *Federal Aviation Regulations, Part 150, "Air Noise Compatibility Planning".*

  As a means of implementing the Aviation Safety and Noise Abatement Act, the FAA adopted Regulations on Airport Noise Compatibility Planning Programs. These regulations are spelled out in FAR Part 150. As part of the FAR Part 150 Noise Control program, the FAA published noise and land use compatibility charts to be used for land use planning with respect to aircraft noise. An expanded version of this chart appears in Aviation Circular 150/5020-1 (dated August 5,

1983) and is reproduced in Exhibit B-12. These guidelines represent recommendations to local authorities for determining acceptability and permissibility of land uses. The guidelines specify a maximum amount of noise exposure (in terms of the cumulative noise metric DNL) that will be considered acceptable or compatible to people in living and working areas.

These noise levels are derived from case histories involving aircraft noise problems at civilian and military airports and the resultant community response. Note that residential land use is deemed acceptable for noise exposures up to 65 DNL. Recreational areas are also considered acceptable for noise levels up to 65 DNL (with certain exceptions for sport activity areas that are allowed higher noise levels). Note that these recreational noise level guidelines are intended for application to zoning of land use around an existing airport as opposed to assessing impacts in a wilderness setting. Several important notes appear for the FAA guidelines including one which indicates that ultimately "the responsibility for determining the acceptability and permissible land uses remains with the local authorities."

- *Federal Aviation Order 5050.4 and Directive 1050.1 for Environmental Analysis of Aircraft Noise Around Airports.*

The FAA has developed guidelines (Order 5050.4) for the environmental analysis of airports. Federal requirements now dictate that increases in noise levels in noise sensitive land uses of over 1.5 DNL are considered significant (1050.1 Directive 12.21.83). For noise sensitive land uses that show an increase in noise over 1.5 DNL, Time Above noise levels are to be presented.

- *Federal Aviation Order 5050.2 for the Environmental Assessment of New Heliports.*

The FAA in December 1983 provided specific guidelines to planners of heliports in "Noise Assessment Guidelines for New Heliports", (Ref: AC 150/5020-2). This document provides a means of compatibility determination in terms of the 24 hour LEQ noise level (LEQ(24)). The criteria specifies that the "maximum recommended cumulative sound level due to the proposed operations of helicopters at a new site should not exceed the ambient noise level already present in the community at the site of the proposed heliport". In other words, that the average cumulative helicopter noise not exceed the ambient noise levels that already exist.

- *Environmental Protection Agency, "Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety".*

In March 1974 the EPA published a very important document (EPA, 1974) entitled "Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare With an Adequate Margin of Safety" (EPA 550/9-74-004). In this document, 55 DNL is described as the requisite level with an adequate margin

Exhibit B-12
FAA Noise Assessment Guidelines

Land Use	*Yearly Day-Night Average Sound Level (L_{dn}) in Decibels*					
	Below 65	*65-70*	*70-75*	*75-80*	*80-85*	*Over 85*
Residential						
Residential, other than mobile homes and transient lodgings	Y	N(1)	N(1)	N	N	N
Mobile home parks	Y	N	N	N	N	N
Transient lodgings	Y	N(1)	N(1)	N(1)	N	N
Public Use						
Schools	Y	N(1)	N(1)	N	N	N
Hospitals and nursing homes	Y	25	30	N	N	N
Churches, auditoriums, and concert halls	Y	25	30	N	N	N
Governmental services	Y	Y	25	30	N	N
Transportation	Y	Y	Y(2)	Y(3)	Y(4)	Y(4)
Parking	Y	Y	Y(2)	Y(3)	Y(4)	N
Commercial Use						
Offices, business and professional	Y	Y	25	30	N	N
Wholesale and retail—building materials, hardware and farm equipment	Y	Y	Y(2)	Y(3)	Y(4)	N
Retail trade—general	Y	Y	25	30	N	N
Utilities	Y	Y	Y(2)	Y(3)	Y(4)	N
Communication	Y	Y	25	30	N	N
Manufacturing And Production						
Manufacturing, general	Y	Y	Y(2)	Y(3)	Y(4)	N
Photographic and optical	Y	Y	25	30	N	N
Agriculture (except livestock) and forestry	Y	Y(6)	Y(7)	Y(8)	Y(8)	Y(8)
Livestock farming and breeding	Y	Y(6)	Y(7)	N	N	N
Mining and fishing, resource production and extraction	Y	Y	Y	Y	Y	Y
Recreational						
Outdoor sports arenas and spectator sports	Y	Y(5)	Y(5)	N	N	N
Outdoor music shells, amphitheaters	Y	N	N	N	N	N
Nature exhibits and zoos	Y	Y	N	N	N	N
Amusements, parks, resorts and camps	Y	Y	Y	N	N	N
Golf courses, riding stables and water recreation	Y	Y	25	30	N	N

Numbers in parentheses refer to notes.

* The designations contained in this table do not constitute a Federal determination that any use of land covered by the program is acceptable or unacceptable under Federal, State, or local law. The responsibility for determining the acceptable and permissible land uses and the relationship between specific properties and specific noise contours rests with the local authorities. FAA determinations under Part 150 are not intended to substitute federally determined land uses for those determined to be appropriate by local authorities in response to locally determined needs and values in achieving noise compatible land uses.

KEY TO TABLE 1

SLUCM	Standard Land Use Coding Manual.
Y (Yes)	Land Use and related structures compatible without restrictions.
N (No)	Land Use and related structures are not compatible and should be prohibited.
NLR	Noise Level Reduction (outdoor to indoor) to be achieved through incorporation of noise attenuation into the design and construction of the structure.
25, 30, or 35	Land uses and related structures generally compatible; measures to achieve NLR of 25, 30, or 35 dB must be incorporated into design and construction of structure.

NOTES

(1) Where the community determines that residential or school uses must be allowed, measures to achieve outdoor to indoor Noise Level Reduction (NLR) of at least 25 dB and 30 dB should be incorporated into building codes and be considered in individual approvals. Normal residential construction can be expected to provide a NLR of 20 dB, thus, the reduction requirements are often stated as 5, 10 or 15 dB over standard construction and normally assume mechanical ventilation and closed windows year round. However, the use of NLR criteria will not eliminate outdoor noise problems.

(2) Measures to achieve NLR of 25 dB must be incorporated into the design and construction of portions of these buildings where the public is received, office areas, noise sensitive areas or where the normal noise level is low.

(3) Measures to achieve NLR of 30 dB must be incorporated into the design and construction of portions of these buildings where the public is received, office areas, noise sensitive areas or where the normal noise level is low.

(4) Measures to achieve NLR of 35 dB must be incorporated into the design and construction of portions of these buildings where the public is received, office areas, noise sensitive areas or where the normal noise level is low.

(5) Land use compatible provided special sound reinforcement systems are installed.

(6) Residential buildings require an NLR of 25.

(7) Residential buildings require an NLR of 30.

(8) Residential buildings not permitted.

(Source: FAR Part 150)

of safety for areas with outdoor uses, this includes residences, and recreational areas. This document does not constitute EPA regulations or standards. Rather, it is intended to "provide State and Local governments as well as the Federal Government and the private sector with an informational point of departure for the purpose of decision-making". Note that these levels were developed for suburban type uses. In some urban settings, the noise levels will be significantly above this level, while in some wilderness settings, the noise levels will be well below this level. The EPA "levels document" does not constitute a standard, specification or regulation, but identifies safe levels of environmental noise exposure without consideration for economic cost for achieving these levels.

- *American National Standards Institute (ANSI) .*

The American National Standards Institute (ANSI) has published "Sound Level Descriptors for Determination of Compatible Land Uses," ANSI S3.23-1980, May 30, 1980. As part of this document ANSI published a "for information only" land use compatibility guidelines. Note: Residential land use with outdoor uses are compatible to marginally compatible with noise exposures up to 65 DNL.

Appendix C

MEASUREMENT EQUIPMENT

Appendix C

NOISE MEASUREMENT EQUIPMENT

GRAND CANYON NATIONAL PARK

System A

B&K 4427	SOUND LEVEL METER	S/N 1167015
B&K 4155	MICROPHONE	S/N 1329673
B&K 2230	SOUND LEVEL METER	S/N 1184383
B&K 4155	MICROPHONE	S/N 1163960
B&K 4230	CALIBRATOR	S/N 1314549
NAGRA IV-SJ	TAPE RECORDER	S/N 1653
B&K UA0237	WIND SCREENS	

System B

B&K 4427	SOUND LEVEL METER	S/N 1166961
B&K 4155	MICROPHONE	S/N 1215168
B&K 2204	SOUND LEVEL METER	S/N 315393
B&K 4131	MICROPHONE	S/N 238514
B&K 4230	CALIBRATOR	S/N 1169765
NAGRA III	TAPE RECORDER	S/N BH 6710256
B&K UA 0237	WIND SCREENS	

Measurement Site	System	Date of Measurements
Shosone Point	A	11/9/87, 11/13/87
Point Sublime	B	11/10/87, 11/11/87
Huxley Terrace	A	11/10/87, 11/11/87
Crystal	B	11/12/87, 11/13/87
Horn	A	11/12/87, 11/13/87

HAWAII VOLCANOES NATIONAL PARK

NI 830	REAL TIME ANALYZER	S/N 11483
B&K 4161	MICROPHONE	S/N 468916
B&K 2230	SOUND LEVEL METER	S/N 1236239
B&K 4155	MICROPHONE	S/N 1394179
B&K 4230	CALIBRATOR	S/N 1169765
B&K UA 0237	WIND SCREEN	

Measurement Dates: January 25, 1988 through January 28, 1988

EDWARDS AIR FORCE BASE

B&K 4427	SOUND LEVEL METER	S/N 1167015
B&K 4155	MICROPHONE	S/N 1215168
B&K 2204	SOUND LEVEL METER	S/N 315393
B&K 4161	MICROPHONE	S/N 468916
SONY TCD-D10	TAPE RECORDER	MGA 001
B&K 4230	CALIBRATOR	S/N 1169765
B&K 2123	REAL TIME ANALYZER	S/N 1407150
B&K UA 0237	WIND SCREENS	

Measurement Dates: June 13, 1988 through June 15, 1988

Exhibit C-1
DAT Recorder Frequency Response Test

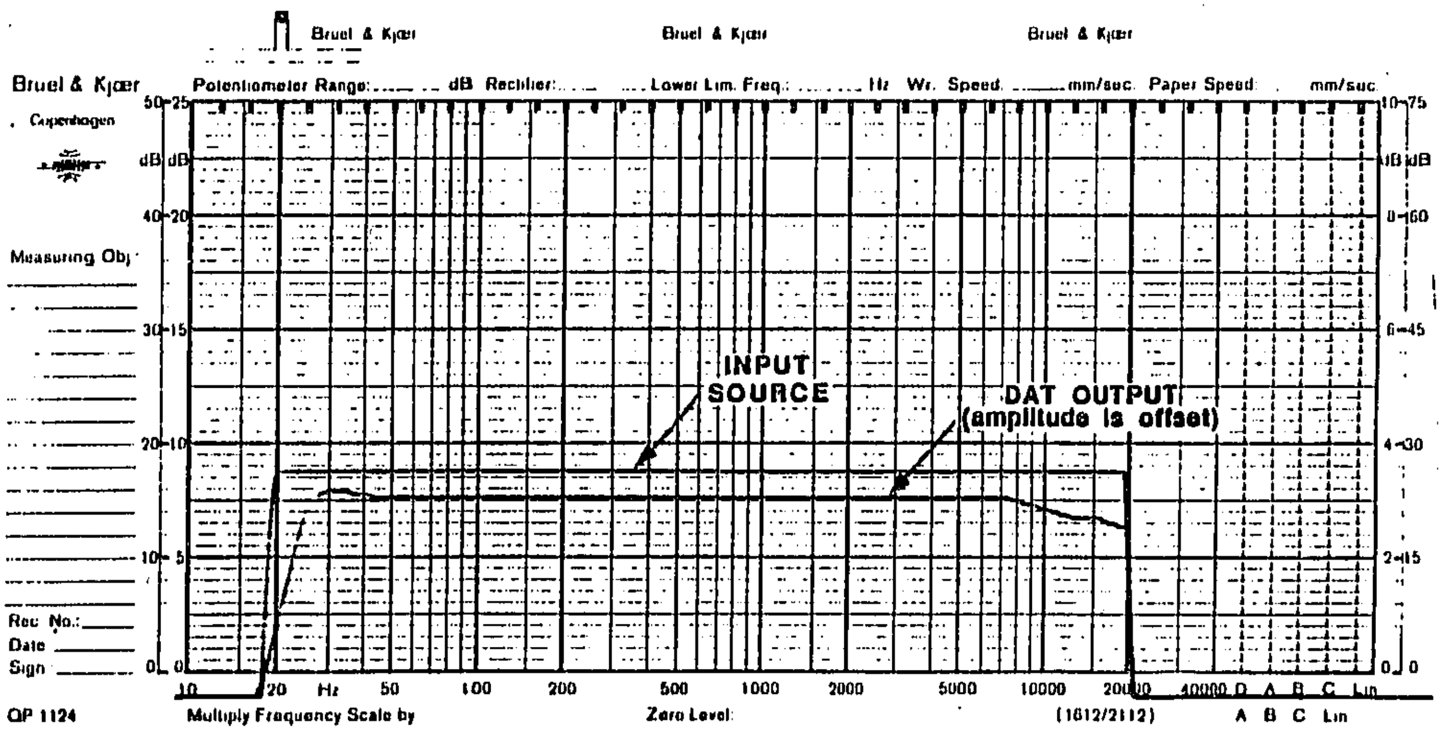


Table C-1
DAT TAPE RECORDER DYNAMIC RANGE TEST
(SIGNAL 1000 Hz)

DAT RECORD LEVEL INDICATOR	***SIGNAL ATTENUATOR***	***SOURCE SIGNAL GENERATOR***	***DAT OUTPUT***	***RANGE***	***COMMENTS***
-5	0	100.6	100.6	0.0	no harmonic distortion
-15	-10	90.6	90.6	10.0	
-30	-20	80.6	80.6	20.0	
-50	-30	70.6	70.6	30.0	
-50	-40	60.6	60.5	40.1	
Off scale	-50	50.6	50.6	50.0	
	-60	40.6	40.7	59.9	
	-70	30.7	30.7	69.9	
	-80	20.6	20.5	80.1	+/- .3 dB
	-90	10.6	10.6	90.0	+/- .6 dB
	-100	0.0	0.0	100.6	+/- 3.0 dB & 3 to 5 dB above noise floor

2230 FSD	***SIGNAL ATTENUATOR***	***SOURCE 2230***	***DAT OUTPUT***	***RANGE***	***COMMENTS***
100	-20	93.8	112.9	0	no harmonic distortion
	-30	83.9	102.8	10.1	
	-40	73.9	92.9	20	
	-50	64.0	82.9	30	
	-60	54.1	72.5	40.4	
	-70	44.3	62.6	50.3	
	-80	-	52.8	60.1	
	-90	-	42.8	70.1	+/- .2 dB
	-100	-	33.5	79.4	+/- .5 dB
90	-10	102.6	132.4	-	Overload w/ harmonic dist.
	-20	93.8	123.6	0	no harmonic distortion
	-30	83.8	113.6	10	
	-40	73.8	103.6	20	
	-50	64.0	93.6	30	
	-60	54.0	83.6	40	
	-70	44.1	73.6	50	
	-80	34.3	63.7	59.9	
	-90	-	53.7	69.9	
	-100	-	43.7	79.9	+/- .5 dB

Appendix D

MEASUREMENT RESULTS

POINT SUBLIME
AMBIENT MEASUREMENTS (LEQ)

Hz	10-Nov 1:23 PM	10-Nov 1:31 PM	10-Nov 2:55 PM	10-Nov 4:05 PM	10-Nov 7:33 PM	11-Nov 7:35 AM	11-Nov 11:48 AM	11-Nov 1:35 PM	ENERGY AVERAGE
20	24	35	33	36	37	32	28	37	35
25	23	31	33	36	34	25	27	35	33
31.5	24	29	34	32	32	22	27	31	31
40	30	30	35	32	33	18	28	31	32
50	34	26	36	33	34	17	30	31	33
63	31	23	33	31	30	16	30	28	31
80	27	25	33	30	30	19	30	26	30
100	25	23	31	30	34	18	31	27	31
125	21	20	28	30	32	16	24	20	28
160	16	25	24	27	24	14	20	19	23
200	12	23	24	28	25	11	20	18	24
250	11	23	23	28	24	12	20	16	23
315	9	23	21	24	25	11	21	17	22
400	10	25	21	22	25	-	22	18	21
500	7	25	20	21	24	-	23	17	21
630	3	23	19	19	22	-	23	15	19
800	2	25	16	18	19	-	21	12	17
1000	2	20	14	16	16	-	18	11	15
1250	1	18	12	15	21	-	18	14	16
1600	0	18	9	4	12	-	13	15	11
2000	1	-	7	3	8	-	11	11	8
2500	1	-	6	2	5	-	7	9	6
3150	2	-	3	2	4	-	5	6	4
4000	3	-	2	2	3	-	3	10	5
5000	3	-	3	3	3	-	3	8	4
6300	3	-	3	3	3	-	3	4	3
8000	2	-	3	3	3	-	3	3	3
Linear	38	-	43	43	44	-	39	42	42
A-Weighted	17	29	26	28	29	20	28	24	27
Wind Dir.	Calm	Calm	West	West	Calm	Calm	West	West	
Speed (kts)			0-3	0-3			0-5	0-3	
	(T1 E7.5)	(BK 2230)	(T2 E7)	(T3 E2.5)	(T3 E7.5)	(BK 2230)	(T5 E2)	(T6 E10)	(Tape Avg)

"-" Denotes values less than 10 dB.

CRYSTAL
AMBIENT MEASUREMENTS (LEQ)

Hz	12-Nov 11:31 AM	12-Nov 2:50 PM	12-Nov 4:58 PM	12-Nov 8:21 PM	13-Nov 8:30 AM	ENERGY AVERAGE
20	33	32	33	18	31	31
25	32	33	28	18	27	31
31.5	31	34	28	17	29	31
40	32	34	20	16	25	32
50	31	34	18	16	24	31
63	28	29	16	14	24	27
80	27	27	15	14	25	25
100	29	23	13	15	20	25
125	23	18	13	15	19	20
160	20	18	14	14	23	18
200	21	13	13	14	-	17
250	17	14	12	14	-	15
315	14	12	12	14	-	13
400	12	10	11	14	-	12
500	11	10	10	14	-	12
630	9	7	-	14	-	11
800	7	6	-	13	-	10
1000	5	3	-	12	-	8
1250	2	1	-	10	-	6
1600	1	1	-	7	-	4
2000	3	1	-	8	-	5
2500	4	1	-	7	-	5
3150	2	2	-	9	-	6
4000	3	2	-	7	-	5
5000	3	2	-	6	-	4
6300	2	2	-	6	-	4
8000	3	3	-	7	-	5
Linear	40	41	-	28	-	39
A-Weighted	20	18	17	22	20	20

Wind Dir. Speed (kts)	South 0-3 (T1 E1.5)	South 0-3 (T4 E.5)	South 0-3 (BK 2230)	Calm (T5 E6)	Calm (BK 2230)	(Tape Avg)

"-" Denotes values less than 10 dB.

HORN
AMBIENT MEASUREMENTS (LEQ)

Hz	12-Nov 2:00 PM	12-Nov 2:11 PM	12-Nov 6:00 PM	12-Nov 6:22 PM	13-Nov 7:57 AM	13-Nov 8:00 AM	ENERGY AVERAGE
20	38	28	27	27	36	38	35
25	40	29	24	25	33	37	36
31.5	34	27	23	24	32	34	32
40	36	24	22	24	31	31	33
50	34	23	22	24	29	31	31
63	32	22	23	23	26	29	29
80	32	22	23	24	28	32	29
100	30	22	23	23	24	27	27
125	29	21	22	22	24	25	26
160	28	20	21	21	23	23	25
200	32	19	20	20	22	22	28
250	26	18	19	18	21	21	23
315	29	16	17	17	19	20	25
400	24	16	16	16	18	19	21
500	23	15	15	15	18	19	20
630	22	14	15	14	17	19	19
800	20	12	14	13	16	18	17
1000	18	-	12	11	15	17	15
1250	14	-	-	9	12	14	12
1600	12	-	-	6	9	10	9
2000	12	-	-	4	5	-	9
2500	11	-	-	5	4	-	8
3150	13	-	-	6	5	-	9
4000	13	-	-	6	6	-	10
5000	15	-	-	8	7	-	11
6300	16	-	-	9	8	-	12
8000	17	-	-	10	7	-	13
Linear	45	41	39	35	41	-	42
A-Weighted	30	21	22	23	24	25	27
Wind Dir.	South	South	South	South	South	South	
Speed (kts)	0-3	0-3	0-3	0-3	0-3	0-3	
	(T1 E10)	(BK 2230)	(BK 2230)	(T3 E5)	(T3 E7)	(BK 2230)	(Tape Avg)

"-" Denotes values less than 10 dB.

HUXLEY TERRACE
AMBIENT MEASUREMENTS (LEQ)

Hz	10/11-Nov Composite	10-Nov 2:32 PM	ENERGY AVERAGE
20	34	36	34
25	34	30	34
31.5	31	27	31
40	29	25	29
50	27	23	27
63	26	19	26
80	25	14	25
100	24	15	24
125	22	18	22
160	20	10	20
200	18	-	18
250	19	-	19
315	16	-	16
400	17	-	17
500	15	-	15
630	14	-	14
800	12	-	12
1000	11	-	11
1250	10	-	10
1600	9	-	9
2000	7	-	7
2500	5	-	5
3150	4	-	4
4000	3	-	3
5000	3	-	3
6300	3	-	3
8000	3	-	3
Linear	40	40	40
A-Weighted	22	16	22

Wind Dir.	South	South	
Speed (kts)	0-3	0-3	
		(BK 2230)	(Tape Avg)

"-" Denotes values less than 10 dB.

SHOSHONE POINT
AMBIENT MEASUREMENTS (LEQ)

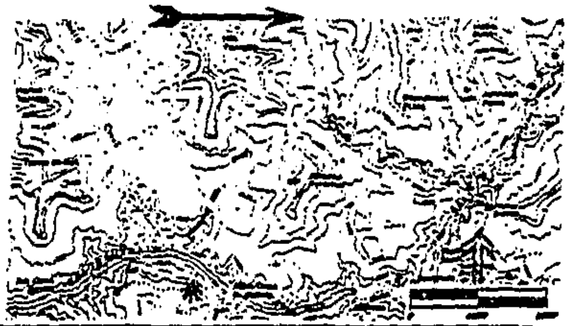
Hz	9-Nov 4:27 PM	13-Nov 4:24 PM	13-Nov 4:28 PM	13-Nov 4:44 PM	ENERGY AVERAGE
20	63	63	70	83	78
25	64	60	67	81	75
31.5	58	57	64	78	73
40	52	53	60	77	71
50	51	50	56	74	68
63	39	47	53	70	64
80	45	45	51	67	61
100	43	42	49	64	58
125	32	38	45	60	54
160	36	35	41	56	50
200	27	32	38	52	46
250	27	30	35	49	43
315	28	29	34	46	40
400	28	31	38	47	42
500	30	30	36	46	41
630	33	29	35	47	41
800	35	27	34	48	42
1000	34	25	33	48	42
1250	33	22	30	47	42
1600	31	20	28	47	41
2000	29	17	25	46	40
2500	27	13	22	44	38
3150	22	11	20	41	35
4000	17	9	19	38	32
5000	16	8	19	35	30
6300	15	10	20	34	28
8000	14	11	22	33	27
Linear	67	66	73	87	81
A-Weighted	42	36	43	58	52
Wind Dir.	East	South	South	South	
Speed (kts)	10-15	10-20	10-20	10-20	
	(BK 2230)	(T1 E3)	(T3 E3)	(T3 E6)	

Horn Measurements
(EL. 3760 ft.)

Tour Fixed Wing - Twin Engine
North Rim to East @ 7500'

11/12/87   1:54 p.m.

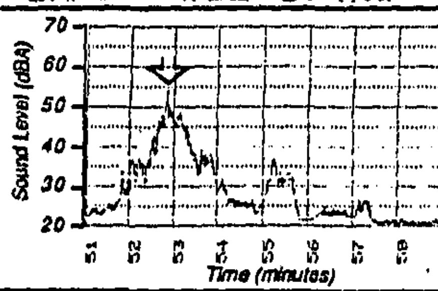
Weather:
S @ 0-3 Clear
64°F   45% Humidity



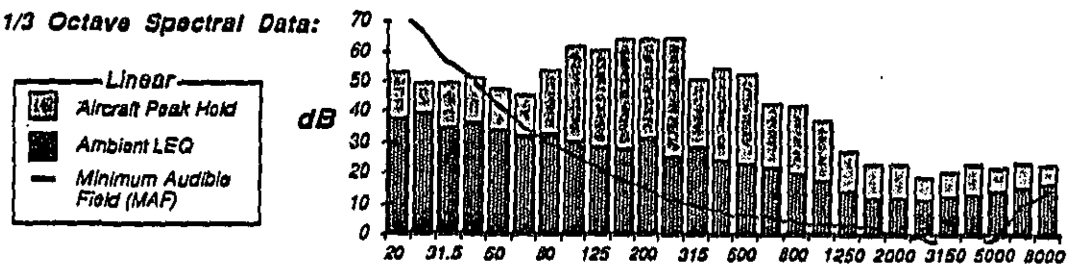
Measurement Results:

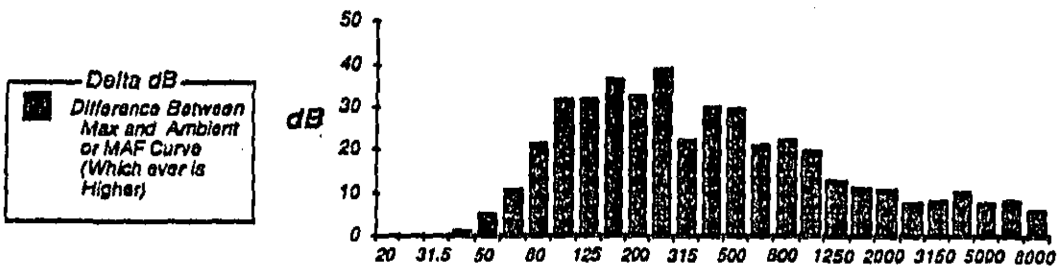
Critical f = 250 Hz
Delta (Max vs. Amb/MAF) = 39 dB
D-Prime = 26,410

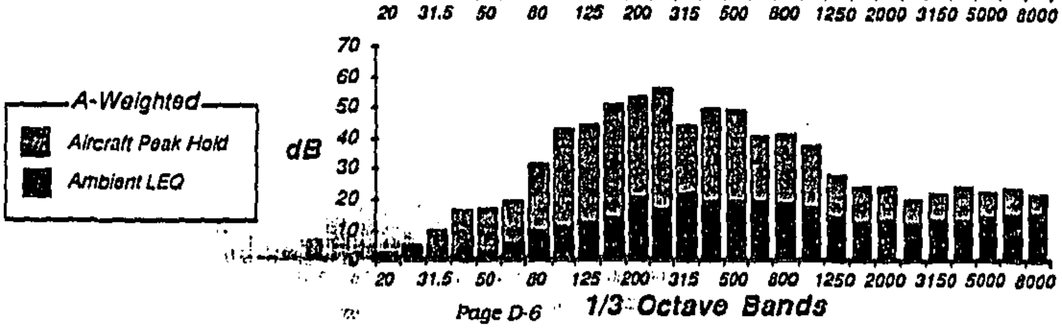
Aircraft (Max) = 54 dBA
Ambient (L90) = 21 dBA
Delta (Max vs. Amb) = 33 dBA
Duration (L90 +3) = 190 Seconds



1/3 Octave Spectral Data:







Horn Measurements
(EL. 3760 ft.)

Tour Helicopter - Bell 206
North Rim to West @ 8000'

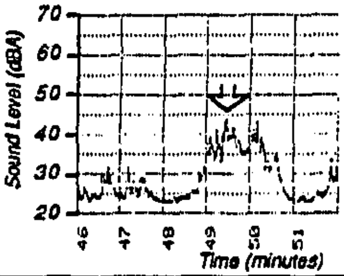
11/12/87   1:41 p.m.

Weather:
S @ 0-3 Clear
64°F   45% Humidity

Measurement Results:

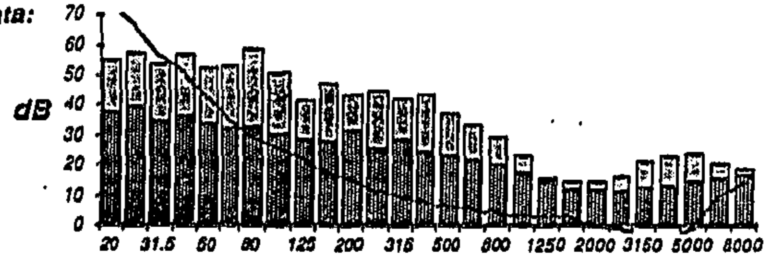
Critical *f* = 80 Hz
Delta (Max vs. Amb/MAF) = 26 dB
D-Prime = 710

Aircraft (Max) = 44 dBA
Ambient (L90) = 21 dBA
Delta (Max vs. Amb) = 23 dBA
Duration (L90 +3) = 150 Seconds

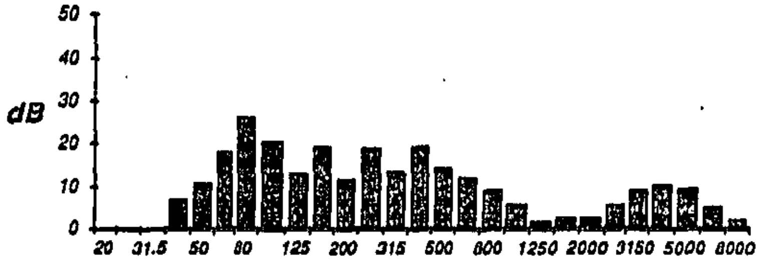


1/3 Octave Spectral Data:

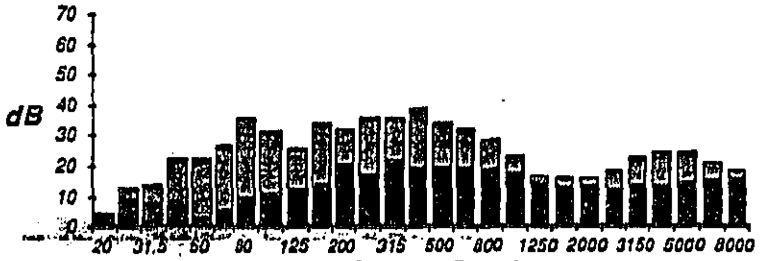
Linear
Aircraft Peak Hold
Ambient LEQ
Minimum Audible Field (MAF)



Delta dB
Difference Between Max and Ambient or MAF Curve (Which ever is Higher)



A-Weighted
Aircraft Peak Hold
Ambient LEQ



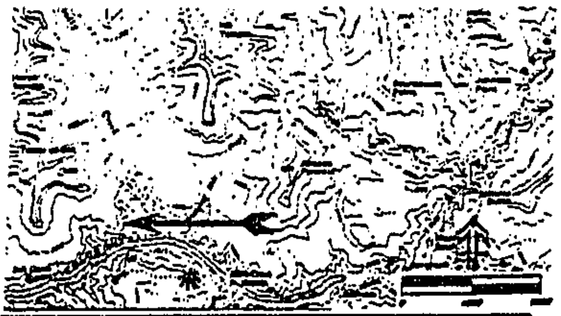
 1/3 Octave Bands

Horn Measurements
(EL. 3760 ft.)

Enroute Jet
High Altitude Over Head

11/12/87 4:33 p.m.

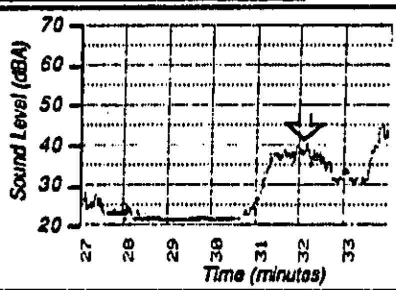
Weather:
S @ 0-3 Clear
64°F 45% Humidity



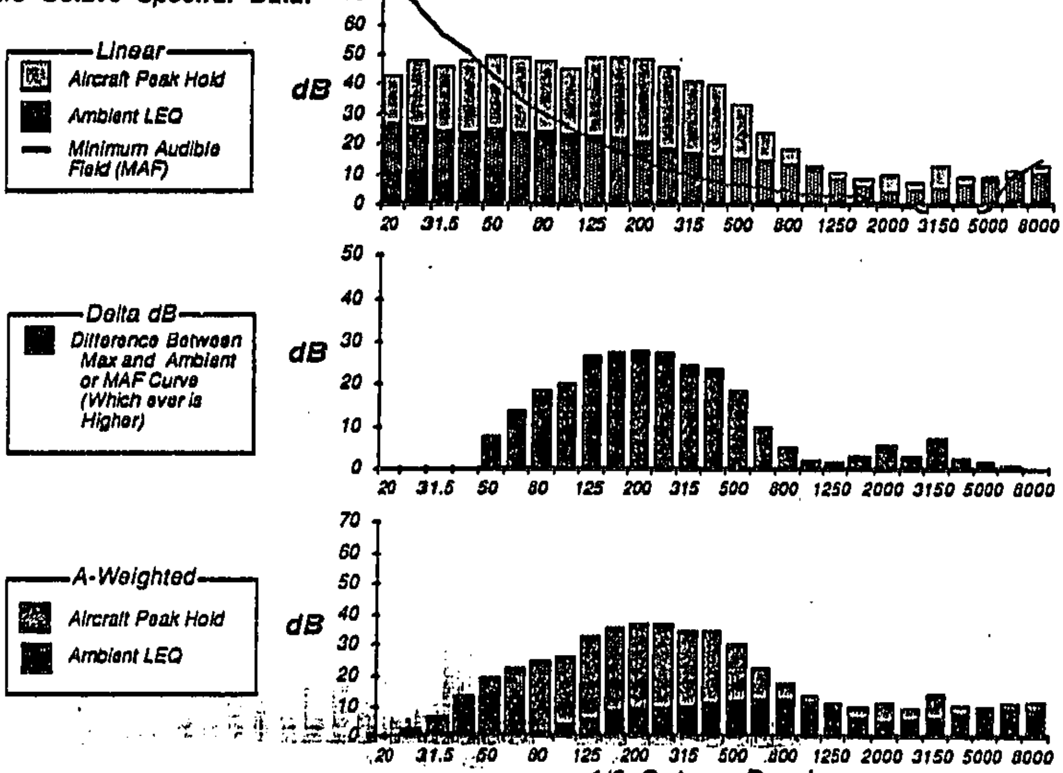
Measurement Results:

Critical ƒ = 250 Hz
Delta (Max vs. Amb/MAF) = 28 dB
D-Prime = 1,769

Aircraft (Max) = 40 dBA
Ambient (L90) = 20 dBA
Delta (Max vs. Amb) = 20 dBA
Duration (L90 +3) = 140 Seconds



1/3 Octave Spectral Data:

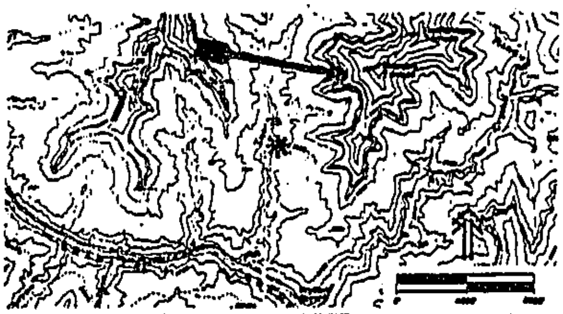


Crystal Measurements
(EL. 3600 ft.)

Tour Fixed Wing - Twin Engine Cessna
North Rim to East @ 8000'

11/12/87 11:38 a.m.

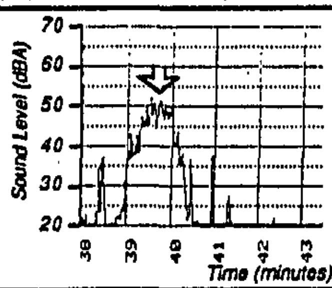
Weather:
S @ 0-3 Clear
62°F 51% Humidity



Measurement Results:

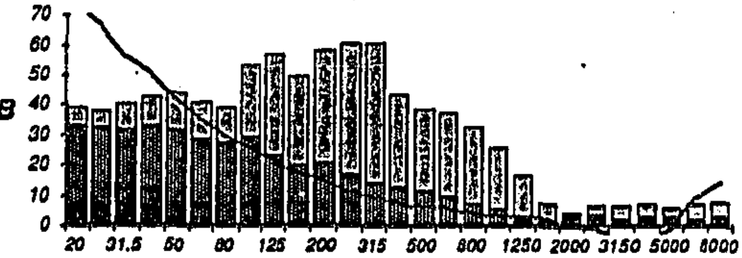
Critical f = 315 Hz
Delta (Max vs. Amb/MAF) = 47 dB
D-Prime = 167,358

Aircraft (Max) = 52 dBA
Ambient (L90) = 20 dBA
Delta (Max vs. Amb) = 32 dBA
Duration (L90 +3) = 85 Seconds

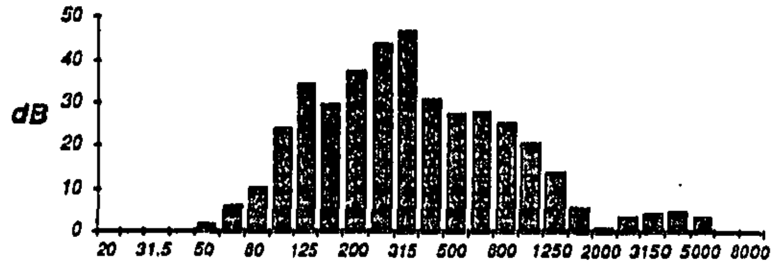


1/3 Octave Spectral Data:

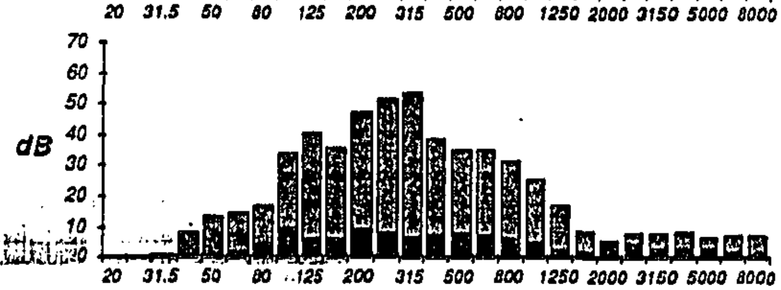
Linear
- Aircraft Peak Hold
- Ambient LEQ
- Minimum Audible Field (MAF)



Delta dB
- Difference Between Max and Ambient or MAF Curve (Which ever is Higher)



A-Weighted
- Aircraft Peak Hold
- Ambient LEQ



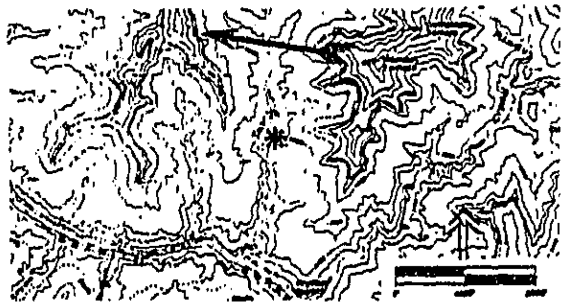
1/3 Octave Bands

Crystal Measurements
(EL. 3600 ft.)

Fixed Wing Tour - Twin Otter
North Of River To West @ 7750

11/12/87 3:28 p.m.

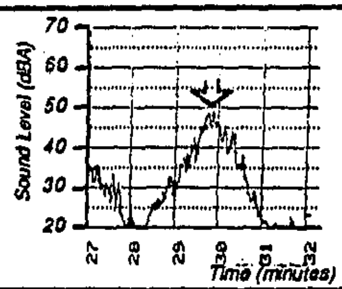
Weather:
S @ 0-3 Clear
64°F 45% Humidity



Measurement Results:

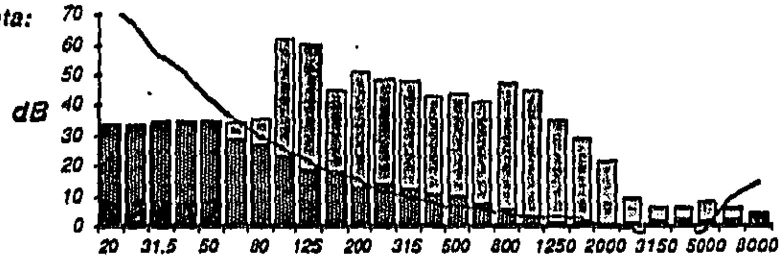
Critical f = 1000 Hz
Delta (Max vs. Amb/MAF) = 42 dB
D-Prime = 88,954

Aircraft (Max) = 49 dBA
Ambient (L90) = 21 dBA
Delta (Max vs. Amb.) = 20 dBA
Duration (L90 +3) = 150 Seconds

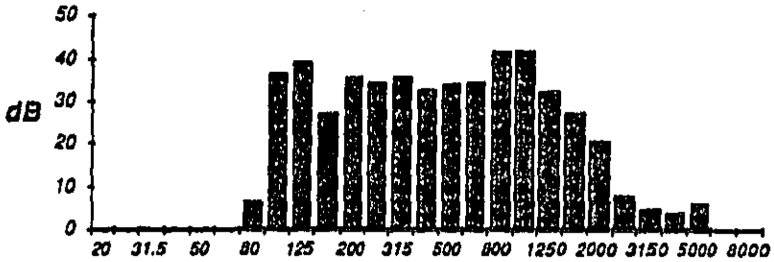


1/3 Octave Spectral Data:

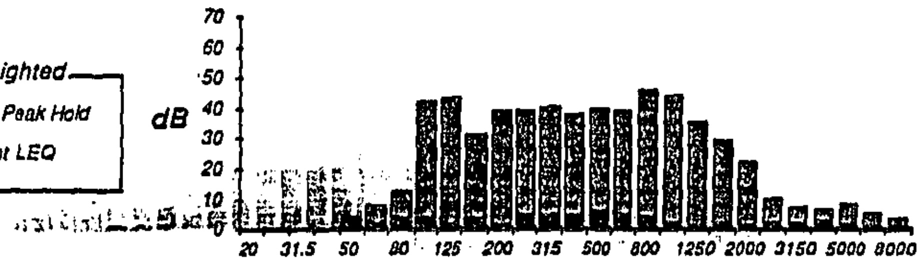
Linear
Aircraft Peak Hold
Ambient LEQ
Minimum Audible Field (MAF)



Delta dB
Difference Between Max and Ambient or MAF Curve (Which ever is Higher)



A-Weighted
Aircraft Peak Hold
Ambient LEQ



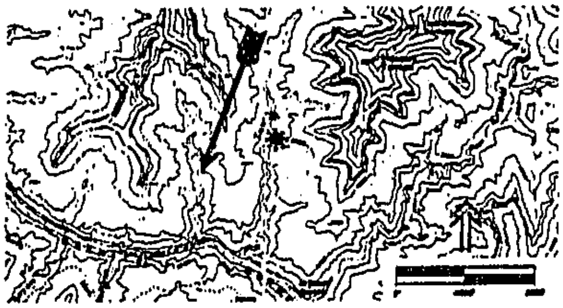
 1/3 Octave Bands

Crystal Measurements
(EL. 3600 ft.)

Tour Helicopter - Bell 206
Point Sublime Tour

11/12/87 11:59 a.m.

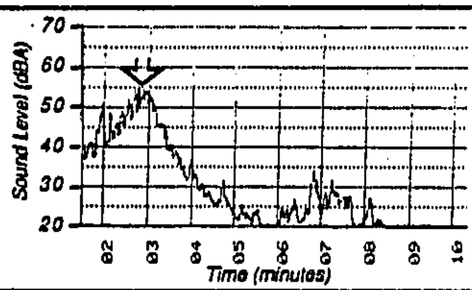
Weather:
S @ 0-3 Clear
62°F 51% Humidity



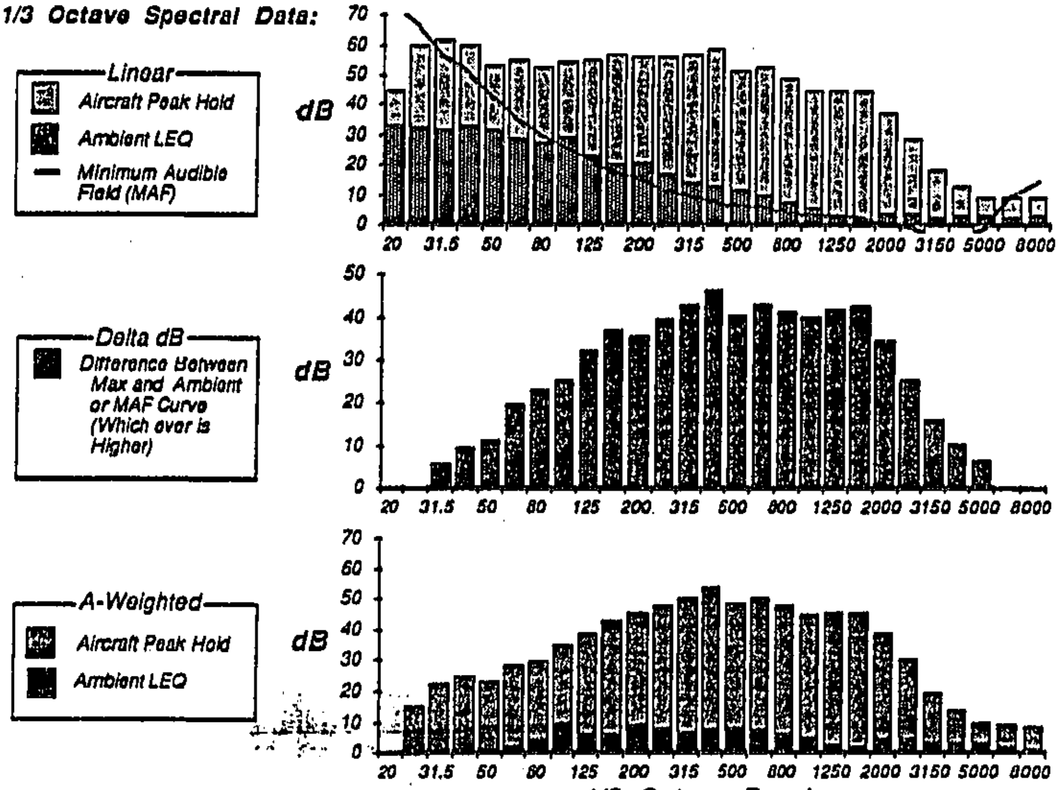
Measurement Results:

Critical f = 400 Hz
Delta (Max vs. Amb/MAF) = 46 dB
D-Prime = 162,544

Aircraft (Max) = 55 dBA
Ambient (L90) = 20 dBA
Delta (Max vs. Amb.) = 35 dBA
Duration (L90 +3) = 355 Seconds (est)



1/3 Octave Spectral Data:

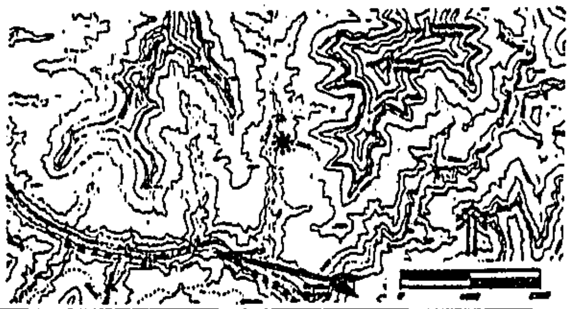


Crystal Measurements
(EL. 3600 ft.)

Enroute Military Jet
High Altitude to West

11/12/87 3:04 p.m.

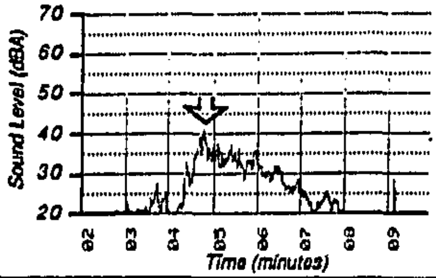
Weather:
S @ 0-3 Clear
64°F 45% Humidity



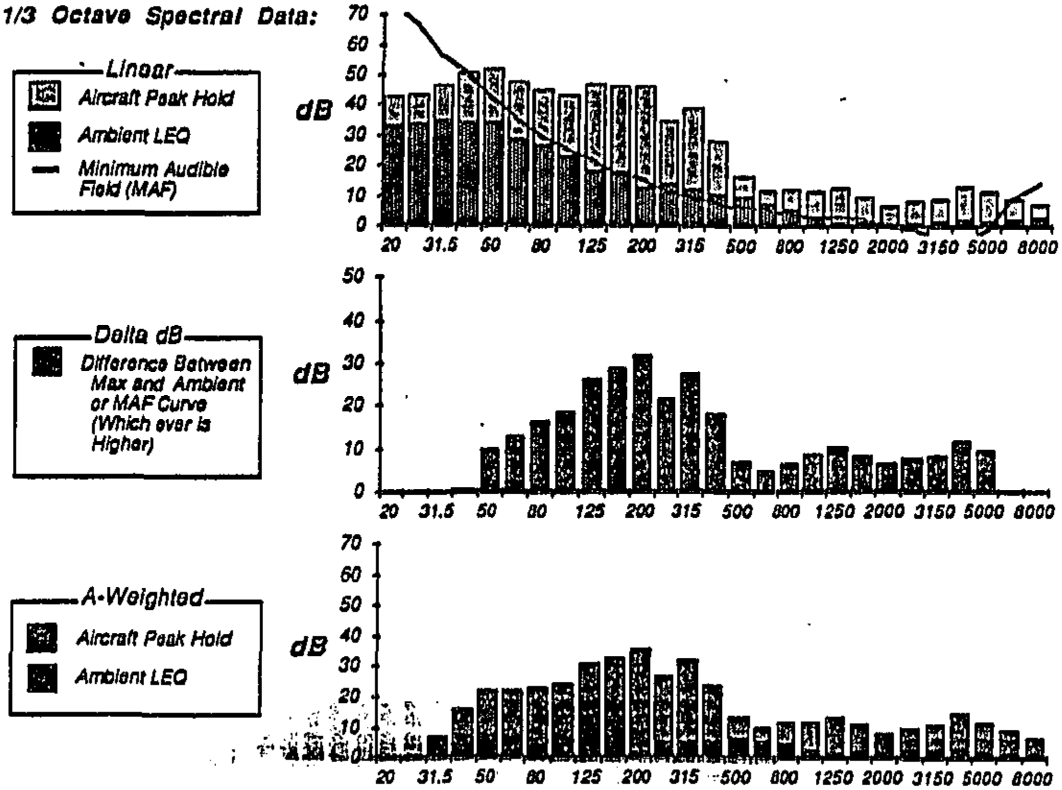
Measurement Results:

Critical f = 200 Hz
Delta (Max vs. Amb/MAF) = 32 dB
D-Prime = 4,154

Aircraft (Max) = 41 dBA
Ambient (L90) = 20 dBA
Delta (Max vs. Amb.) = 21 dBA
Duration (L90 +3) = 185 Seconds



1/3 Octave Spectral Data:



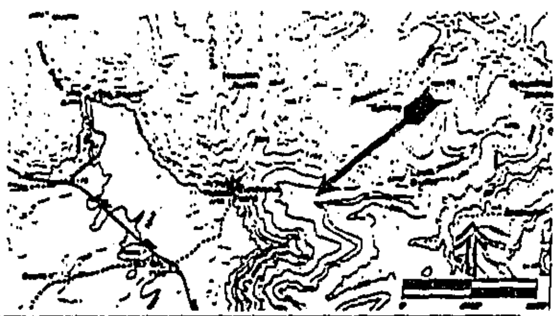
1/3 Octave Bands

Shoshone Pt. Measurements
(EL. 7200 ft.)

Fixed Wing Tour - Twin Otter
Approach To Grand Canyon Airport

11/13/87   4:55 p.m.

Weather:
S @ 10 to 20   E120 -OVC
45°F   66% Humidity

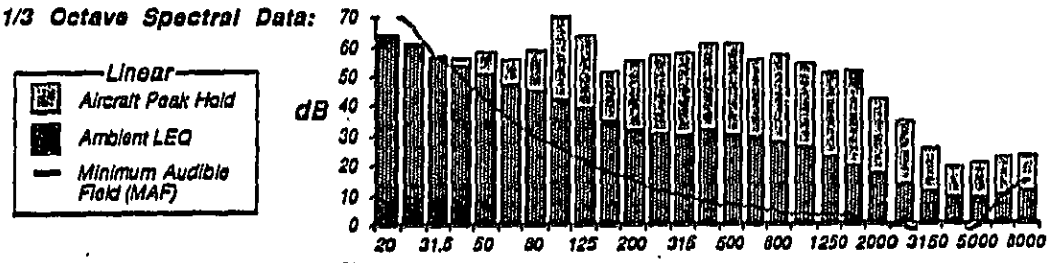


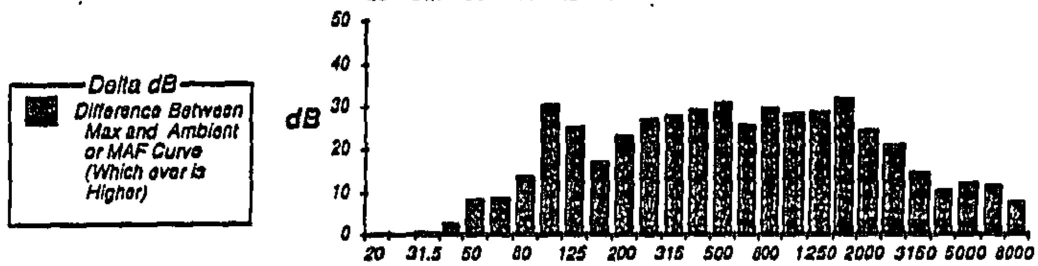
Measurement Results:

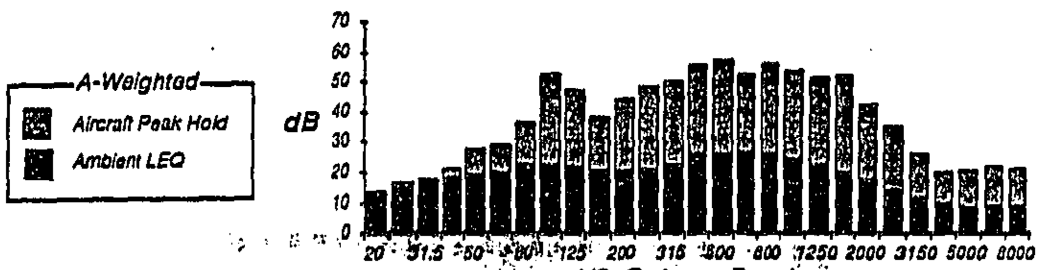
Critical f = 1600 Hz
Delta (Max vs. Amb/MAF) = 32 dB
D-Prime = 12,028

Aircraft (Max) = 59 dBA
Ambient (L90) = 36 dBA
Delta (Max vs. Amb.) = 23 dBA
Duration (L90 +3) = 90 Seconds (est)

1/3 Octave Spectral Data:





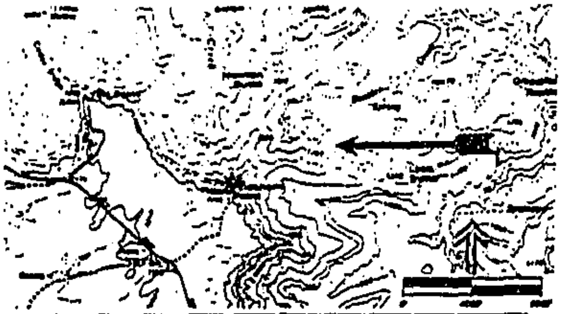


Shoshone Pt. Measurements
(EL. 7200 ft.)

Enrout Jet
High Altitude Over Head

11/13/87   5:13 p.m.

Weather:
N @ 10 to 20   E120 -OVC
45°F   66% Humidity

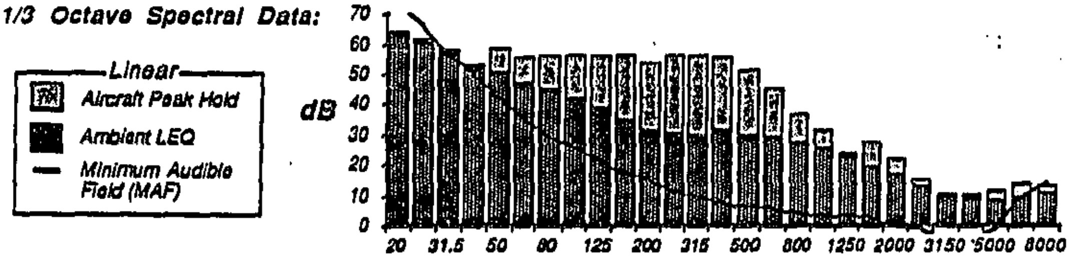


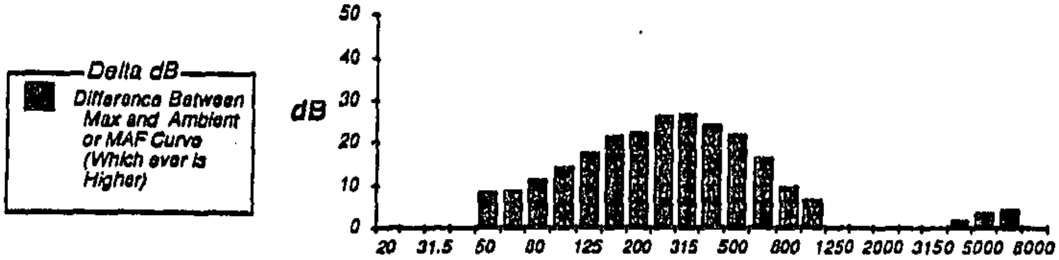
Measurement Results:

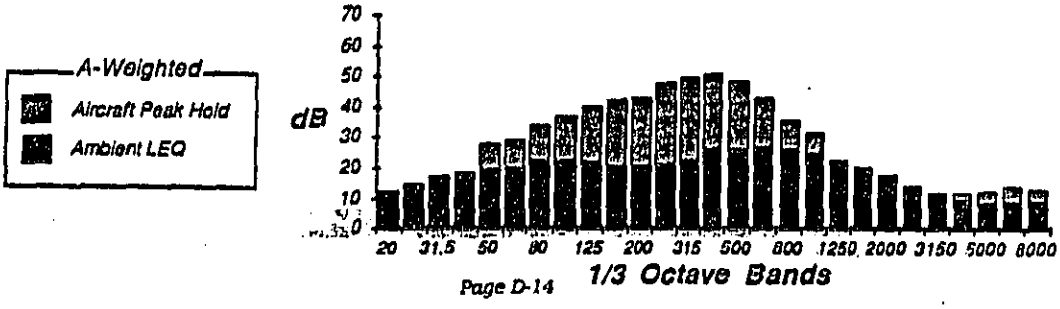
Critical f = 315 Hz
Delta (Max vs. Amb/MAF) = 27 dB
D-Prime = 1,636

Aircraft (Max) = 51 dBA
Ambient (L90) = 36 dBA
Delta (Max vs. Amb.) = 15 dBA
Duration (L90 +3) = 230 Seconds (est)

1/3 Octave Spectral Data:





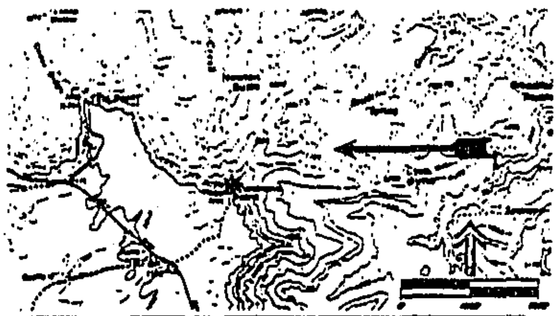


Shoshone Pt. Measurements
(EL. 7200 ft.)

Enrout Jet
High Altitude Over Head

11/13/87   5:13 p.m.

Weather:
N @ 10 to 20   E120 -OVC
45°F   66% Humidity



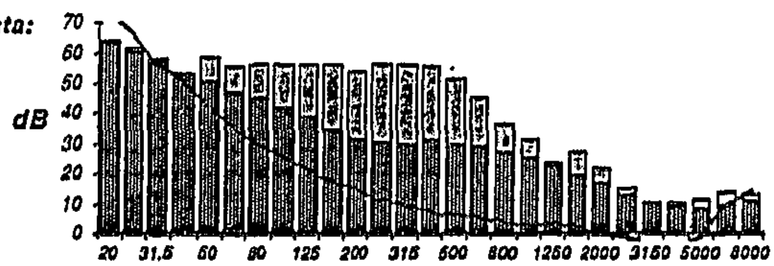
Measurement Results:

Critical f = 315 Hz
Delta (Max vs. Amb/MAF) = 27 dB
D-Prime = 1,636

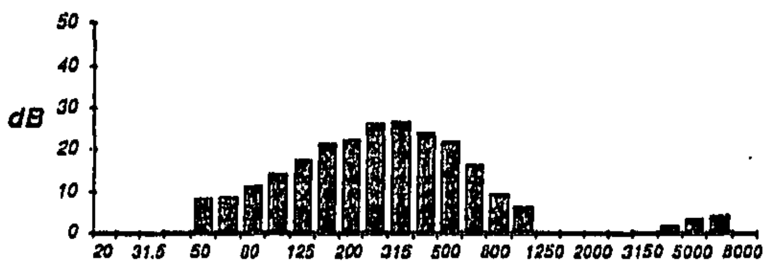
Aircraft (Max) = 51 dBA
Ambient (L90) = 36 dBA
Delta (Max vs. Amb.) = 15 dBA
Duration (L90 +3) = 230 Seconds (est)

1/3 Octave Spectral Data:

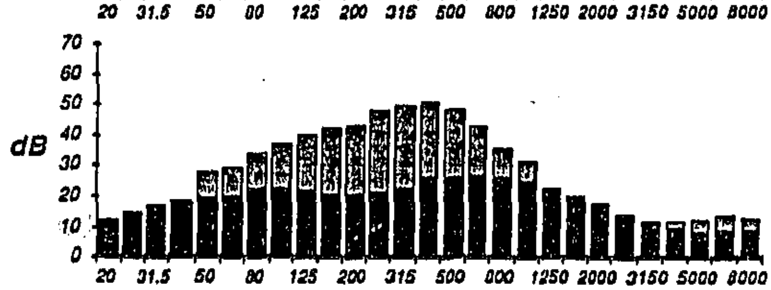
Linear
Aircraft Peak Hold
Ambient LEQ
Minimum Audible Field (MAF)



Delta dB
Difference Between Max and Ambient or MAF Curve (Which ever is Higher)



A-Weighted
Aircraft Peak Hold
Ambient LEQ



 1/3 Octave Bands

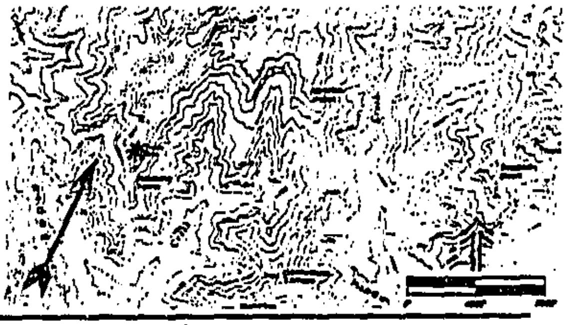
Pt. Sublime Measurements

(EL. 7400 ft.)

Enroute Military Jet
Northeast Bound @ High Altitude

11/11/87   12:25 p.m.

Weather:
W @ 3-5 E250 -SCT
46°F   70% Humidity

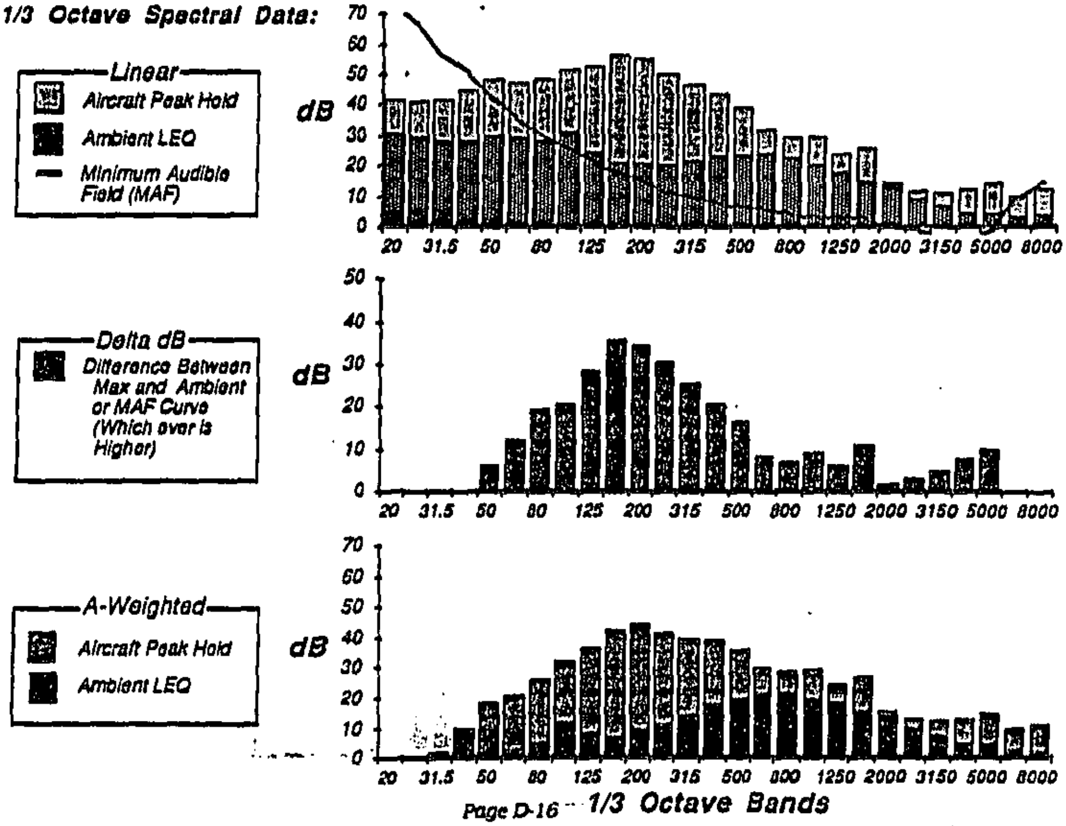


Measurement Results:

Critical f = 160 Hz
Delta (Max vs. Amb/MAF) = 36 dB
D-Prime = 8,916

Aircraft (Max) = 46 dBA
Ambient (L90) = 24 dBA
Delta (Max vs. Amb.) = 22 dBA

1/3 Octave Spectral Data:



Pt. Sublime Measurements
(EL. 7400 ft.)

Enroute Jet
Westbound @ High Altitude

11/11/87 12:10 p.m.

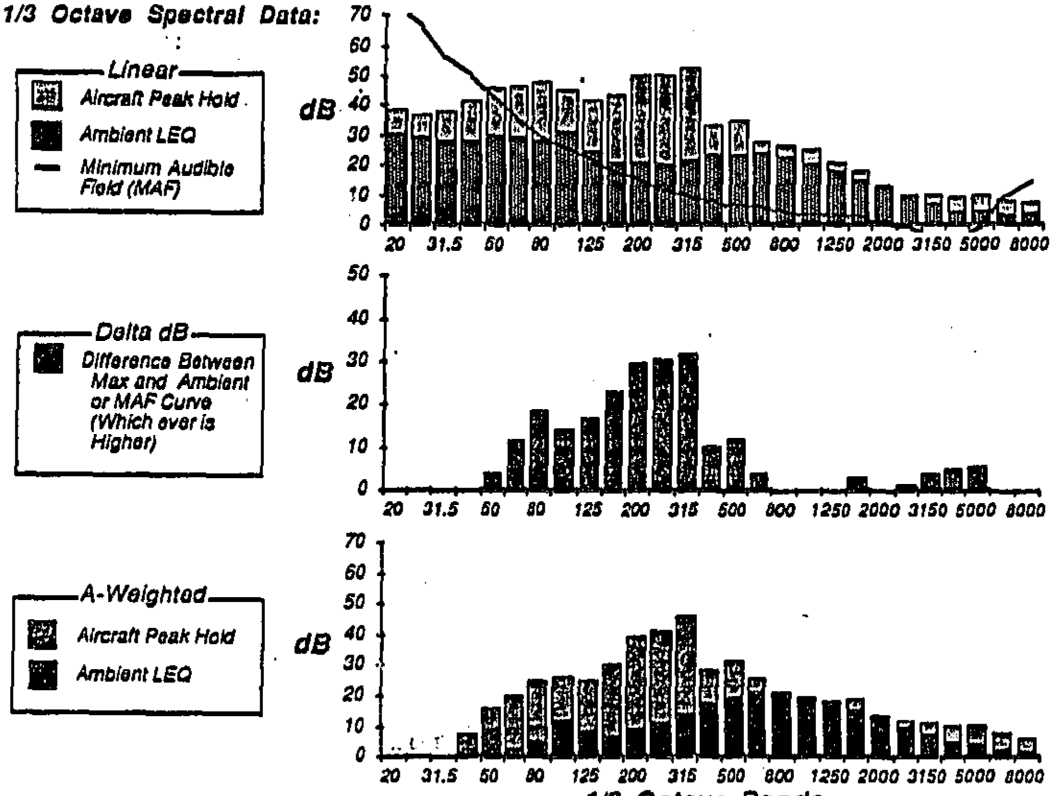
Weather:
W @ 3-5 E250 -SCT
46°F 70% Humidity

Measurement Results:

Critical ƒ = 315 Hz
Delta (Max vs. Amb/MAF) = 32 dB
D-Prime = 5,221

Aircraft (Max) = 45 dBA
Ambient (L90) = 24 dBA
Delta (Max vs. Amb.) = 21 dBA
Duration (L90 +3) = 115 Seconds (est)

1/3 Octave Spectral Data:

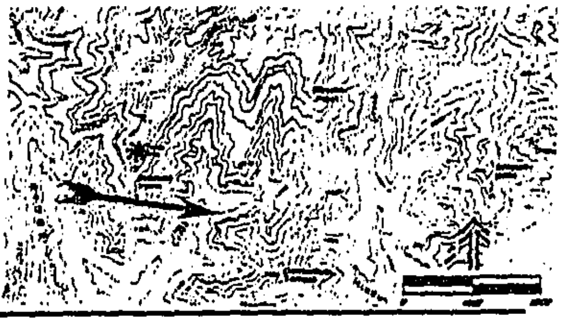


Pt. Sublime Measurements
(EL. 7400 ft.)

Fixed Wing Tour - Cessna 340
North Rim Eastbound @ 8000'

11/11/87 13:35 p.m.

Weather:
W @ 3-5 E250 -SCT
46°F 70% Humidity

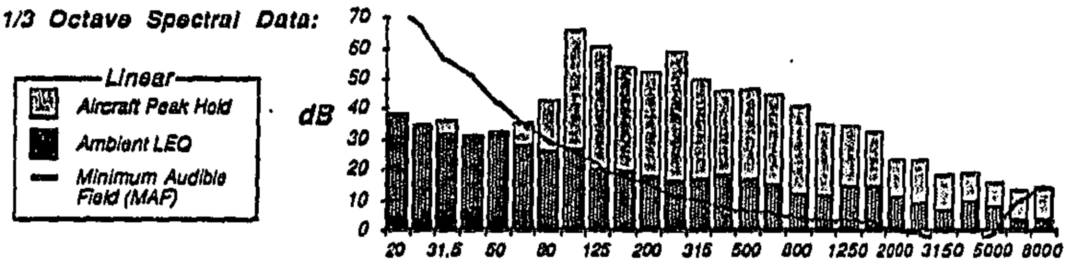


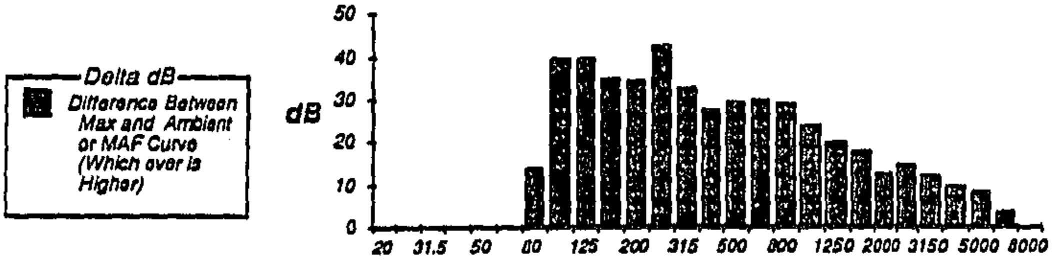
Measurement Results:

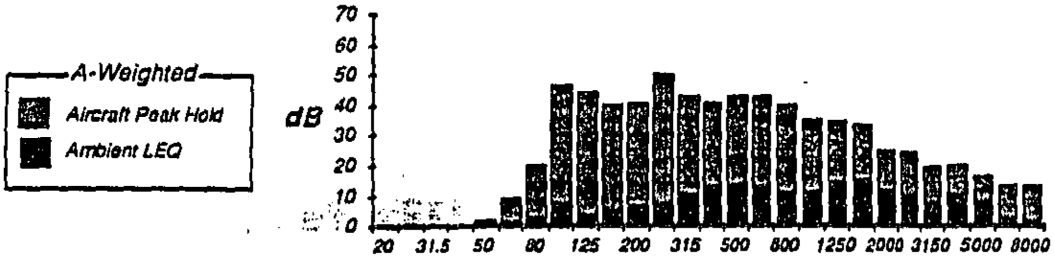
Critical *f* = 250 Hz
Delta (Max vs. Amb/MAF) = 42 dB
D-Prime = 53,183

Aircraft (Max) = 50 dBA
Ambient (L90) = 24 dBA
Delta (Max vs. Amb.) = 26 dBA
Duration (L90 +3) = 175 seconds (est.)

1/3 Octave Spectral Data:







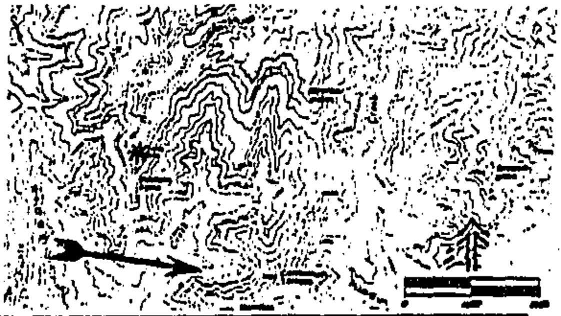
1/3 Octave Bands

Pt. Sublime Measurements
(EL. 7400 ft.)

General Aviation - Twin Piston
North Rim Eastbound @ 8000'

11/10/87 1:40 p.m.

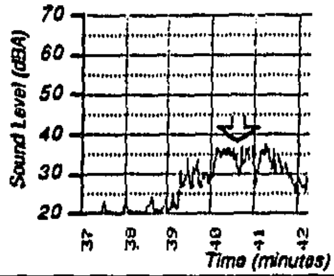
Weather:
Calm E250 -SCT
52°F 66% Humidity



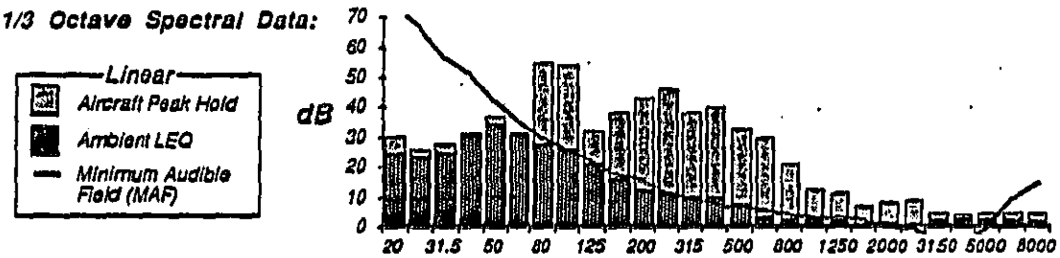
Measurement Results:

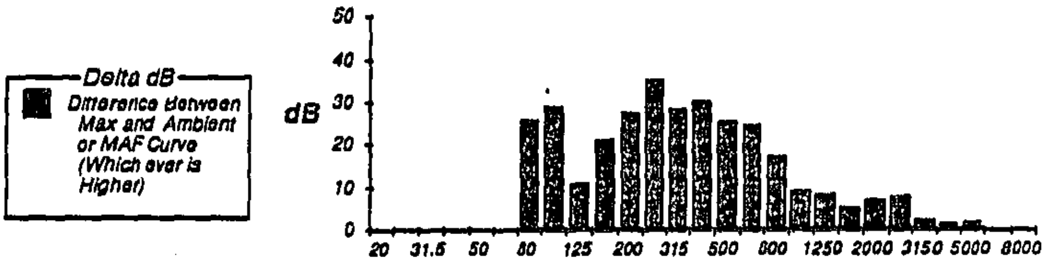
Critical f = 250 Hz
Delta (Max vs. Amb/MAF) = 35 dB
D-Prime = 10,087

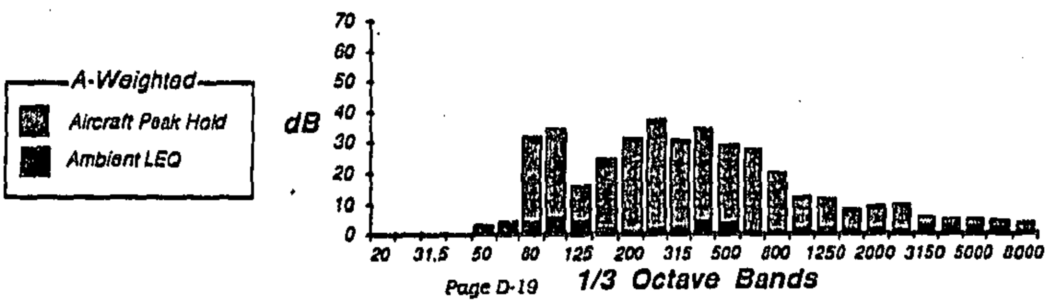
Aircraft (Max) = 37 dBA
Ambient (L90) = 20 dBA
Delta (Max vs. Amb.) = 17 dBA
Duration (L90 +3) = 220 Seconds (est)



1/3 Octave Spectral Data:





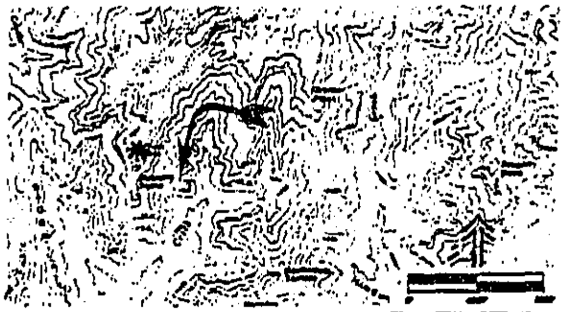


Pt. Sublime Measurements
(EL. 7400 ft.)

Tour Helicopter - Bell 206
Point Sublime Tour

11/10/87 4:12 p.m.

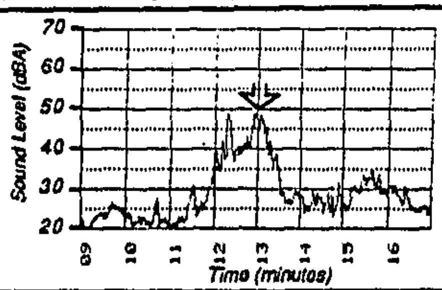
Weather:
W @ 0-3 E250 -SCT
46°F 70% Humidity



Measurement Results:

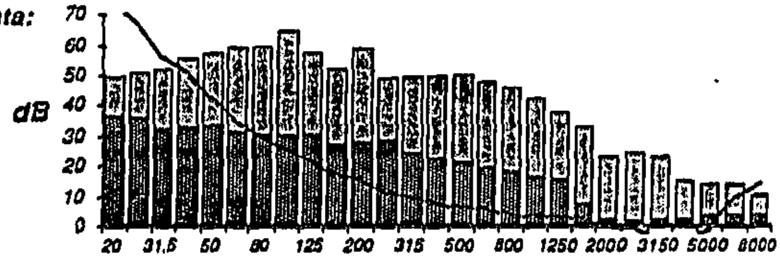
Critical f = 100 Hz
Delta (Max vs. Amb/MAF) = 35 dB
D-Prime = 5,546

Aircraft (Max) = 50 dBA
Ambient (L90) = 21 dBA
Delta (Max vs. Amb.) = 29 dBA
Duration (L90 +3) = 205 Seconds (est)

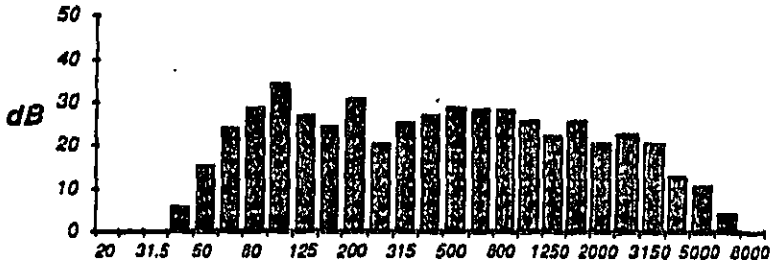


1/3 Octave Spectral Data:

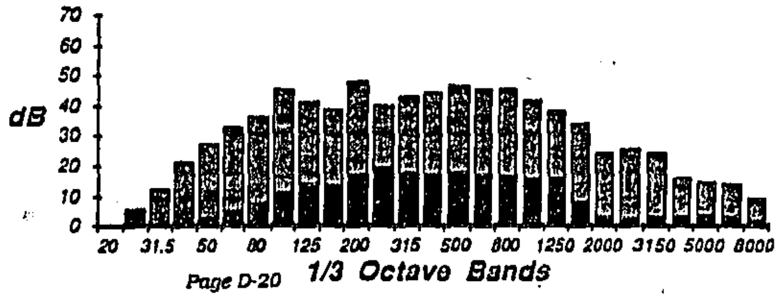
Linear
Aircraft Peak Hold
Ambient LEQ
Minimum Audible Field (MAF)



Delta dB
Difference Between Max and Ambient or MAF Curve (Which ever is Higher)



A Weighted
Aircraft Peak Hold
Ambient LEQ

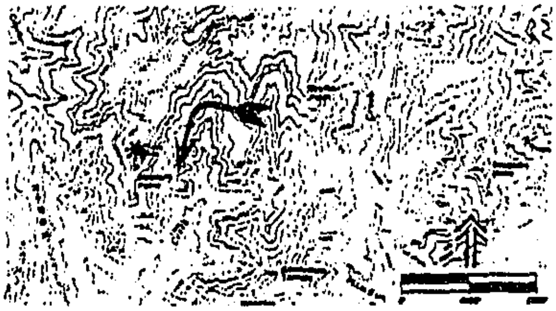


Pt. Sublime Measurements
(EL. 7400 ft.)

Tour Helicopter - Bell 206
Point Sublime Tour

11/10/87 4:12 p.m.

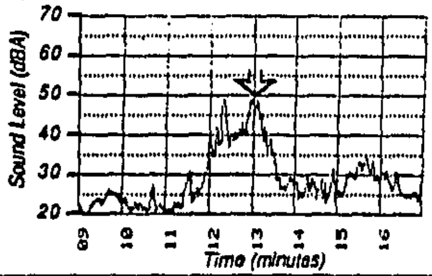
Weather:
W @ 0-3 E250 -SCT
46°F 70% Humidity



Measurement Results:

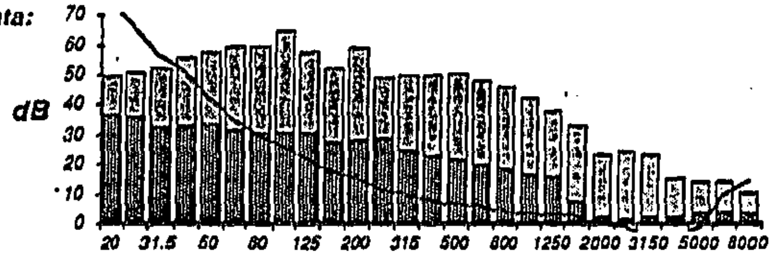
Critical *f* = 100 Hz
Delta (Max vs. Amb/MAF) = 35 dB
D-Prime = 5,546

Aircraft (Max) = 50 dBA
Ambient (L90) = 21 dBA
Delta (Max vs. Amb.) = 29 dBA
Duration (L90 +3) = 205 Seconds (est)

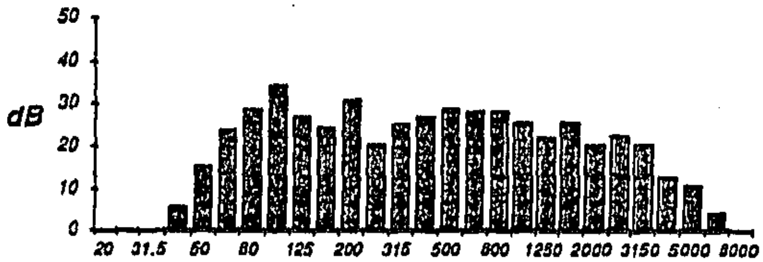


1/3 Octave Spectral Data:

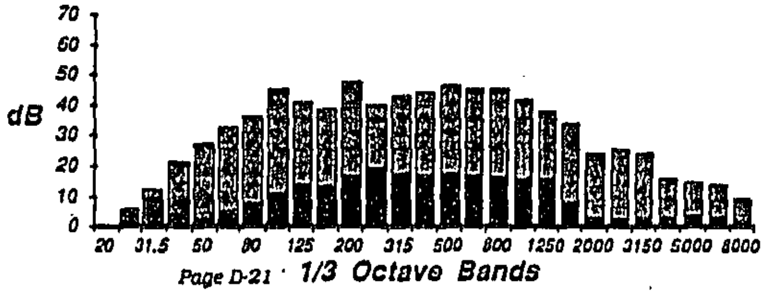
Linear
Aircraft Peak Hold
Ambient LEQ
Minimum Audible Field (MAF)



Delta dB
Difference Between Max and Ambient or MAF Curve (Which ever is Higher)



A-Weighted
Aircraft Peak Hold
Ambient LEQ

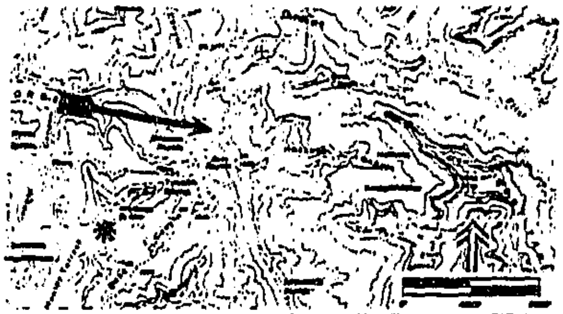


Huxley Terrace Measurements
(EL. 5700 ft.)

General Aviation - Single Engine
Over River to East @ 8500'

11/11/87 10:47 a.m.

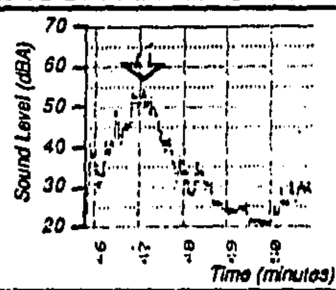
Weather:
E @ 0-3 Clear
50°F 60% Humidity



Measurement Results:

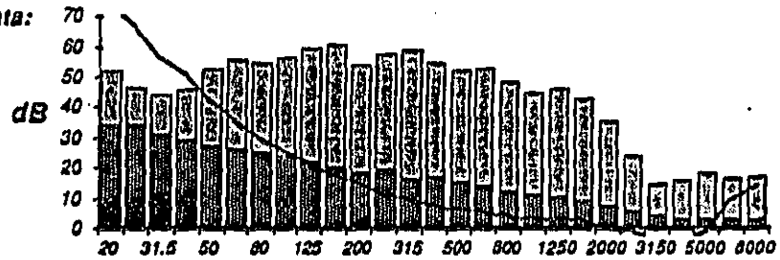
Critical f = 315 Hz
Delta (Max vs. Amb/MAF) = 43 dB
D-Prime = 66,485

Aircraft (Max) = 55 dBA
Ambient (L90) = 20 dBA
Delta (Max vs. Amb) = 35 dBA
Duration (L90 +3) = 164 Seconds

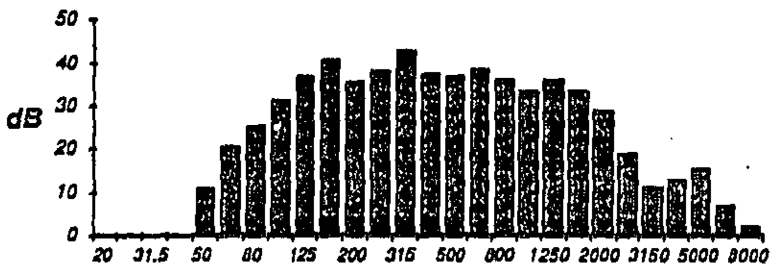


1/3 Octave Spectral Data:

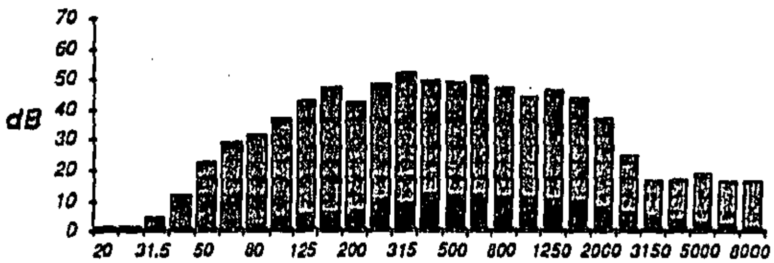
Linear
- Aircraft Peak Hold
- Ambient LEQ
- Minimum Audible Field (MAF)



Delta dB
- Difference Between Max and Ambient or MAF Curve (Which ever is Higher)



A-Weighted
- Aircraft Peak Hold
- Ambient LEQ



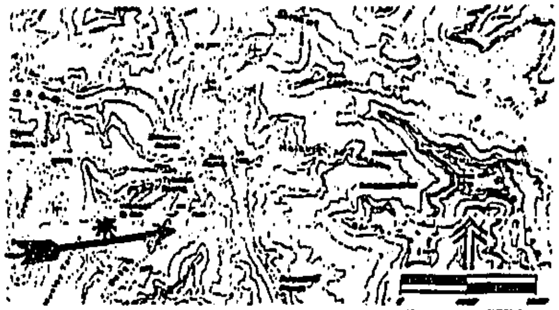
1/3 Octave Bands

Huxley Terrace Measurements
(EL. 5700 ft.)

Fixed Wing Tour
Over Site to East @ 7500'

11/11/87 11:16 a.m.

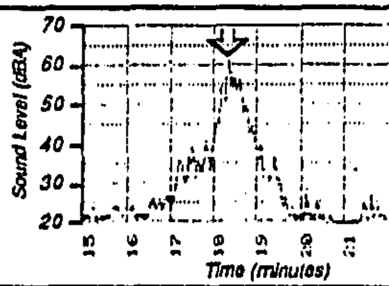
Weather:
E @ 0-3 Clear
50°F 60% Humidity



Measurement Results:

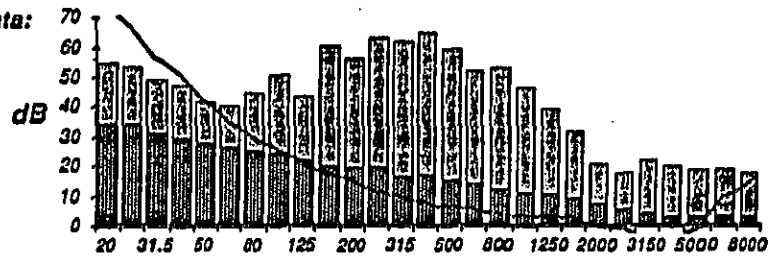
Critical f = 400 Hz
Delta (Max vs. Amb/MAF) = 48 dB
D-Prime = 238,756

Aircraft (Max) = 61 dBA
Ambient (L90) = 21 dBA
Delta (Max vs. Amb) = 40 dBA
Duration (L90 +3) = 180 Seconds

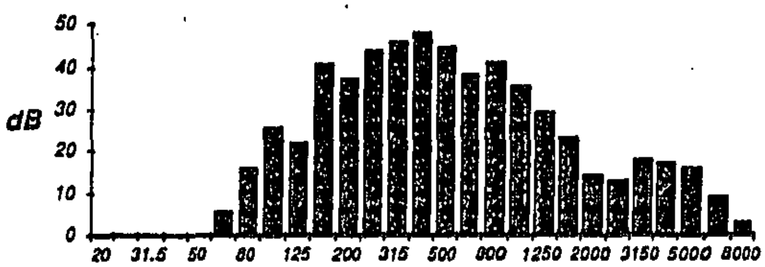


1/3 Octave Spectral Data:

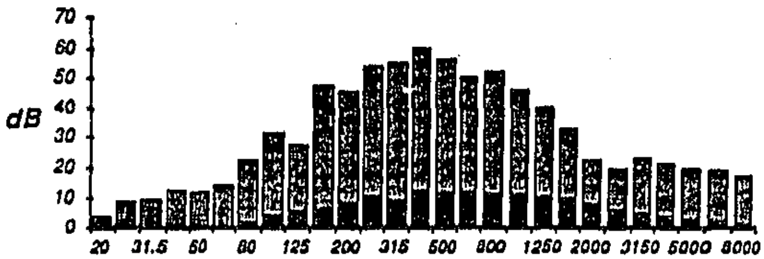
Linear
- Aircraft Peak Hold
- Ambient LEQ
- Minimum Audible Field (MAF)



Delta dB
- Difference Between Max and Ambient or MAF Curve (Which ever is Higher)



A-Weighted
- Aircraft Peak Hold
- Ambient LEQ



1/3 Octave Bands

Table D-1
Crystal Aircraft Flight Log

Date	Time	Aircraft Category	Type	Flight Track	Aircraft Lmax (dBA)	Ambient L90 (dBA)	A-Wt Difference	Duration (min) L90+3 dBA	Weather Data
12-Nov	11:11	Fixed	Otter	N Rim to E @ 8000'	49	20	29	-	Wind Dir. S
12-Nov	11:12	Fixed	Otter	N Rim to E @ 8000'	55	20	35	4.2	Speed 0-3 kts
12-Nov	11:15	INR	JET	S Rim to W @ High Alt	NR	20	-		Temp. °F 62 °F
12-Nov	11:16	INR	JET	N Rim to W @ High Alt	27	20	7	-	Humidity 51 %
12-Nov	11:16	INR	JET	S Rim to W @ High Alt	-	20	-	-	Cover Clear
12-Nov	11:18	Fixed	Twin	N Rim to E @ 8000'	-	20	-	-	
12-Nov	11:18	Heli	B206	Sublime Tour	53	20	33	-	
12-Nov	11:19	Heli	B206	Sublime Tour	59	20	39	-	
12-Nov	11:20	Fixed	Navajo	N Rim to E @ 8000'	-	20	-	-	
12-Nov	11:22	Fixed	SE 206	-	-	20	-	-	
12-Nov	11:22	INR	JET	E of Site to S @ High Alt	-	20	-	6.7	Wind Dir. S
12-Nov	11:25	INR	JET	N Rim to E @ High Alt	39	20	9	-	Speed 0-3 kts
12-Nov	11:28	Heli	B206	River to W	49	20	19	-	Temp. °F 62 °F
12-Nov	11:30	Fixed	Tw Cessna	N Rim to E @ 8000'	55	20	35	-	Humidity 51 %
12-Nov	11:31	INR	High Alt Jet	to W @ high alt	-	20	-	6.7	Cover Clear
12-Nov	11:33	INR	High Alt Jet	to W @ high alt	33	20	13	-	
12-Nov	11:33	Fixed	TCESSNA	N Rim to E @ 8000'	52	20	32	-	
12-Nov	11:35	Fixed	TCESSNA	N Rim to E @ 8000'	48	20	28	-	
12-Nov	11:36	Fixed	TCESSNA	N Rim to E @ 8000'	58	20	38	4.7	
12-Nov	11:36	Fixed	TWIN	N Rim to E @ 8000'	52	20	32	1.8	
12-Nov	11:44	INR	JET	High Alt	35	20	15	3.1	Wind Dir. S
12-Nov	11:49	Heli	B206	Sublime Long Tour	45	20	25	2.5	Speed 0-3 kts
12-Nov	11:58	Heli	B206	Sublime Tour	55	20	35	5.9	Temp. °F 62 °F
12-Nov	12:06	Fixed	SE	-	34	20	34	2.1	Humidity 51 %
12-Nov	12:11	Heli	B206	Sublime Tour	56	20	36	-	Cover Clear
12-Nov	12:13	INR	MIL JET	to N @ High Alt	NA	20	-	4.6	
12-Nov	12:19	Fixed	TWIN	to S	37	20	17	-	
12-Nov	12:22	INE	COMJET	to S @ High Alt	27	20	7	-	
12-Nov	12:25	Tour	SE	Sublime to W @ 8500'	49	20	29	-	
12-Nov	12:27	Tour	TWIN	S Rim to W	31	20	11	-	
12-Nov	12:30	Tour	TWIN	S Rim to W	26	20	6	11.1	Wind Dir. S
12-Nov	12:36	Tour	TWIN	S Rim to W	25	20	5	0.8	Speed 0-3 kts
12-Nov	12:38	Tour	TWIN	S Rim to E	27	20	7	-	Temp. °F 62 °F
12-Nov	12:39	Tour	OTTER	N Rim to E @ 8000'	45	20	25	2.4	Humidity 51 %
12-Nov	12:41	Tour	TWIN	S Rim to E	34	20	14	-	Cover Clear
12-Nov	12:43	Heli	B206	Sublime Tour	57	20	37	-	
12-Nov	12:46	Fixed	OTTER	N Rim to E @ 8000'	51	20	31	6.9	
12-Nov	13:06	Fixed	OTTER	N Rim to E @ 8000'	50	20	30	-	
12-Nov	13:08	INR	JET		25	20	5	-	
12-Nov	13:09	Fixed	OTTER	N Rim to E @ 8000'	52	20	32	-	
12-Nov	13:11	Heli	B206	Sublime Tour	58	20	38	-	Wind Dir. S
12-Nov	13:15	Heli	B206	Sublime Tour	56	20	36	-	Speed 0-3 kts
12-Nov	13:19	Fixed	TWIN	N Rim to E @ 8000'	52	20	32	14.6	Temp. °F 62 °F
12-Nov	13:22	Fixed	TWIN	N Rim to E @ 8000'	65	20	45	1.7	Humidity 51 %
12-Nov	13:25	Fixed	TWIN	S Rim to W	27	20	7	1.7	Cover Clear
12-Nov	13:34	INR	JET	to S	27	20	7	2.2	
12-Nov	13:36	Heli	B206	Sublime Tour	46	20	26	-	
12-Nov	13:38	CA	SE	N Rim to W	56	20	36	-	
12-Nov	13:44	FIXED	TCESSNA	N Rim to W	51	20	31	-	
12-Nov	13:46	HELI	B206	Sublime Tour	61	20	41	-	
12-Nov	13:47	FIXED	TCESSNA	N Rim to E @ 8000'	55	20	35	-	Wind Dir. S
12-Nov	13:49	HELI	B206	Sublime Tour	59	20	39	-	Speed 0-3 kts
12-Nov	13:50	FIXED	TCESSNA	N Rim to E @ 8000'	54	20	34	16.1	Temp. °F 64 °F
12-Nov	13:59	HELI	B206	Sublime Tour	59	20	39	-	Humidity 45 %
12-Nov	14:03	INR	JET	N Rim to W	-	20	-	5.2	Cover Clear
12-Nov	14:06	HELI	B206	Sublime Tour	55	20	35	-	
12-Nov	14:14	FIXED	TOTTER	S Rim to E	30	20	10	5.9	
12-Nov	14:16	HELI	B206	Sublime Tour	60	20	40	-	

Table D-1 (Cont.)
Crystal Aircraft Flight Log

Date	Time	Aircraft Category	Type	Flight Track	Aircraft Lmax (dBA)	Ambient L90 (dBA)	A-Wt Difference	Duration (min) L90+3 dBA	Weather Data
12-Nov	14:19	HELI	B206	Sublime Tour	61	20	41	-	
12-Nov	14:23	FIXED	SE 206	N Rim to W	50	20	30	10	
12-Nov	14:26	FIXED	T OTTER	N Rim to W	44	20	24	1.7	Wind Dir. S
12-Nov	14:29	FIXED	T OTTER	N Rim to E @ 8000'	51	20	31	1.8	Speed 0-3 kts
12-Nov	14:32	HELI	B206	Sublime Tour	58	20	38	6.1	Temp. °F 64 °F
12-Nov	14:38	FIXED	T OTTER	Over River to E	51	20	31	-	Humidity 45 %
12-Nov	14:39	FIXED	T CESSNA	Over River to E	46	20	26	-	Cover Clear
12-Nov	14:42	HELI	B206	Sublime Tour	58	20	38	-	
12-Nov	14:44	FIXED	T CESSNA	N Rim to E @ 8000'	49	20	29	-	
12-Nov	14:44	FIXED	T OTTER	N Rim to E @ 8000'	53	20	33	-	
12-Nov	14:46	FIXED	T OTTER	N Rim to E @ 8000'	51	20	31	-	
12-Nov	14:48	HELI	B206		58	20	38	-	
12-Nov	14:48	FIXED	T OTTER	N Rim to E @ 8000'	55	20	35	11.7	Wind Dir. S
12-Nov	14:50			S Rim	31	20	11	-	Speed 0-3 kts
12-Nov	14:50	HELI	B206	Sublime Tour	58	20	38	6.9	Temp. °F 64 °F
12-Nov	15:04	INR	MIL JET	High Alt. to West	41	20	21	3.1	Humidity 45 %
12-Nov	15:12	INR	JET	Over N Rim	33	20	13	2.1	Cover Clear
12-Nov	15:18			To South East Of Site	33	20	13	1.4	
12-Nov	15:24	FIXED	OTTER	E Over River	41	20	21	3.1	
12-Nov	15:28	FIXED	OTTER	Over River To W @8000	49	20	29	2.8	
12-Nov	15:38	GA	SE	Over River to E @ 8000'	48	20	28	4.2	
12-Nov	15:43	FIXED	OTTER	Vegas To G.C. Over N Rim	49	20	29	--	
12-Nov	15:46	FIXED	SE	N Rim To W	51	20	31	--	Wind Dir. S
12-Nov	15:47	HELI	206	Sublime Tour	53	20	33	--	Speed 0-3 kts
12-Nov	15:52	HELI	206	Sublime Tour	59	20	39	--	Temp. °F 64 °F
12-Nov	15:56	FIXED + INR	SE + JET	W Over River + To N	51	20	31	16	Humidity 45 %
12-Nov	16:03	FIXED	TWIN	S Of River To E	35	20	15	3.4	Cover Clear
12-Nov	16:06	HELI	206	Over River To E	45	20	25	2.2	
12-Nov	16:12	FIXED	SE	Over River To W	39	20	19	3	
12-Nov	16:24	HELI + FIX	206 +?	Sublime Tour + To S	51	20	31	5.2	
12-Nov	16:32	INR	JET	Over River To W	38	20	18	--	
12-Nov	16:34	FIX + INR	OTTER + JET	N River To E + River To W	50	20	30	8	
12-Nov	16:46	FIXED	OTTER	N Of River To E	57	20	37	1.4	Wind Dir. S
12-Nov	16:52	FIXED	SE	N Over Sublime @ 10000	42	20	22	3.2	Speed 0-3 kts
12-Nov	17:36	INR	JET	South	24	20	4	0.5	Temp. °F 56 °F
12-Nov	19:58	INR	JET		NM	NM	NM	NM	Humidity 49 %
12-Nov	20:16	INR	JET	High Alt. to South	31	20	11	2.1	Cover Clear
12-Nov	20:25	INR	JET		37	20	17	2.6	
12-Nov	21:56				38	20	18	5	
12-Nov	22:40				36	20	16	3.6	
13-Nov	1:33				28	20	8	1	
13-Nov	2:06				41	20	21	2.6	
13-Nov	2:10				38	20	18	1.7	Wind Dir. S
13-Nov	2:16				33	20	13	1.0	Speed 0-3 kts
13-Nov	5:02				36	20	16	1.6	Temp. °F 40 °F
13-Nov	5:49				40	20	20	3.6	Humidity 82 %
13-Nov	6:42				37	20	17	2.6	Cover E250 -SCT
13-Nov	7:13				30	20	10	2	
13-Nov	8:22	HELI	206	S Of River	30	20	10	--	
13-Nov	8:25	INR	JET		34	20	14	2.4	
13-Nov	8:29	HELI	206	Sublime Tour	51	20	31	4.4	
13-Nov	9:03	FIXED	OTTER	N Of River To GCAP	51	20	31	1.7	
13-Nov	9:06	HELI	206	S Over Sublime	51	20	31	--	Wind Dir. S
13-Nov	9:07	FIXED	SE CESSNA	N West Of Sublime	45	20	25	--	Speed 0-3 kts
13-Nov	9:09	FIXED	OTTER	N Of River To GCAP	53	20	33	4	Temp. °F 40 °F
13-Nov	9:16	HELI	206	Sublime Tour	56	20	36	5.7	Humidity 82 %
13-Nov	9:24	FIXED	SE CESSNA	N Of River To W	53	20	33	--	Cover E250 -SCT
13-Nov	9:26	INR	MIL JET	Over River To E @15000	50	20	30	--	

Table D-1 (Cont.)
Crystal Aircraft Flight Log

Date	Time	Aircraft Category	Type	Flight Track	Aircraft Lmax (dBA)	Ambient L90 (dBA)	A-W Difference	Duration (min) L90+3 dBA	Weather Data	
13-Nov	9:27	FIXED	TWIN		55	20	35	3.9		
13-Nov	9:34	FIXED	SE CESSNA		29	20	9	1		
13-Nov	9:37	FIXED	SE CESSNA	N Over River To W	46	20	26	3.1		
13-Nov	9:40	FIXED	SE CESSNA	S Over Sublime	55	20	35	3		
13-Nov	9:46	INR	JET	Over River To W @ 9000	52	20	32	4.1	Wind Dir,	
13-Nov	9:54	FIXED	SE	Over River To E @ 9000	36	20	16	- -	Speed	0 kts
13-Nov	9:56	FIXED			40	20	20	3	Temp. °F	61 °F
13-Nov	9:57	INR	JET	Over River To E	43	20	23	- -	Humidity	67 %
13-Nov	9:58	FIXED	SE CESSNA	N Of River To W	54	20	34	2.6	Cover	E250 -BKN
13-Nov	10:02	FIXED	SE	N Of River To W	50	20	30	1.6		
13-Nov	10:09	INR	JET	South	40	20	20	- -		
13-Nov	10:10	FIXED	SE CESSNA	South	53	20	33	5.4		
13-Nov	10:20	FIXED + INR	SE CESS + JET	N Of River TO W + To South	54	20	34	2.3		
13-Nov	10:31	2 INR	2 JET		53	20	33	- -		
13-Nov	10:34	FIXED	SE CESSNA	Over River To East	42	20	22	7.7	Wind Dir,	
13-Nov	10:43	INR	JET	Over River To West	31	20	11	2.1	Speed	0 kts
13-Nov	10:46	HELI	206	Sublime Tour	46	20	26	3	Temp. °F	61 °F
13-Nov	10:53	INR	JET		38	20	18	5.5	Humidity	67 %
									Cover	E250 -BKN
						TOTAL		302.6		

Appendix E

SAMPLE MEASUREMENT SITES

Appendix E
SAMPLE MEASUREMENT SITES

In order to illustrate the site selection process, the preliminary number and location for sound measurement sites for three park units was estimated. Measurement sites were selected for Grand Canyon, Hawaii Volcanoes, Everglades National Park, and Fort Jefferson National Monument. Measurement locations are presented in Exhibits E-1 through E-3 for Everglades, Hawaii Volcanoes, and Grand Canyon respectively.

The measurement locations for Everglades and Fort Jefferson are described in Table E-1. This table presents a description of each site, type of visitor use, access, types of aircraft that affect each site, and the type of measurement data to be determined.

Exhibit E-1, Sample Measurement Locations for the Everglades National Park

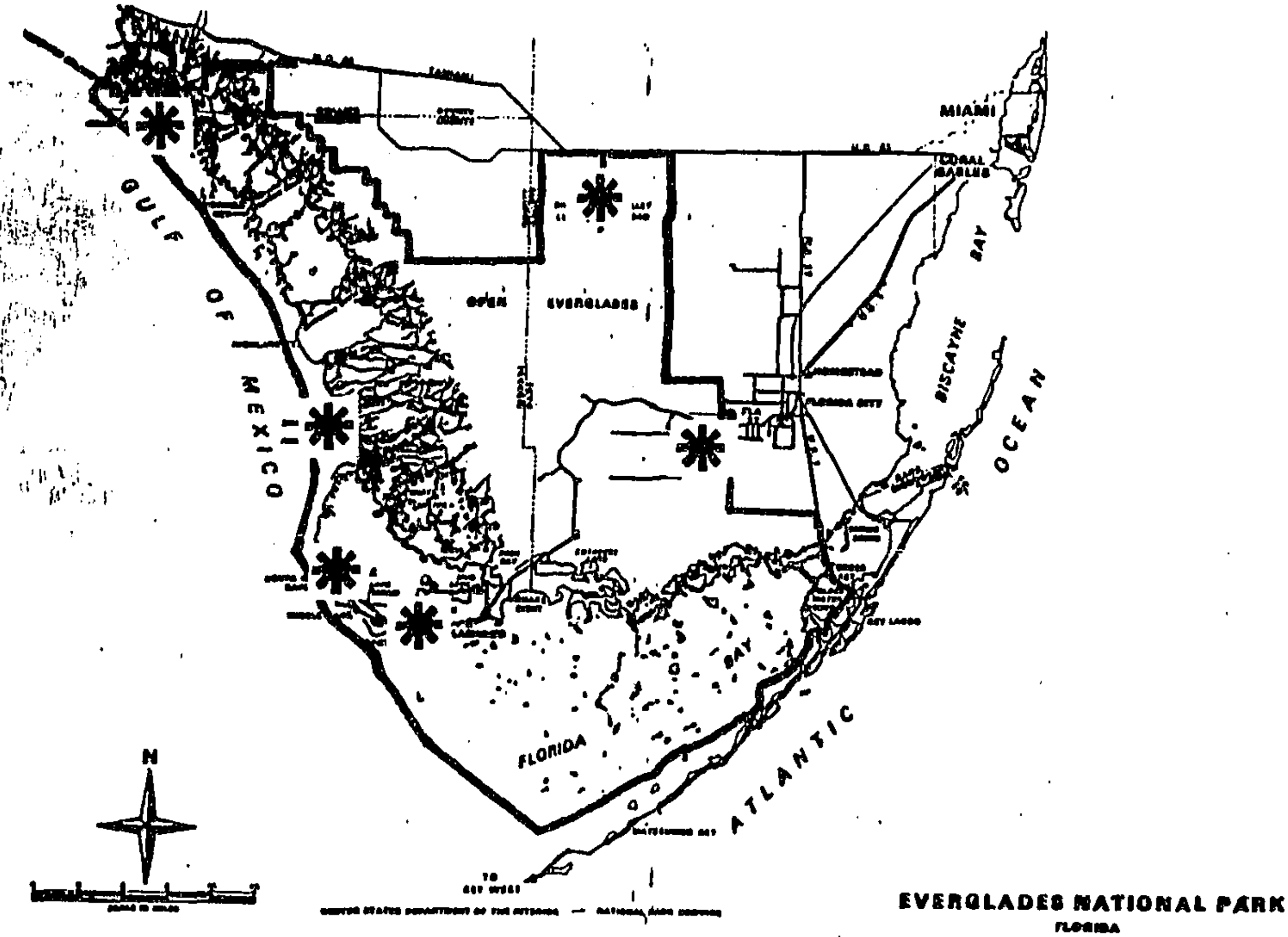


Exhibit E-2, Sample Measurement Locations for the Hawaii Volcanoes National Park

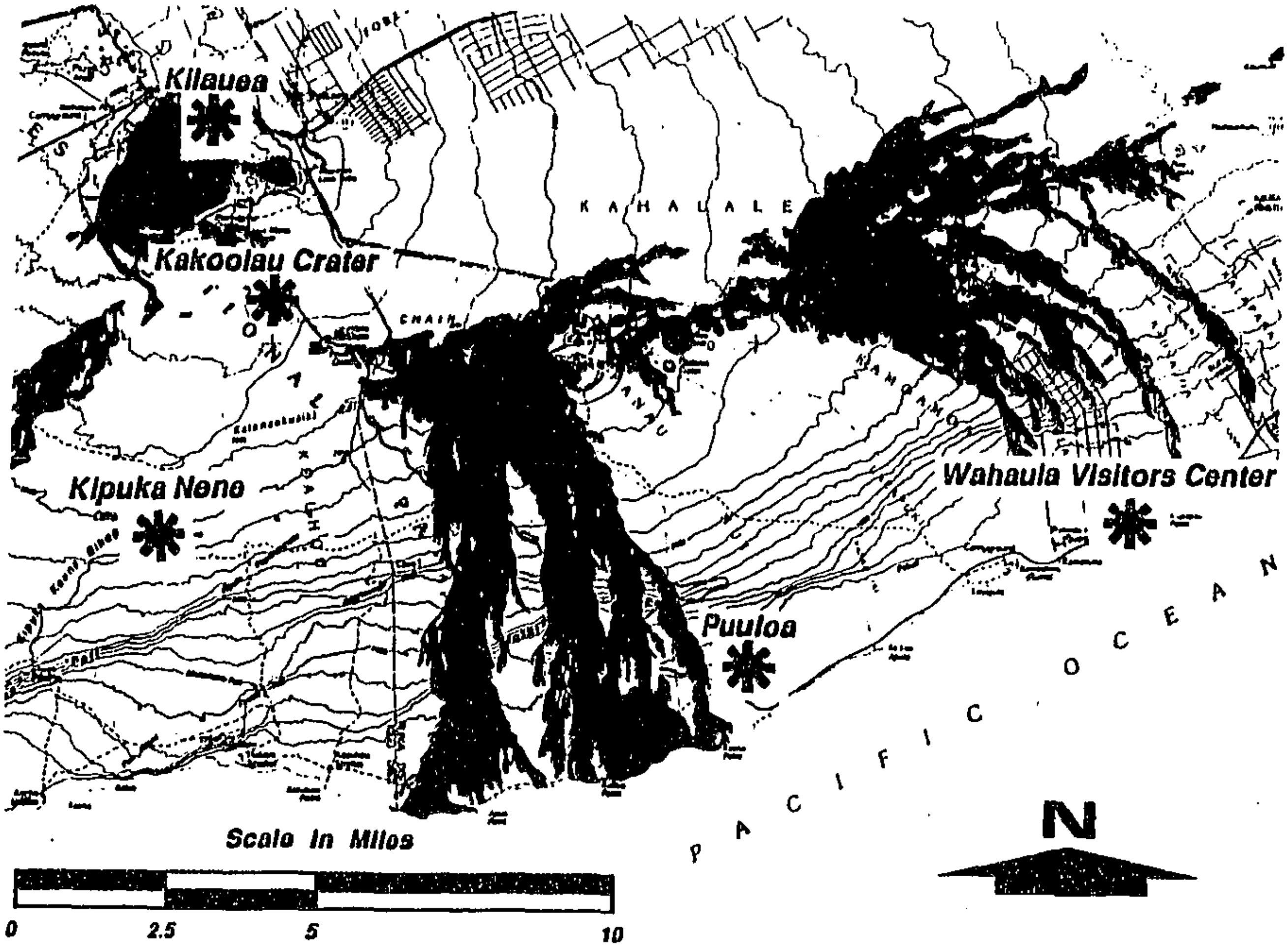


Exhibit E-3, Sample Measurement Locations for the Grand Canyon National Park

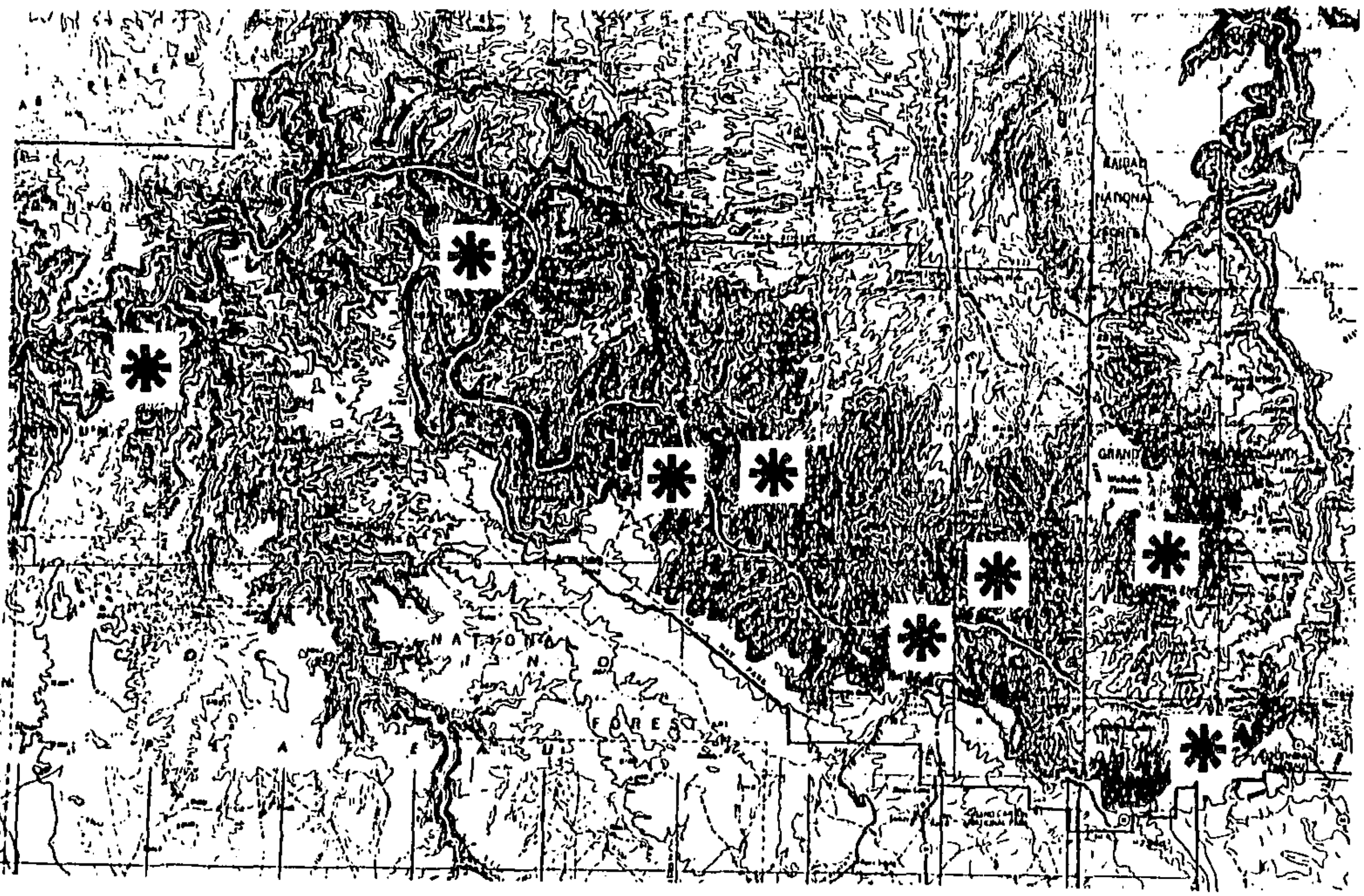


Table E-1
SAMPLE MEASUREMENT LOCATIONS FOR EVERGLADES NATIONAL PARK

SITE	TYPE OF VISITOR ACTIVITY	ACCESS	TYPES OF AIRCRAFT OPERATIONS	TYPE OF NOISE MEASUREMENTS
EVERGLADES NP				
Shark Valley area	Front Country Undeveloped Recreation	Tram/Vehicle	Enroute Commercial Commercial Training Transient Military	Attended Spectral & dBA
Flamingo Visitors Center area	Front Country Developed Recreation	Vehicle	Transient all types	Attended Spectral & dBA
Sandfly Island area	Front Country Undeveloped Recreation	Vehicle	Transient all types Start of MTR	Attended Spectral & dBA Unattended dBA & Onset
Cape Sable	Backcountry Dispersed Recreation	Boat/Helicopter	MOA MTR Transient all types	Attended Spectral & dBA Unattended dBA & Onset
Lostmans Key	Backcountry Dispersed Recreation	Boat/Helicopter	MOA MTR Transient all types	Attended Spectral & dBA Unattended dBA & Onset
Royal Palm	Front Country Developed Recreation	Vehicle	Transient all types	Attended Spectral & dBA
FORT JEFFERSON NM				
Fort Jefferson	Cultural Site	Boat/Helicopter	MTR Transient all types	Unattended dBA & Onset Unattended Structural Vibration