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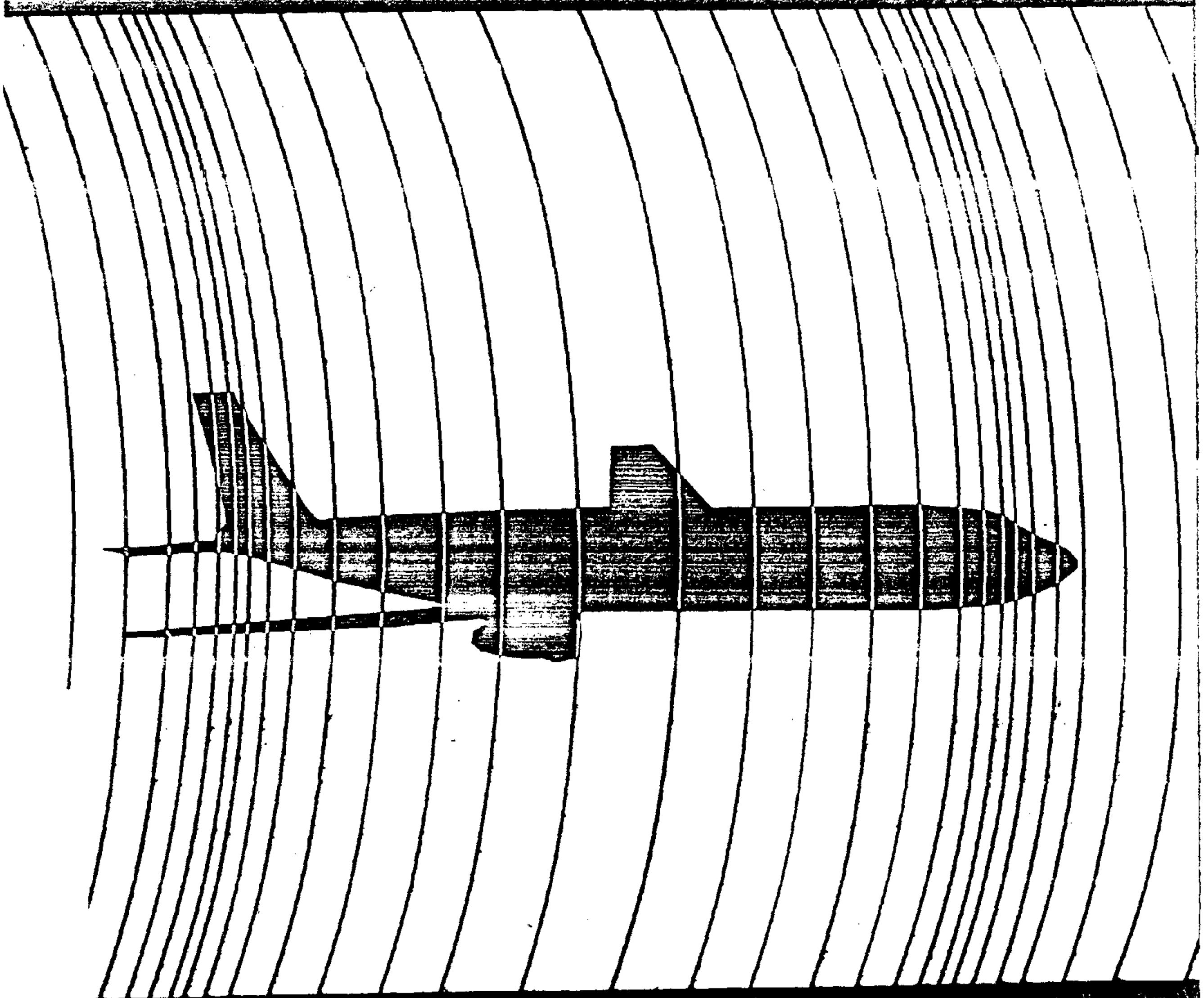
Office of Environment and Energy
Washington, D.C. 20591

Aviation Noise Effects



Report No. FAA-EE-85-2

March 1985

by
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(1) ORI, Inc., 1375 Piccard Drive, Rockville, MD 20850

16. Abstract

This report summarizes the effects of aviation noise in many areas, ranging from human annoyance to impact on real estate values. It also synthesizes the findings of literature on several topics. Included in the literature were many original studies carried out under FAA and other Federal funding over the past two decades. Efforts have been made to present the critical findings and conclusions of pertinent research, providing, when possible, a "bottom line" conclusion, criterion or perspective for the reader. Issues related to aviation noise are highlighted, and current policy is presented.

Specific ~~areas~~ addressed ~~in the report~~ include: ~~the following:~~

- Annoyance;
- Hearing and Hearing Loss;
- Noise Metrics;
- Human Response to Noise;
- Speech Interference;
- Sleep Interference;
- Non-Auditory Health Effects of Noise;
- Effects of Noise on Wild and Domesticated Animals;
- Low Frequency Acoustical Energy;
- Impulsive Noise;
- Time of Day Weightings;
- Noise Contours;
- Land Use Compatibility
- Real Estate Values.

This document is designed for a variety of users, from the individual completely unfamiliar with aviation noise to experts in the field. Summaries are provided at the beginning of each section; references are also included.

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LIST OF TERMS

AI	Articulation Index
AICUZ	Air Installation Compatible Use Zones
AIR	Aerospace Information Report
ALM	A-Weighted Maximum Sound Level
ANSI	American National Standards Institute
ARP	Aerospace Recommeded Practice
CHABA	Committee on Hearing, Bioacoustics and Biomechanics
CNEL	Community Noise Equivalent Level
CNR	Composite Noise Rating
dB	Decibel
DNL	Day-Night Average Noise Level
DOT	Department of Transportation
DRC	Damage Risk Criteria
EPA	Environmental Protection Agency
EPNL	Effective Perceived Noise level
HUD	Housing and Urban Development
Hz	Hertz
ICAO	International Civil Aviation Organization
IEC	International Electrotechnical Commission
ISO	International Standards Organization
Ldn	Day-Night Average Sound Level
Leq	Equivalent Sound Level
Lx	An Airport Cumulative Metric Derived from dBA

NASA	National Aeronautics and Space Administration
NEF	Noise Exposure Forecast
NIPTS	Noise Induced Permanent Threshold Shift
NNI	Noise and Number Index
NREM	Non-Rapid Eye Movement Sleep
NTSB	National Transportation Safety Board
OSHA	Occupational Safety and Health Administration
PNL	Perceived Noise Level
PNLT	Tone Corrected Perceived Noise Level
PSIL	Preferred Speech Interference Level
REM	Rapid Eye Movement Sleep
SAE	Society of Automotive Engineers
SEL	Sound Exposure Level
SIL	Speech Interference Level
SST	Super Sonic Transport
TA	Time Above (a certain noise level)
TTS	Temporary Threshold Shift

Section 1.0 General Introduction

Aviation noise significantly affects several million people in the United States. In a great number of instances, aircraft noise simply merges into the urban din, a cacophony of buses, trucks, motorcycles, automobiles and construction noise. However, in locations closer to airports and aircraft flight tracks, aircraft noise becomes more of a concern. The Federal Aviation Administration (FAA) presents this report in an effort to enhance public understanding of the impact of noise on people and to answer many questions that typically arise. Information on aircraft noise indices, human response to noise, and criteria for land use controls is included. Additionally, information on hearing damage is presented, along with occupational health standards for noise exposure.

This document has been developed after reviewing the rather extensive literature in each topical area, including many original research papers, and also by taking advantage of literature searches and reviews carried out under FAA and other Federal funding over the past two decades. Efforts have been made to present the critical findings and conclusions of pertinent research, providing, when possible, a "bottom line" conclusion, criterion, or perspective to the reader concerned with aviation noise.

How to Read This Document

1. If you want only a general, non-technical presentation of the fundamental issues and concerns with aircraft noise, read this introduction and the one-page summaries at the beginning of each section.

2. If you are an engineer, planner, social scientist or an individual conducting an environmental impact assessment, consider reading each section of interest in its entirety.

3. If you wish to do an in-depth study, assessment or analysis, delve into the text and the references listed. For more information, consider contacting the staff of the FAA Office of Environment and Energy, Noise Abatement Division, in Washington, D.C. 20591.

What is Sound?

Sound is a complex vibration transmitted through the air which, upon reaching our ears, may be perceived as beautiful, desirable, or unwanted. It is this unwanted sound which people normally refer to as noise.

TABLE 1.1

Comparative Noise Levels

Typical Decibel (dBA) Values Encountered in Daily Life and Industry*

	dBA
Rustling leaves	20
Room in a quiet dwelling at midnight	32
Soft whispers at 5 feet	34
Men's clothing department of large store	53
Window air conditioner	55
Conversational speech	60
Household department of large store	62
Busy restaurant	65
Typing pool (9 typewriters in use)	65
Vacuum cleaner in private residence (at 10 feet)	69
Ringing alarm clock (at 2 feet)	80
Loudly reproduced orchestral music in large room	82
Beginning of hearing damage if prolonged exposure over 85 dBA	
Printing press plant	86
Heavy city traffic	92
Heavy diesel-propelled vehicle (about 25 feet away)	92
Air grinder	95
Cut-off saw	97
Home lawn mower	98
Turbine condenser	98
150 cubic foot air compressor	100
Banging of steel plate	104
Air hammer	107
Jet airliner (500 feet overhead)	115

* When distances are not specified, sound levels are the value at the typical location of the machine operator.

How Does Sound Get Around?

Sound moves outward from its point of origin in waves just as ripples move outward from the point at which a pebble enters a pond.

Sound, just as the ripple in the pond, requires a medium in which to travel; this medium is usually air.

What is a Decibel?

The decibel (dB) is a shorthand way to express the amplitude of sound (the relative height of those ripples in the pond). Because the "ripples" of sound typically experienced may vary in height from 1 to 100,000 "units", it becomes rather cumbersome to maintain an intuitive feeling for what different values represent. The decibel allows people to understand sound strength using numbers ranging between 20 and 120, a more familiar and manageable set of values. Table 1.1 provides a listing of some typical sounds and their respective sound levels (expressed in decibels) at given distances.

The decibel also relates well to the way in which people perceive sound. A 10 dB increase in a sound seems twice as loud to the listener, while a 10 dB decrease seems only half as loud. In general, changes in sound level of 3 or 4 dB are barely perceptible.

What is Frequency or Pitch?

Some of the ripples in the pond may be very short; these are analogous to high pitched sounds such as the voice of a soprano. Other wavelets might be very broad; these waves are analogous to a bass or baritone voice. Most sounds we hear are composed of a mixture of these different length sound waves, giving complexity, richness and character to our experience of sound.

What is the Most Important Effect of Aviation Noise?

Annoyance is the most prevalent effect of aircraft noise. It is important to note that while the overall, or average, community attitude about a noise level is usually what is reported, some individuals will be much more and others much less upset or annoyed with the sound in question. Figure 1.1 shows this typical response pattern. This variation in response is what makes the science of measuring "community response" a rather complicated matter.

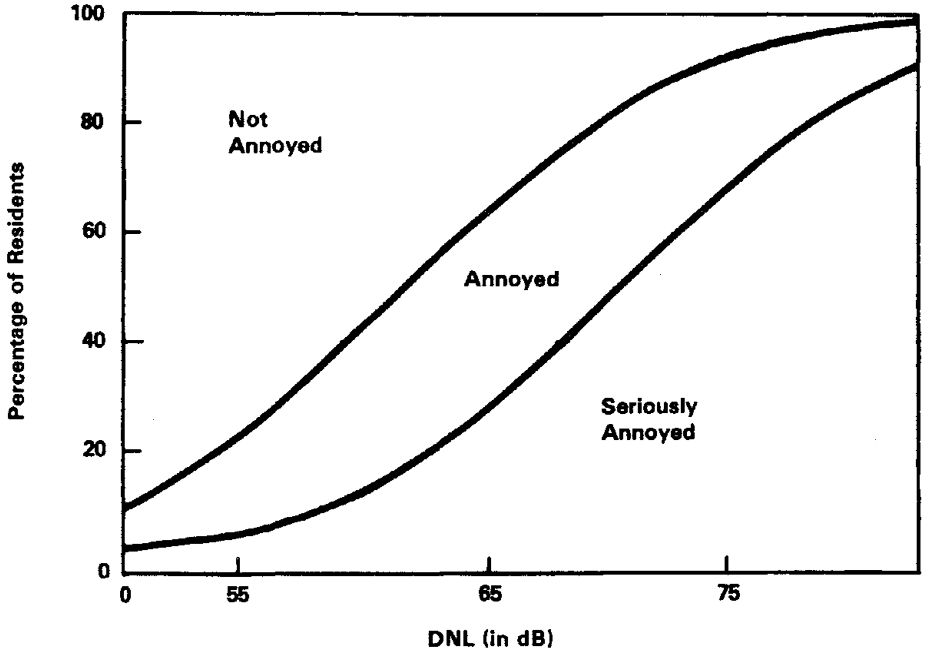
What are Other Principal Effects of Aircraft Noise?

1. speech interference

2. sleep interference

3. hearing damage risk

Figure 1.1



Annoyance Caused by Aircraft Noise in Residential Communities Near Major Airports

(Ref. 1)

While hearing damage is not a common result of aircraft noise exposure, speech and sleep interferences are major concerns of neighbors close to airports.

<u>What are Some Less Frequently Identified Effects of Noise on Humans?</u>

1. physiological (cardiovascular and circulatory) problems

2. psychological problems (stemming from intense annoyance)

3. social behaviorial problems

At the present time there is no conclusive evidence to link these effects with aircraft noise. As discussed in the text, these topical areas are often rife with conflicting research results and are very controversial. The summary of the non-auditory effects section (Section 8.0) provides current guidance for interpreting these reported effects.

<u>What Other Areas May be Affected by Aircraft Noise?</u>

1. real estate values

2. land use

3. wildlife

4. farm animals

Years of experience in airport planning and development have resulted in guidelines which match uses of land -- like hospitals or concert halls -- with normally compatible noise levels; these guidelines are published in an FAA regulation called Federal Aviation Regulation (FAR) PART 150. Implementation of an FAR 150 Study will assist airport operators and neighbors in minimizing the extent of non-compatible land uses.

While the reactions of animals to noise have been studied, it is another research area plagued with widely varying results. In all but extreme cases (such as in pristine wilderness or in the case of excessive noise levels) wildlife and domesticated animals rarely display any reactions to aviation noise.

How Do You Measure Aircraft Noise?

Sound is often measured using a sound level meter with a filter which simulates the human hearing response. This filter and the human ear give greater emphasis to sounds in the speech-important frequency bands and less emphasis to the lower and higher frequencies. This differential response in the human ear may have developed over the course of human evolution as a way to filter the sounds of wind and water which might interfere with survival-related communications such as "Here comes a Tyrannasaurus Rex--run for it!". In any event, this filter is called the A-weighting filter, and the sound measured with this filter is called the A-level (AL).

Now I Know What AL is, but I Am Confused About "Energy Dose". What Exactly is the Sound Exposure Level (SEL)?

When our sound level meter is measuring the AL, think of the sound falling on the microphone like rain or snow. The maximum rate of rainfall is the maximum AL. Now consider the sound level meter as a bucket or pail. After the "noise event" has passed (aircraft flyover or truck passby) the rain or snow collected in the bucket (having passed through the microphone) is the noise dose or Sound Exposure Level (SEL). Essentially, loud noise events create a large bucket (dose) of sound energy, while quieter events create smaller buckets.

Now What Do I Do With "Buckets" of Noise (the Leq and DNL)?

The buckets are typically collected over a 24-hour time period and are poured into a large container. The total volume collected during the 24-hour time period is averaged to formulate a value called the "Equivalent Sound Level", or Leq. When the buckets collected during the nighttime hours are multiplied by 10 (because of greater potential for disturbing people) and then the volume averaged, we formulate a value called the "Average Day Night Sound Level" or DNL. The Leq and DNL are values one often encounters in looking at the overall noise exposure from an airport operation.

REFERENCE

1. Richards, E. S. and J. B. Ollerhead. Noise Burden Factor--New Way of Rating Airport Noise. Sound and Vibration, V. 7, No. 12, December 1973.

Section 2.0 NOISE METRICS

SUMMARY

INTRODUCTION

This section describes the noise metrics utilized in conducting analyses of aircraft noise. While dozens of additional metrics exist, this section focuses on the officially designated family of indices. A working knowledge of these measures is extremely valuable in understanding the remainder of this report.

AVIATION APPLICATIONS/ISSUES

1. Correlation between human response and various measures of sound.

2. Selection of the best metrics for specific applications.

3. Selection of weighting factors for sound occurring at various times of day.

4. Selection of metrics which are accurate, relatively easy to measure, compute and understand.

GUIDANCE/POLICY/EXPERIENCE

1. The fundamental sound level metric designated as the A-Weighted Sound Level, or AL. This metric has often appeared in the literature as dBA. It is designated for measuring niose at an airport and surrounding areas by Part 150.

2. Single event dose or energy metric designated as the Sound Exposure Level or SEL.

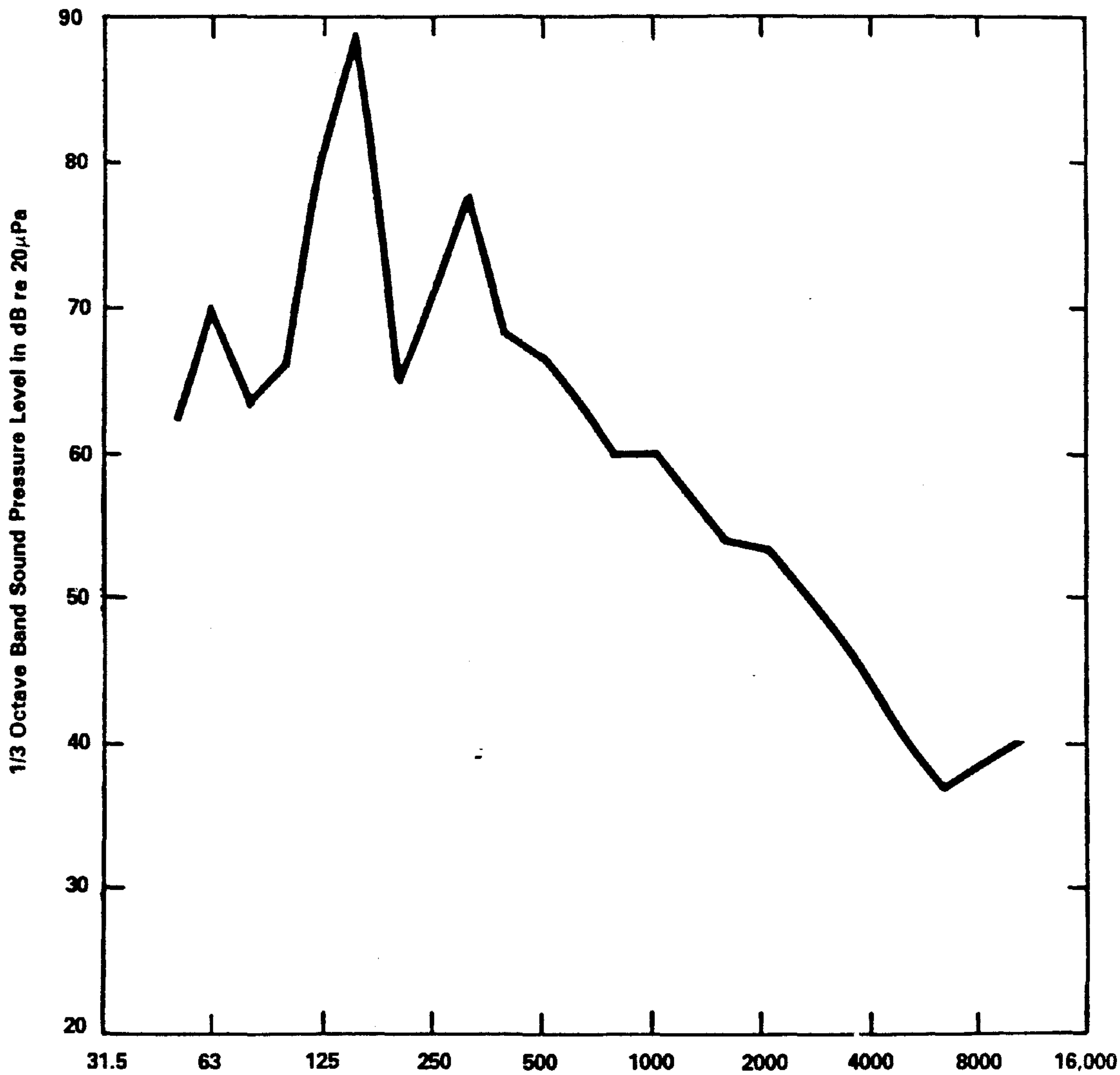
3. Airport yearly average noise exposure measure designated as the Yearly Average Day Night Level or DNL. The DNL has often appeared in the literature as Ldn. Required by Part 150 to measure the exposure of individuals to noise resulting from the operation of an airport.

4. Effective Perceived Noise Level or EPNL designated as the certification metric for large transport turbojet aircraft and helicopters.

5. Time functions of ALm (such as Time Above, TA and L-Values, L-10) identified as supplementary metrics for use in environmental impact analyses.

6. Octave and one-third octave spectra identified as important in specific applications such as sound proofing and speech interference studies.

Figure 2.1



Typical One-Third Octave Band Spectrum

2.1 INTRODUCTION

The topic of noise metrics has traditionally involved a rather confusing proliferation of units and indices. In response to the requirements of the Aviation Safety and Noise Abatement Act of 1979 (P.L. 96-193), the FAA established a single system of metrics for measuring and evaluating noise for land use planning and environmental impact assessment. The FAA also has another system of metrics which it employs for certification of commercial aircraft. This section describes both systems of metrics. It also identifies other noise metrics frequently and necessarily employed in noise certification and provides detailed analysis of noise effects such as speech interference, hearing impact and sleep disturbance.

Sound measures, or more academically, acoustical metrics, all consist of three basic building blocks: 1) sound pressure level, expressed in decibels, 2) frequency or pitch of the sound, and 3) time. The sound pressure levels at various frequencies (points 1 and 2 above), for a given point in time, are usually combined into a frequency spectrum (see Figure 2.1), which is somewhat analogous to the fingerprint of the sound. This spectrum, which varies with time, represents the real starting point for the metric story (see Figure 2.2). From this point of origin, the following classes of metrics have evolved:

(1) Single Event Maximum Sound Levels
(2) Single Event Energy Dose
(3) Cumulative Energy Average Metrics
(4) Cumulative Time Metrics

The paragraphs below describe and differentiate these four generic classes of acoustical metrics. An understanding of these four classes is essential for an individual undertaking a comprehensive assessment of noise effects. (For mathematical formulations of each of the noise metrics, the reader is referred to The Handbook of Noise Ratings (Ref. 1).

2.2 SINGLE EVENT MAXIMUM SOUND LEVEL METRICS

The following noise metrics are generally related, each representing a maximum sound level. The applications of these metrics are diagrammed in Figure 2.2.

2.2.1 A-Weighted Sound Level: ALm (Historically dBA), Expressed in dB. The A-weighted Sound Level is the single event maximum sound level metric. A-weighted sound pressure level is sound pressure level which has been filtered or weighted to reduce the influence of the low and high frequency extremes. Because unweighted sound pressure level does not correlate well with human assessment of the loudness of sounds, various weighting networks are added to sound level meters to attenuate low and high frequency noise in accordance with accepted equal loudness contours. One of these weighting networks is designated "A" (shown in Figure 2.3).

Figure 2.2

FAA NOISE METRIC POLICY—1985

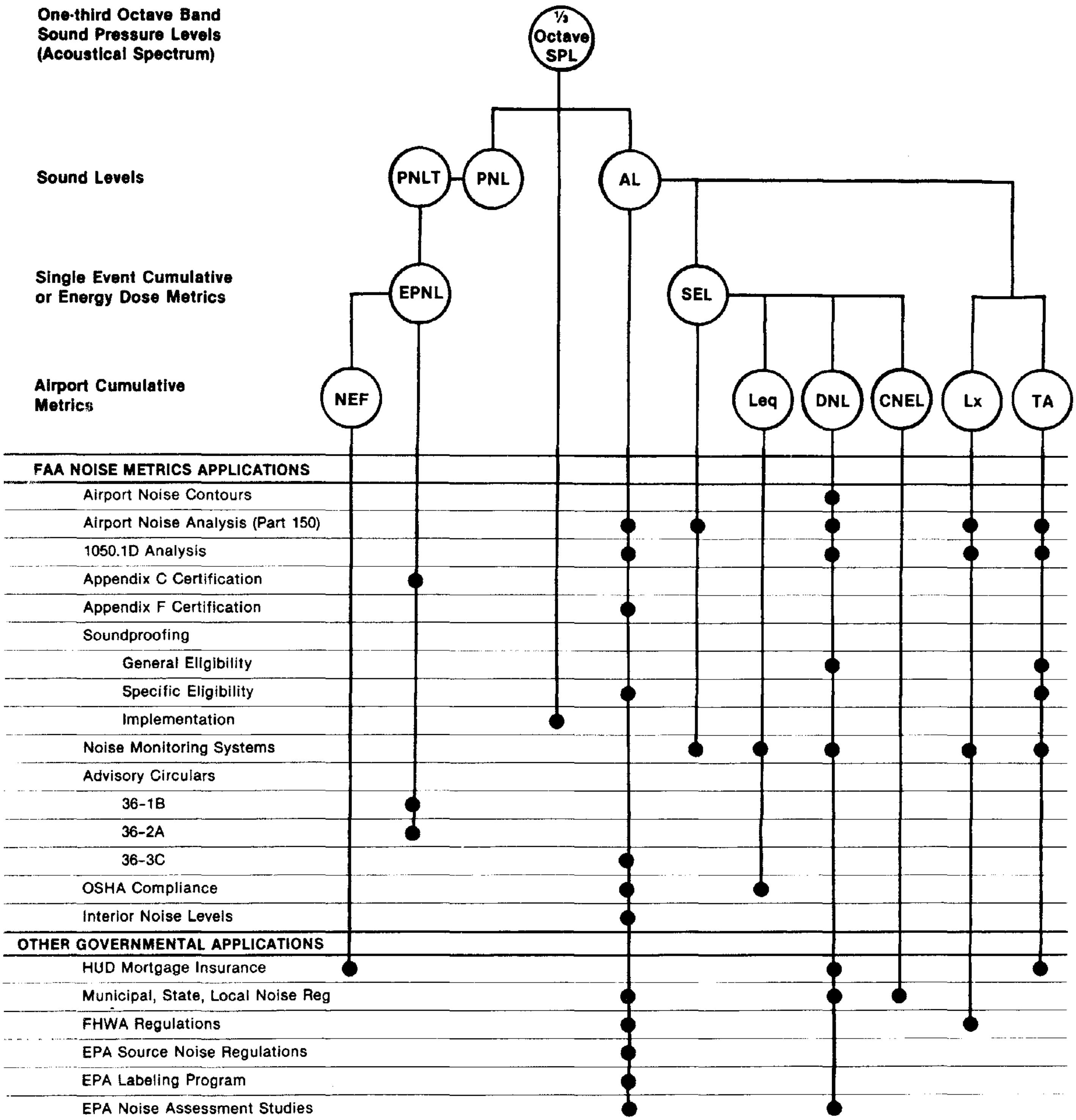
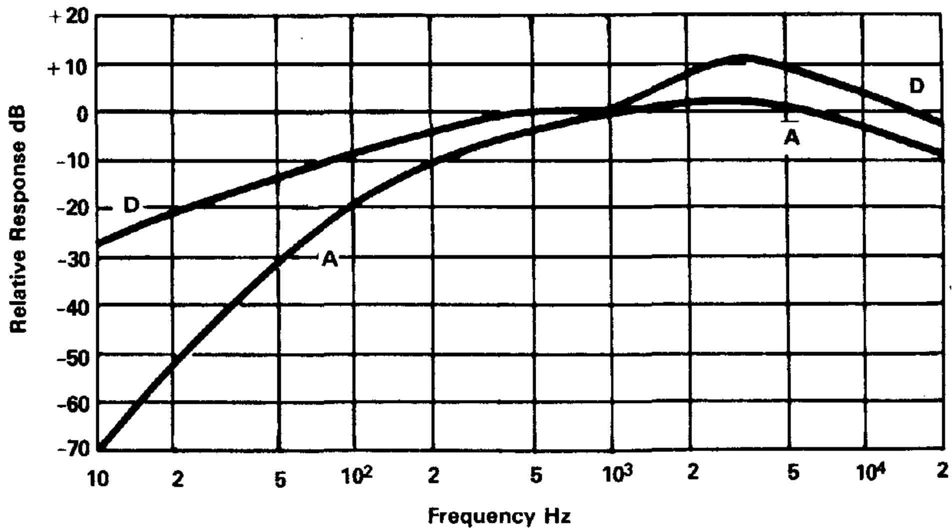


Figure 2.3



The Internationally Standardized "A" and "D" Weighting Curves for Sound Level Meters

(Ref. 2)

It was originally employed for sounds less than 55 dB in level; now A-level is used for all levels of sound because it has been found to correlate well with people's subjective judgment of the loudness of sounds. Its simplicity and superiority over unweighted SPL in predicting people's responses to noise have contributed to its wide acceptance. The ALM is currently used for noise certification of small propellar-driven aircraft; also, in FAA Advisory Circular 36-3C it is used as the basis for airport access restrictions which discriminate solely on the basis of noise level.

2.2.2 D-Weighted Sound Level: DLm (Historically dB(D)), Expressed in dB. D-weighted sound pressure level or D-level is sound pressure level which has been frequency-filtered to reduce the effect of the low frequency noise and to recognize the annoyance at higher frequencies. D-level is measured in decibels with a standard sound level meter with contains a "D" weighting network with the response curve shown in Figure 2.3. D-level was developed as a simple approximation of perceived noise level (PNL) for use in assess aircraft noise. PNL, addressed in the next paragraph, can be estimated from the D-level by this equation: PNL = dB(D) + 7.

2.2.3 Perceived Noise Level (PNL), Expressed in dB. Perceived Noise Level (PNL) is a rating of the noisiness that has been used almost exclusively in aircraft noise assessment. PNL is computed from sound pressure levels measured in octave or one-third octave frequency bands. This rating is most accurate in estimating the perceived noisiness of broadband sounds of similar time duration which do not contain strong discrete frequency components. Currently it is used by the FAA and foreign governmental agencies in the noise certification process for all turbojet -- powered aircraft and large propellar-driven transports. The perceived noise level is expressed in decibels. These units translate the subjective linearly additive noisiness scale to a logarithmic dB-type scale, where an increase of 10 dB in PNL is equivalent to a doubling of its perceived noisiness.

2.2.4 Tone Corrected Perceived Noise Level (PNLT), PNdB. Tone Corrected Perceived Noise Level is basically the Perceived Noise Level adjusted to account for the presence of discrete frequency components. PNLT was developed to aid in prediction of perceived noisiness for aircraft flyovers and vehicle noise which contain pure tones, or have pronounced irregularities in their spectrum. The method for calculating PNLT adopted by the FAA involves calculation of the PNL of a sound and the addition of a tone correction based on the tonal frequency and the amount that the tone exceeds the noise in the adjacent one-third octave bands.

2.3 SINGLE EVENT ENERGY DOSE METRICS

The following noise metrics are generically related, each representing a noise energy dose. Each metric reflects both the maximum sound level and the duration of the event. As shown in Figure 2.2, these metrics are derived from single event sound level metrics.

2.3.1 Effective Perceived Noise Level (EPNL), Expressed in dB or EPNdB. Effective Perceived Noise Level is a single number measure of complex aircraft flyover noise which approximates human annoyance responses. It is derived from PNL and PNLT and includes correction terms for the duration of an aircraft flyover and the presence of audible pure tones or discrete frequencies (such as the whine of a jet aircraft) in the noise signal. The EPNL is used by the FAA as the noise certification metric for large transport and turbojet aircraft and helicopters.

2.3.2 Sound Exposure Level (SEL), Expressed in dB. SEL is a measure of the effect of duration and magnitude for a single event measured in A-weighted sound level above a specified threshold which is at least 10 dB below the maximum value. In typical aircraft noise model calculations, SEL is used in computing aircraft accoustical contribution to the Equivalent Sound Level (Leq) and the Day-Night Sound Level (DNL).

2.4 CUMULATIVE ENERGY AVERAGE METRICS

The cumulative energy average noise metrics are usually derived from single event energy dose metrics. These metrics can also be computed from continuous noise measurement data. Cumulative metrics correlate well with aggregate community annoyance response. They were not designed as single source measures, so they do not account adequately for tonal components. Nor do they relate accurately to speech interference, sleep disturbance or other phenomena requiring analysis using single event maximum and energy dose sound level data. In practice, these measures are not used in determining source standards or for certification of product noise.

2.4.1 Equivalent Sound Level (Leq), Expressed in dB. Equivalent sound level, Leq, is the energy average noise level (usually A-weighted) integrated over some specified time. Equivalent signifies that the total acoustical energy associated with the fluctuating sound (during the prescribed time period) is equal to the total acoustical energy associated with a steady sound level of Leq for the same period of time. The purpose of Leq is to provide a single number measure of noise averaged over a specified time period.

2.4.2 Day-Night Sound Level (DNL), Expressed in dB. Day-Night Sound Level (DNL) was developed as a single number measure of community noise exposure. It is often referred to as Ldn in the literature. DNL was introduced as a simple method for predicting the effects on a population of the average long term exposure to environmental noise. It is an enhancement of the Equivalent Sound Level (Leq) because a correction for nighttime noise intrusions was added. A 10 dB correction is applied to nighttime (10 p.m. to 7 a.m.) sound levels to account for increased annoyance due to noise during the night hours. DNL uses the same energy equivalent concept as Leq. The specified time integration period is 24 hours. As in the case of Leq, there is no stipulation of a minimum noise sampling threshold. The DNL can be derived directly from the A-weighted sound level or the sound exposure level, as shown in Figure 2.2. For assessing long term moise exposure, the yearly average DNL (DNL y-avg) is the specified metric in the FAA FAR Part 150 noise compatibility planning process. In the remainder of this document, the term DNL will be used (in lieu of DNL y-avg), yearly average being implied.

2.4.3 Community Noise Equivalent Level (CNEL), in dB. CNEL, like DNL, incorporates the energy average A-weighted sound level integrated over a 24-hour period. Weightings are applied for the noise levels occurring during the evening (7 p.m. - 10 p.m.) and nighttime (10 p.m. - 7 a.m.). CNEL differs from DNL in the addition of the evening weighting step function of 3 dB which is intended to account for activity interference and annoyance during that time period. It was originally used by the state of California, but it is being phased out.

2.4.4 Noise Exposure Forecast (NEF), in dB. Noise Exposure Forecast performs the same role as DNL or CNEL but is developed using EPNL as the intermediate single event dose metric. The NEF metric incorporates a weighting factor which effectively imposes a 12.2 dB pnealty on sound occurring between 10 p.m. and 7 a.m. This corresponds to a nighttime event multiplyer of 16.7. NEF correlates extremely well with DNL and the equivalency DNL = NEF + 35 is often used.

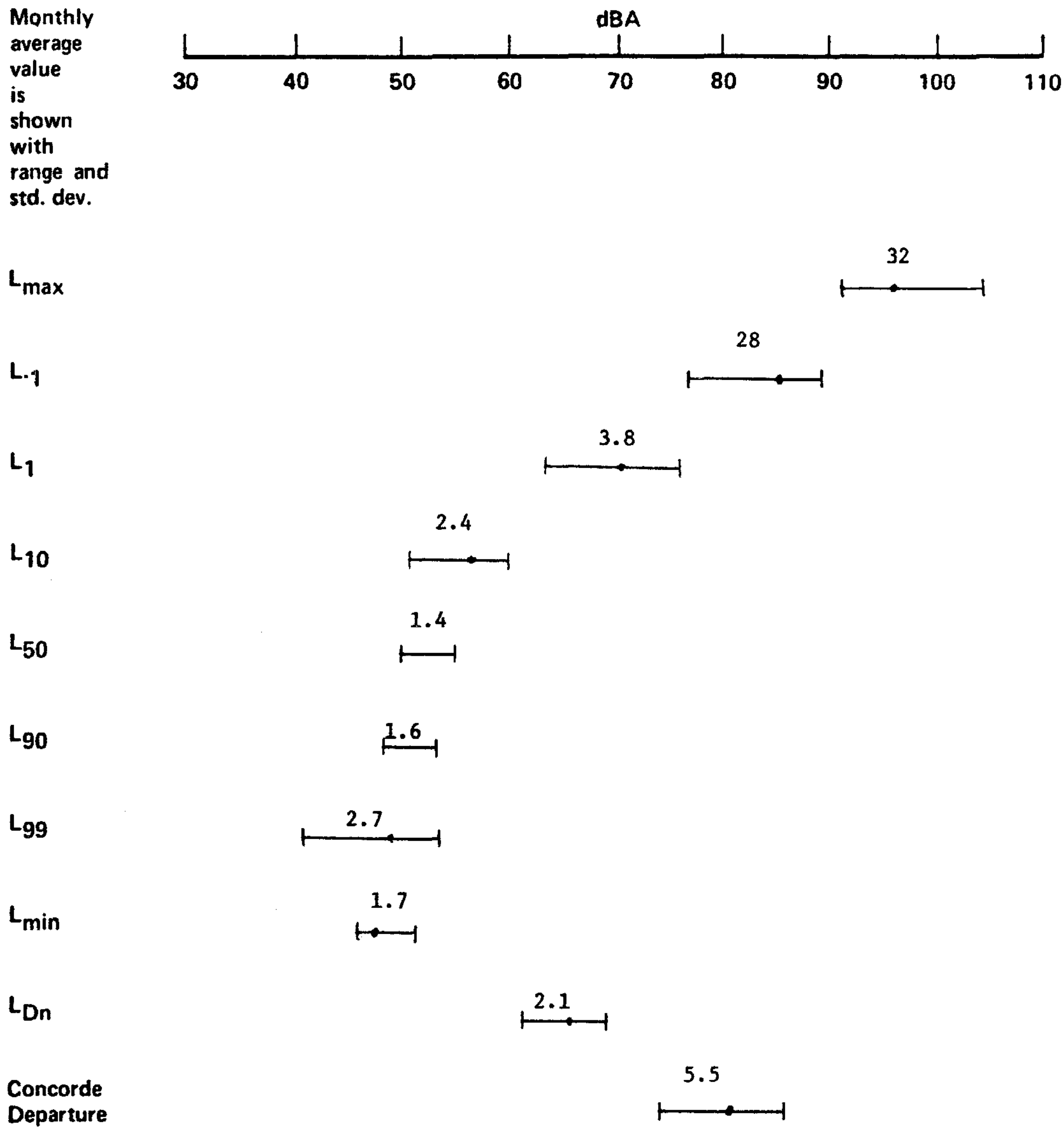
2.5 CUMULATIVE TIME METRICS

2.5.1 24-Hour Time Above (TA), Expressed in Minutes. The 24-hour TA metric provides the duration in minutes for which aircraft related noise exceeded specified A-weighted sound levels. An example of a TA contour is shown in Figure 2.4. TA is one of the criteria specified in HUD Circular 1390.2 for determining eligibility for HUD construction funding (Ref. 3). TA's inverse, the L-value (e.g., L_{10}) is used (along with Leq) as the FHWA criteria for planning and design of Federal-aid highways Further, TA can be related directly to some "threshold activated" physiological or annoyance effects.

Figure 2.4

CONCORDE AND COMMUNITY LEVELS
STATISTICAL CONCEPT

MEASUREMENT LOCATION Arcola MONTH August



2.5.2 Day, Evening, Night (TA), Expressed in Minutes. The Day-TA metrics provide the duration in minutes for which aircraft related noise exceeded specified A-weighted sound levels during the period 7:00 a.m. to 7:00 p.m. The Evening TA metrics provide the duration in minutes for which aircraft related noise exceeded A-weighted sound levels during the period from 7:00 p.m. to 10:00 p.m. The Night TA metrics provide the duration in minutes for which aircraft related noise exceeded A-weighted sound levels during the period from 10:00 p.m. to 7:00 a.m.

2.6 DNL: THE STANDARD CUMULATIVE AVERAGE ENERGY METRIC

The FAA selected DNL as the cumulative average energy metric to be used in airport noise exposure studies. While a dialogue continues within research circles concerning weighting functions, the DNL has emerged as a sound and workable tool for use in land use planning and in relating aircraft noise to community reaction. The substantiating basis for the DNL can perhaps best be summarized as follows:

1) Pragmatically speaking, it works. Engineers and planners have acquired over 30 years working experience with a nominal 10 dB nighttime weighting function. This experience has been successful, contributing to wise zoning and planning decisions.

2) The nominal 10 dB decrease in ambient noise levels in many residential areas at nighttime provides a sensible basis for the weighting factor.

2.7 EVALUATION OF THE DNL METRIC FOR HELIPORT/HELISTOP NOISE IMPACT ASSESSMENT

With the increase in helicopter operations in and around urban areas, the FAA has sought to include helicopters in the environmental planning process. In this context, the question has arisen of whether or not the average cumulative energy metric DNL, which is used in the analysis of noise from conventional aircraft, would also be appropriate for analysis of helicopter noise. Most commercial airports have hundreds of operations a day, while heliports generally handle fewer than thirty. The metric used to analyze helicopter noise would have to be sensitive enough to accurately reflect community response at comparatively low levels of noise exposure (lower cumulative levels because of fewer flights).

In order to investigate whether or not DNL would be appropriate, the FAA supported a field test program to examine subjective response to helicopter operations. The actual study was conducted by NASA Langley Research Center and is summarized below (Ref. 4). In the study, researchers examined the reaction of community residents to low numbers of helicopter noise events. Residents of the selected community were interviewed twenty-three times about their general noise annoyance on particular days. Unknown to them, on those days helicopter flights had been controlled for the test purpose; the number of flights per day varied from 0 to 32. The exposure varied randomly through each of the

TABLE 2.1

METRIC	DESCRIPTION
One-third Octave Sound Presure Levels	The one-third octave band sound pressure levels are the starting point for all other metrics; useful in implementation of soundproofing.
PNL	Sound Level from which EPNL was developed
PNLT	Sound Level from which EPNL was developed
EPNL	A maximum sound level single event cumulative metric developed from the PNLT and PNL sound level. Used in FAR Part 36, Appendix C Certification, Advisory Circular 36-1B and Advisory Circular 36-2A.
NEF	An Airport cumulative metric no longer in use in the U.S. but often used in older studies; replaced by DNL (the FAA approved metric)
ALm	A sound level metric applied as follows: Airport Noise Analysis 1050.1C Analysis FAR Part 36 Appendix F Certification Specific eligibility for Soundproofing Implementation of Soundproofing Noise Monitoring Systems FAA Advisory Circular
TA	An airport cumulative metric derived from dB(A) and applied as follows: Airport Noise Analysis 1050.1D Analysis Noise Monitoring Systems
Lx	An airport Cumulative metric derived from dB(A) and applied as follows: Airport Noise Analysis 1050.1D Analysis Noise Monitoring Systems
SEL	A maximum sound level, single event cumulative metric derived from dB(A) and applied as follows: Airport Noise Analysis Noise Monitoring Systems
Leq	An airport cumulative metric derived from SEL; no application in aviation
DNL	An airport cumulative metric derived from SEL with the following applications: Airport Noise Contours Airport Noise Analysis FAR 1050.1D Analysis General Eligibility for Soundproofing Noise Monitoring Systems
CNEL	An airport cumulative metric derived from SEL used only by the state of California; CNEL will be phased out in the next few years.

twenty-three (non-consecutive) test days. It was found that the (1) maximum noise level, (2) the number of noise events, and (3) the duration of the events (reflected in cumulative energy noise indices) correlated well with community annoyance response.

The results of this program provided strong evidence that the same analytical tool, the DNL metric, employed at airports with large numbers of operations can be used with confidence in assessing the environmental impact (human response) of comparatively small numbers of helicopter operations.

2.8 SUMMARY OF NOISE METRIC POLICY

The FAA noise metric usage policy is presented in Figure 2.2. The figure shows the genealogy of the various types of metrics starting from the one-third octave sound pressure level data. The dBA, PNL and PNLT are identified as pertinent sound levels. SEL and EPNL are identified as significant single event cumulative energy (or dose) metrics while Leq, DNL, CNEL and NEF are recognized as airport cumulative exposure metrics along with TA and Lx. The policy outline reflects the stated position supporting ALm as the single event maximum sound level metric, SEL as the single event dose metric, and DNL as the airport cumulative noise metric. EPNL is retained as a certification noise metric. The SEL, TA and Lx metrics are all descendents of the A-weighted sound level and their use is consistent with stated policy.

2.9 NOISE METRICS APPLICATIONS

Each of the noise metrics discussed above has a specific set of applications for which it is most appropriate, as detailed in Table 2.1.

REFERENCES

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Section 3.0 ANNOYANCE AND AIRCRAFT NOISE

SUMMARY

INTRODUCTION

The typical response of humans to aircraft noise is annoyance. Annoyance response is remarkably complex and, considered on an individual basis, displays wide variability for any given noise level. Fortunately, when one considers average annoyance reactions within a community, one can develop aggregate annoyance response/noise level relationships. This section introduces the reader to the factors which influence individual annoyance response. Also included are examples of research findings which display aggregate community annoyance responses.

AVIATION APPLICATION/ISSUES

Annoyance is the number one consequence of excessive aircraft noise. The continued growth of the aviation industry and expansion of airport capacity is in part dependent on how well noise compatibility planning is handled.

GUDIANCE/POLICY/EXPERIENCE

It is the charter of the FAA to assure safety and promote civil aviation. Promoting civil aviation means, among other things, addressing the problems of aircraft noise annoyance. The FAA, working with other members of the community, has taken a series of steps designed to bring about greater compatibility between aircraft noise levels and affected individuals. Actions include:

1. Source noise certification regulations
2. FAR Part 150 Airport Noise Exposure / Land Use Compatibility Planning Process
3. Research into the mechanism of annoyance to aircraft noise
4. Advisory publications designed to mitigate aircraft noise impact on noise sensitive areas.

3.1 INTRODUCTION

Responses of annoyance are the most common reaction to aircraft noise. This section discusses, first, how people perceive noisiness, and second, some of the emotional and physical variables which may influence an individual's response to a sound. A review of pertinent research concludes this section.

3.2 PERCEPTION OF NOISE

How people perceive loudness or noisiness of any given sound depends on several measurable physical characteristics of the sound. These factors are:

A. Intensity. In general, a ten decibel increase in intensity may be considered a doubling of the perceived loudness or noisiness of a sound; however, other psychoacoustic evidence suggests that a somewhat greater than 10 decibel increase in peak level of airplane flyover noise is required to produce a perceived doubling of loudness.

B. Frequency Content. Sounds with concentration of energy between 2,000 Hz and 8,000 Hz are perceived to be more noisy than sounds of equal sound pressure level outside this range.

C. Changes in Sound Pressure Level. Sounds that are increasing in level are judged to be somewhat louder than those decreasing in level (consider police and emergency vehicle sirens).

D. Rate of Increase of Sound Pressure Level. Impulsive sound (ones reaching a high peak very abruptly, such as pile drivers or jack hammers) are usually perceived to be very noisy.

3.3 VARIABLES AFFECTING RESPONSE

Individual human response to noise is subject to considerable natural variability. Over the past 35 years, researchers have identified many of the factors which contribute to the variation in human reaction to noise.

3.3.1 Emotional Variables. Knowledge of the existence of these individual variables helps to understand why it is not possible to state simply that a given noise level from a given noise source will elicit a particular community reaction or have a certain environmental impact. In order to do that, it would be necessary to know how much each variable contributes to human reaction to noise. Research in psychoacoustics has revealed that an individual's attitudes, beliefs and values may greatly influence the degree to which a person considers a given sound annoying. The aggregate emotional response of an individual to noise has been found to depend on:

A. Feelings about the Necessity or Preventability of the Noise. If people feel that their needs and concerns are being ignored, they are more likely to feel hostile towards the noise. This feeling of being

alienated or of being ignored and abused is the root of many human annoyance reactions. If people feel that those creating the noise care about their welfare and are doing what they can to mitigate the noise, they are usually more tolerant of the noise and are willing and able to accommodate higher noise levels.

B. Judgment of the Importance and Value of the Activity which is Producing the Noise. If the noise is produced by an activity which people feel is vital, they are not as bothered by it as they would be if the noise-producing activity was considered superfluous.

C. Activity at the Time an Individual Hears a Noise. An individual's sleep, rest and relaxation have been found to be more easily disrupted by noise than his communication and entertainment activities.

D. Attitudes about Environment. The existence of undesirable features in a person's residential environment will influence the way in which he reacts to a particular intrusion.

E. General Sensitivity to Noise. People vary in their ability to hear sound, their physiological predisposition to noise and their emotional experience of annoyance to a given noise.

F. Belief about the Effect of Noise on Health. The extent to which people believe that exposure to aircraft noise will damage their health affects their response to aviation noise.

G. Feeling of Fear Associated with the Noise. For instance, the extent to which an individual fears physical harm from the source of the noise will affect his attitude toward the noise.

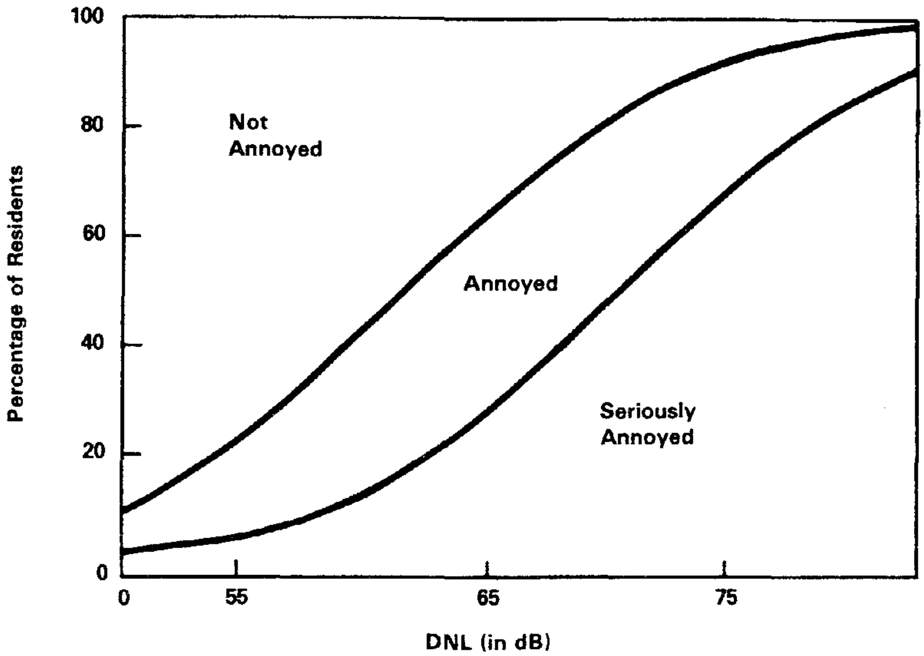
3.3.2 Physical Variables. A number of physical factors have also been identified by researchers as influencing the way in which an individual may react to a noise. These factors include:

A. Type of Neighborhood. Instances of annoyance, disturbance and complaint associated with a particular noise exposure will be greatest in rural areas, followed by suburban and urban residential areas, and then commercial and industrial areas in decreasing order. The type of neighborhood may actually be associated with one's expectations regarding noise there. People expect rural neighborhoods to be quieter than cities. Consequently, a given noise exposure may produce greater negative reaction in a rural area.

B. Time of Day. A number of studies has suggested that noise intrusions are considered more annoying in the early evening and at night than during the day.

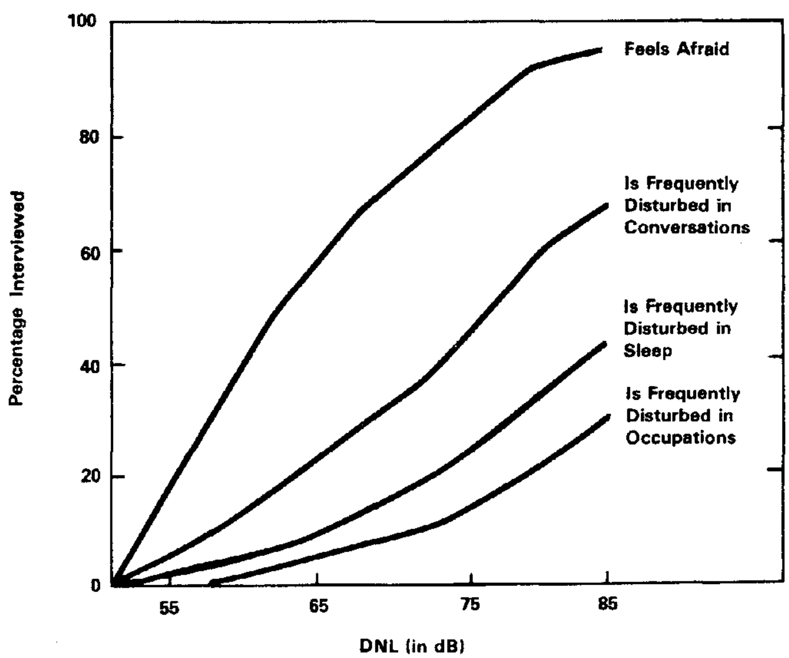
C. Season. Noise is considered more disturbing in the summer than in the winter. This is understandable since, during the summer, windows are likely to be open and recreational activities take place out of doors.

Figure 3.1



Annoyance Caused by Aircraft Noise in Residential Communities Near Major Airports
(Ref. 1)

Figure 3.2



Community Response to Aircraft Noise-Netherlands Survey
(Ref. 2)

D. Predictability of the Noise. Research has revealed that individuals exposed to unpredictable noise have a lower noise tolerance than those exposed to predictable noise.

E. Control over the Noise Source. A person who has no control over the noise source will be more annoyed than one who is able to exercise some control.

F. Length of Time an Individual Is Exposed to a Noise. There is little evidence supporting the argument that annoyance resulting from noise will decrease with continued exposure; rather, under some circumstances, annoyance may increase the longer one is exposed.

3.4 REVIEW OF RECENT RESEARCH

The inherent variability in the way individuals react to noise makes it impossible to predict accurately how any one individual will respond to a given noise. However, when one considers the community as a whole, trends emerge which relate noise to annoyance. In this way it is possible to correlate DNL with community annoyance. This measure will represent the average annoyance response for the community.

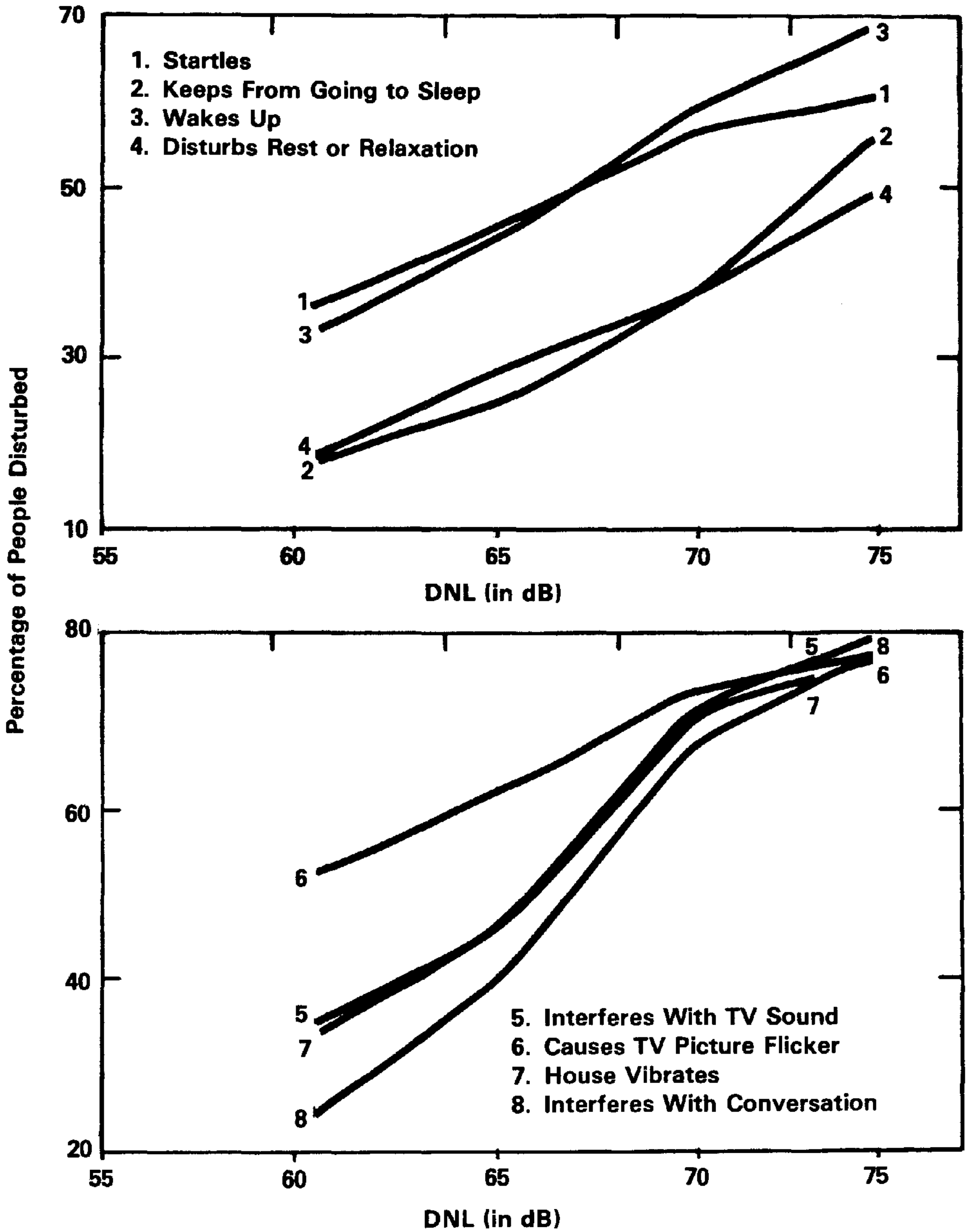
In any community there will be a given percentage of the population highly annoyed, a given percentage mildly annoyed and others who will not be annoyed at all. The changing percentage of population within a given response category is the best indicator of noise annoyance impact.

Various studies have focused on the relationship between annoyance and noise exposure. One researcher, in analyzing the results of numerous social surveys conducted at major airports in several countries, derived the curves shown in Figure 3.1 relating degree of annoyance and percent of population affected with noise exposure expressed in DNL (Ref. 1). A survey conducted in the Netherlands investigated the relationship between the DNL and the percentage of those questioned who suffered feelings of fear, disruption of conversation, sleep or work activities (Ref. 2). Figure 3.2 reflects these findings.

In 1960 the "Wilson Committee" was appointed by the British Government to investigate the nature, sources and effects of the problem of noise (Ref. 3). The final report, published in 1963, included results of extensive examination of community response to aircraft operations at London Heathrow Airport. Figure 3.3, adapted from that report, shows the relationship between DNL and the percent of the population disturbed in various activities including sleep, relaxation, conversation and television viewing. Disturbance response categories for startle and house vibration are also included.

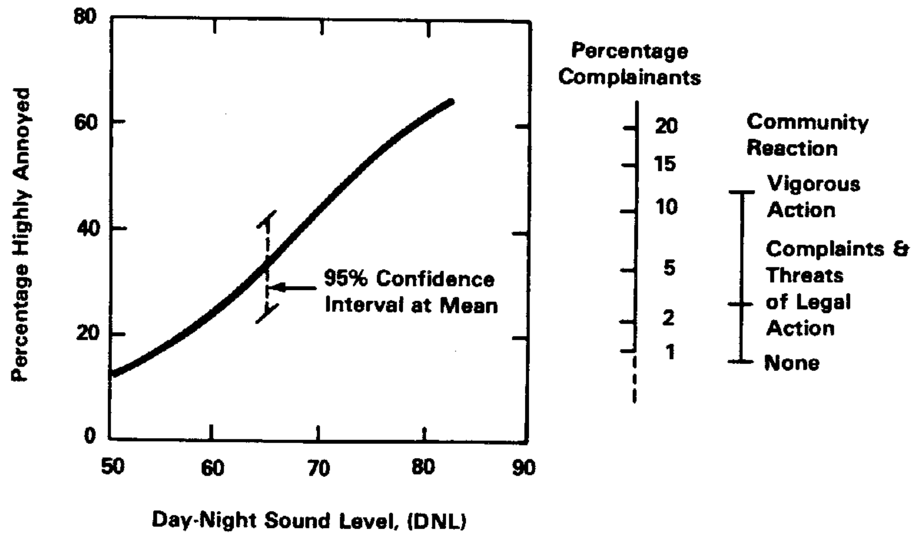
The EPA publication "Information on Levels of Environmental Noise Requisite to Protect Health and Welfare with an Adequate Margin of Safety" provides a relationship between the percent of population highly annoyed and the Day-Night Sound Level (DNL) (Ref. 4). These data are shown in Figure 3.4, along with the relationship between annoyance, complaints and community reaction.

Figure 3.3



Community Response to Aircraft Operations-
London Heathrow Airport (Ref. 3)

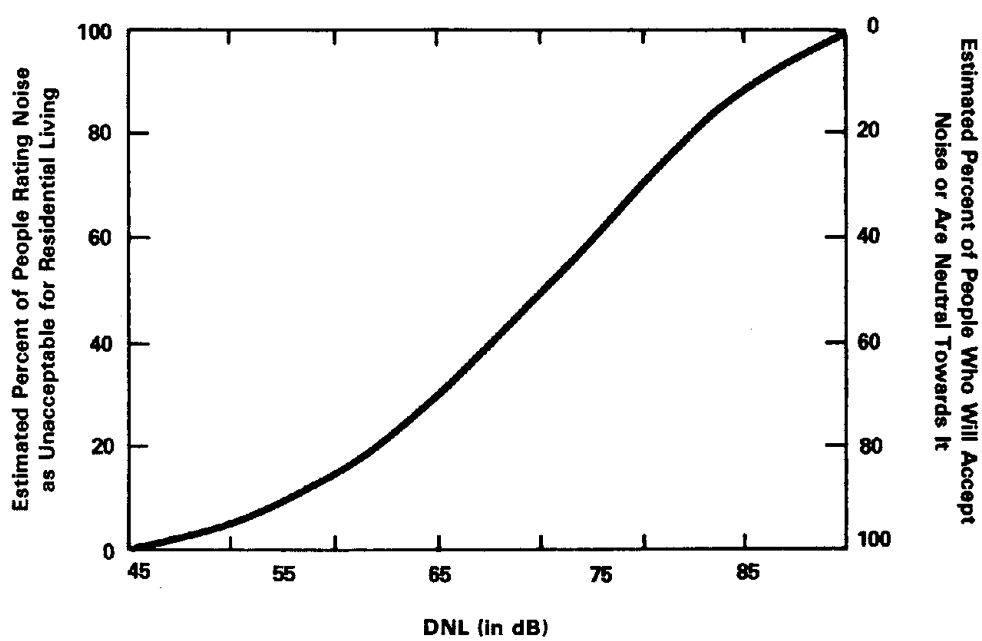
Figure 3.4



Comparison of Various Measures of Individual Annoyance and Community Reaction

An investigation of attitudes to be expected from non-fear provoking noise in residential areas led Kryter to develop the curve shown in Figure 3.5 (Ref. 2). The figure also shows percent of population rating the noise associated with a given DNL level as acceptable or unacceptable.

Figure 3.5



Attitudes Toward Aircraft Noise in the Residential Community

3.5 CONCLUSION

This section has presented a series of relationships useful in interpreting average community response to aircraft noise. These data should provide the reader with the necessary perspective to begin understanding the human reactions to various levels of cumulative noise exposure (DNL).

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Section 4.0 DIFFERENT SOURCES/DIFFERENT HUMAN RESPONSE?

SUMMARY

INTRODUCTION

This section addresses a fundamental question raised from time to time in connection with aviation noise related law suits, environmental impact assessments, and research studies. It has been suggested that aircraft noise levels should be treated as more annoying to people than the same sound levels generated by other sources. A review of the research shows that very strong positions have been taken both supporting and opposing the theory. The most recent papers appearing in the scientific journals concede that a differential in response may exist but it can not be shown to be statistically significant.

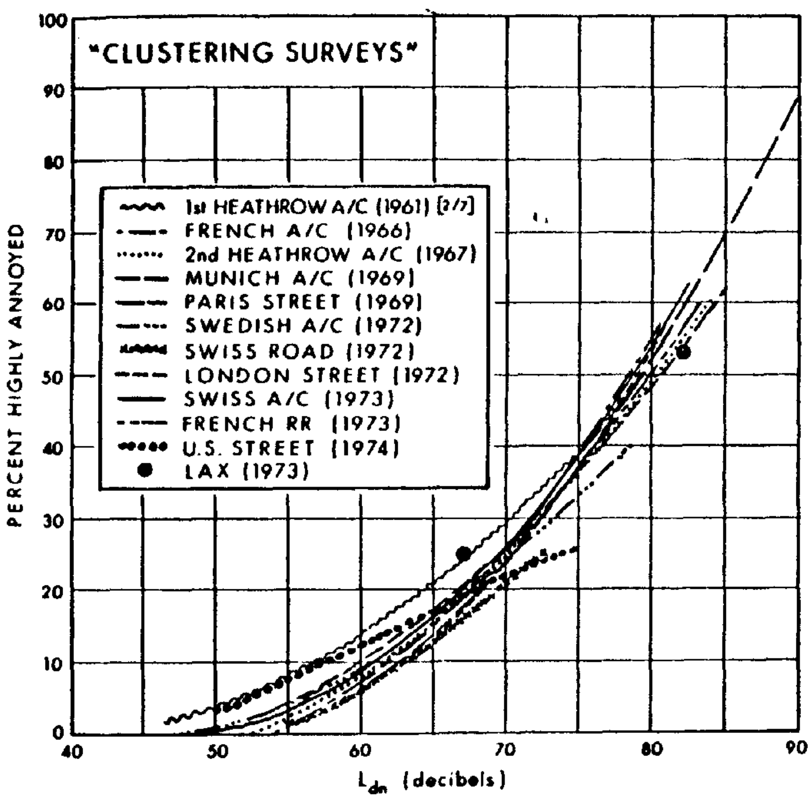
AVIATION APPLICATIONS/ISSUES

Should aircraft noise be considered as comparable to noise from other sources in the land use planning and environmental assessment process?

GUIDANCE/POLICY/EXPERIENCE

In the general application of noise exposure/land use criteria, aircraft noise should be considered in the same manner as noise from other sources.

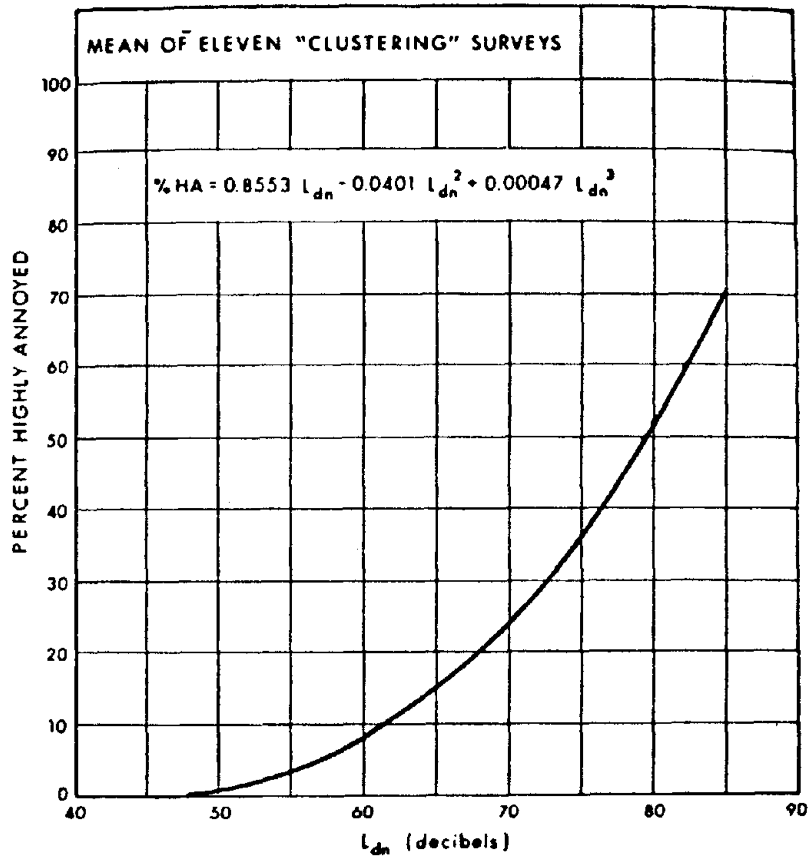
Figure 4.1



Summary of annoyance data from 11 surveys that show close agreement and two points from a (BBN, unpublished) study of aircraft noise annoyance at Los Angeles International Airport (LAX).

(Ref. 1)

Figure 4.2



Synthesis of all the clustering survey results. The mean of the "clustering surveys" data, shown here, is proposed as the best currently available estimate of public annoyance due to transportation noise of all kinds. It may also be applicable to community noise of other kinds.

(Ref. 1)

4.1 INTRODCUTION

In assessing comparative contributions to the overall annoyance with noise experienced by an individual, the issue of whether or not aircraft noise should be compared with other ambient sources continues to arise. The issue is an important one in terms of establishing acceptable cumulative noise exposure levels for various land use categories. This section reviews current literature on this controversial topic.

4.2 SCHULTZ - KRYTER DEBATE

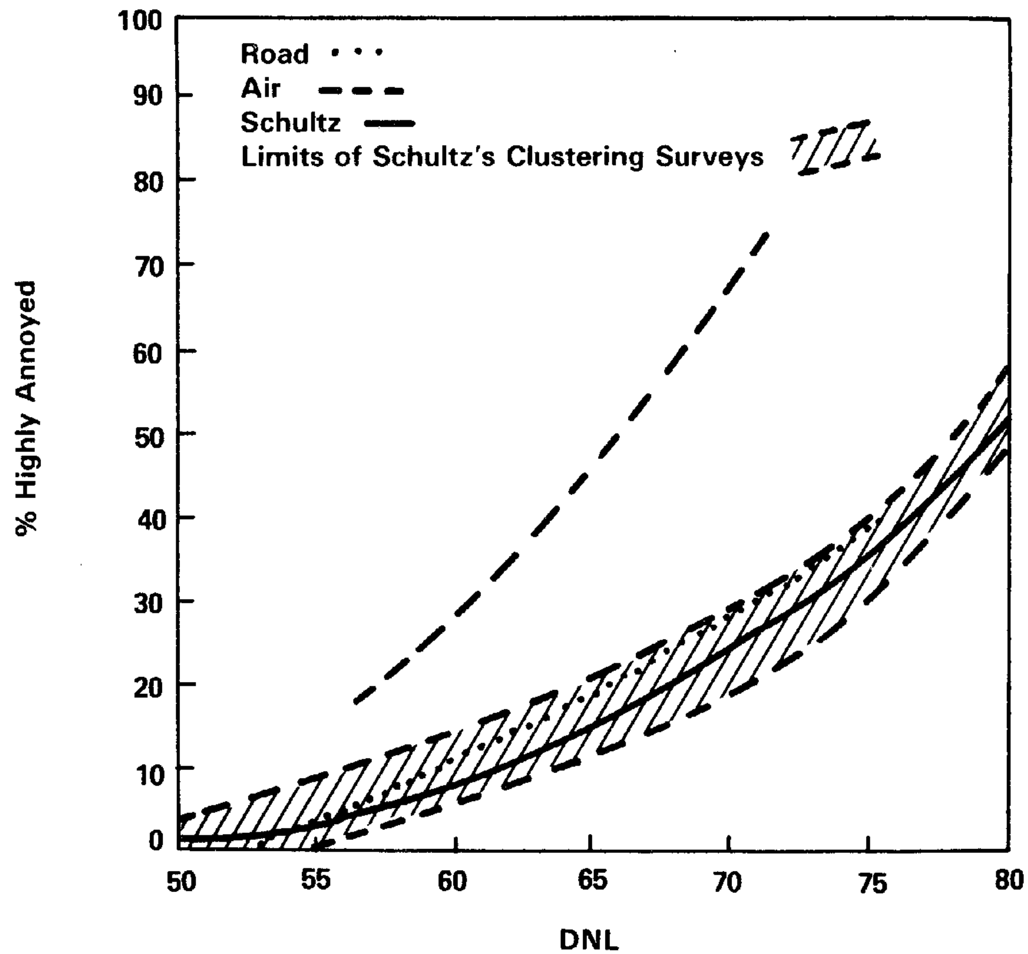
In 1978, Theodore Schultz published an article synthesizing results from many social surveys on noise annoyance. In this article he stated that it is possible to compare aircraft and other transportation noise equally, and to find and use a median annoyance response curve for them (Ref. 1). In order to compare these various results, Schultz developed some theories and formulas with which he determined which parts of each survey would fall into the "highly annoyed" category. He also figured the DNL indices for these surveys and plotted them (see Figure 4.1). Figure 4.2 reproduces Schultz's "synthesis curve", the median of all the noise surveys.

Karl Kryter, responding in 1982 to Schultz's article, proposed a different relationship (Ref. 2). While Schultz only considered people who were highly annoyed, Kryter stated that <u>all</u> individuals annoyed should be considered in these comparisons. He also developed the DNL values for each study differently, so his values varied significantly from those of Schultz. Kryter also attempted to explain the poor correlation between noise exposure and annoyance in individuals by explaining that, while it is assumed that noise exposure is homogeneous over a given neighborhood, an individual's particular dose of noise may vary quite a bit.

Kryter cited Grandjean (Ref. 3), another researcher who found that aircraft noise is significantly more disturbing than other noise. This Swiss study stated that it took a DNL of 10 to 15 dB higher for road traffic noise to cause equal disturbance as aircraft. Kryter then explained his concept of the "effective exposure" of noise, rather than the exposure that may actually be measured or reported. Kryter suggests that because aircraft noise falls over a structure, like a house, equally, as opposed to passing through interfering structures as traffic noise would do (as in moving from the front to the back of a house), the "effective noise exposure" would be greater than that of traffic noise. Kryter further submits that, for a house facing the road, residents in the back yard would experience diminished noise from those in the front yard; however, they would all experience equal aircraft noise. Likewise, each room in the house would experience nearly identical exposure to aircraft noise (Kryter evidently only considered single - level homes). Kryter found a front to back of house difference of 17 - 21 dB for road traffic and only 0.3 dB for aircraft noise. Thus, Kryter suggests that aircraft noise must be considered separately from other transportation noise.

Figure 4.3

Limits of Schultz's Clustering Surveys



Comparison of Air, Road, and Schultz Synthesis Curves.

(Ref. 4)

Fortunately, other researchers have examined this topic; their views aid in going past the Schultz - Kryter stalemate.

4.3 HALL'S RESEARCH AND ANALYSIS

In 1981, Fred Hall reported on data which had been collected around the Toronto International Airport (Ref. 4). For the first time, data had been collected on both aircraft and ground traffic noise using comparable questions and measured in DNL, thus alleviating the need for juggling survey results to fit DNL, as Kryter and Schultz had to do. His conclusion was that there is indeed a difference between community responses to aircraft noise and to road traffic noise when each is measured by DNL. Figure 4.3 relates his findings in relation to Schultz's synthesis curve; Hall notes that the aircraft noise curve falls out of proportion with the others.

> For the same noise level, a greater percentage of people are highly annoyaed by aircraft noise. The difference in annoyance at the two sources is not constant but instead increases as Ldn increases. The difference in annoyance is equivalent to about 8 dB at Ldn of 55 dB increasing to about 15 dB at Ldn of 65 dB.

Hall puts forth some possible explanations of these variations. For example, the sporadic time pattern of aircraft noise differs from the relatively steady noise of road traffic. Thus, maximum levels for aircraft noise will be higher. Hall suggests that until further work can be done, "Ldn is a reasonable predictor of response to any particular source, but there are differences in response to different sources at the same Ldn value." Hall concluded that the best thing to do, then, would be to use separate functions to estimate community response to different types of noise.

In a later article (published in December 1984), Hall further addressed this complex issue, substantially altering his previous conclusions (Ref. 5). He references about a dozen papers published on this subject over the last five years. Hall suggests that intrinsic differences may exist but can not be substantiated as statistically significant. His summary statements are excerpted below:

> The overwhelming conclusion from the recent literature is that different studies have led to different dose-response functions. This has happened for different sources, for different types of one source, and even for different studies at the same location (e.g., Heathrow). There is some consistency of evidence that the annoyance response function for rail noise is lower than for road or aircraft noise. (Rohrmann reaches the same conclusion in his review of relevant literature.) There is also some indication, but with fewer studies pertaining to it, that the aircraft annoyance function is higher than that for road traffic. However, the evidence is not strong enough to totally reject the hypothesis that all of this is just random variation about the "average" response.

Lastly, an "average" dose-response function appears to be useful in two contexts, both defined by limited information. The first is the general situation we are now in, in which it appears that different dose-response functions are warranted, but we cannot specify precisely the conditions calling for each. Although we suspect the variance in results is not simply random, it almost behaves as if it were, in which case the "average" function represents our best current estimate. The second situation will arise in the future, when we may be able to specify clearly the conditions calling for separate dose-response functions. Even then, there will undoubtedly be conditions which we cannot categorize, in which case again the "average" response function would be the best one to use.

4.4 CONCLUSION

For matters of policy, there does not exist at this time enough evidence to support the requirement of a differential for comparing aircraft noise with noise from other sources. All transportation and other ambient noise sources therefore can be treated as comparable when considering aviation noise impact.

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Section 5.0 HEARING and HEARING LOSS

SUMMARY

INTRODUCTION

This section describes the human hearing mechanism and the processes of temporary and permanent hearing loss. The results of research are presented and the potential for hearing loss in aviation noise environments evaluated. OSHA hearing protection criteria are also addressed.

AVIATION APPLICATIONS/ISSUES

1. Permanent or temporary hearing loss.
    a. cockpit crew
    b. flight attendants
    c. passengers
    d. persons in communities exposed to aircraft overflight

2. Temporary hearing loss for the same categories of individuals listed above.

GUIDANCE/POLICY/EXPERIENCE

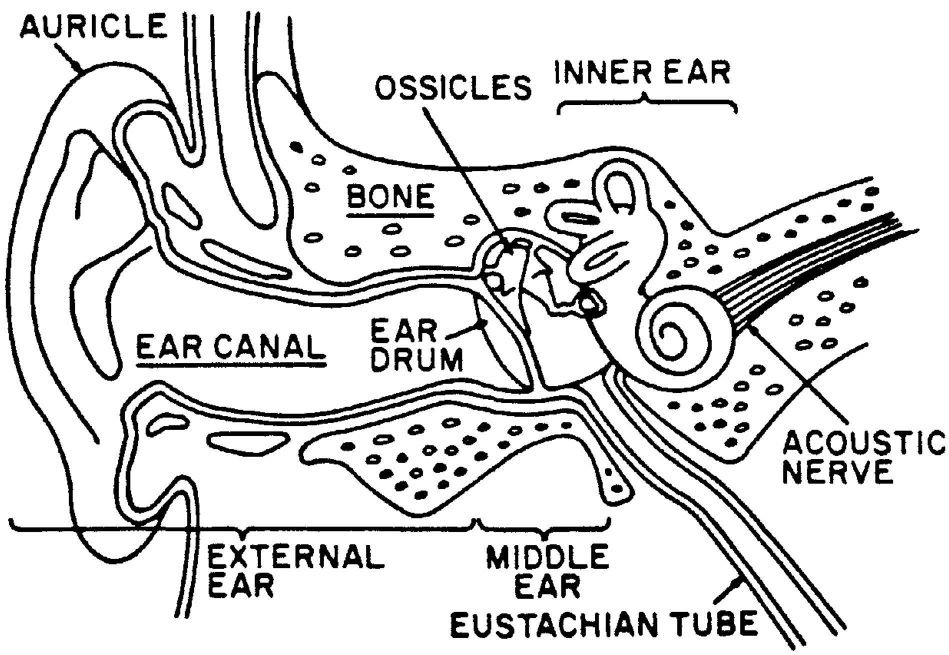
1. FAA-sponsored research results show that permanent hearing loss is not a likelihood for a) cockpit crew, b) flight attendants, c) passengers, d) people exposed to overflights.

2. Temporary hearing loss (up to several hours recovery time) may occur in commercial aviation noise environments. These temporary sensitivity shifts are not unusual in the industrial setting and do not exceed OSHA criteria.

3. Persons on the ground exposed to aircraft overflights would typically not experience any temporary hearing loss due to the relatively short duration of the noise exposure.

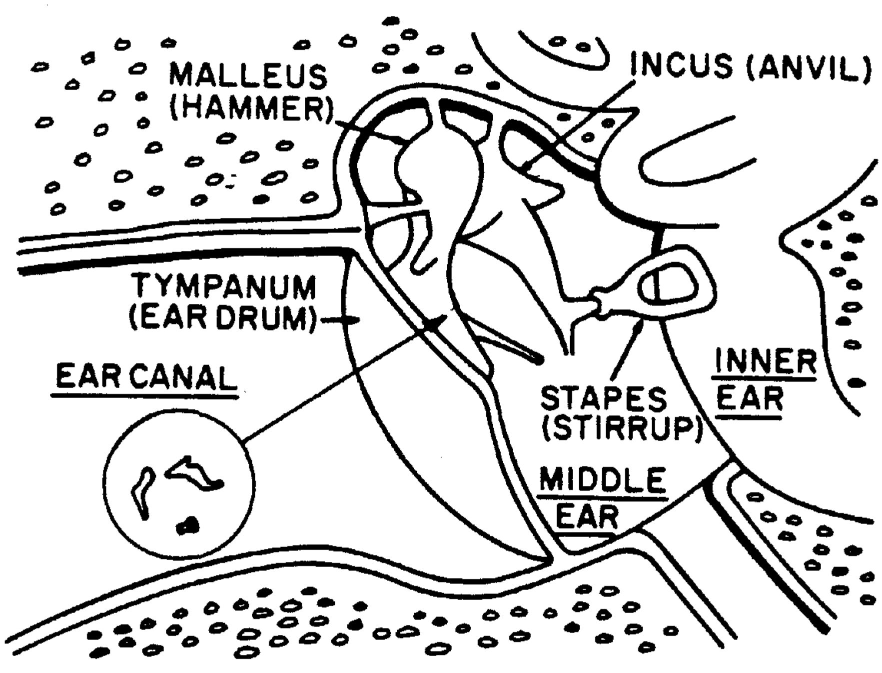
4. A greater degree of temporary and possible permanent hearing loss can result in the case of long exposure times in certain small propeller driven aircraft.

Figure 5.1



Schematic cross-section of the ear. (Ref. 1)

Figure 5.2



Schematic cross-section of the middle ear. Inset shows actual size of ossicles. (Ref. 1)

5.1 INTRODUCTION

It is well established that continuous exposure to high levels of noise will damage human hearing. This section begins with a description of the hearing mechanism, followed by discussion of the effects of noise on hearing, along with criteria for hearing protection established by the military, the FAA and OSHA. Finally, methods for protection of hearing are discussed.

5.2 THE HEARING MECHANISM

The ear is an external sense organ designed to receive and respond to air-borne acoustic vibratory energy. Figure 5.1 provides a schematic cross section showing the outer, middle and inner ears. The external ear, made up of the auricle (the outer portion of the ear) and the ear canal, transmits sounds to the eardrum. The eardrum, which is a very thin membrane that moves very slightly in response to sound pressure levels, separates the ear canal from the middle ear.

The middle ear is an air-filled cavity that lies between the outer and the inner ear (see Figure 5.2). It acts as a mechanical amplifier of the air pressure vibrations from the eardrum and through a series of bones called the ossicles. Air pressure vibrations displace the eardrum, which then displaces the ossicles, a link of three small bones which reach across the middle ear cavity to the delicate, fluid-filled membranes of the inner ear. The ossicles, made up of the malleus, the incus and the stapes, rest against the opening to the inner ear, the oval window; when the ossicles are displaced, the stapes pushes through the oval window, displacing the fluid in the inner ear.

The middle ear allows pressure variations in air to be transmitted into pressure variations in fluid with very little loss of energy. This is due in part to the relative size difference between the eardrum and the oval window (the eardrum has an area 20 times that of the oval window). Thus, the force exerted on the inner ear fluid by the stapes is about the same as the force exerted on the eardrum by the sound wave in the air, but the resulting pressure is much greater -- as much as a ratio of 22 to 1.

The inner ear contains the final section of the organ of hearing, the cochlea, which rests, coiled like a snail, against the oval window. As the stapes forces the oval window in and out, the fluid of the cochlea is also moved. About thirty thousand hair cells (called cilia) located in the cochlea react to the fluid motions, translating them to nerve impulses (and converting them from mechanical to electrical energy), then transmitting the impulses to the brain for interpretation.

Acoustical energy may also be conducted to the inner ear through vibration of bone. An example is the sound of one's own voice. Bone-conducted vibrations set up similar patterns of vibration of the cochlear partition as does air-conducted sound.

5.3 AUDITORY RANGE

The ear is capable of hearing a frequency range of about nine octaves and a dynamic range of more than 120 dB. The least pressure needed to make a tone audible (the "threshold pressure") depends on the frequency of the tone. The lower frequency limit of hearing is a vague boundary because hearing merges into the sensation of vibration; the upper intensity limit of hearing is sometimes taken as the threshold of discomfort, which is a sound pressure level of about 120 dB (independent of frequency). At 120 dB, there may be a sensation of tickling in the middle ear. However, the threshold of pain appears to be 140 dB, with sound continuing to sound louder, with increasing pressure, until auditory fatigue or acoustical injury is reached.

5.4 EFFECTS OF NOISE ON HEARING

The sensitivity of the ear is not constant with frequency. Both the threshold at which a tone can be heard and how loud it sounds may vary considerably as a result of previous exposure to sounds of the same or of different frequencies. Even sounds below 90 - 100 dB may bring about short-term changes in hearing; these changes, however, are simply adjustments of the balance within the ear, much like the process of light or dark adaptation in the eye.

Other sounds may produce longer-lasting changes in the threshold of hearing; the chances of these changes occurring increase with continuing exposure to loud noise. The three principle effects are:

1. temporary reduction in hearing acuity, which is referred to as temporary threshold shift (TTS)

2. permanent hearing loss referred to as a "Noise Induced Permanent Threshold Shift" or NIPTS

3. ringing in the ears, or tinnitus

5.4.1 TTS. A temporary threshold shift is a common effect of noise on hearing in noisy industrial and entertainment situations. When an individual is tested for hearing acuity, an audiometer is used to establish the lowest levels of sound that person can perceive at different frequency bands. After exposure to high noise levels for a short time, or moderate noise levels over a long time, the minimum level that the person can perceive may shift to a higher level. Temporary shifts of 20 to 30 dB are usual in healthy ears in noisy situations with a typical eight-hour exposure. This shift is only temporary, however; a 100% recovery of the pre-noise exposure hearing acuity usually occurs within several hours. TTS is also known as "auditory fatigue."

5.4.2 NIPTS. NIPTS, or noise induced permanent threshold shift, is just that -- the minimum level at which a person can perceive sound permanently shifts to a higher level. In layman's terms, a person incurs a permanent hearing loss of some degree. It is hypothesized that years of incurring a daily TTS may eventually lead to an NIPTS of similiar magnitude.

5.5 DAMAGE RISK CRITERIA

In order to determine at what levels and under what conditions an NIPTS may occur, damage risk criteria (DRC), or noise limits which should not be exceeded for specified time periods, were developed. DRC are generally set out in a table or curve such as that shown in Figure 5.3 specifying the allowable relationship between noise level and time of exposure. The guiding hypothesis in most of the criteria is the maintenance of "equal energy" in acoustical dose, which is defined by the level and duration of the noise exposure. In each case, there is a level of risk (of incurring an NIPTS) associated with the specified criteria. It is also worth pointing out that damage risk criteria exist for several different classes of hearing protection: (1) no protection, (2) protected by ear plugs, and (3) protected by ear plugs and headphones. One also encounters damage risk criteria established for specific classes of "unusual" noises, such as impulsive noise (gun shots, punch presses), very loud sounds, and sounds dominated by narrow bands of acoustical energy (tones).

The basic damage risk criteria in use today were set forth by the Committee on Hearing Bioacoustics and Biomechanics (CHABA) in 1965, after comparison of studies related to the effects of noise on hearing. The committee concluded that a sound environment would be acceptable if people, after ten years of almost daily exposure to the environment, had permanent hearing loss of no more than 10 dB at 1000 Hz or below, 15 dB at 2000 Hz or 20 dB at 3000 Hz or above (Ref. 2). Thus, 50% of the people would have losses greater than these amounts, and 50% of the people would have less. The development of this criterion was based on three points:

1. Temporary Threshold Shift is a constant measure of the effects of a single day's exposure to noise.

2. All exposures that produce a given TTS_2 (TTS measured two minutes after cessation of noise exposure) will be equallv hazardous.

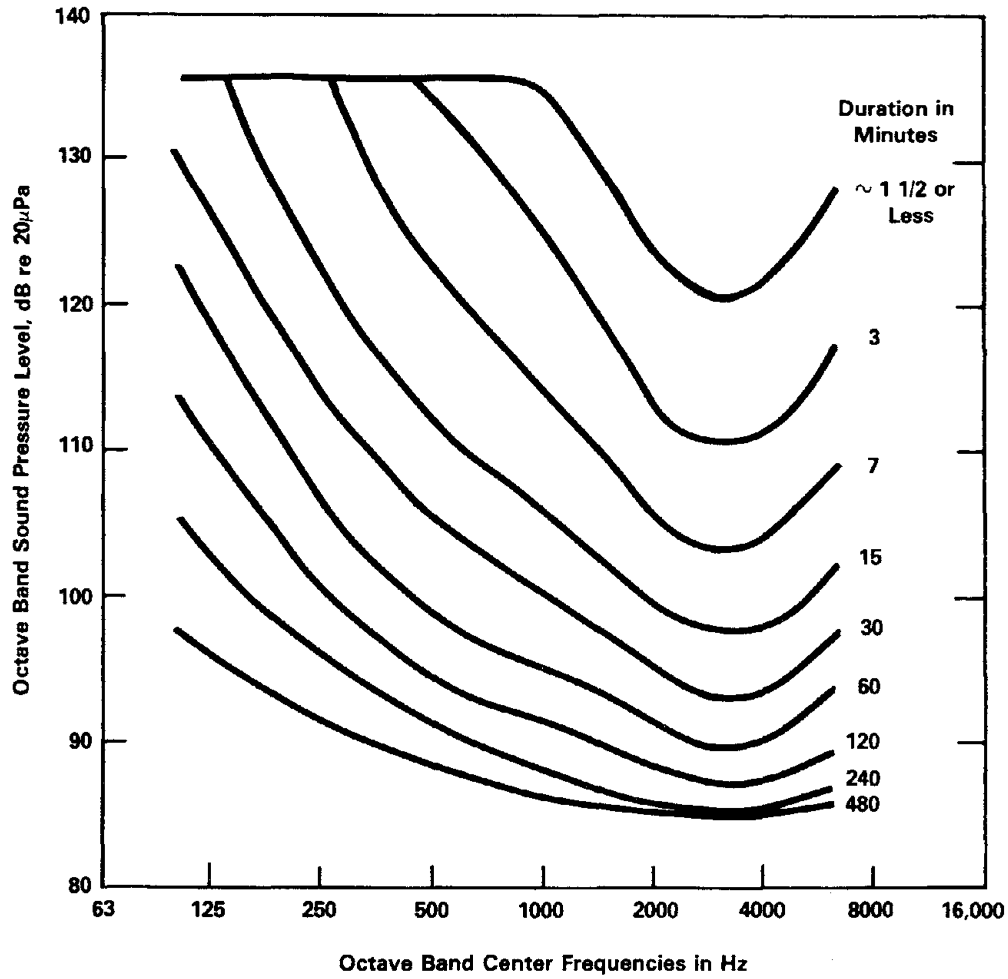
3. TTS_2 is approximately equal to the noise induced permanent threshold shift (NIPTS) after ten years.

Final limits for both broad-band noise are given as damage risk contours in Figure 5.3. These contours provide the maximum octave or one-third octave band levels for specified daily amounts of time, or conversely, the maximum amount of time an individual may be exposed at a specified sound level. Octave or one-third octave band data may be plotted on this figure to determine which particular one-third octave band controls or limits the noise exposure for a specific environment. Similar damage risk criteria for pure tones show the ear to be slightly more susceptible to damage from pure tones.

5.6 REVIEW OF STUDIES

A number of studies have been sponsored by the FAA to determine the effect of aircraft noise on hearing; the studies tend to focus either on

Figure 5.3



Damage Risk Contours for One Exposure Per Day to Octave Bands of Noise

the effects of noise on the crew and passengers inside an aircraft or on the effects of noise on individuals regularly exposed to aviation noise, such as people who reside around airports.

5.6.1 Interior Aircraft Noise. The FAA, in 1981, sponsored research to investigate the potential impact of interior aircraft noise on the crew and passengers of an aircraft (Ref. 2). The researchers concluded that the damage risk criteria of CHABA, discussed in the above paragraphs, is adequate for evaluation of potential hearing damage in both commercial and business jet-powered aircraft. Interior noise levels in both types of aircraft were tested, and none of the average levels in commercial or business jets exceeded the CHABA recommended levels. The study reports that less than 0.1% of the commercial and less than 1% of business jets are expected to exceed damage risk contours. Given these small percentages, the researchers drew the following conclusions:

For the crew of an aircraft, long exposures to noise of as many as sixteen hours flight time should not present any problems as long as the average daily exposure is four hours. (Four hours is currently the maximum average daily amount flown in commercial jet aircraft.)

For the passengers of an aircraft, the report concluded that "A passenger would need to fly at least 400,000 miles per year over 10 years to attain exposures equivalent to the exposure of airline crews." Since the crews are at so little risk themselves, an aircraft passenger is at virtually no risk of hearing damage from interior noise.

5.6.2 Community Hearing Loss. There are three studies known to have specifically addressed the question of community hearing loss around airports. The first, a 1972 study funded by FAA, compared the hearing acuity of two groups of residents, one group near Los Angeles International Airport and the second group from a relatively quiet area away from the airport. There was no significant difference in the hearing acuity of the two groups of people, and there was no correlation between hearing acuity and length of residency near the airport (Ref. 3).

The second, 1974 laboratory study conducted near Los Angeles International Airport, exposed two small groups of young men to recorded aircraft flyover noise consisting of forty events per hour, each event with a maximum level of 111 A-weighted decibels, over six hour periods (Ref. 4). The recorded flyovers were repeated every three minutes for one group, and every 90 seconds for the second group. The measured temporary threshold shifts for these subjects were negligible. Since temporary threshold shift is considered to represent a precursor to permanent hearing loss, the finding of no temporary threshold shift in this study is interpreted to indicate that there is no danger of permanent hearing loss from high levels of aircraft noise.

The third study repeated the above experiment in a Japanese laboratory, with the same conclusions found (Ref. 5).

5.7 CURRENT STANDARDS ON HEARING PROTECTION

The Occupational Safety and Health Administration (OSHA), the EPA and the U.S. Air Force have issued various statutes and regulations for hearing protection. In 1971, OSHA issued regulations for the protection of the hearing of industrial workers. (Ref. 7) These standards prescribe permissible noise exposure limits for an eight hour work day, which is a contiuous A-weighted sound level (AL) of 90 dB. The OSHA standards also incorporate the time-level tradeoff approach (5 dB increase in level per halving of time) as seen in Table 5.1. A maximum level of 140 dB is also specified for any impact or impulsive noise exposure. The EPA has recommended an average equivalent noise level of 70 A-weighted decibels for continuous 24-hour exposure as the maximum exposure level required to protect hearing with an adequate margin of safety (Ref. 7). The EPA criterion is extremely conservative, however, and is based on the probability of negligible hearing loss (less than five decibels in 100% of the exposed population) at the human ear's most damage-sensitive frequency (4,000 Hz) after a 40-year exposure.

The U.S. Air Force has conducted its own research into this area. Table 5.2 shows 1982 Air Force regulations on noise levels that are acceptable without hearing protection when the noise exposure occurs only once a day, for a given time of exposure (Ref. 8).

Table 5.1

Permissible Noise Exposure*

Duration Per day (Hours)	Sound Level (dBA)
8	90
6	92
4	95
3	97
2	100
1 1/2	102
1	105
1/2	110
1/4 or less	115

* When the daily exposure is composed of two or more periods of noise exposure of different levels, their combined effect should be considered, rather than the individual effect of each.

(Ref. 8)

Table 5.2

Limiting Values for Total Daily Exposure.

Duration of Total Daily Exposure Time (T)

As A Function of A-Weighted Sound Level (dB(A)) **

Sound Level, dB(A)	T * (Minutes)	Sound Level, dB(A)	T * (Minutes)
Above 115	Ear Protection Required		
115	2.2	96	60
114	2.7	95	71
113	3.2	94	85
112	3.8	93	101
111	4.5	92	120
110	5	91	143
109	6	90	170
108	8	89	202
107	9	88	240
106	11	87	285
105	13	86	339
104	15	85	404
103	18	84	480
102	21	83	571
101	25	82	679
100	30	81	807
99	36	80	960 ***
98	42	79	1142
97	50	78	1358
		Below 78	No limit

* Rounded to nearest 0.1 below 5 minutes and nearest integer above 5 minutes.

** The A-weighted sound level is used to assess hearing damage risk due to exposure to noise; for engineering noise control, other measures are required. These limiting values apply to the estimated noise level in the ear canal. The limiting duration of daily exposure at any noise level can be determined from the equation:

LDD (Hours) = 16 ÷ exp [(L−80) ÷ 4[= 2 exp [(96−L) ÷ 4], where.
L is the A-weighted sound level, measured with slow time constant.

*** If exposures longer than 16 hours at levels above 80dB(A) do occur, allow exposed personnel to recover in a relatively quiet environment (less than 70 dB(A)) from the noise for a period at least as long as the exposure duration.

(Ref. 9)

5.8 PROTECTION OF HEARING

Since work must often be carried out in high noise level environments, much attention has been given to methods of hearing protection. Earplugs, when they are the correct size and are inserted to form a good acoustical seal, provide good attenuation below 500 Hz. They are also comfortable to wear. Figure 5.4 shows the attenuation rate of typical earplugs. Earmuffs, whether liquid or foam filled, provide attenuation as great as that of earplugs, but they are not comfortable to wear for very long. The solution that provides the most protection is a combination of earplugs and earmuffs. Although the total attenuation provided by the two is not as great as the sum of the attenuation provided by the devices individually, Figure 5.5 clearly illustrates that the two working in tandem provide greater attenuation -- and thus protection -- for the listener (Ref. 9).

Figure 5.4

(Ref. 9)

Attenuation by Earplugs

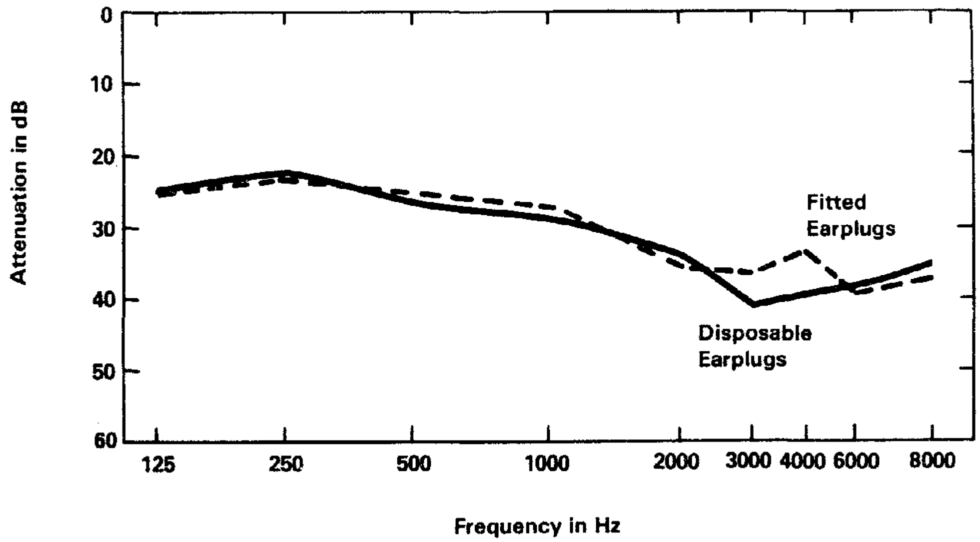
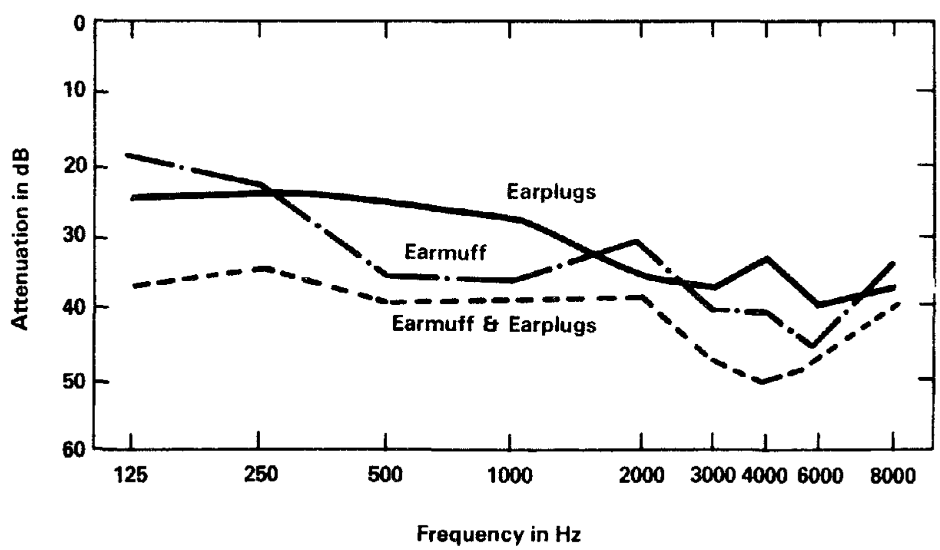


Figure 5.5

(Ref. 9)

Attenuation by Earmuffs Combined With Earplugs



5.9 CONCLUSION

Research continues in the area of hearing damage as a result of aircraft noise, but the conclusions from the studies discussed above may be summarized as follows:

1. The flight crew of an aircraft will incur virtually no hearing damage, if the crew follows the proper procedures of wearing earplugs and earmuffs and of regulating flight time.

2. The passengers in an aircraft would have to fly an extraordinary number of miles over a long period of time before they would be in danger of any hearing loss.

3. The people in a community surrounding an airport are in no danger (under normal circumstances) of hearing damage due to aircraft noise.

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Section 6.0 SPEECH INTERFERENCE

SUMMARY

INTRODUCTION

Speech interference is a principal factor in human annoyance response. It can also be a critical factor in situations requiring a high degree of intelligibility essential to safety. This section contains a summary of research results useful in estimating the degree of speech intelligibility as a function of distance in various ambient noise environments. Criteria are also presented defining levels of intelligibility deemed acceptable (through experience) in various work situations.

AVIATION APPLICATIONS/ISSUES

1. Annoyance to aircraft noise

2. Interference with cockpit communication

GUIDANCE/POLICY/EXPERIENCE

1. Speech intelligibility is adequately assessed using single event noise measures such as ALm, SIL or PSIL.

2. Activities where speech intelligibility is critical include class room instruction, outdoor concerts and other leisure listening endeavors.

3. Advisory information for speech intelligibility in aircraft cockpit environment has been developed by the FAA.

4. Surveys of annoyance to aircraft noise reflect to a large extent reactions to activity interference very often associated with speech interference.

6.1 INTRODUCTION

A major annoyance associated with aircraft noise is interference with verbal communication. This section discusses the various measures of speech intelligibility that have been developed, explains how to assess speech intelligibility and outlines the implications of speech interference for individuals on the ground and in the cockpit of an aircraft.

6.2 MEASURES OF SPEECH INTELLIGIBILITY

A number of noise metrics have evolved for assessing the influence of noise on speech.

1. The Preferred Speech Interference Level (PSIL) is defined as the arithmetic average of the sound pressure levels in the 500 Hz, 1000 Hz and 2000 Hz octave bands.

2. The Speech Interference Level (SIL) is defined as the arithmetic average of the sound presure levels at the 500, 1000, 2000 and 4000 Hz octave bands.

3. The Articulation Index (AI) is a value, between zero and 1.0, which describes the masking of speech by background noise; this value is found by evaluating the signal to noise ratio in specific frequency bands. There are different methods specified for different bandwidths, depending on the resolution required. For example, a masking noise with a continuous spectrum can be evaluated with fewer points than a spectrum punctuated by sharp spikes and deep valleys. The AI can be adjusted upward through the use of visual cues. Figure 6.1 reflects the relation between the calculated AI and the effective AI for communications where the listener can see the lips and face of the talker. The AI is the most sophisticated and most accurate technique developed to assess speech

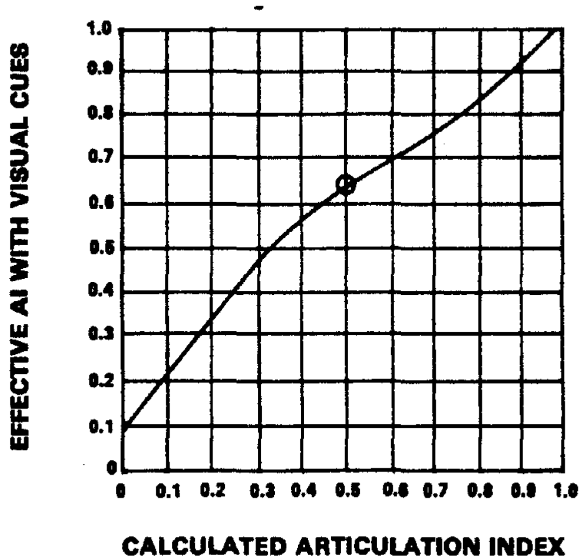
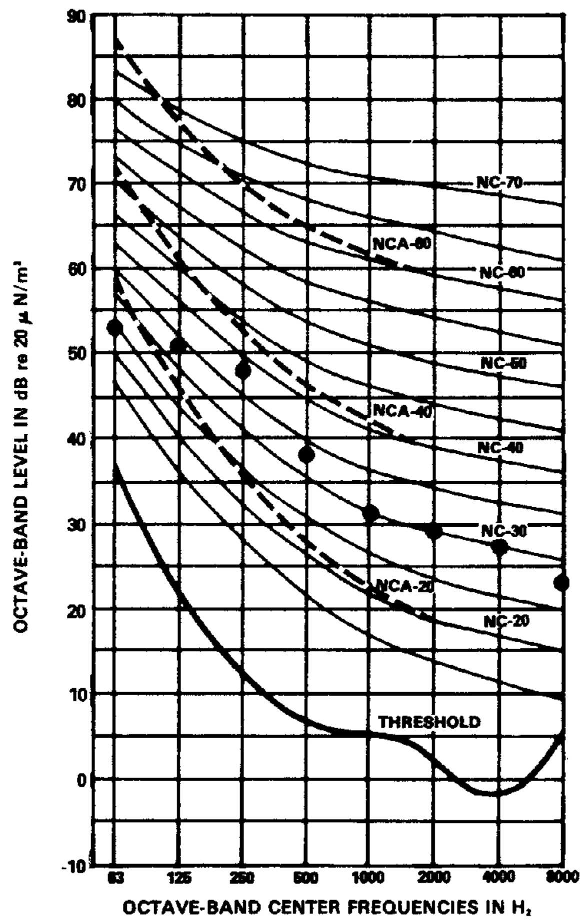


FIGURE 6.1

intelligibility. To be used accurately, however, it requires an extensive knowledge of both the expected speech levels and of background levels. Other, simpler methods (PSIL, SIL and AL) are somewhat less accurate but are adequate for evaluating continuous spectrum masking sounds like those found in aircraft cockpits.

4. Noise Criterion Curves utilize the ambient noise spectrum plotted on a noise criteria curves graph, such as the one shown in Figure 6.2. The plotted spectrum (the circled crosses) in that figure represents typical ambient noise in an office. The graph shows the Noise Curve (NC) rating of the office to be 38, the highest Noise Curve value attained. A table is then consulted to evaluate the degree of speech intelligibility for that environment (see Table 6.2, discussed below).



NOISE CRITERION CURVES

FIGURE 6.2

(Ref. 1)

5. A-Weighted Sound Level (AL), defined in Section 2.0, is found to correlate well with SIL and PSIL for most sounds associated with aviation.

6.3 ASSESSING SPEECH INTELLIGIBILITY

There are many ways to assess speech intelligibility using the methods discussed above. Various tables exist throughout speech interference

TABLE 6.1

Effectiveness of Communication	
SPEECH INTERFERENCE LEVEL (dB)	**PERSON-TO-PERSON COMMUNICATION**
30-40	Communication in normal voice satisfactory, 6 to 30 ft. Telephone use satisfactory.
40-50	Communication satisfactory in normal voice 3 to 6 ft, and raised voice 6 to 12 ft. Telephone use satisfactory-to-slightly-difficult.
50-60	Communication satisfactory in normal voice, 1 to 2 ft; raised voice, 3 to 6 ft. Telephone use slightly difficult.
60-70	Communication with raised voice satisfactory, 1 to 2 ft; slightly difficult, 3 to 6 ft. Telephone use difficult. Earplugs and/or earmuffs can be worn with no adverse effects on communication.
70-80	Communication slightly difficult with raised voice, 1 to 2 ft; slightly difficult with shouting 3 to 6 ft. Telephone use very difficult. Earplugs and/or earmuffs can be worn with no adverse effects on communication.
80-85	Communication slightly difficult with shouting, 1 to 2 ft. Telephone use unsatisfactory. Earplugs and/or earmuffs can be worn with no adverse effects on communication.
OVERALL SPEECH LEVEL (dB) MINUS SIL (dB)**	**COMMUNICATIONS VIA EARPHONES OR LOUDSPEAKER**
+10 dB or greater	Communication satisfactory over range of SIL 30 to maximum SIL permitted by exposure time.***
+5 dB	Communication slightly difficult. About 90% of sentences are correctly heard over range of SIL 30 to maximum SIL permitted by exposure time.***
0 dB to -10 dB	Special vocabularies (i.e., radio-telephone voice procedures) required. Communication difficult-to-completely-unsatisfactory over range of SIL 30 to maximum SIL permitted by exposure time.***

**Overall long-time rms sound pressure level of speech and the SIL for the noise must be measured at or estimated for a position in the ear canal of the listener. Long-time rms value of speech can be approximated by subtracting 4 dB from the peak VU meter readings on monosyllabic words.

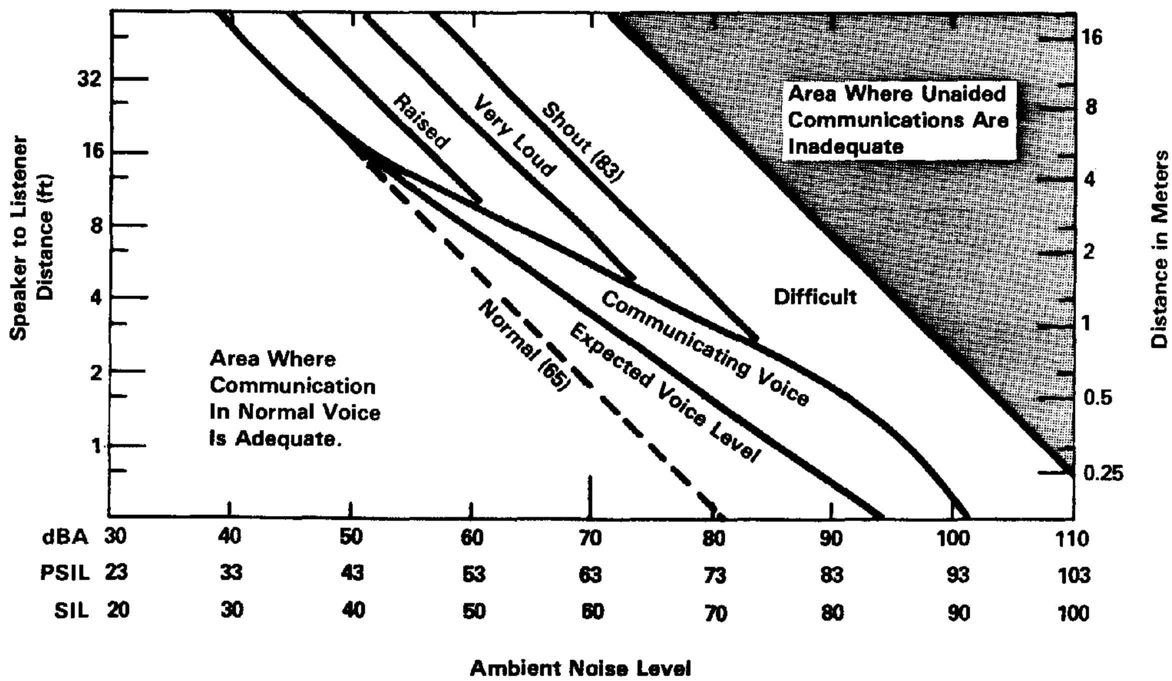
***See Para 4 of DN 3F1. Earplugs and/or muffs worn in noise having SIL's above 60 dB will not adversely affect communication and will extend maximum permissible SIL in accordance with protection provided.

(Ref. 2)

literature which relate AI levels, SIL and PSIL to levels of speech intelligibility. Table 6.1 is one example of such a table; it relates speech interference levels to levels of effective communication. Figure 6.3 provides the permissible distance between a speaker and listeners for specified voice levels and ambient noise levels, using AL (referred to in the table as dBA).

Another helpful interpretive scheme has been developed by the U.S. Army, which has determined through research and experience the levels of speech or sentence intelligibility appropriate for various workspaces. Table 6.2 depicts the relationship between NC values and speech quality.

Figure 6.3



Permissible Distance Between a Speaker and Listeners for Specified Voice Levels and Ambient Noise Levels

(The Levels in Parantheses Refer to Voice Levels Measured One Meter From the Mouth.)

6.4 SPEECH INTERFERENCE ON THE GROUND

Speech interference associated with aircraft noise is a primary source of annoyance to individuals on the ground. The disruption of leisure activities such as listening to the radio, television, music and conversation gives rise to frustration and irritation. Quality speech communication is obviously also important in the classroom, office and industrial settings. In one 1963 study, sponsored by the British government, researchers found that aircraft noise of 75 dB annoyed the

TABLE 6.2

Recommended Noise Criteria for Offices and Workspaces*

NC (or NCA) CURVE	COMMUNICATION ENVIRONMENT
OFFICES	
NC-20 to NC-30	Very quiet office; suitable for large conferences. Telephone use satisfactory.
NC-30 to NC-35	"Quiet" office; satisfactory for conferences at a 15-ft table; normal voice, 10 to 30 ft. Telephone use satisfactory.
NC-35 to NC-40	Satisfactory for conferences at a 6- to 8-ft table; normal voice, 6 to 12 ft. Telephone use satisfactory.
NC-40 to NC-50	Satisfactory for conferences at a 4- to 5-ft table; normal voice, 3 to 6 ft; raised voice 6 to 12 ft. Telephone use occasionally slightly difficult.
NC-50 to NC-55	Unsatisfactory for conferences of more than two or three people; normal voice, 1 to 2 ft; raised voice 3 to 6 ft. Telephone use slightly difficult.
Above NC-55	"Very noisy." Office environment unsatisfactory. Telephone use difficult.
WORKSPACES, SHOP AREAS, ETC.	
NC-60 to NC-70	Person-to-person communication with raised voice satisfactory, 1 to 2 ft; slightly difficult, 3 to 6 ft. Telephone use difficult.
NC-70 to NC-80	Person-to-person communication slightly difficult with raised voice, 1 to 2 ft; slightly difficult with raised voice, 1 to 2 ft; slightly difficult with shouting, 3 to 6 ft. Telephone use very difficult.
Above NC-80	Person-to-person communication extremely difficult. Telephone use unsatisfactory.

NOTE: Noise measurements made for the purpose of comparing the noise in an office with these criteria should be performed with the office in normal operation, but with no one talking at the particular desk or conference table where speech communication is desired (i. e.), where the measurement is being made). Background noise with the office unoccupied should be lower, say by 5 to 10 dB.

* Extracted in part from Ref 682

(Ref. 2)

highest percentage of the population when it interfered with the television sound (Ref. 3). Eighty percent of the test population reported being annoyed. Also high on the list of annoyances for the surveyed population was flickering of the television picture and interference with casual conversation by aircraft noise.

6.5 SPEECH INTERFERENCE IN THE COCKPIT

The concern of cockpit speech intelligibility has been addressed in recent years because of the potential safety hazard. In 1981 the problem came to the forefront with the crash of a turboprop aircraft near Spokane, Washington. The captain of the craft had complained earlier that "he believed the cockpit noise levels precluded normal speech," and he concluded that "the cockpit noise levels could have interfered with verbal communication" (Ref. 4). The National Transportation Safety Board (NTSB) concluded that during approach and flight operations, the noise in the cockpit prevented effective verbal communication (when headphones were not used). Consequently, the NTSB recommended that the FAA consider publication of advisory information concerning speech intelligibility in aircraft with particularly high cockpit sound levels.
The FAA responded to the NTSB's recommendation for action with an advisory circular which remains in draft form at the present time. Pertinent sections are reproduced below (Ref. 5):

1. Above a cockpit noise level of 88 dB(A), (PSIL = 78) efforts made to aid communications by use of one or more of the methods discussed in the Advisory Circular will significantly improve communication between crew members. (The Circular discussed the use of well-fitted hearing protectors, noise-cancelling microphones, and miniature headsets with circumaural muffs as possible methods of increasing speech intelligibility.)

2. An Articulation Index of 0.3 was defined as equivalent to a PSIL 78 or 88 dB(A).

3. An Articulation Index of 0.3 was identified as adequate for acceptable communication. When coupled with visual cues, this AI value relates to an intelligibility level of 97% in the known sentence test.

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Section 7.0 SLEEP INTERFERENCE

SUMMARY

INTRODUCTION

This section describes the sleep process and reviews research relating the percentage of an exposed population experiencing awakening to noise level. Design criteria are also identified for avoiding unacceptable rates of awakening.

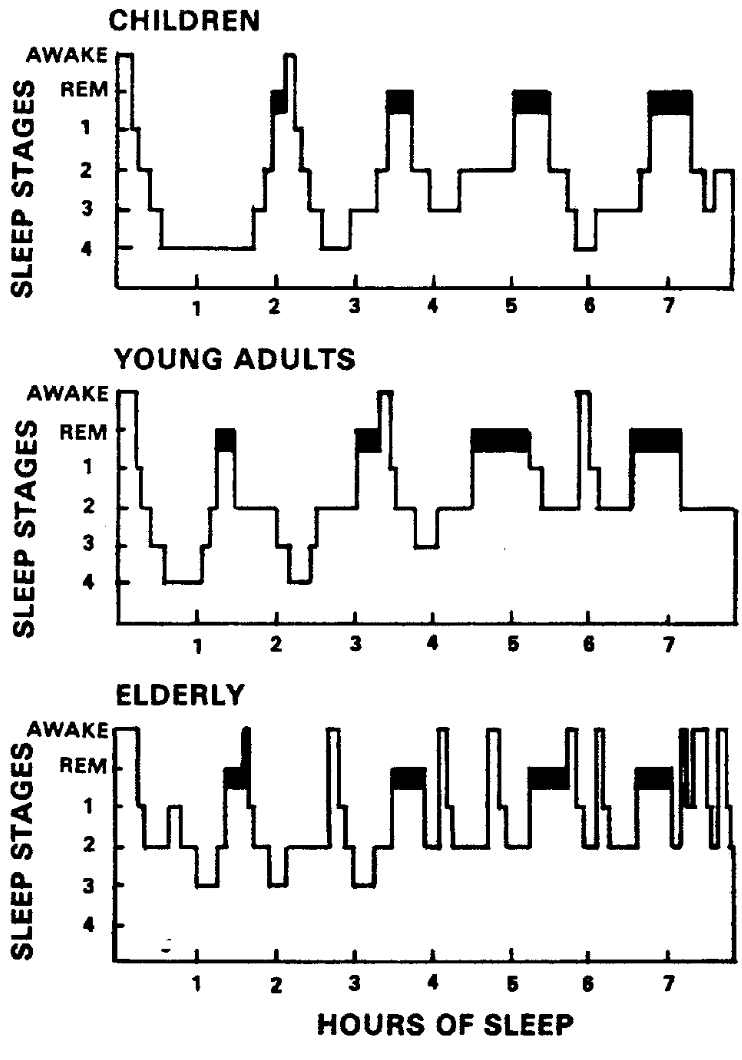
AVIATION APPLICATIONS/ISSUES

Sleep interference associated with aircraft noise.

GUIDANCE/POLICY/EXPERIENCE

Sleep interference is one of the factors contributing to aircraft noise annoyance. Airport nighttime restrictions have been employed to minimize this annoyance. In the case of nighttime operations an exterior maximum sound level (ALm) of 72 dB is identified as an acceptable sleep interference threshold for windows closed condition. This corresponds to an interior ALm of about 55 dB.

Figure 7.1



NORMAL SLEEP CYCLES

REM sleep (darkened area) occurs cycically throughout the night at intervals of approximately 90 minutes in all age groups. REM sleep decreased slightly in the elderly, whereas stage 4 sleep decreases progressively with age, so that little, if any, is present in the elderly. In addition, the elderly have frequent awakenings and a notable increase in wake time after sleep onset.

(Ref. 1)

7.1 INTRODUCTION

Sleep can be divided into two stages: REM (rapid eye movement) and NREM (non-REM). NREM, the heavier sleep, is further divided into four substages, the fourth of which is the deepest sleep. The two stages (REM and NREM) appear throughout the night in cycles, with REM sleep recurring in all ages at approximately 90 minute intervals. The amount of time spent in stage 4 sleep, however, decreases progressively with age. The elderly also have more occurances of waking after falling asleep than do younger people. Figure 7.1 is a graph of these cycles (Ref. 1).

Sleep has been identified as having a number of beneficial effects which any sleep interference can inhibit. These include the restorative processes of body organs, the recovery of the brain from "fatigue", the consolidation into memory of information gained during wakefulness, and, in children, the release of growth hormones. Interestingly, sleep deprivation does not appear to affect mental and psychomotor performance adversely. However, it is a generally accepted conclusion that sleep is necessary for a healthy life, so the question of to what extent noise can interfere with an individual's sleep naturally arises.

7.2 SLEEP DISTURBANCE RESPONSE

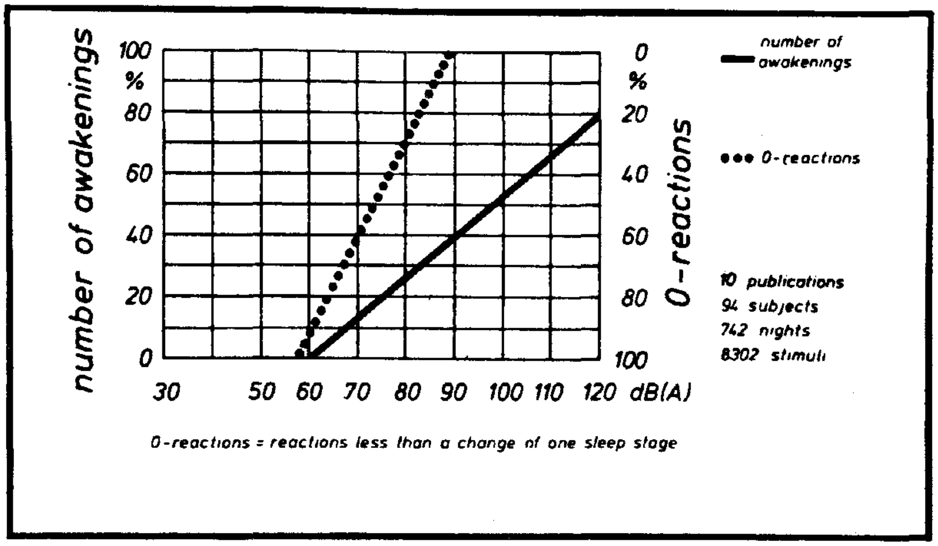
In most sleep research experiments, arousal is said to have occurred when (1) within one minute of a noise stimulus, the subject's EEG pattern changes to one of wakefulness, or (2) the subject gives some sort of motor signal indicating he or she is awake. If the subject's EEG changes within one mnute of a noise stimulus but the change is normal for that sleep stage, an 0-reaction (meaning a reaction less than a change of one sleep stage) is said to have taken place. Research has shown that fewer awakening reactions were found in deep sleep than in light sleep, and that REM sleep provided more 0-reactions than NREM sleep. Only relatively high exposure to aircraft noise could cause arousal from substages 3 and 4 of NREM sleep.

Figure 7.2 illustrates the number of awakenings and 0-reactions which take place at different noise levels (Ref. 2). The figure represents a collation of ten publications involving 94 subjects and 742 nights of testing. The relationship illustrated in the figure provides the basis for currently accepted policy that interior noise levels of up to 55 dBA are acceptable.

7.3 RECENT LITERATURE REVIEW

In 1983, the FAA requested NASA Langley Research Center to review the literature and "state of the art" in sleep interference research. This study was part of a larger reevaluation of weightings proposed for nighttime noise events. The pertinent findings of this study are outlined below (Ref. 3).

FIGURE 7.2



Sleep disturbances by noise—number of reactions and noise level.

(Ref. 2)

7.3.1 Arousal from Sleep. The study revealed that, while research has yielded widely varying conclusions as to what the threshold of arousal from sleep is, the level of a noise which can interfere with falling or waking from sleep ranges from 35 to 70 dB. The varied results of researchers arise because several factors affect how easily a person will be awakened from sleep. As mentioned above, a person's age is a prominent factor affecting arousal. Children sleep the heaviest, the elderly the lightest, sleep. Thus, older people have a much lower arousal threshold than do younger people.

As one might expect, there is also a rise in the threshold of arousal as sleep stages deepen. The average difference in the arousal threshold from being awake to stage 4 NREM sleep is about 17.5 dB. Lastly, because of the cyclical nature of the two sleep stages (REM and NREM), an individual's susceptibility to arousal varies throughout the night. However, in a normal 8-hour sleep night, more time is spent in lighter stages of sleep in the last half than in the first half. This implies that airport use restrictions limiting early morning flight from 3 a.m. to 7 a.m. are particularly important. Although people are also susceptible to arousal at the beginning of a sleep period when they are just trying to fall asleep, in general arousal is more likely during the late hours of sleep.

7.3.2 Measuring Sleep Interference. Some studies have shown generally that the single event energy dose of a noise event (EPNL or SEL), and not the maximum level (in PNL or AL) is a better predictor of sleep interference (Refs. 4, 5). These findings have been contradicted in a report by Ohrstrom and Rylander, who assert that peak levels should be used to determine tolerable night levels of noise (Ref. 6). Researchers continue to debate this question.

7.3.3 Adaptation. Studies conducted to determine adaptation to the sleep arousal noise threshold over a number of successive nights revealed only slight adaptation. Researchers speculate that perhaps even this small degree of adaptation involved subjects' acclimatization to the laboratory setting and instruments rather than to the noise.

Another researcher found that subjects exposed to noise either 0, 6 or 24 times in one night demonstrated habituation during the night: The subjects showed less arousal response on the nights when 24 stimuli were presented than during 6-stimuli nights (Ref. 7). However, subjects' morning performance was better following a 6-stimuli night than a 24-stimuli night despite increased average arousal. The value of habituation to more frequent sleep disturbances in a given night is thus questionable.

In an interesting but unusual study of infants near Osaka airport (in Japan), it was determined that babies who were born of mothers exposed to intense aircraft noise before conception and/or during the first five months of pregnancy had habituated themselves to aircraft noise below approximately 90 dBA, although still reacting to music (the control sound) below that level (Ref. 8). Babies having less or no "exposure" before birth to aircraft noise reacted both to aircraft noise and to music below 90 dBA. While this particular report suggested that the babies habituated during the first five months of prenatal growth to a greater extent than the babies with less or no prenatal exposure to aircraft noise, other researchers consider this conclusion "highly speculative."

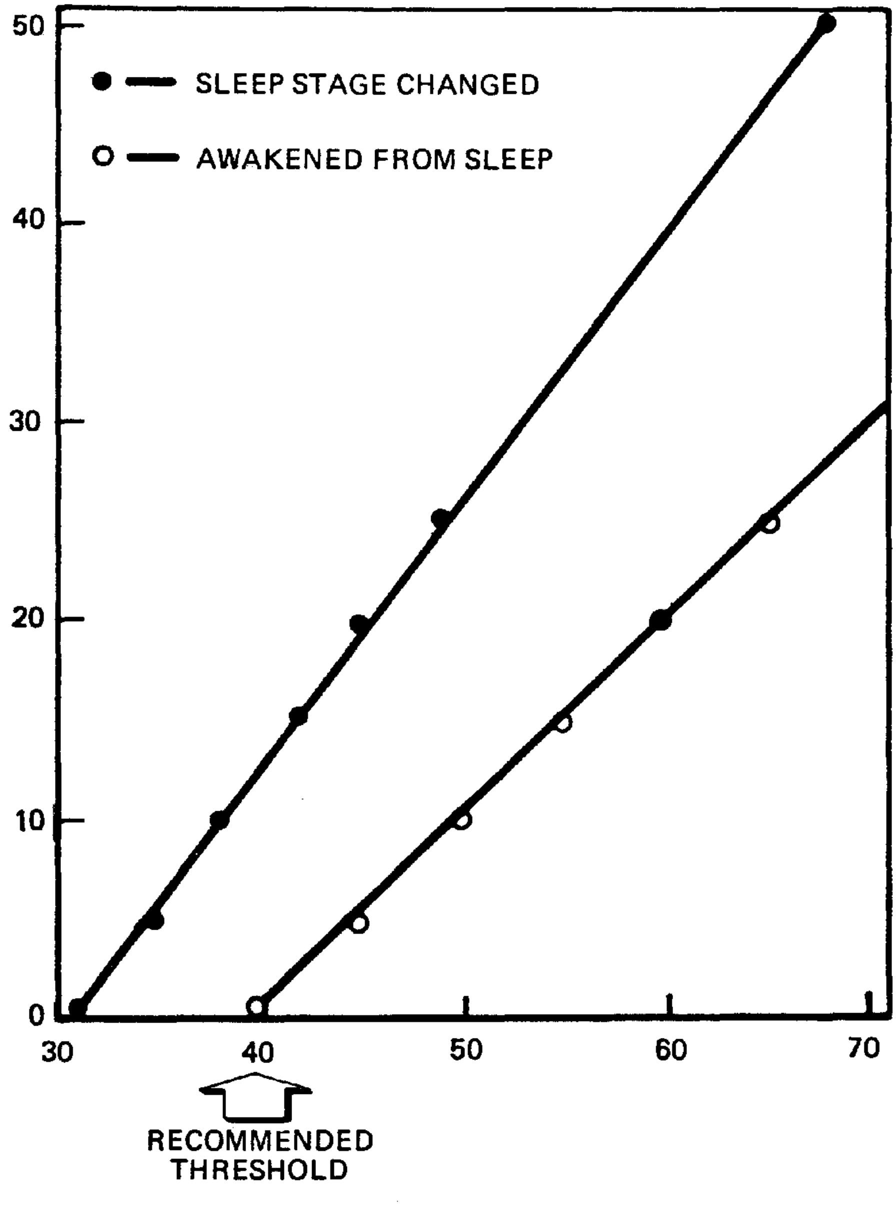
It is generally accepted that people adapt psychologically to new environmental noises. This adaptation involves learning how often and when environmental noises are likely to occur, and how to adjust behavior patterns to prevent sleep arousal or other effects of noise. Research suggests that adaptation to noise is a constant. In one study, for example, cessation of aircraft landing operations between 11 PM and 6 AM at Los Angeles International Airport had no appreciable effect on subjects' reports of sleep interference (Ref. 9).

7.4 1977 LITERATURE REVIEW

An earlier review of sleep interference was also carried out under FAA support in 1977 as part of a Congressional mandate to assess the feasibility of soundproofing schools and hospitals in the vicinity of airports (Ref. 10). Key observations and conclusions from that study are provided below.

Although the effects of noise on sleep are not completely understood, the noise environment of a hospital area must be considered, because sleep is crucial to patient recovery. A level of 40 dBA is a conservative estimate of the threshold level of noise for sleep disturbance of patients in hospitals and public health facilities. Noise exposure below this level is not expected to interfere with sleep.

Figure 7.3



COMPOSITE OF LABORATORY DATA FOR SLEEP INTERFERENCE VERSUS MAXIMUM A–WEIGHTED NOISE LEVEL

(Ref. 10)

Other studies have also attempted to set noise levels for sleep disturbance and have basically supported this limit. The U.S. EPA set 35 dB as the A-weighted disturbance leve for a steady noise; it also concluded that single event maximum levels (ALm) of 40 dB result in a 5% probability of awakening. Figure 7.3 is a composite of laboratory data for sleep interference versus maximum A-weighted noise levels.

The recommended interior noise levels for hospitals and sleeping environments was identified in the 1977 report as being between 34 and 47 dNA. A study conducted in patient rooms of eight hospitals revealed a background noise level ranging from 35 to 60 dBA, and an average 24-hour level of between 40 and 45 dBA. Aircraft noise effects in a hospital depend, of course, on how high the background level is without aircraft noise, and the intensity, duration, and frequency of noise disturbance from aircraft.

7.5 SUMMARY

In summary, the following conclsions can be drawn from the research studies reviewed:

1. The threshold level of a noise which will cause arousal from seep depends on sleep stage and the age of the subject, among other things. Noise levels which can cause sleep disturbance cover a range of 35 to 70 dB (ALm).

2. Little or no pysiological adaptation to sleep interference from noise occurs, although adaptation to new sleep environments does occur.

3. Psychological annoyance from the effects of sleep interference from aircraft noise is probably more significant than the direct physiological consequences.

4. The recommended interior noise levels for hospitals is between 34 and 47 dB; for other sleeping environments, the maximum acceptable intrusive level is 55 dB.

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Section 8.0 NON-AUDITORY EFFECTS

SUMMARY

INTRODUCTION

This section summarizes a series of contemporary research studies which hypothesize correlation between noise exposure in general (in many cases aircraft noise exposure) and various human physiological or behavioral effects. While some studies show a significant correlation, other studies show none. Although research continues, there does not exist a succession of studies which corroborate the "cause and effect" theory. While the reader should be aware of research in this area, the topics reviewed in this section are considered to be beyond the realm of normally accepted and recognized aircraft noise effects.

AVIATION APPLICATION/ISSUES

1. Cardiovascular effects

2. Achievement scores

3. Birth weight

4. Mortality rates

5. Psychiatric admissions

GUIDANCE/POLICY/EXPERIENCE

1. As cited above the relationship between these suggested "effects" and aircraft noise has not been repeatedly and consistently demonstrated. On the contrary, many studies directly contradict those which show an effect.

8.1 INTRODUCTION

Frequently, statements and claims are made that aviation noise damages the health of airport neighbors. The fact that aircraft noise above a certain level annoys those neighbors is generally accepted, but whether or not that noise causes any physical or mental damage is far less established. This section briefly reviews the pertinent reports and journal articles dealing with the non-auditory effects of aviation on people.

8.2 INTERPRETATION OF RULINGS

Section 611 of the Federal Aviation Act, as amended, requires the Administrator of the FAA to prescribe and amend standards and regulations "In order to afford present and future relief and protection to the public health and welfare from aircraft noise..." There is no clear definition of "public health and welfare" as used in this mandate. The U.S. EPA has interpreted the phrase as "complete physical, mental and social well-being and not merely the absence of disease and infirmity." (Ref. 1) More often, "public health" is interpreted to cover physical or mental damage to individuals and the public, as, for example, the loss of hearing acuity as a result of exposure to high levels of noise. Correspondingly, "public welfare" is interpreted to cover mental or emotional reaction to noise, often characterized as annoyance or interference with a normal activity (speech, sleep or solitude).

FAA's statutory mandate requires relief and protection from both levels of impact, so that a clear distinction between the two effects is largely academic. In many legal actions, however, a distinction may be sought in order to place more emphasis and importance on "health" impacts than on possibly less permanent "welfare" effects. Indeed, a 1982 decision by the U.S. Court of Appeals held that the effects on people's psychological health and community well-being should be included in an environmental impact statement associated with the proposed restart of Three Mile Island Unit 1 (Ref. 2). A strict interpretation of this decision could add comparable new assessments into many aviation-related actions.

8.3 REVIEW OF STUDIES

A brief review was carried out of available scientific journal articles and reports dealing with possible health and welfare effects of airport noise on residents of neighboring communities (Ref. 3). The effects of aircraft noise on the physical, mental and emotional health of airport neighbors (the so-called non-auditory effects) are not nearly so clear as those for hearing loss. Most survey reports on this subject find that there is little reliable evidence on the relationship between noise exposure and mental or physical health. Although there are many studies available attempting to relate these factors -- one study cites 150 references, another 83 -- most do not employ scientifically rigorous methods or provide fully descriptive information on which their validity can be judged. It is interesting to note that a recent EPA-sponsored

survey judged only one study out of 83 to rate higher than "4" on a scale of 0 to 9, in terms of study quality (Ref. 3). Thus, in general, it is difficult to prove -- or disprove -- any connection between mental or physical health and noise, and more particularly, airport noise.

Three pairs of studies, included in this section, directly contradict each other. One 1979 study apparently found a higher mortality rate for residents near Los Angeles International Airport, compared with a lower noise-exposure area (Ref. 5). A 1980 study used exactly the same data, and found that the mortality rates were nearly identical. The latter analysis appears far more thorough and scientifically valid (Ref. 6).

A 1978 study, which received national press coverage, apparently showed a higher rate of birth defects for residents east of Los Angeles International Airport, compared to the remainder of Los Angeles County (Ref. 7). A 1979 study reported exactly the same type of analysis around Atlanta's Hartsfield International Airport, and found no significant differences in 17 categories of birth defects for residents near the airport and those in quieter locales (Ref. 8). Again, the second study appears far more rigorous and scientifically valid (but it apparently received no press attention at all). A third pair of studies examined mental hospital records in relation to airport residents, and also reached different conclusions (Ref. 9, Ref. 10).

Perhaps the most striking set of studies concerning the effects of airport noise on neighbors was that published in 1977 by Knipschild (Ref. 11 through Ref. 14). These studies examined the incidences of cardiovascular problems, doctor contacts, and drug purchases for areas near Amsterdam's Schiphol Airport, and concluded that "airport noise, as prevalent around many airports, constitutes a very serious threat to public health in all its aspects: affection of well-being, mental disorders, somatic symptoms and diseases (especially cardiovascular diseases)." The EPA-sponsored survey included one of these studies, however, but did not seem to find it convincing. Incidently, the Knipschild studies have been cited in a recent court case and apparently was considered important in that decision (Ref. 15).

8.4 SUMMARY

Although many airport neighbors have cliamed a direct health impact from aviation noise, there is little valid scientific basis for such claims.

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Section 9.0 EFFECTS OF NOISE ON WILD AND DOMESTICATED ANIMALS

SUMMARY

INTRODUCTION

This section summarizes research concerning the effects of aviation noise on wild mammals, birds and fish, on farm animals (swine, cattle, poultry and mink), and on a variety of laboratory animals. While a significant amount of research has been conducted on the reactions of animals to noise, it has proven difficult to draw any general conclusions on the subject because there is much variability in response both between and within species. Thus, no clear policies or guidelines have been developed concerning noise exposure and animals.

AVIATION APPLICATION/ISSUES

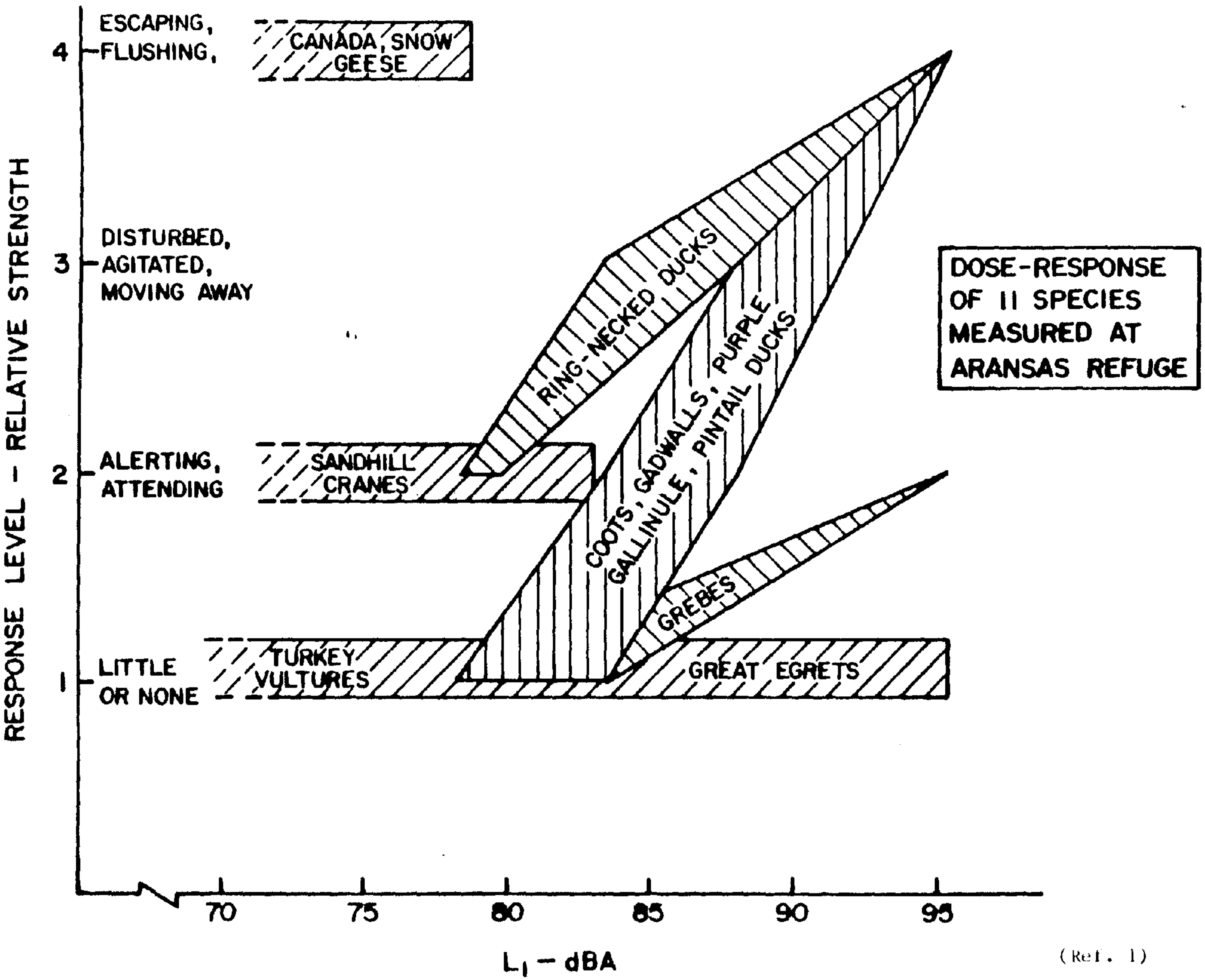
1. Harm to animals in U.S. wildlife refuges, national parks, and wilderness areas

2. Effects on the productivity of domestic animals

GUIDANCE/POLICY/EXPERIENCE

Animals are rarely exposed to high noise levels outside of the laboratory, and most have proven impervious to the aircraft noise they do experience. Nevertheless, a few species have demonstrated little tolerance of aircraft noise and have shown few signs of adapting to it. Since no well-established guidelines concerning noise and animals exist, it is important to remain aware of the issue and alert to the possiblity that "off-limits" wildlife areas may be desirable in the future for selected wildlife areas.

Figure 9.1



(Ref. 1)

9.1 INTRODUCTION

The effects of aviation noise on animals have been studied rather extensively over the past 20 years, with much of the work being conducted by U.S. Air Force-sponsored researchers. The studies have revealed that the effects are highly species-dependent and that the degree of the effect may vary widely. Responses of animals to aircraft noise vary from almost no reaction to virtually no tolerance of the sound. The question of how adaptable animals are remains largely unanswered. Both wild and domesticated animals have been studied, though more research has centered on domesticated or laboratory animals (such as rats and mice). The research summarized below reflects the extensive variation in the sensitivity and response of animals to noise.

9.2 WILDLIFE

It has proven difficult to study the effects of aviation noise on wild animals in their own environment and under natural conditions. Yet, as urban areas of the U.S. continue to grow, protecting natural habitats and their inhabitants thereof becomes a greater concern.

9.2.1 Birds. A test employing helicopters and other aircraft was conducted at Aransas National Wildlife Refuge in Texas (Ref. 1). Eleven different avian species were observed and their reactions gauged on a scale of 1 (no reaction) to 4 (violent reaction, left the area). Figure 9.1 depicts the results of this study. Of the eleven species, five--Canadian and Snow Geese, Sandhill Cranes, Turkey Vultures and Great Egrets--showed no change in response as a function of helicopter noise level, while the other six species appeared to alter their response depending upon the noise intensity. The grebes' response increased only slightly while the response of ring-necked ducks, coots, gadwalls, purple gallinules, and pintail ducks were found to increase more strongly as a function of the helicopter noise level. Canadian and Snow Geese did not tolerate helicopter noise at any level. The authors concluded that because any tendency among the geese to adapt remains to be demonstrated, "off-limits" areas may possibly be necessary for such sensitive species.

9.2.2 Fish. Fish have been noted to respond to noise within their environment such as underwater explosions and the sound of fishing vessels; however, aircraft noise is very rarely a part of that environment. Most airborne sound is reflected off the water's surface, with only a small fraction actually penetrating the air-water boundary. The impact of sonic boom on aquatic life has also been evaluated. When a sonic boom sweeps an expanse of water, only the vicinity of the water surface is affected. The ICAO Sonic Boom Committee, after conducting various tests, concluded that typical sonic booms are not likely to harm aquatic life (Refs. 2, 3). Also, the U.S. Department of the Interior, Bureau of Sport Fisheries and Wildlife conducted a study of the effect of sonic boom on fish and fish eggs. Trout and salmon eggs were reared in the normal manner until reaching the most critical stage of development and then were exposed to sonic boom. Mortality rates for the exposed eggs were compared with a control group. No mortality differential was discernible (Ref. 4).

9.3 DOMESTICATED (FARM) ANIMALS

A 1963 study found that pigs exposed to recorded jet and propeller aircraft sounds of 120 to 135 dB daily from 6 a.m. to 6 p.m. from weaning time or before, until slaughter at 200 pounds body weight, showed no differences in feeding or weight gain from pigs unexposed to the sounds (Ref. 5).

Another study also reported that dairy cattle showed no differences in milk production when exposed to aircraft noise. The researchers compared milk cow herds located within three miles of a number of air force bases using jet aircraft (13 percent of the herds were within 1 mile of the end of an active runway). Dairy cattle studied in the vicinity of Edwards Air Force Base (California) showed few abnormal behavioral reactions due to sonic booms, though they had been exposed to the booms for several years and so may have become habituated (Ref. 6). Other studies also supported this evidence that cattle are generally not affected by the sonic boom or other aircraft noise.

Poultry have shown no more reaction to aircraft noise than swine or cattle. In a 1958 study, recorded aircraft flyover noise at 80 to 115 dB at 300 to 600 Hz was played daily and every third night from the beginning of the hens brooding until the chicks were 9 weeks old. There resulted no difference in weight gain, feeding efficiency, meat tenderness or yield, or mortality between sound-exposed and non-exposed chicks (Ref. 7). Broad breasted bronze turkeys were exposed to recordings of low flying jet planes at 110 to 135 dB for 4 minutes during the third day of brooding. The turkeys typically ceased brooding but resumed it shortly, with no decrease in egg laying (Ref 8). A final study showed that chicken eggs exposed to daily sonic booms for 21 days during their incubation hatched normally (Ref. 9).

In a 1968 study on mink, one hundred twenty animals were exposed to simulated sonic booms ranging from 2.0 to 0.5 lb per sq ft. The litters of mink exposed to the booms were larger than those of mink not exposed. No racing, squealing or other signs of panic were observed in the animals. Animals that died naturally were examined; no disorders which could be traced to the sonic booms were found (Ref. 10). Female mink showed little or no response to exposure to sonic boom during breeding, birth of kits, or whelping. Again, no signs of panic were observed.

9.4 LABORATORY ANIMALS

Mice, rats, monkeys, and rabbits have been examined in numerous studies, the results of which are briefly reviewed here (Ref. 11). The studies generally exposed the test animals to a certain level of noise for a predetermined period of time; response was measured in terms of physiological change. Increases and decreases in body chemicals and in the weights of body organs were typically observed in the tests. Although some of the bodily changes were typical of reactions to stress (and noise is often considered stressful), it was not clear that the changes were significant or dangerous. As with humans, hearing damage occurred when the animals were exposed to high level noise; however, animals are rarely exposed to extreme aircraft noise.

9.5 CONCLUSION

While instances may arise in which aviation noise does create a concern for those protecting wildlife or involved in animal husbandry, in general, aviation noise has a minimal impact on animals.

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Section 10.0 EFFECTS OF STRONG LOW FREQUENCY ACOUSTICAL ENERGY

SUMMARY

INTRODUCTION

This section reviews the effects of strong low frequency acoustical energy in creating some of the more unusal (albeit rare) aircraft noise effects. The consideration of low frequency sound in creating vibration (and secondary noise) in structures is discussed. While structural vibration is not a common concern for commercial transport airplanes, there may be some need to exercise caution in helicopter operations in close proximity to buildings. A brief review is also provided addressing human physiological reactions to intense low frequency sound as one might encounter near engine test stands. Criteria are presented for both annoyance to vibration and human physical damage risk for exposure to intense infrasound.

AVIATION APPLICATIONS/ISSUES

1. Vibration of wall and windows

2. Radiation of secondary noise

3. Human physiological response to intense low frequency sound

4. Sonic Booms (illegal in U.S. for civil aircraft operations)

GUIDANCE/POLICY/EXPERIENCE

The issue of low frequency energy and its impact on buildings and people was explored in detail in regard to the Concorde SST operations in the U.S. Impacts were found to be negligible. Consequently low frequency effects from civil commercial aircraft remains a minor issue in most environmental impact assessments. There remains the need however to consider carefully possible effects of low frequency energy in the operation of helicopters in close proximity to buildings.

10.1 INTRODUCTION

The lower end of the audible acoustical spectrum is approximately 20 Hz. Below this frequency people cannot generally hear sound but can easily sense vibrations in their bodies. Intense sound in this frequency range can also excite resonances in various body cavities causing a feeling of nausea or discomfort. Intense infrasound can also cause walls and floors to vibrate, rattling windows and household items. The effects of this low frequency sound are discussed in this chapter.

10.2 STRUCTURAL EFFECTS

Potential damage to building structures from low frequency sound vibration became a topic of concern during the environmental assessment of the supersonic jet transport, the Concorde. Subsequent studies revealed that low frequency vibration from the Concorde causes little to no structural damage. Analyses conducted of five historic sites near the proposed subsonic flight path of the Concorde aircraft revealed breakage probabilities from noise-induced vibration for windows, brick chimneys, a stone bridge, and a plaster ceiling to be less than .001 percent per year (Ref. 1). It was found that exposure to normal weather (such as thunder or wind loads) produces a higher probability of breakage than vibrations from the Concorde.

At Sully Plantation, Virginia, the test location nearest the Concorde flight path and therefore most likely to sustain vibration damage, calculations were based on a sound level of 104 dBA for each overflight, or an effective pressure of .313 psf. Estimates of the probability of breakage of one flight from Concorde overflights are about one in every million years. The Concorde's contribution to the cumulative damage of a house in the neighborhood of Kennedy Airport was found to be insignificant. Everyday vibrations from wind and household activities were greater than those caused by aircraft in the worst conditions around normal airports.

Studies show that the Concorde causes five times the vibration to normal buildings as the older model Boeing 707 (with JT3D engines) (Ref. 2). Considering the higher levels of noise produced by the Concorde in relation to other aircraft, the danger of breakage from noise-induced vibration at all frequencies is therefore slight.

10.3 ANNOYANCE WITH STRUCTURAL VIBRATION

It has also been theorized that the vibrations induced in buildings and windows by low frequency sound might increase the annoyance of the occupants to a greater degree than the effects of the vibration on the human body. This annoyance is due to human perception of the vibration of a wall or window and rattle created by household objects when the structure vibrates. Infrasound characterized by long wavelengths is not attenuated by walls, partitions, acoustic absorbers, or the atmosphere to the same degree as audible sound.

U.S. Army researchers conducted a study to measure the role of vibration and rattle in human response to helicopter noise (Ref. 3). Helicopter noise annoyance was judged against annoyance from a control noise by

subjects in the living-dining area of a frame farmhouse, in a mobile home, and outdoors. Subjects in the living-dining area of the house were most annoyed by vibration and rattle; results suggest that, when high levels of vibration and rattle are present, a control noise would have to be 20 dB higher than the helicopter noise to produce equivalent annoyance. This offset was 3 to 6 dB outdoors with an average of 4 1/2 dB. Subjects in the mobile home, most likely because of the low frequency resonance created by the helicopter, display a 3 to 14 dB offset with an average of about 8 dB. The researchers concluded that vibration and rattle can significantly increase the annoyance associated with a particular sound level.

Reiher and Meister conducted an investigation of subjective human response to different levels of structural vibration, and used this data to develop the tolerance criteria shown in Figure 10.1 (Ref. 4). Their study revealed that, when compared with these criteria, wall vibration caused by takeoff and approach of the Concorde are imperceptible or barely perceptible, causing no adverse effects on human beings (See Figure 10.2).

10.4 PHYSIOLOGICAL EFFECTS

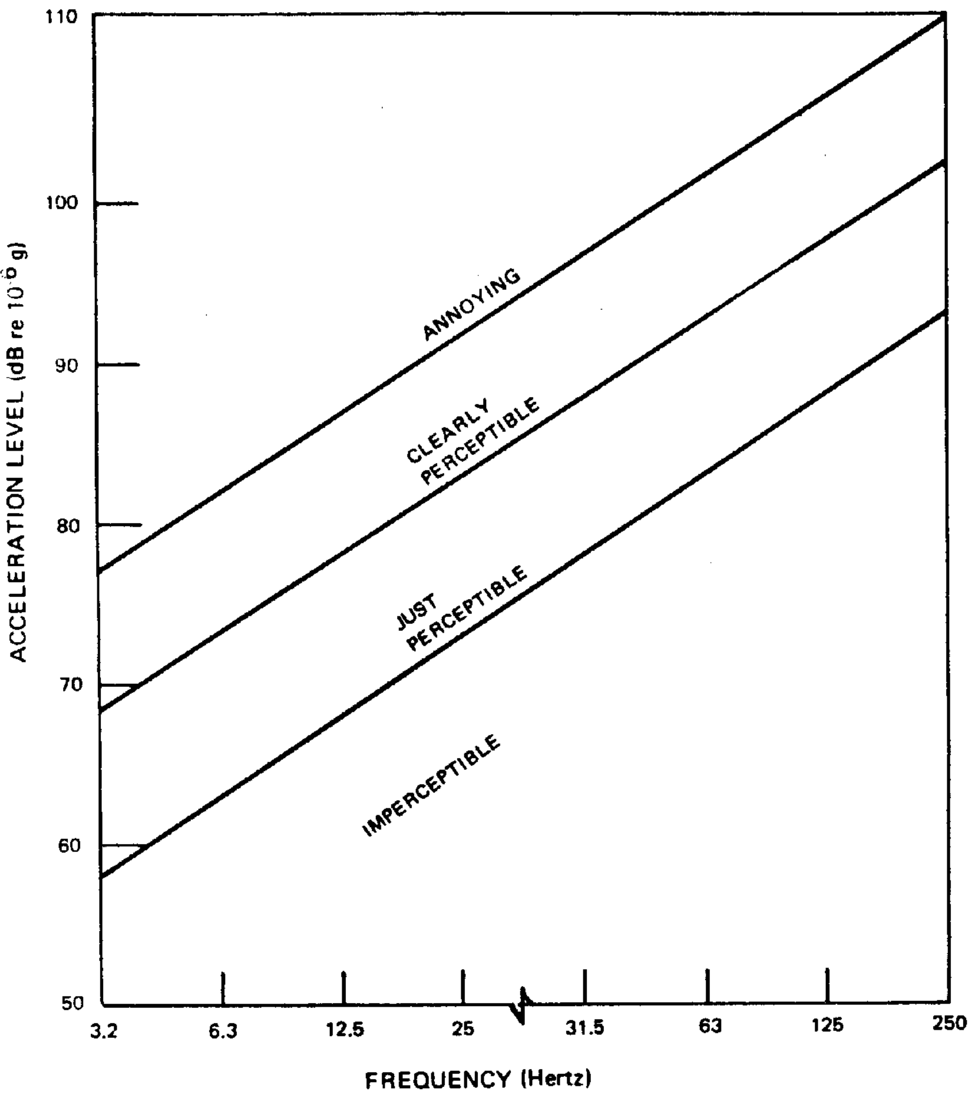
Low frequency sound can be directly absorbed through the surface of the body and can excite sense organs other than the ears. The effect is similiar to the effect of mechanical vibration on the body, causing the internal organs to vibrate and disturbing the nervous system, digestion and sight. Most physiological effects of vibration and noise are limited to a narrow frequency range. Very intense low frequency noise (0-20 Hz) can cause a sensation of vibration, disequilibrium, motion sickness, speech disturbance, and blurring of vision, just to name a few. Frequencies from 5-9 Hz have been shown to affect the liver, spleen, and stomach, while somewhat higher frequencies may result in mouth, throat, bladder or rectal pain.

Workers in extremely noisy situations complain of distraction from nausea, disequilibrium, disorientation, headache, lassitude, and blurring of vision. French workers have reported disorders of the circulatory and nervous systems as a result of exposure to infrasound, but the presence of permanent effects on the body has not been verified (Ref. 5). Industrial equipment often produces inaudible vibrations which, after prolonged exposure, cause specific complaints of giddiness, nausea, and anxiety not found after similar exposure to noise in the audible range.

10.5 CRITERIA FOR INTENSE LOW FREQUENCY SOUND (INAUDIBLE), INFRASOUND

10.5.1 EPA Levels Document. According to the EPA Levels Document extremely high levels of infrasound can cause mild stress reactions and such unusual auditory sensations as pulsating or fluttering (Ref. 5). The threshold for these symptoms is about 120 dB sound pressure level in the 1-16 Hertz range. The EPA sees no serious health hazard in infrasound intensities where the sound pressure level is below 130 dB. To consider a

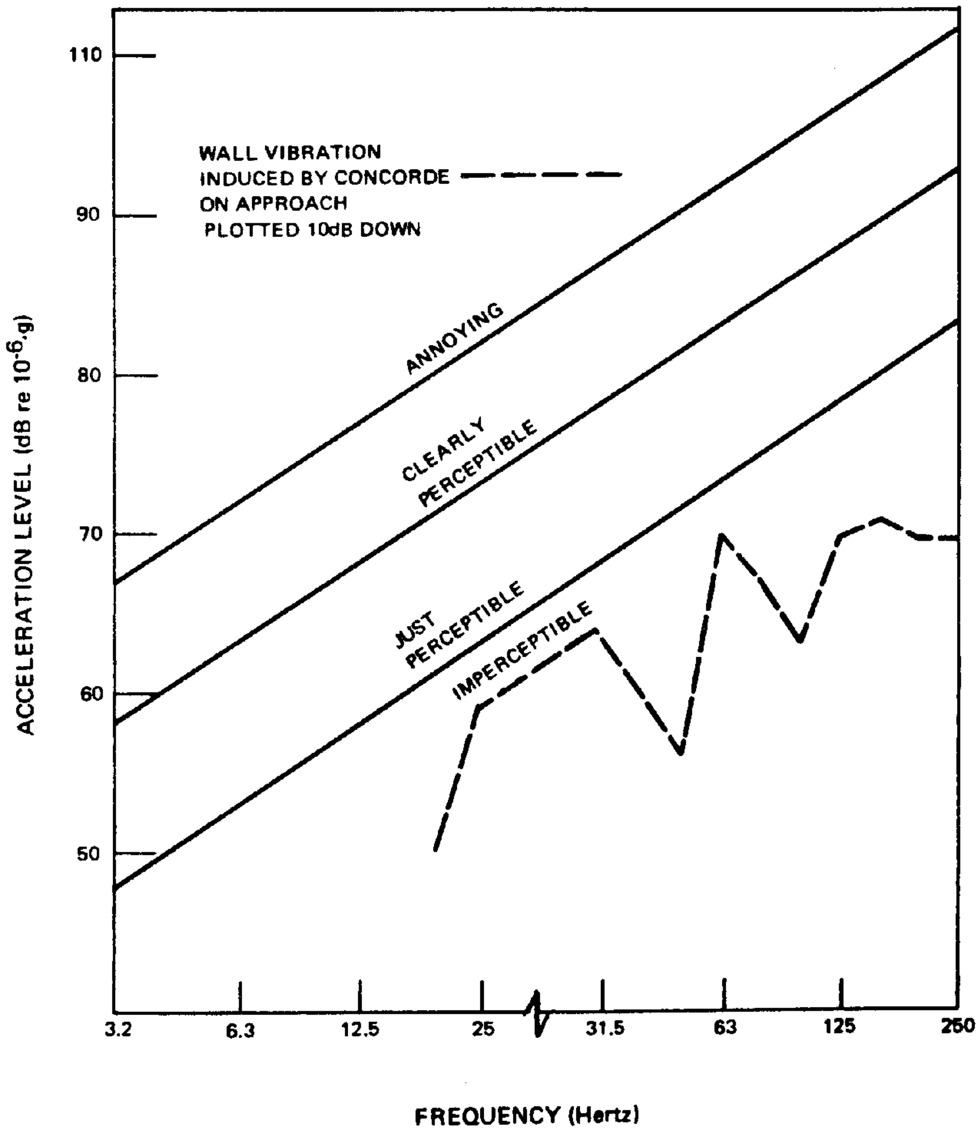
Figure 10.1



RELATIONSHIPS BETWEEN VERTICAL SINUSOIDAL VIBRATION LEVELS AND SUBJECTIVE RESPONSE

(Ref. 4)

Figure 10.2



RELATIONSHIPS BETWEEN VERTICAL SINUSOIDAL VIBRATION LEVELS AND SUBJECTIVE RESPONSE

(Ref. 4)

worst case example, the Concorde supersonic transport creates sound pressure levels at low frequencies (below 30 Hz) which are well below EPA sensation and damage risk levels. All other commercial transport levels fall below those of the Concorde, indicating no potential health effects associated with low frequency noise from in-service commercial aircraft.

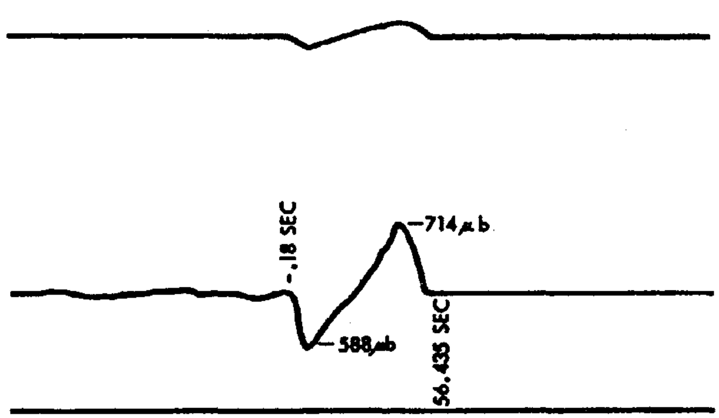
10.5.2 International Standards Organization (ISO). Generally, human tolerance of vibration is lowest in the 4-8 Hz frequency range, and this is the basis of limits proposed by the ISO Technical Committee 108 Working Group. Human tolerance to vibration also depends on situational factors; for example, the blurring of vision which is merely an annoyance to a train passenger could impair safety and efficiency in the workplace. It is also not known to what extent non-auditory sensations of noise are symptoms of psychological stress.

10.6 SONIC BOOM

FAA flight rules require civil aircraft to fly at subsonic speed over U.S. land areas in order to prevent sonic booms from impacting the U.S. environment. For supersonic aircraft approaching or leaving U.S. boundaries, flight rules stipulate that the aircraft be operated in a manner that will not cause direct sonic shock waves to encroach upon the U.S. (Ref. 6).

Sonic booms result when a projectile such as an aircraft exceed the speed of sound. The phenomenon we call a boom is similar in many ways to an explosion, characterized by a rapid increase in pressure above the ambient pressure, followed by a negative pressure excursion. An example of this N-wave signature is shown in Figure 10.3.

Figure 10.3



Sonic Boom (Ref. 7)

A great deal of research was conducted in the 1950's and 1960's by the U.S. Air Force and prospective manufacturers of the an American SST. (The U.S. SST program was eventually cancelled). The relationships between sonic boom overpressures and resulting damage and community response are presented in Table 10.1 (Ref. 7). One publication concludes "The human reaction to shock wave noise has been fairly well correlated. It has been concluded that 1.0 pound per square foot (overpressure) will cause no damage to ground structures and no significant public reaction day or night."

Table 10.1

Interim Prediction of Effects of Ground Overpressures

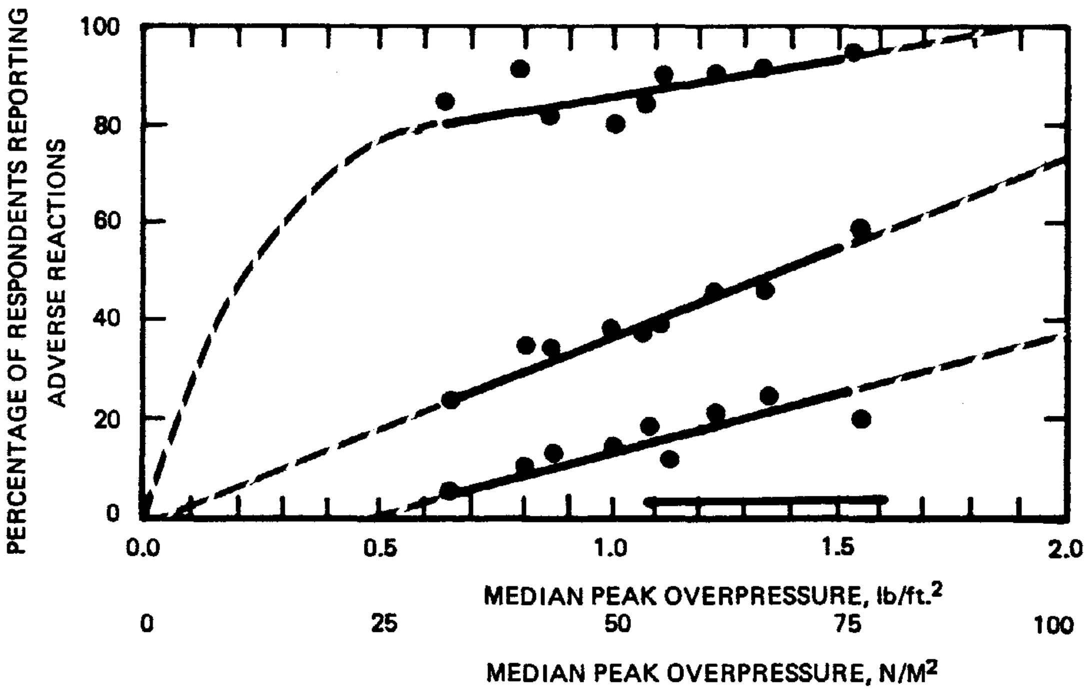
Reference ground overpressures psf	Predicted effects
0–1	No damage to ground structures; no significant public reaction day or night.
1.0–1.5	No damage to ground structures; probable public reaction.
1.5–1.75	No damage to ground structures; significant public reaction particularly at night.
1.75–2.0	No damage to ground structures; significant public reaction.
2.0–3.0	Incipient damage; widespread public reaction day and night.

(Ref. 7)

One of the most famous studies on the sonic boom was conducted in 1964 over Oklahoma City (Ref. 8). Eight sonic booms a day at a median peak overpressure level of 1.2 psf (57.46 pascals) were experienced by this community over a six-month period. Figure 10.4, below, reveals the percentage of responding residents who reported adverse reactions to the sonic booms. Based on this and many other studies, the U.S. EPA has stated that "the peak overpressure of a sonic boom that occurs during the day should be no more than 35.91 pascals (0.75 psf) if the population is not to be annoyed or the general health and welfare adversely affected " (Ref. 9).

As a matter of interest, a rather unusual phenomenon called secondary sonic booms were observed shortly after the introduction of Concorde service to the U.S. In essence, sonic shock waves from the Concorde were refracting off the discontinuity at the top of the earth's atmosphere and bending back down to the earth. While the level of the overpressures was not high enough to cause any damage, people did take notice. After a study of these "mystery booms" by the FAA / DOT (Ref. 10), the Concorde pilots implemented changes in their operational procedures to minimize the occurrences.

Figure 10.4



PERCENTAGE OF RESPONDENTS REPORTING ADVERSE REACTIONS TO SONIC BOOMS

NOTE: Data compiled from Oklahoma City Study. Dashed lines are extrapolations.
All data for 8 sonic boom/day.

(Ref. 8)

10.7 CONCLUSION

As discussed in this section, low frequency sound and its effects are relatively minor considerations in assesing aircraft nose impact. The case of helicopter operations in close proximity to buildings, however, remains an area warranting close scrutiny.

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Section 11.0 IMPULSIVE NOISE

SUMMARY

INTRODUCTION

Over the past 10 years, researchers in aviation acoustics have suggested that penalties be assessed (dB increments added) for sounds which possess impulsive characteristics. Helicopter blade slap which accompanies certain modes of flight operation has been the primary subject of this research. This section reviews the research and, as elsewhere, finds conflicting results. While some researchers find the need for an adjustment others do not. Complex distinctions between detectability and annoyance are key to the debate. In the end, the position adopted by the International Civil Aviation Organization (ICAO) was that no correction is necessary. Nonetheless, the Helicopter Association International (HAI), and the FAA continue to conduct research to minimize impulsive helicopter noise.

AVIATION APPLICATION/ISSUES

The question is raised, in connection with helicopter noise, whether or not an impulsivity correction is necessary to properly assess human reaction.

GUIDANCE/POLICY/EXPERIENCE

After years of research, ICAO concluded that an impulsivity adjustment was unnecessary to properly certificate aircraft; this, in effect, implies that human response is adequately assessed without a special impulsivity adjustment to the EPNL metric. Nonetheless efforts continue to reduce impulsive noise which dominates helicopter noise in certain flight regimes.

11.1 INTRODUCTION

During the past ten years, a great deal of research was devoted to evaluating the need for a correction factor or term to account for possible increased annoyance associated with highly impulsive acoustical noise events. The main focus of this activity has been impulsive helicopter noise which occurs during specific operational flight regimes, primarily high speed level flight and particular descent modes. This impulsive sound is sometimes characterized as slapping or banging. These research concerns were driven by the need to develop an adequate metric for use in a proposed international helicopter noise certification standard.

11.2 REVIEW OF STUDIES

The findings of many studies concluded that the currently used aircraft noise certification metric, EPNL, did an adequate job of quantifying human annoyance response to impulsive helicopter noise events. The studies briefly synopsized below found, for the most part, that no adjustment would be needed to the EPNL metric to account for impulsiveness.

11.2.1 1977 French Report. In a 1977 report, French researchers concluded that impulsive noise is up to 6 dB more annoying than non-impulsive noise (Ref. 1). They had carried out an evaluation of impulsive noise using subjects who compared pairs of non-impulsive and impulsive noises. Pulse duration, type, degree, level and repetition frequency were all considered; the degree of impulsivity, or the magnitude of impulsive compared with non-impulsive noise, seemed to have the most influence on the subjects' responses.

11.2.2 1977 U.S. Army Report. The U.S. Army Medical Research Laboratory also issued a report in 1977 which addressed the issue of a penalty for impulsive noise (Ref. 2). In their test, subjects listened to a fixed wing aircraft as it passed overhead, then rated each flyover of a rotary-wing aircraft relative to the fixed-wing. Although the Army stated in the conclusion of its report that a 2 dB penalty for helicopters was suggested by their results, they asserted that "no correction for blade slap was found which improves the prediction of annoyance."

11.2.3 1978 NASA Report. In 1978 NASA sponsored a field study of helicopter blade slap noise. (Ref. 3). Subjects in this study, located both indoors and out, judged the noisiness of two helicopters and a propeller-driven airplane during controlled flyovers. One helicopter was operated to provide several levels of blade slap (impulsiveness); the other varied little in impulsiveness. Among the results of the study was the finding that, for equal EPNL, the more impulsive helicopter was consistently judged less noisy than the less impulsive helicopter. The report published from this study concluded that no significant improvement in the "noisiness predictive ability of EPNL" was provided by a crest impulsiveness correction.

11.2.4 1981 United Kingdom Paper. In December of 1981, researchers of the United Kingdom presented a paper to the ICAO Committee on Aircraft

Noise which supports the conclusions of the U.S. Army and NASA. (Ref. 4). These researchers found that a proposed impulsive correction does not make EPNL a better annoyance predictor; in fact, the opposite seems to hold true.

11.3 CONCLUSION

There is no need for a separate impulse correction to existing noise metrics to adequately quantify annoyance with helicopter noise. While efforts to reduce impulsive noise continues, research indicates that more detectable sounds are not necessarily more annoying.

REFERENCES

1. Wright, S.E. and A. Damongeot. Psychoacoustic Studies of Impulsive Noise. Paper #55, Third European Rotorcraft Powered Lift Aircraft Forum, Aeronautical and Astronautical Association of France, September 1971.

2. Patterson, James, Ben T. Mizo, Paul D. Schomer, Robert T. Camp. Subjective Ratings of Annoyance Produced by Rotary-Wind Aircraft Noise. U.S. Army Aeromedical Research Laboratory, Report No. 77-12. May 1977.

3. Powell, Clemans A. A Subjective Field Study of Helicopter Blade-Slap Noise. NSA Technical memorandum 78758, July 1978.

4. Loughborough University of Technology. Studies of Helicopter Noise Perception: Background Information Paper. ICAO Committee on Aircraft Noise, Working Group B, December 1981.

Section 12.0 TIME OF DAY WEIGHTINGS FOR AIRCRAFT NOISE

SUMMARY

INTRODUCTION

The issue of whether noise occurring at different times of the day should be assigned weighting factors to represent different human sensitivity to noise intrusion has been a subject of much concern and research over the past 35 years. This section briefly reviews the research and practice. The metric selected by the FAA as the standard for use in airport noise impact assessment uses a 10 dB nighttime weighting factor.

AVIATION APPLICATON/ISSUES

1. Should aircraft noise occurring in the evening or at nighttime be assigned a weighting penalty to account for increased sensitivity to noise intrusions?

2. If a weighting is appropriate, what is the value of the weighting function?

GUIDANCE/POLICY/EXPERIENCE

The FAA has designated the Yearly Average Day Night Sound Level as the metric for assessing airport cumulative noise impact. This metric assigns a 10 dB weighting between the hours of 10 p.m. and 7 a.m.

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12.1 HISTORICAL BAKCGROUND

12.1.1 CNR. The question of time-of-day first gained attention around 1951, when the Composite Noise Rating (CNR) scheme was developed. This method attempted to relate the noise and attributes of a community to a method which would estimate community response to aircraft noise. The CNR considered the background, or ambient noise level as well as just aircraft noise at night. The CNR penalized aircraft noise 5 dB just because it occurred at night, and another 5 dB because the background noise decreases about 5 dB at night. This reasoning has remained constant, in part forming an historical basis for the FAA's decision to penalize nighttime noise 10 dB. Later, revisions were made to the CNR, but in each case the 10 dB nighttime penalty was retained.

12.1.2 NNI. Another system of measuring noise differences was the British Noise and Number Index (NNI). This index, when reduced to similar terms as the CNR, indicated an 11 dB penalty for nighttime noise, a value comparable to the 10 dB in use.

12.1.3 NEF. In 1967, yet another measure was developed -- the Noise Exposure Forecast (NEF). NEF was the first measure which was derived from the effective perceived noise level (EPNL). The NEF imposed a 12.2 dB adjustment for nighttime noise events. The 12.2 dB adjustment corresponds to a nighttime multiplier of 16.7.

Several other methods of measuring the noise around airports were pursued, but eventually the FAA and much of the community that deals with noise settled on the day/night average sound level (DNL) as the accepted measure. Using this measure, the 10 dB penalty for nighttime noise remains intact.

12.2 REVIEW OF THE CHOICE OF DNL

The choice of DNL as the "accepted" time of day metric was extensively examined at a workshop held at NASA Langley Research Center in 1980. (Ref. 1) There was much comment on the validity of DNL. One discussion group pointed out that the 10 dB penalty of the DNL was borrowed from earlier cumulative noise measures which were based on limited data and intuitive judgements. Many current studies suggest that people may actually be more sensitive to noise in the evening rather than late at night. Other conference members asked whether the penalty of 10 dB was a valid number clearly related to community response or if it merely indicates that nighttime noise is less desirable than daytime noise.

The merits and deficiencies of the DNL metric were also examined. Table 12. relates the outcome of that discussion.

Table 12.1

DNL Merits	DNL Deficiencies
Accepted by all levels of government	Energy summation method sometimes yields bizarre results with nighttime weighting factor. Lacks uniform confidence in the scientific community
Accepted internationally Used to assess all community noise sources	Hides some value judgments from the user
Relates to L_{eq}--generally accepted for hearing loss assessment	Ignores time of week and seasonal variations
Allows one to relate exposure to instaneous rms level and single event level	Not known if the 10dB penalty is truly representative of all effects
Correlates well with human response	Not known if the time periods of appication or the magnitude of the penalty are valid
Nighttime penalty looks reasonable with regard to range of data	
Ability to account for more than annoyance puts an adequate weight on other health effects	
Quantifies dose as a single number	

Various recommendations were offered by conference participants concerning DNL. The representatives of several governmental agencies spoke in favor of maintaining agreement between Federal agencies as to what metric to use; they also stated a desire to have that metric be one that is applicable to all kinds of noise, (i.e. traffic, background, aircraft) which DNL is. Other recommendations from conference discussion groups and individuals included the following:

1. Researchers were urged to reconsider changing lifestyles and to reflect on whether 10 PM to 7 AM is the most sensitive portion of the day. Evening or transition may be more important.

2. DNL should remain a rough screening device. The DNL penalty, for example, could impact school operations if a large number of operations were shifted to the day. The public is urged to pursue local independent decisions on this matter.

3. Several individuals suggested removing the nighttime weighting altogether and displaying day/night and weekend/seasonal information separately, using the L_{eq} metric for the respective time periods.

4. DNL is intended to measure annoyance, not health, effects. However, any new nighttime penalty should perhaps consider sleep disturbance, speech interference and other effects.

The consensus of the conference groups seemed to be that, given its long history, its current wide acceptance and use, and the fact that there has been no strong alternative offered by research to date, DNL should remain the "accepted" measure.

12.3 STUDY RESULTS

As was noted by the NASA Langley Workshop discussed above, the nighttime noise penalty was derived intuitively - researchers assumed that nighttime noise is more disturbing to people than daytime noise. While there are a few studies that do support this assumption, many others present conflicting or contradictory views. A recent report sponsored by NASA Langley/FAA summarized conflicting report findings on time of day considerations (Ref. 2).

The many reports on time of day have revealed a number of variables that make it difficult (if not impossible) to make a clear statement about when noise is most annoying. For instance, various studies have found that:

- people report at least one awakening per night regardless of the presence or absence of noise
- actual sleep disturbance and people's report of sleep disturbance is weakly related
- people's reported annoyance/disturbance did not decrease after actual flights were reduced.
- People's age and sex both seem to partially determine how much and how easily a person is awakened at night.

There is also the possibility that people's perception of and annoyance with daytime noise affects their perception of nighttime noise. Some researchers feel that there may be more complaints about nighttime noise because people view it as a more valid complaint than something like television disruption; thus, the perspective on time-of-day may be skewed. One study suggested that daytime activities, which usually involve communicating or concentrating tasks, might be more sensitive to interruption than sleep.

The report stated that the one point that researchers seem to agree on -- although again, empirical evidence is scant -- is that the most annoying/disturbing times for noise to occur are when a person is trying to go to sleep and when he is preparing to awaken. However, bedtime varies greatly for people; it could be anywhere from 9:30 p.m. to 12:30 a.m. Thus it is hard to designate a specific time that is the most disturbing for aircraft noise to occur. The NASA Langley/FAA report concluded that no solid conclusion could be drawn about the suitability of present time-of-day models.

In addition to social surveys which attempt to determine people's nighttime annoyance with noise, a few studies have been conducted on the ambient noise level and its relationship to aircraft noise. The findings, once again, appear to be contradictory. Some studies (Ref. 3) seem to suggest that with higher background noise, annoyance with aircraft noise will be greater, while others suggest (Ref. 4) that there is little or no correlation between annoyance and ambient noise. Thus, no firm conclusion may be drawn concerning ambient levels and aircraft noise.

12.4 CONCLUSION

After fifteen years of use, the DNL has shown itself to be a workable tool for the noise community. Its use as the accepted measure in time of day considerations, with its nighttime penalty of 10 dB between 10 p.m. and 7 p.m., will continue unless future research can suggest a reasonable alternative.

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1. Workshop Proceedings, NASA Langley Research Center. Time of Day Corrections to Aircraft Noise Metrics. Rep. No. FAA-EE-80-3, March 1980.

2. Fields, James M. Research on the Effect of Noise at Differenct Times of Day: Models, Methods and Findings. Unpublished Report, August 1984.

3. Pearson, K. S. The Effects of Duration and Background Noise level on Perceived Noisiness. FAA ADS-78, Federal Aviation Administration, April 1966.

4. Taylor S. M., F. L. Hall and S. E. Bernie. Effect of Background Levels on Community Responses to Aircraft Noise, J. Sound & Vib, Vol. 71, No. 2, July 22, 1980.

Section 13.0 NOISE CONTOURS

SUMMARY

INTRODUCTION

Noise contours or footprints are the accepted technique for displaying airport cumulative noise exposure. Noise contours are also employed in comparing the noise footprints of individual aircraft. Contours can be developed for different noise indicies, but airport contours generally express DNL while individual aircraft contours usually portray either SEL, EPNL or ALm.

AVIATION APPLICATION/ISSUES

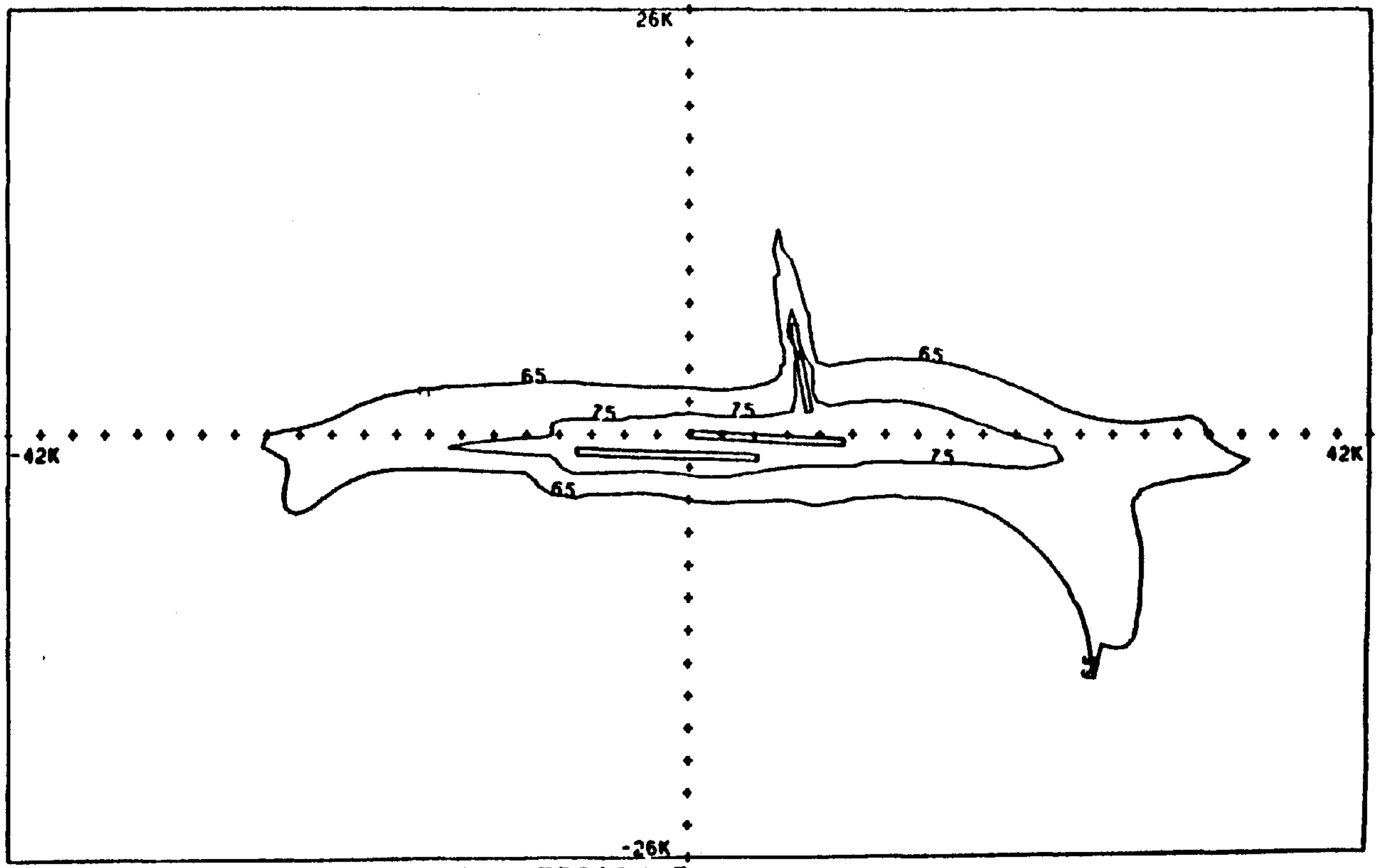
1. Contours are used as the tool to assess land use compatibility.

2. Contours are also used to portray the noise exposure of single operations of various aircraft types.

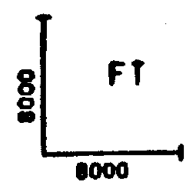
GUIDANCE/POLICY/EXPERIENCE

The noise contour program developed by the FAA and approved for use in FAA funded airport land use compatibility studies is the Integrated Noise Model or INM. This program can also generate single event contours. A new microcomputer-based model which will generate noise contours for helicopers is now under development.

FIGURE 13.1



FAA INTEGRATED NOISE MODEL VERSION 3
ANNUAL AVERAGE EXPOSURE AT AN EXAMPLE OF A MEDIUM HUB AIRPORT
EXAMPLE (MHA)
METRIC= LDN



13.1 INTRODUCTION

The principal tool for analyzing land use compatibility in the vicinity of airports and heliports is the noise footprint or contour. The noise contour represents a line of equal exposure. Noise exposure is expressed using the yearly average day-night sound level, DNL expressed in decibels.

The noise contours are generated using a computer simulation of the yearly average daily operations. The computer program developed for this purpose by the FAA is known as the Integrated Noise Model, or INM. This program has traditionally run on a mainframe computer, but is now available on at least two microcomputers (IBM XT and AT). In addition to the INM, the FAA is presently involved in developing a microcomputer-based Heliport Noise Model (HNM).

Noise contours are usually presented as overlays on 1" = 2000 feet U.S. Geological Survey quarter sectional maps. This allows easy identification of land use categories and surface references. Figure 13.1 displays the standard INM test case noise contour.

Information on noise contours is available from the FAA. Reports on the use of FAA-approved noise contour methodology include:

Flythe, M. C., "INM Integrated Noise Model, Version 3 User's Guide," FAA-EE-81-17, October 1982.

Federal Aviation Administration, "INM Integrated Noise Model, Version 3--Installation Instruction," October 1982.

Connor, T. L. and D. N. Fortescue, "Area Equivalent Method on VISICALC®," FAA-EE-84-8, February 1984.

Warren, D. G., "Area Equivalent Method on LOTUS 1-2-3," FAA-EE-81-12, July 1984.

To acquire any of these noise impact models or for any additional information, contact:

FAA Office of Environment and Energy
Noise Technology Branch
AEE-120
ATTN: Tom Connor or Donna Warren
800 Independence Avenue
Washington, D.C. 20591

13.2 THE USES AND INTERPRETATION OF NOISE CONTOURS

The uses of the noise contour include compatibility planning and parametric studies of airport operations such as:

1) variation in aircraft ground tracks
2) departure profiles
3) aircraft mix
4) introduction of new aircraft
5) changes in numbers of operations, and
6) introduction of new runways

13.3 APPLICATION AND INTERPRETATION OF NOISE CONTOURS

13.3.1 DNL 65 Contour. Noise contours provide the important guidance necessary to make sensible zoning and planning decisions, avoiding incompatible land use in areas of high noise levels. Noise contours, especially at lower levels, can be visualized as somewhat fuzzy bands which become more and more discrete and sharp as the exposure level increases. For example, a DNL 55 contour would be rather fuzzy, while a 75 DNL line would be sharply in focus. In effect, the confidence one has in a noise contour and its interpretation increases as the exposure level increases. It is therefore worthwhile to review the strengths and potential weakness of noise contours in representing noise impact.

The applications of the DNL 65 contour are diagramed in Figure 13.2 and are outlined below. The cautions previously alluded to are also set out below. It is worth noting that these qualifications simply identify possible misinterpretations and do not detract from the important general planning strengths.

Applications

1. Soundproofing may be required to achieve desired sound levels for certain building uses.

2. Conflicts may exist between certain land uses and predicted noise exposure as set out in FAA Compatible Land Use Guidelines.

3. General caution is offered to prospective home buyers.

4. Contour provides average net change, but may not be applicable at individual locations.

5. Homes within the contour may not be eligible for HUD mortgage insurance (discretionary).

Precautions

1. It is most important to emphasize that the DNL 65 contour does not form a boundary line between acceptable and unacceptable noise exposure.

2. Locations within contours do not necessarily require soundproofing nor are public buildings within contours automatically eligible for soundproofing assistance;

Figure 13.2

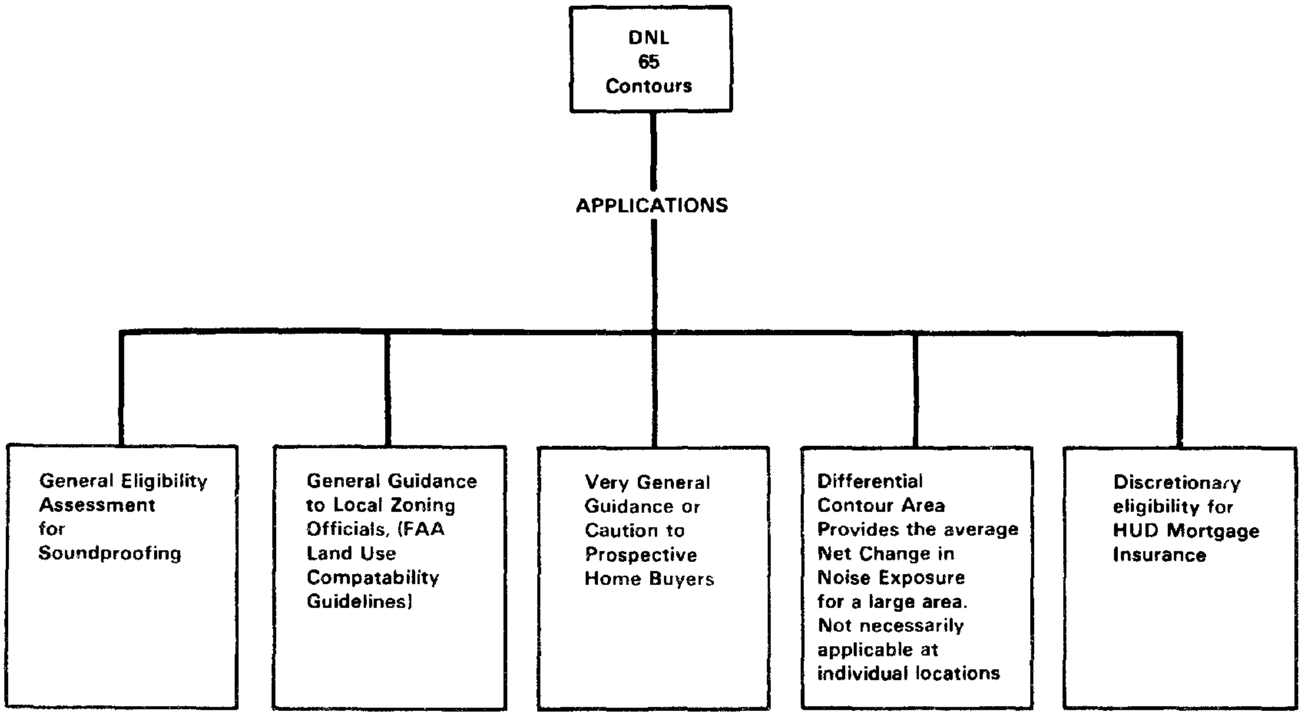
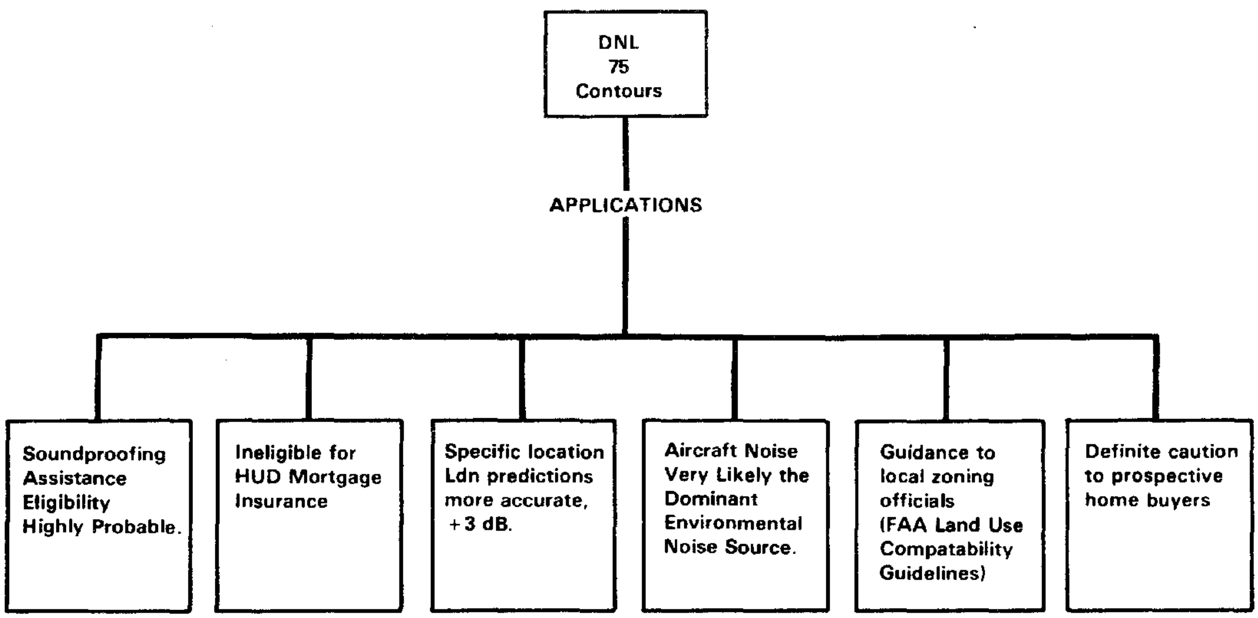


Figure 13.3



3. DNL contours or grid analyses do not accurately reflect noise exposure at specific locations. Predicted levels may vary ± 5 dB around actual measured levels for any given location.

4. Other noise sources in the environment may contribute as much or ore than aircraft to the total noise exposure at a specific location.

13.3.2 DNL 75 Contour. The DNL 75 contour is often considered the boundary between high (75) and moderate (65 - 75) noise exposure. The following interpretations are appropriate for those areas within DNL 75 contours:

1. Soundproofing is very likely required in many buildings (depending on use).

2. Homes are ineligible for HUD mortgage insurance.

3. Aircraft noise is very likely the dominant environmental noise source.

4. DNL prediction accuracy at specific locations improves to ± 3 dB.

5. Conflicts very likely exist between predicted DNL values and land uses as set out in FAA Land Use Compatibility Guidelines.

6. Definite caution is offered to prospective home buyers.

Figure 13.3 diagrams these applications of DNL 75 contours. It is recommended that perspective home buyers be firmly advised of the above conditions.

Section 14.0 AIRPORT NOISE EXPOSURE AND LAND USE COMPATIBILITY

SUMMARY

INTRODUCTION

This section describes the development of criteria linking cumulative airport noise exposure and compatible land use. Criteria are presented which have been designated for use in FAA funded compatibility studies.

AVIATION APPLICATION/ISSUES

1. FAR PART 150, Airport Noise Compatibility Programs
2. Planning guidance for developers and zoning officials.
3. Guidance for the granting of HUD and VA mortgage guarantees.
4. Airport master plans.
5. Environmental Impact Assessments

GUIDANCE/POLICY/EXPERIENCE

The FAA has published criteria in FAR PART 150 for use in compatibility studies. Other similiar criteria have been published by the Department of Defense, the Federal Interagency Committee on Urban Noise, and the American National Standards Institute (ANSI).

14.1 INTRODUCTION

Throughout the past 25 years, architects, engineers, planners, and zoning officials have developed and employed a variety of land use noise exposure guidelines. Regardless of the particular set of guidelines selected, there is always a range of noise exposure levels associated with a given land use. The relative position of the compatibility interval is arbitrarily defined, usually within 5 to 10 dB of some absolute level. The non-exact, fuzzy-edged nature of compatibility intervals is important to note in application of land use guidelines. Land use guidelines are a planning tool and as such provide general indications as to whether particular land uses are appropriate for certain measured noise exposure levels. The FAA has elected to use criteria based on

(1) Federal Interagency Committee on Urban Noise: Guidelines for Considering Noise in Land use Planning and Control, and

(2) American National Standard Institute (ANSI) publication, "Sound Level Descriptions for Determination of Compatible Land Use (ANSI S3.23-1980)

for establishing airport noise land use compatibility guidelines (Ref. 1). In making compatibility decisions, noise contours are generally used as guidelines; Section 13.0 discusses applications of DNL contours.

14.2 FAA FAR PART 150 GUIDELINES

In FAR Part 150, the FAA has identified land uses which are normally compatible (or noncompatible) with various exposures of individuals to noise (Ref. 1). This was done in compliance with the Aviation Safety and Noise Abatement Act of 1979 and is the criteria for use inpreparing Airport Noise Exposure Maps and Airport Noise Compatibility Programs submitted under FAR Part 150. All Federal grants issued after Fiscal Year 1986 for noise compatibility planning or development at airports must be in accordance with FAR Part 150. This table is a refinement of Federal and International noise/land use compatibility criteria and is compatible with criteria used by other Federal agencies. It is the only noise/land use compatibility table in the U.S. Code of Federal Regulations (CFR) (14 CFR 150). The Part 150 Table is also compatible in most essential areas with the table published by the American National Standards Institute (ANSI). Table 14.1 offers sample comparisons of the Part 150 table and the ANSI table.

Table 14.2 reproduces the FAA land use table (Ref. 2). (The categories of this table are detailed further in FAA Advisory Circular 150/5020-1.). In addition to FAA and ANSI guidelines, other land use compatibility tables have also been developed.

TABLE 14.1

Land Use	ANSI Standard	FAA Standard
Livestock Farming	Compatible to 65 dB Marginally compatible to 75 dB Incompatible above 75 dB	Compatible to 75 dB
General Manufacturing	Compatible to 70 dB Marginally to 80 dB Incompatible above 80 dB	Compatible to 85 dB Incompatible above 85 dB
Music Shells	Marginally to 65 dB	Compatible to 64 dB
Playground, Riding, Golf	Compatible to 60 dB Marginally to 75 dB Incompatible above 75 dB	Compatible to 70 dB Compatible with special details up to 80 dB

14.3 FEDERAL INTERAGENCY CRITERIA

Guidelines for considering Noise in Land use Planning and Control was published in June 1980 by the Federal Interagency Committee on Urban Noise. This Committee is comprised of representatives from the Departments of Defense, Transportation and Housing and Urban Development, the Veterans' Administration and the Environmental Protection Agency, the five Federal agencies most involved in noise, land use, or environmental policy. Without overriding any agency's existing policies or regulations, the Guidelines provide a foundation for an integrated Federal system of noise/land use policy. As a consequence, FAA, DoD and HUD policy and regulations relative to airport noise and housing are quite compatible.

The Interagency document also contains a summary of the many techniques that local governments can use to reduce the effect of noise on surrounding land uses. These techniques range from simply increasing public awarenes of noise levels, to developing land use codes and zoning policies, to the drastic but effective measure of public purchase of severely exposed land.

14.4 DEPARTMENT OF DEFENSE AICUZ CRITERIA

The Department of Defense has also developed a comprehensive program to minimize the harmful effects of aircraft noise (Ref. 4). The Air Installation Compatible Use Zones (AICUZ) program requires that all military installations be studied in depth to determine those land areas which should be specially considered in development because they are

TABLE 14.2

—LAND USE COMPATIBILITY* WITH YEARLY DAY-NIGHT AVERAGE SOUND LEVELS

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 use 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 FOR TABLE 1

(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 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 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 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.

affected by aircraft noise (the AICUZ program also considers how susceptible an area is to aircraft accidents in its compatibility decisions). This system is also based on the DNL metric. Three zones are identified in the AICUZ structure:

NOISE ZONE	DNL	RESPONSE
3	Greater than 75 dBA	Zone of highest intensity; frequency and intensity of noise is such as to be loud and annoying. (Inhabitants may complain repeatedly and even form groups to protest.)
2	65-75 dBA	Second most intensive zone; noise is more moderate in character. (Inhabitants may complain vigorously and concerted group action is a possibility.)
1	Less than 65 dBA	Lowest noise level zone; the noise may, however, interfere occasionally with certain activities of the residents.

The AICUZ recommends that land around airports on air installations be developed with consideration to these noise zone guidelines. The AICUZ also offers recommended land uses for each zone -- see Table 14.3 below.

14.5 HUD AND VA CRITERIA.

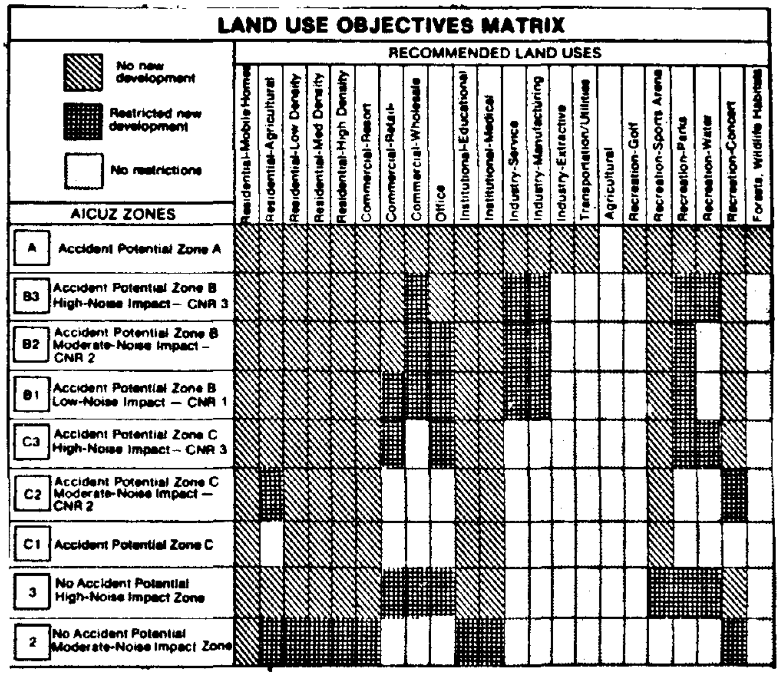
Both the Department of Housing and Urban Development and the Veterans' Administration have issued noise regulations. The purpose of the HUD regulations is to protect individuals from noise in their communities and places of residence. Basically, HUD policy states that HUD assistance is prohibited for projects with "Unacceptable" noise exposures (noise levels above 75 dB (DNL) and is discouraged for projects with "Normally Unacceptable" noise exposures (i.e. a noise level above 65 dB but under 75 dB). These noise levels take into account noise from highways, railroads and aircraft.

The Veterans' Administration has also issued a series of statements of policy regarding noise and land use planning.

14.6 CONCLUSION

This section has described numerous sets of land use compatibility guidelines. All of them may prove useful to local governments in their efforts to pursue development that is compatible with various noise levels in their area. For matters involving FAA policy, the guidelines presented in Table 14.2 are the recommended compatibility assessment tool.

Table 14.3



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2. FAA Code of Federal Regulations, Part 150.

3. Federal Interagency Committee on Urban Noise. Guidelines for Considering Noise in Land Use Planning and Control. June 1980.

4. U.S. Air Force. Manual 19-10. Planning in the Noise Environment. Chapter 4.

Section 15.0 EFFECT OF AIRCRAFT NOISE ON REAL ESTATE VALUES

SUMMARY

INTRODUCTION

This section reviews research conducted to assess the effect of aircraft noise on real estate values. While an effect is observed it is considered an influence which is often offset by the advantages associated with ready access to the airport and employment opportunities.

AVIATION APPLICATION/ISSUES

The effect of aircraft noise on real estate values is a topic often associated with environmental assessments.

GUDIANCE/POLICY/EXPERIENCE

Studies indicate that a one decibel change in cumulative airport noise exposure (in DNL) usually results in a 0.5 to 2% decrease in real estate values.

15.1 INTRODUCTION

Studies have shown that aircraft noise does decrease the value of residential property located around airports. Although there are many socio-economical factors which must be considered because they may negatively affect property values themselves, all research conducted in this area found negative effects from aviation noise, with effects ranging from a 0.6 to 2.3 percent decrease in property value per decibel increase of cumulative noise exposure. This section reports on those studies.

15.2 RESEARCH CONSIDERATIONS

A number of socio-economic factors besides aircraft noise can negatively affect real estate values. Such factors include:

--the size of the houses
--number of rooms per house
--the repair of the houses
--number of homes that are air-conditioned
--distance from business district
--percent of the housing that is minority
--number of lakes, parks or other amenities in the surrounding area

The absence of aircraft noise, then, is just one of many considerations the consumer must evaluate in buying or selling a residence. Researchers have been careful to consider these other effects and to normalize their influences in research studies. Yet even with other factors considered, increased aircraft noise does appear to lower property values.

15.3 REVIEW OF RESEARCH

To date, studies have been conducted analyzing nine airports in the U.S. and Canada comparing property values and noise exposure levels. These studies, which assess data gathered between 1960 and 1970, all employed the NEF, a noise measurement that has been superceded by the DNL as the FAA's accepted unit of cumulative noise measurement (see glossary and Section 2 for description of NEF and DNL). These studies are summarized by Jon Nelson in Economic Analysis of Transportation Noise Abatement; his summary is reproduced, with conversions to DNL, in Table 15.1 and discussed below (Ref. 1).

TABLE 15.1

Summary of Empirical Damage Estimate for Aircraft Noise and Property Values in Nine Urban Areas

Study Area (year, mean property value)	Range of Noise Levels (DNL)	Best NDI-DNL Estimate* (Percent)
New York (1960, $16,656)	55 - 75	1.9%
Los Angeles (1960, $19,772)	55 - 75	1.8
Dallas (1960, $18,011)	55 - 75	2.3
All Areas (1960, $18,074)	55 - 75	2.0
Minneapolis (1967, $19,683)	55 - 85	0.6
San Francisco (1970, $27,600)	60 - 80	1.5
San Jose (1970, $21,000)	60 - 80	0.7
Boston (1970, $13,000)	60 - 80	0.6
Toronto (1969-1973, $30-35,000)	55 - 70	0.9
Dallas (1970, $22,000)	55 - 90	0.6
Washington, D.C. (1970, $32,724)	55 - 70	1.0

*The NDI-NEF is the percentage decrease in a given property value per unit increase in the DNL.

Nelson found that the studies can be divided into two groups and some conclusions drawn. The first group of estimates in the table was based on 1960 data (and included New York, Los Angeles and Dallas) and suggests a range of 1.8 to 2.3 percent decrease in value per decibel (DNL). The second group of estimates, covering the period from 1967 to 1970, suggests a mean of 0.8 percent devaluation per decibel change in DNL. Nelson then excludes the San Francisco data (which was influenced by unique climatic and political differences) and finds a mean of 0.7 percent devaluation per decibel change in DNL.

Nelson also notes that there seems to be a decline in the noise depreciation index over time, from 1960-1970. This could be due either to noise sensitive people being replaced by those less bothered by noise, or to the enhanced commercial value of land near airports. Evidence exists to support either of these hypotheses (Ref. 2).

15.4 CONCLUSION

The bottom line is that noise has been shown to decrease the value of property by only a small amount -- approximately 1% decrease per decibel (DNL). At a minimum, the depreciation of a home due to aircraft noise is equal to the cost of moving to a new residence. Because there are many other factors that affect the price and desirability of a residence, the annoyance of aircraft noise remains just one of the considerations that affect the market value of a home.

REFERENCES

1. Nelson, Jon P. Economic Analysis of Transportation Noise Abatement. Ballenger Publishing Company: Cambridge, Massachusetts, 1978.

2. Crowley, R. W. A Case Study of the Effects on an Airport on Land Values. Journal of Transport Economics and Policy, Vol. 7, May, 1978.

AVIATION NOISE TECHNICAL STANDARDS AND RECOMMENDED PRACTICES

A vast amount of literature on aviation acoustics has been published by national and international standards organizations. These groups included:

International Electrotechnical Commission
1-3, rue de Varembe
CH-1211 Geneva 20, SWITZERLAND

International Organization for Standardization
1, rue de Varembe
Case postale 56
CH-1211 Geneva 20, SWITZERLAND

American National Standards Institute
1430 Broadway
New York, New York 10018

Society of Automotive Engineers
400 Commonwealth Drive
Warrendale, Pennsylvania 15096

The reader interested in more information on particular aviation noise-related topics may find the following reference list helpful.

IEC 225(1966): Octave, half-octave and third-octave band filters intended for the analysis of sounds and vibrations.

IEC 537 (1976): Frequency weighting for the measurement of aircraft noise (D-weighting).

IEC 561 (1976): Electro-acoustical measuring equipment for aircraft noise certification.

IEC 651 (1979): Sound level meters.

IEC 655 (1979): Values for the difference between free-field and pressure sensitivity levels for one-inch standard condenser microphones.

ISO 266-1975: Acoustics--Preferred frequencies for measurements.

ISO 2204-1979: Acoustics--Guide to International Standards on the measurement of airborne acoustical noise and evaluation of its effects on human beings.

ISO 2249-1973: Acoustics: Description and measurement of physical properties of sonic booms.

ISO 3891-1978: Acoustics: Procedure for describing aircraft noise heard on the ground.

ISO 5129-1981: Acoustics: Measurement of noise inside aircraft.

ANSI S1.1-1960 (R1979): American national standard acoustical terminology.

ANSI S1.4-1983: American national standard specification for sound level meters

ANSI S1.6-1984: American national standard preferred reference quantities for acoustical measurements.

ANSI S1.8-1969 (R1974): American national standard preferred reference quantities for acoustical levels.

ANSI S1.13-1971 (R1979): American national standard methods for the measurement of sound pressure levels.

ANSI S1.40-1984: American national standard specification for acoustical calibrators.

ANSI S3.5-1969 (R1978): American national standard methods for the calculation of the Articulation Index.

ANSI S3.14-1977: American national standard for rating noise with respect to speech interference.

ANSI S3.19-1974 (R1979): American national standard method for the measurement of real-ear protection of hearing protectors and physical attenuation of earmuffs.

ANSI/ASTM E336-77 (1977): Standard test method for measurement of airborne sound insulation in buildings.

ANSI/ASTM E413-73 (1980): Standard classification for sound transmission class.

ANSI/SAE ARP1071: Definitions and procedures for computing the effective perceived noise level for flyover aircraft noise.

ASA 22-1980: American national standard sound level descriptors for determination of compatible land use.

ASA 23-1978: American national standard method for the calculation of the absorption of sound by the atmosphere.

SAE AIR-852 (1965): Methods of comparing aircraft takeoff and approach noises.

SAE AIR-902 (1966): Determination of minimum distance from ground to aircraft for acoustic tests.

SAE AIR-923 (1966): Method for calculating the attenuation of aircraft ground-to-ground noise propagation during take-off and landing.

SAE AIR-1079 (1972): Aircraft noise research needs.

SAE AIR-1081 (1971): House noise-reduction measurements for use in studies of aircraft flyover noise.

SAE AIR-1115 (1969): Evaluation of headphones for demonstration of aircraft noise.

SAE AIR-1216 (1972): Ground runup and flyover noise levels: comparison.

SAE AIR-1286 (1973): Helicopter and V/STOL aircraft noise measurement problems.

SAE AIR-1407 (1977): Prediction procedure for near-field and far-field propeller noise.

SAE ARP-796 (1965): Measurements of exterior aircraft noise in the field.

SAE ARP-865B (1983): Definitions and procedures for computing the perceived noise level of aircraft noise.

SAE ARP-866A (1975): Standard values of atmospheric absorption as a function of temperature and humidity.

SAE ARP-1071 (1972): Definitions and procedures for computing the effective perceived nose level for flyover aircraft noise.

SAE ARP-1080 (1969): Frequency weighting network for approximation of perceived noise level for aircraft noise.

SAE ARP-1279 (1972): Standard indoor method of collection and presentation of the turboshaft base, engine noise data for use in helicopter installations.

SAE ARP-1307 (1979): Measurement of exterior noise produced by aircraft auxiliary power units (APUs) and associated equipment during ground operation.

SAE ARP-1323 (1978): Measurements of interior sound pressure levels in cruise type aircraft.