15 June 1978

Environmental Protection

PLANNING IN THE NOISE ENVIRONMENT

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DEPARTMENTS OF THE AIR FORCE,
THE ARMY, AND THE NAVY

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PLANNING IN THE NOISE ENVIRONMENT

This publication is to be used by installation planners as a procedural tool designed to aid in the development of acceptable noise environments for facilities on military installations. It presents guidance for selecting sites for new facilities within existing or expected future noise environments and discusses noise reduction techniques which may be applied to render marginally acceptable locations suitable for use. The guidelines presented are consistent with the Air Installation Compatible Use Zone (AICUZ) Program and land use recommendations generally accepted by the planning community. Recommendations for improvement of this publication should be addressed to HQ USAF/PREV.

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CHAPTER 1 INTRODUCTION

1-1 PURPOSE AND ORGANIZATION

This manual is a procedural tool designed to aid the creation of acceptable noise environments. It is written primarily for installation planners and other individuals concerned with the noise environment. It should also be useful to persons involved with environmental assessments.

The manual should be used by planners to provide an awareness of noise considerations which may be encountered during the planning process. Most of Chapters 1, 2, and 4 and other selected sections cover basic background information which is a prerequisite for dealing with noise problems. The balance of the manual contains information and procedures which will be referred to during the problem solving process.

Chapter 1 - Introduction

Introduction to the manual for the first-time reader.

Chapter 2 - Characteristics and Measurement of Noise

Background information on basic physical characteristics of noise and terminology used to describe them. Discussion of frequently used noise measures.

Chapter 3 - Noise Assessment Techniques

Procedures for estimating noise exposure from individual noise sources. Explanations of hand calculation techniques and methods to obtain more complete analyses, including computer generated contours.

Chapter 4 - Recommended Noise Levels

Background information describing allowable noise levels. Rationalization for the noise levels recommended.

Chapter 5 - Reducing Noise Conflict

Source by source discussion of noise abatement measures, their effectiveness, usage, and cost.

Chapter 6 - Noise Planning Strategies and Their Application

Procedural problem solving framework. Recommendations for developing ongoing noise planning programs dealing with siting and existing noise problems.

1-2 BACKGROUND OF NOISE PLANNING

Noise, or unwanted sound, can be harmful to an individual's health (physiological and psychological) and can degrade the quality of life. Additionally, it can interfere with ‘effective task accomplishment and cause economic costs.

Noise problems are inherent to most military installations because of frequent use of specialized equipment and operation of industrial type facilities. For example, high noise levels result from aircraft, artillery, tracked vehicle and shipyard operations. People subjected to such an environment may suffer loss or impairment of hearing (permanent or temporary hearing threshold shift). Mental well-being may be affected by frequent interruption of sleep, conversation, or concentration. Such noise impacts may result in economic losses; medical and legal expenses and lowered rates of individual productivity.

Personnel with Noise Environment Responsibility

The fundamental goal is to protect individuals from noise levels which may jeopardize their health and welfare, within the context of facilitating installation missions. The responsibility for achieving this goal lies with the following personnel:

- o installation commanders
- o Medical authorities and bioenvironmental engineers
- o Scientists and technologists
- o Planners
- o Architects and engineers
- o Operators

Installation Commanders

The installation commander is responsible for the health and welfare of installation personnel and the efficient operation of the installation in the fulfillment of the assigned mission. He/she must insure that the individuals enumerated below meet their prescribed obligations with respect to maintaining an acceptable noise environment.

Medical Authorities

Among the responsibilities of medical and related authorities are the following: issue health and medical guidance, identify and evaluate noise related effects, provide consultation on the health aspects of noise, and identify hazardous or impacted noise environments (Reference 1-1 through 1-5). Furthermore, through medical research the more subtle effects of noise are being discovered and protection devices, such as ear plugs, are being improved,

Scientists and Technologists

The efforts of this group are directed mainly towards the noise source, as exemplified by the development of quieter engines, more effective mufflers and baffles, protective insulation, and other devices to reduce noise.

Planners

Installation planners are charged with maintaining noise compatible land use patterns. Because acceptable sites are not always available for noise sensitive uses, the planner must be aware of other noise abatement techniques such as building orientation, building attenuation, barriers, etc.

Architects and Engineers

As designers, architects and engineers have key roles in implementing structural and site specific noise abatement measures in the design and construction phase.

Operators

The largest group of individuals with noise abatement responsibility are operators, installers, and mechanics of noise producing machinery. This group is often! the least informed of its responsibility to adhere to noise oriented engineering and operational controls.

Broad Approach to Noise Reduction

Responsibilities for noise abatement rest with several groups and must be met in every quarter of the noise environment before the problem can be alleviated. There will usually be a choice of abatement approaches, and the most cost effective may be the best approach. Therefore,, planners must understand techniques outside their direct control. If planners are to create or maintain an environment of an acceptable quality, they must understand the techniques and the combinations thereof which will be effective. Therefore, this manual deals not only with abatement through land use planning but introduces the planner to the entire noise system and the points within this system where noise abatement is possible.

Because planners must take this broad view of noise planning, they must be prepared to assume a wide range of responsibilities. They will have to operate as information officers educating others (the public, activity commanders and officers, etc.) about noise considerations. They will have to draw activity commanders and experts together to develop noise abatement strategies. They will have to be advocates, recommending specific action by others. Planners (with assistance from others) will have to assess the problem, develop and recommend solutions, and provide monitoring to assure that implemented solutions are effective.

Future Noise Problems

This manual deals with preventing future problems as well as solving existing ones. Noise problems often require great expense or radical change to resolve but the planner, with the use of siting and other basic techniques, can prevent such problems. Awareness of potential problems is paramount in all modes of noise planning. The reader should be ever cognizant that the noise environment is not static.

1-3 OVERVIEW OF THE NOISE ABATEMENT SYSTEM

Noise, its creation, effects, and abatement, can be thought of in systemic terms. Achievement of the goal of protecting individuals from harmful noise levels requires a knowledge of the interrelationships of the noise system elements. Figure 1-3 depicts this system in a simplified form. All elements and relationships cannot be shown, but the model does illustrate how the elements are related and also how the sections of this manual fit together. in the following paragraphs, the various elements of the noise abatement system are described briefly and referenced to the appropriate section of the manual.

Source - Path - Receiver

The physical basis of the noise system is the noise source,, path, and receiver relationship. Noise emanates from a source, travels along a path, and is perceived by the receiver. Awareness of this concept is essential in the formulation of abatement techniques. Background data on this basic relationship is presented in Section 2-1, Basic Concepts.

Quantified Noise Data

Before a noise problem can be resolved, the nature and intensity of the noise must be quantified. As illustrated in Figure 1-3, noise is measured at a point in the path; the exact point between the source and the receiver dependent on the purpose of the measurement. Because of the different types of noise, (e.g., impulse, steady state, tonal, etc.), different types of measures have been developed to increase descriptive accuracy. The concepts behind various noise measures are covered in Section 2-2, Noise Measures. In Chapter 3, Noise Assessment Techniques, the appropriate measurement techniques for common sources are explained.

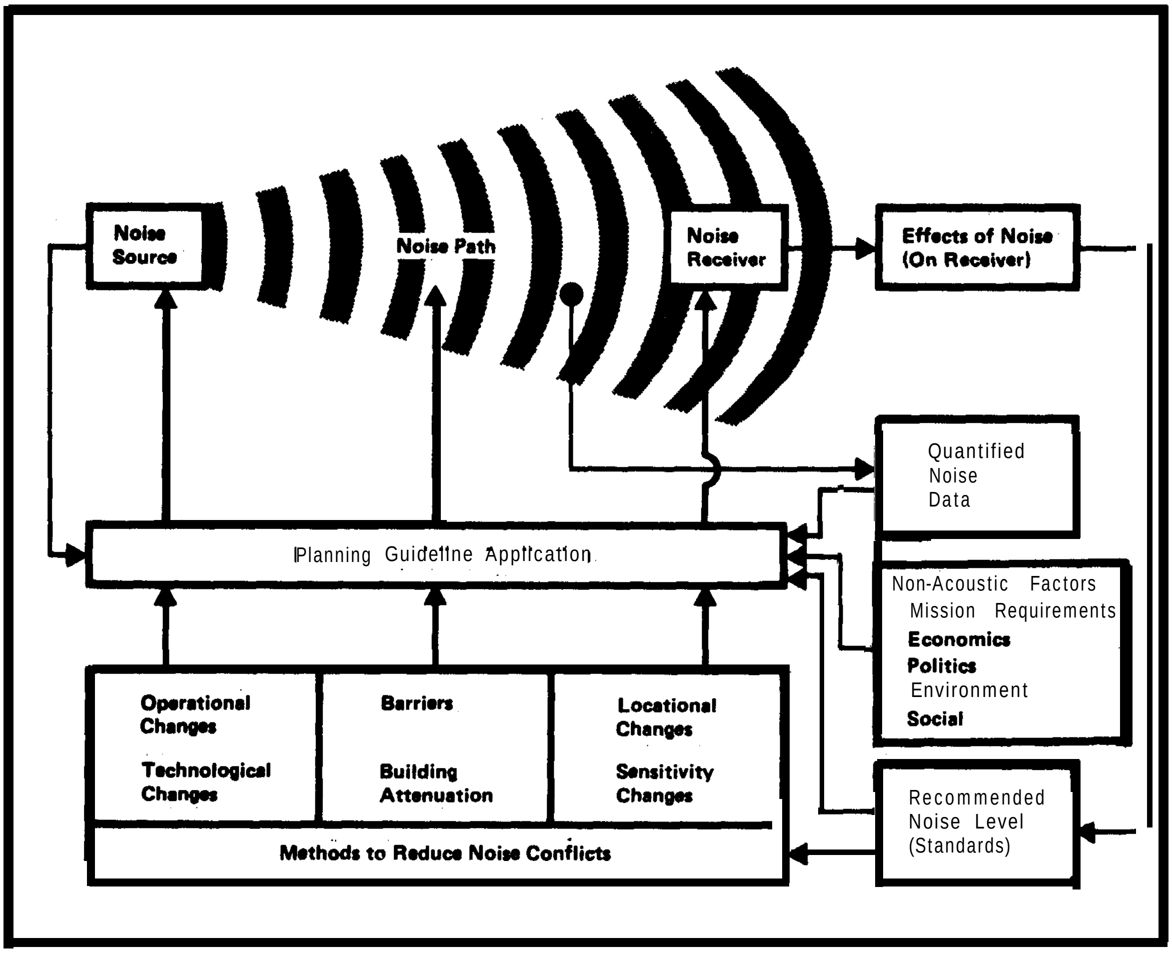
Effects of Noise (on Receiver)

The effect of noise on the receiver can be considered the focal point of the entire system because it is these effects which should be minimized. The physiological and psychological effects of noise are discussed and related to quantified noise levels in Chapter 4.

Recommended Noise Levels

With documentation of the effects of noise and relating these effects to corresponding noise levels, it is possible to produce recommended noise levels or standards. In Chapter 4, this topic is treated at length.

FIGURE 1-3 NOISE ABATEMENT SYSTEM



Reducing Noise Conflicts

Given standards on allowable noise levels and knowledge of the nature of the noise source, path, and receiver, it is possible to devise methods to reduce noise conflicts. As indicated on the bottom of Figure 1-3, methods to reduce adverse effects of noise may be applied at the noise source, along the path, or near the receiver. This subject is treated In Chapter 5, Reducing Noise Conflicts.

Planning Guidelines Application

The means available to reduce the adverse effects of noise on individuals are described in Chapter 6. In Chapter 6, Noise Planning: Guidelines and Application, the process is taken one step further, and a methodology for choosing and applying the optimal abatement techniques is presented. Referring again to Figure 1-3, the numerous arrows directed to the "planning guidelines application" box indicate that before implementation can occur planners must have quantified noise data and recommended noise levels, so that the problem can be identified. They must also have thorough knowledge of the source, path, and receiver and of the methods to reduce noise conflict so that they can judge which methods might be most effective. The final decision will be made in light of these data as well as local economic, political, environmental, and social factors and mission requirements.

CHAPTER 2 CHARACTERISTICS AND MEASUREMENTS OF NOISE

2-1 BASIC CONCEPTS

2-1.1 SOUND WAVES

As an object vibrates back and forth in the atmosphere, it collides with the surrounding air particles creating a pressure disturbance. These air particles collide with other air particles, thus causing the pressure disturbance to spread away from the source of vibration. At the ear this disturbance generates a vibration in the ear drum, which is transmitted via the network of bones in the ear to the cochlea, which converts the vibration into an electrical signal interpreted by the brain as sound.

The alternate grouping together ("compression") and spreading apart ("rarefaction") of the particles results in a variation of pressure above and below atmospheric pressure (see Figure 2-1.1). This "sound wave" travels in air at about 1,100 feet (335 meters) per second. The distance between successive compressions or successive rarefactions is the <u>wavelength</u> of the sound; the number of compressions or rarefactions occurring per unit time is the <u>frequency</u> of the sound.

These various parameters of the sound wave are related by the formula:

$$\lambda = \frac{c}{f}$$

where :

λ (Lambda) = wavelength in feet (or meters)

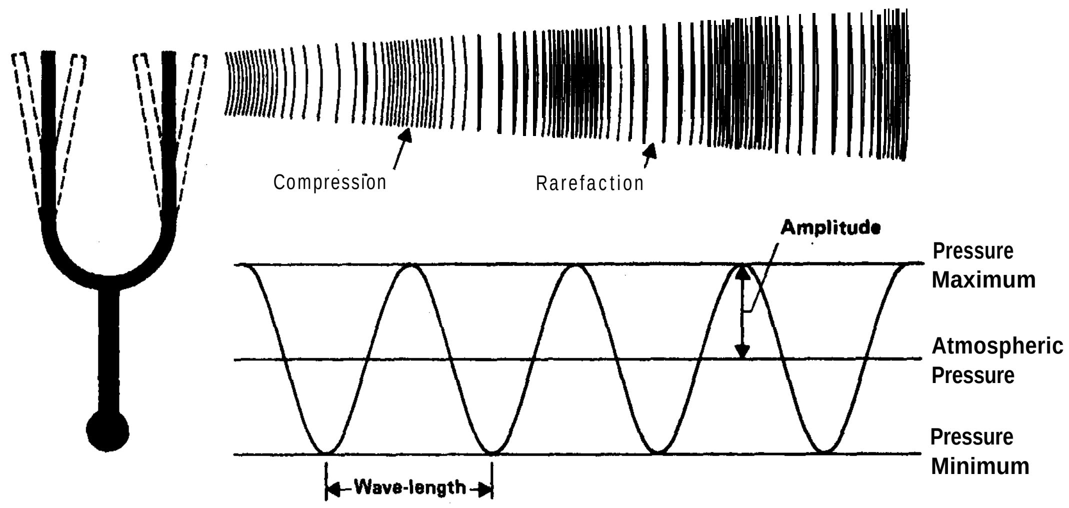
c - speed of sound in feet (or meters) per second

f = frequency in Hertz (Hz), cycles per second

2-1.2 DECIBEL SCALE

The sound pressure of a loud sound, such as that generated by a rocket engine, may be one billion times the sound pressure of a quiet sound such as a soft whisper. Because of this large range, and because the ear responds more closely to a logarithmic rather than linear base, sound levels are usually expressed on a logarithmic scale. The sound pressure level (SPL) of an acoustic signal is defined as:

FIGURE 2-1.1 **REPRESENTATION OF A SOUND WAVE**



$$SPL = 10 \log \left(\frac{P}{P_o}\right)^2 \qquad \text{(Eq.2-1)}$$

where :

P = the sound pressure of the acoustic signal above atmospheric pressure

P_o = a reference pressure, standardized at 20 micropascals (this reference pressure represents the weakest sound that can be heard by an average young undamaged ear).

SPL is expressed in units of decibels (dB)

As explained below, there are numerous noise measures in use, most of which are expressed in units of dB. There are major spectral and temporal (and possibly reference pressure) differences among these measures ; thus, to ensure proper use of decibel values, all underlying assumptions and characteristics should be understood.

Since decibels are logarithmic units, sound levels cannot be added by ordinary arithmetic means. For example, if a single engine on an aircraft produces a sound level of 90 dB at a particular location, two identical engines would not produce 180 dB. The term $(P/P)^2$ is a measure of the energy in theacoustic signal; addition of sound levels must be performed on an "energy basis" (see Example 2-1.2a).

Figure 2-1.2a illustrates a "short cut" approach to decibel addition. To add 90 and 90 the table indicates that 3 dB must be added to give 93 dB, as before. To add 90 and 95, 1 dB is added to 95 to yield 96 dB. When it is necessary to add more than two sound levels together, the levels should be rank ordered, and then added together two at a time starting with the lowest two levels, as illustrated in Example 2-1.2b.

Although a 3 dB increment in noise level represents a doubling of sound energy, for two noise signals differing by 3 dB the higher level does not sound twice as loud as the lower. in reality, a 3 dB difference in noise levels is only moderately detectable by the human ear. It has been found that a difference on the order of 10 dB represents a subjective doubling of loudness. Thus, 3 dB corresponds to a factor of two in sound <u>energy</u>, while 10 dB corresponds approximately to a factor of two in subjective <u>loudness</u>.

PROBLEM:

At location X the noise levels from two sources (No. 1 and No. 2) are each 90dB. Determine the dB value when the sources are operating simultaneously.

SOLUTION:

1. Sound pressure level source No. 1 = $10 \log \left(\frac{P_1}{P_o}\right)^2$

2. Sound pressure level source No. 2 = $10 \log \left(\frac{P_2}{P_o}\right)^2$

3. $SPL_{total} = 10 \log \left[\left(\frac{P_1}{P_o}\right)^2 + \left(\frac{P_2}{P_o}\right)^2\right]$

4. $P_1 = P_2$

5. $SPL_{total} = 10 \log 2 \left(\frac{P_1}{P_o}\right)^2$

$$= 10 \log 2 + 10 \log \left(\frac{P_1}{P_o}\right)^2$$

$$= 3 + 10 \log \left(\frac{P_1}{P_o}\right)^2$$

$$= 3 + 90 \text{ dB}$$

$SPL_{Total} = 93$ dB

Total dB at location X is 93 dB.

FIGURE 2-1.2a METHOD FOR ADDITION OF SOUND LEVELS

When Two Decibel Values Differ By	Add the Following To The Higher Value
O to 1 dB	3
2 to 3 dB	2
4 to 9 dB	1
10 or more dB	0

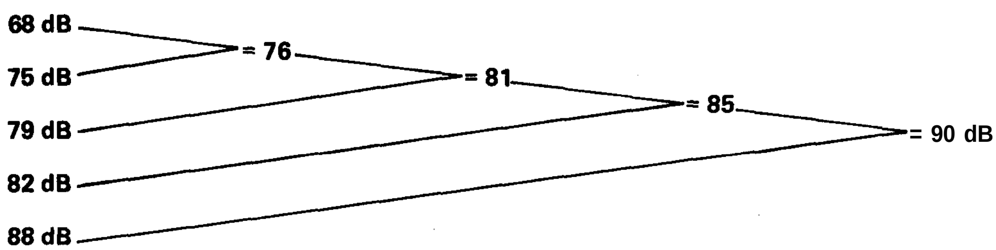
NOTE: To add more than two levels, start with lowest value

EXAMPLE 2-1.2b SIMPLIFIED DECIBEL ADDITION

PROBLEM:

Determine the sum of the following noise levels.

SOLUTION:



2-1.3 FREQUENCY CHARACTERISTICS

As discussed previously, a vibrating object produces a sound wave with a characteristic frequency. In practice, a particular noise signal is a complex combination of frequency components produced by many different vibrational and oscillatory modes of the noise source. Each frequency component may be of different magnitude and may vary as a function of time.

In order to properly represent the noise characteristics of a source, it is necessary to divide the total noise signal into its frequency components. Know1 edge of the frequency "spectrum" of a noise signal Is important because:

(1) People have different hearing sensitivity and react differently to various frequencies.

(2) Different noise sources have different frequency characteristics.

(3) Engineering solutions for reducing or controlling noise are frequency dependent.

One may determine the frequency distribution of a noise signal by successively passing it through several different filters which will separate the noise into 8 or 9 octaves on a frequency scale. Just as an octave on a piano keyboard, an octave in sound analysis represents the frequency interval between a given frequency such as 350 Hz, and twice that frequency, 700 Hz. The normal frequency range of hearing for most people extends from a low frequency of about 20 Hz up to a high frequency of 10,000 to 15,000 Hz. Most octave band noise analyzing filters cover the audio range of 22 Hz to 11,200 Hz in 9 octave frequency bands. These filters are identified by their geometric mean frequencies; hence, the octave frequency band of 700 to

Listed in Figure 2-1.3a are the range and mean of each of the nine standard octave bands. It is possible to analyze the noise signal with filters narrower than an octave in width. One- third octave bandwidth filters are frequently used. The sum of the individual octave band levels is the "overall" level.

To demonstrate noise signal frequency analysis, the typical frequency spectrum for jet exhaust noise is illustrated in Figure 2-1.3b. A piano keyboard is shown for reference.

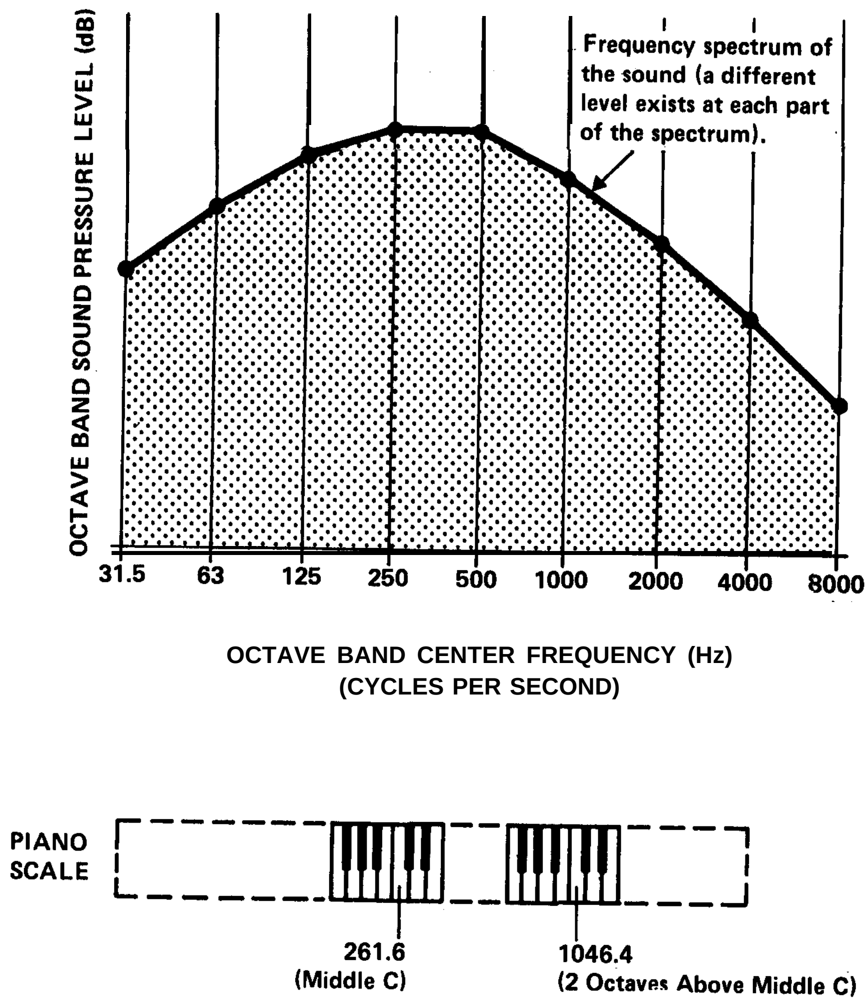
FIGURE 2-1.3a OCTAVE FREQUENCY BANDS

Octave Frequency Range (Hz)	Geometric Mean Frequency of Bend (Hz)
22 -- 44	31
44 -- 88	63
88 -- 175	125
175 -- 350	250
350 -- 700	500
700 -- 1,400	1,000
1,400 -- 2,800	2,000
2,800 -- 5,600	4,000
5,600 -- 11,200	8,000

NOTE: Sum of individual octave bend levels equals "overall" level.

FIGURE 2-1.3b

TYPICAL FREQUENCY SPECTRUM OF JET EXHAUST NOISE



2-1.4 PROPAGATION CHARACTERISTICS

Sound from a single source, on the ground or in the air, spreads out uniformly as it travels away from the source. For each doubling of distance, the sound energy per unit area decreases by a factor of four, resulting in a 6 dB attenuation in the sound signal (3 dB for each factor of 2 in sound energy). This effect, referred to as the inverse square law, is common to all types of energy originating from a "point" source free of focusing.

The energy drop-off characteristics differ for other types of sources. Near a "line" source the attenuation is 3 dB per doubling of distance. A heavily travelled highway approximates a line source.

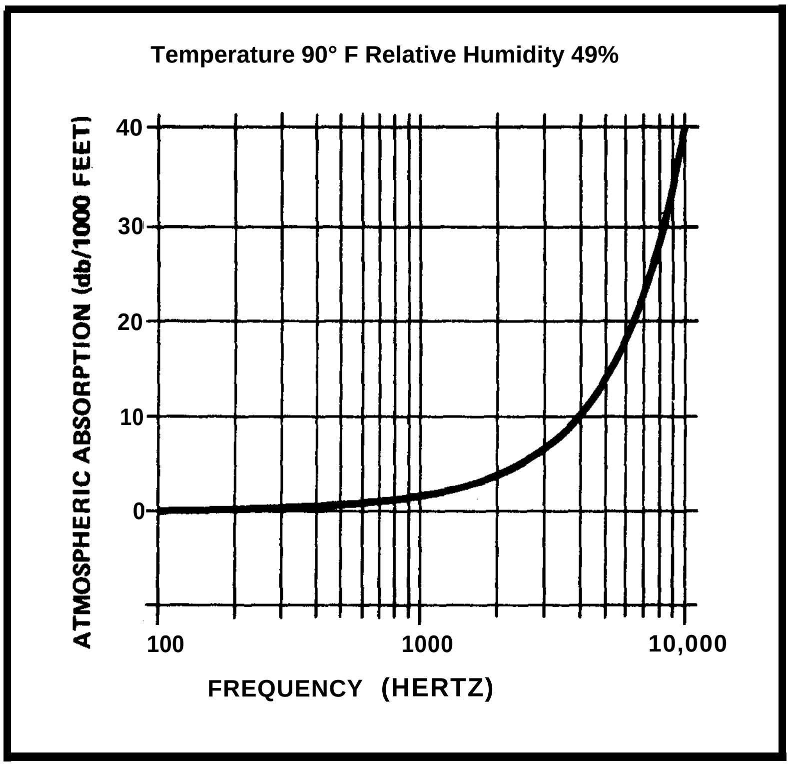
In addition to the decline that results from the spreading of the sound waves, there are atmospheric effects which further attenuate sound. Through molecular absorption, the air absorbs a certain amount of high frequency energy over relatively long distances. This effect is dependent upon air temperature and relative humidity as well as sound frequency. The atmospheric absorption for typical weather conditions of 60" F and 49% relative humidity is shown in Figure 2-1.4a.

This effect can have a significant influence on noise signals with high frequency content, such as aircraft. The typical noise level variation with distance with and <u>without</u> atmospheric absorption effects is illustrated in Figure 2-1.4b. As can be seen, the attenuation of high frequency (1000 Hz and above) sound in addition to inverse square attenuation is quite significant; over very large distances, this atmospheric attenuation becomes important for mid frequency (around 500 Hz) sound as well.

In addition to molecular absorption, there are a variety of atmospheric phenomena, such as wind and temperature gradients, which affect the propagation of sound through the air. Sound propagating from ground level sources is also influenced by terrain and structures which may either absorb or reflect sound, depending upon their surface and location relative to the sound source.

Both air and ground attenuation. or absorption effects increase with distance, and can thus be sizeable (greater than 10 dB) for those sources which propagate over large distances (thousands of feet). Also, since these effects are temperature/humidity and/or wind dependent, they can vary somewhat from day-to-day, and appreciably over a year. Therefore, it is best to use average conditions to assess noise exposure for long-term planning purposes (with special consideration given to portions of the year having weather conditions which might provide "worst case" noise exposure). Also short-term field monitoring (either to gather new data or check existing data) must include an appraisal of measured and average meteorological conditions.

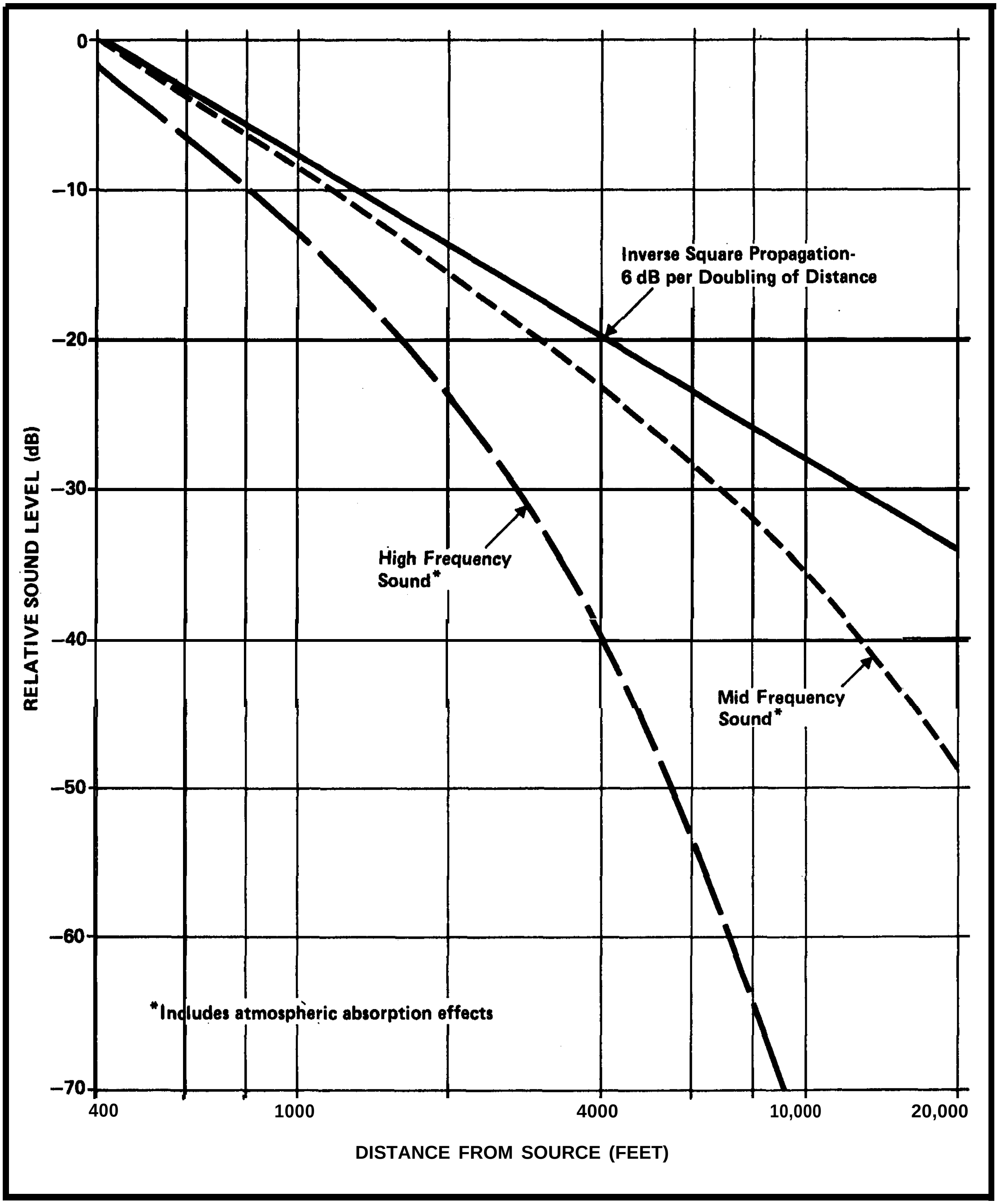
FIGURE 2-1.4a **TYPICAL ATMOSPHERIC ABSORPTION OF SOUND**



Reference 2-3

FIGURE 2-1.4b

TYPICAL ATTENUATION WITH DISTANCE FOR A POINT SOURCE



While many noise sources are omnidirectional (i.e., radiate sound energy equally in all directions), certain sources exhibit distinct directionality characteristics. The noise of a jet engine, for example, is typically at a maximum at an angle of about.45 degrees relative to the jet exhaust axis. For ground-based noise sources, directional characteristics can often be exploited by orienting the source so that the primary propagation paths are directed away from sensitive land uses.

2-2 NOISE MEASURES

Over the past 30 years, a wide variety of noise measures or rating scales have been developed for the purpose of quantifying the noise generated by particular sources. The multiplicity of noise measures has resulted from wide variations in the spectral and temporal characteristics among noise sources. For an engineering analysis of the noise exposure of a particular source, one noise measure may have many advantages over another. However, for the purposes of this manual, it is desirable to utilize a common measure for all sources.

The noise measures used throughout this manual, and other measures of particular interest, are presented below. The first several are uses to describe single, discrete events; they are descriptors which incorporate the frequency and/or temporal characteristics of the noise signal into a single number rating. These measures form the basis for the cumulative measures which follow. The relationship of these various measures is illustrated in Figure 2-2.

The discussion which follows provides a conceptual description of the noise measures. Explicit details and defining equations are presented in the Glossary.

Z-2.1 FREQUENCY CONSIDERATIONS

The human ear is more sensitive to sound of high frequency (1,000 Hz and above) than to mid or low frequency (125 Hz and below) sound. For this reason it is appropriate to apply a weighting function to the noise spectrum which will approximate the response of the human ear. The A-weighted sound level was developed in this manner. It is a single number measure of the magnitude of a noise signal, with a weighting characteristic which de-emphasizes the low-frequency portion of the spectrum. Similarly, the perceived noise level was developed, based upon the subjective assessment of the relative noisiness of the different frequency components of the noise signal.

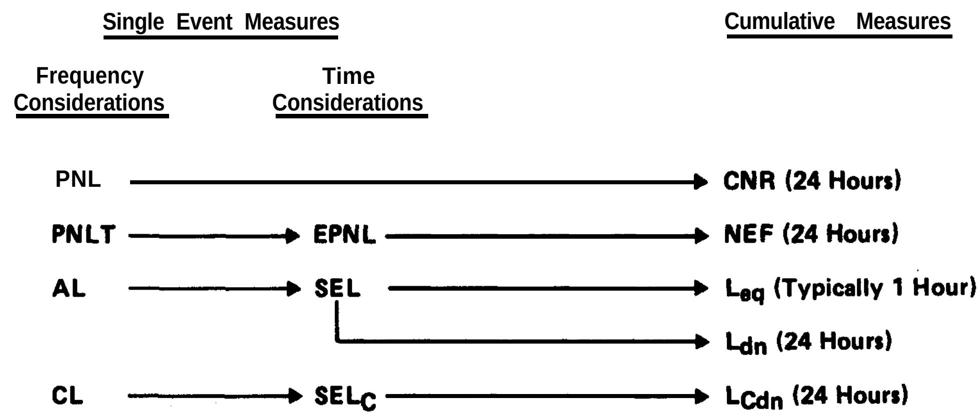
On many installations, large amplitude impulsive sounds are a significant portion of the total noise exposure. Such sounds (which include sonic booms and blasts from quarry and artillery operation;) may cause vibrations of bulldings and other structures which can result in annoyance beyond that due to the noise exposure alone. This increased annoyance can be assessed using the C-weighted sound level.

2-2.1.1 A-WEIGHTED SOUND LEVEL (AL)

The A-weighted level of a signal, in dB, is obtained by measuring the signal on a sound level meter with an A-weighted-network. This weighting network is an electrical circuit that represents the

FIGURE 2-2

RELATIONSHIP AMONG NOISE MEASURES



PNL, perceived noise level

PNLT, tone corrected PNL

AL, A-weighted sound level

CL, C-weighted sound level

EPNL, effective perceived noise level

SE L, sound exposure level

SEL_c, C-weighted sound exposure level

CNR, composite noise rating

NEF, noise exposure forecast

L_{eq}, equivalent sound level (for given time interval)

L_{dn}, day-night average sound level

L_{Cdn}, C-weighted day-night average sound level approximate frequency response characteristics of an average young ear. The upper portion of Figure 2-2.1.1, shows the frequency 'response of the A-weighting network. The effect of applying this weighting function to a diesel truck spectrum is illustrated in the bottom portion of the figure.

In several studies, it has been found that a person's judgment of the loudness of a noise correlates well with the A-weighted sound levels of these noises. Thus, a noise signal with an A-weighted level of 65 dB would typically be judged louder than another noise at 60 dB when both are considered in a similar context. The A-weighted sound level, or A-level, has been used extensively In this country for the measurement of community and transportation noises.

2-2.1.2 PERCEIVED NOISE LEVEL (PNL)

The high frequency component of jet aircraft noise makes comparisons of aircraft noise levels inappropriate unless frequency weighted. The perceived noise level was developed specifically to compensate for this factor. While the A-level is measured using an electrical circuit, the perceived noise level can be obtained only through a calculative procedure which applies a weighting factor to each frequency component of the signal.

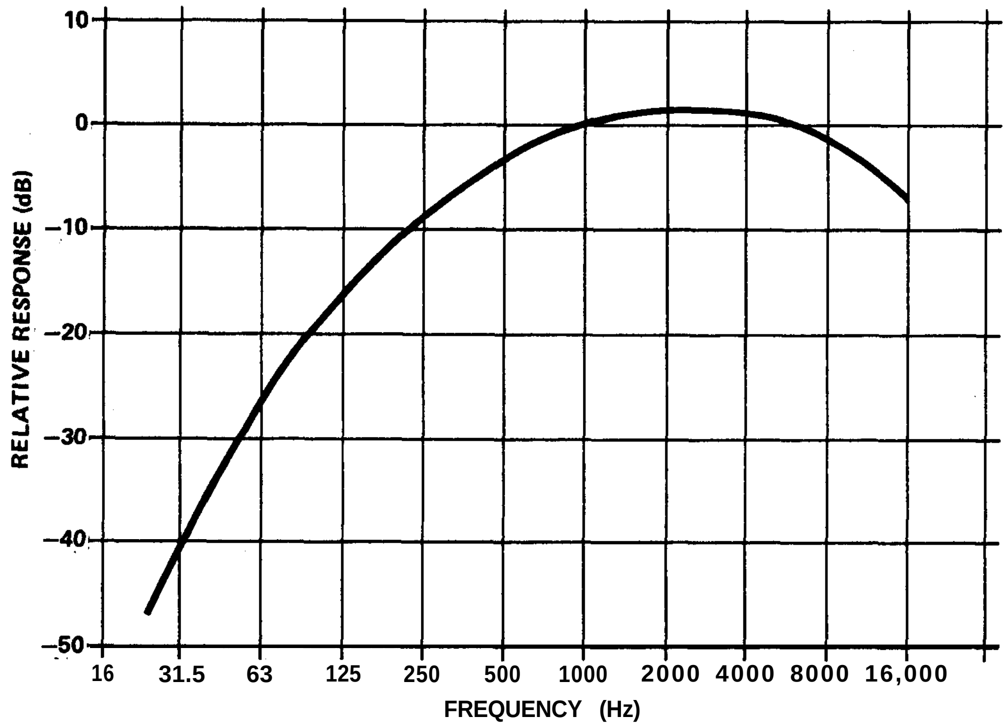
In further contrast to the A-level, the perceived noise level weighting function is based upon subjective assessment of the noisiness of the various frequency components of the signal, rather than upon loudness considerations. There is more emphasis on the upper portion of the noise spectrum (2,000 - 4,000 Hz) in this weighting function than in the A-weighting function. The perceived noise level, in units of PNdB, has been used for many years in the U.S. as a measure of aircraft noise.

2-2.1.3 TONE-CORRECTED PERCEIVED NOISE LEVEL (PNLT)

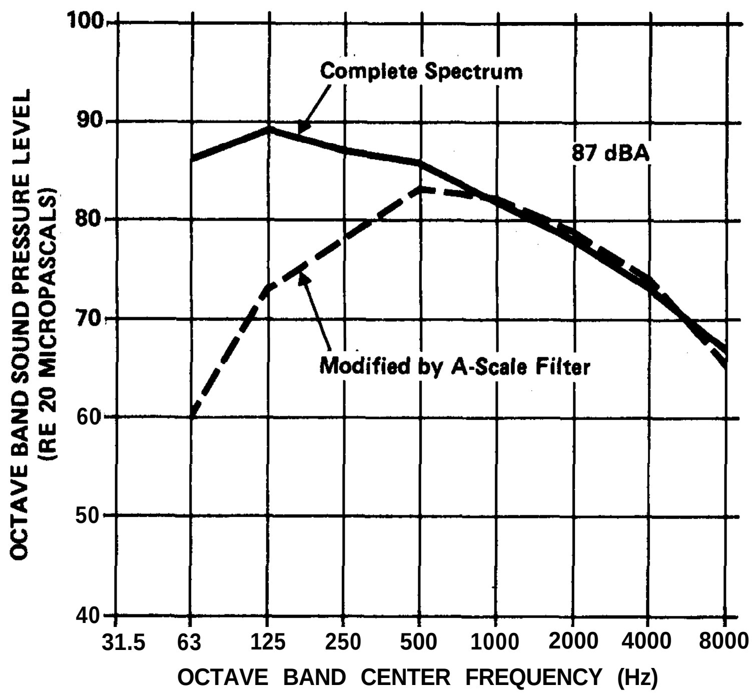
The tone-corrected perceived noise level is the perceived noise level with an adjustment for pure tones. This measure attempts to account for human sensitivity to strong discrete frequency components in the noise signal, over and above the sensitivity to high frequency noise.

2-2.1.4 C-WEIGHTED SOUND LEVEL (CL)

The C-weighted level of a signal, in dB, is obtained by measuring the signal on a sound level meter with a C-weighting network. In contrast to the A-weighting network, which has pronounced emphasis and de-emphasis characteristics in order to represent the ear's frequency response, the C-weighting network provides no adjustment to the noise signal over most of the audible frequency range except a slight de-emphasis of the signal below 100 Hz and above 3,000 Hz.



ELECTRICAL FREQUENCY RESPONSE SPECIFIED FOR THE A-SCALE FILTER OF SOUND LEVEL METERS (ANSI S1.4.1971)



GENERALIZED SPECTRUM FOR DIESEL TRUCK NOISE AT 50 FT DISTANCE FOR ALL SPEEDS

2-2.2 TEMPORAL CONSIDERATIONS

Subjective tests indicate that human response to noise is not only a function of the maximum level, but of the duration of the signal and its temporal variation. Time related changes may range from a sound level constant over time, as produced by a continuously operating machine, to the typical hay stack-shaped time history produced by an aircraft flyover, to the constantly varying noise levels perceived near highways.

Historically, several methods have been used to introduce time characteristics. With recent advances in electronics and instrumentation technology, there are now instruments which can integrate, or sum, noise signals as a function of time.* (Integrated noise levels are a measure of the physical energy in the noise signal.)

Significant evidence indicates that two signals with equal sound energy will produce the same subjective response (Ref. 2-1, 2-2). For example, a noise with a constant level of 85 dB occurring for ten minutes would be judged equally as annoying as an 82 dB noise signal lasting for 20 minutes, i.e., one-half the energy lasting for twice the time period. This is known as the "equal energy" principle.

In practice, the integration process is often replaced by a summation of levels occurring at one-half second intervals over the upper 10 dB of the noise signal. For an individual event, the process of dividing the signal into one-half second increments is shown in Figure 2-2.2 .

2-2.2.1 SOUND EXPOSURE LEVEL (SEL)

Integration of the A-weighted noise level over the period of a single event (such as an aircraft flyover) gives the sound exposure level, in dB. Therefore, incorporated in this measure are both frequency and duration considerations.

2-2.2.2 EFFECTIVE PERCEIVED NOISE LEVEL (EPNL)

The effective perceived noise level is obtained by integrating the tone-corrected perceived noise level (PNLT) over the period of a single

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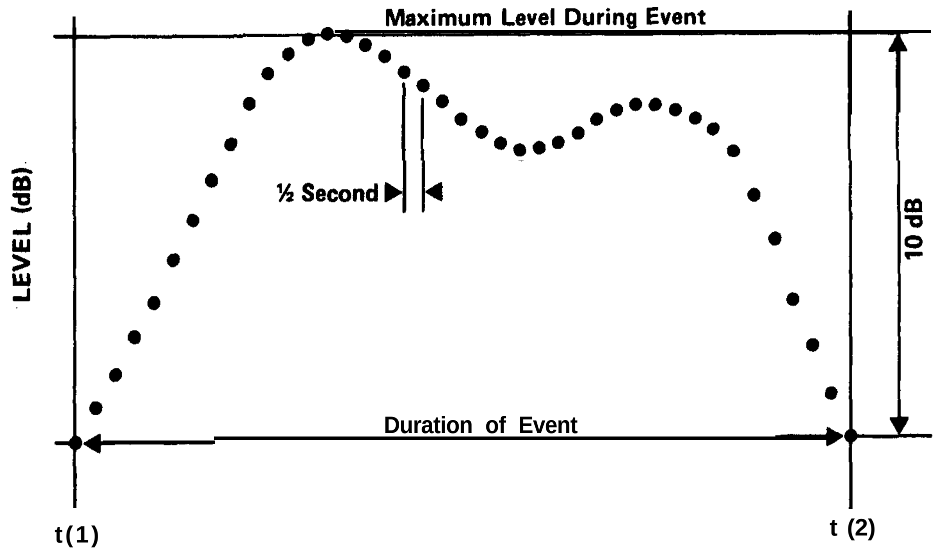
*Electronic noise signal integration typically utilizes networks with "fast" or "slow" dynamic' characteristics, which may not provide a true integration, particularly for impulsive signals. in most cases, however, this approach will sufficiently approximate true integration time.

FIGURE 2-2.2

INTEGRATION PROCEDURE FOR A SINGLE NOISE EVENT



NOTE: Integration performed by summing (on an energy basis) each noise level within 10 dB of the maximum level.

event. EPNL, in units of EPNdB, thus utilizes a pure-tone adjustment in addition to frequency and duration considerations.

2-2.2.3 C-WEIGHTED SOUND EXPOSURE LEVEL (SEL_c)

The C-weighted sound exposure level, in dB, is obtained by integrating the C-weighted sound level over the period of a single event.

2-2.3 CUMULATIVE MEASURES

While the measures discussed previously are appropriate for rating the noise of individual noise "events", in practice the effects of noise on people and their activities is due to the accumulated influence of many noise events occurring during a day. Thus a cumulative measure of noise exposure is a useful rating of the noise environment.

Noises which occur during nighttime hours are usually judged more annoying or intrusive than 'those occurring during the day. This is because there is a greater desire for freedom from noise intrusions during periods of relaxation and sleep, and because the effects of a noise signal are accentuated at night due to the decrease in background noise levels. Therefore, with most 24-hour cumulative measures, the day is divided into daytime (0700 to 2200 hours) and nighttime (2200 to 0700 hours) periods, and a penalty or adjustment is made for nighttime noise exposures.

2-2.3.1 COMPOSITE NOISE RATING (CNR)

For more than a decade the composite noise rating has been used as a measure of the 24-hour noise environment at both military and civilian airfields. Graphically, CNR is depicted by three noise environment zones. These zones are determined by overlaying perceived noise level (PNL) contours of equal noise levels. These contours are based on flight paths and aircraft types. Five decibel adjustments in the PNL contours are made to take into account the number of flights occurring on typically busy days (twenty-four hour period). A final map of the three CNR zones is produced by superposition of the several adjusted PNL contours.

Ground runup operations can also be assessed using the CNR procedure. To incorporate the observed adverse community reaction to runup operations, a 20 dB adjustment is applied to runup contours.*

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* This 20 dB adjustment results from a 15 dB penalty for runup operations plus a 5 dB normalizing adjustment.

2-2.3.2 NOISE EXPOSURE FORECAST (NEF)

NEF values are determined by calculative rather than graphical means, and computer programs are usually utilized to assist in the preparation of the contour maps. The noise exposure forecast is based upon the EPNL, rather than the PNL, as the measure of individual aircraft events, The NEF definition of the aircraft created noise environment is an explicit summation of daytime and nighttime (with penalties) noise levels. A 10 dB penalty is applied to ground runup operations.

2-2.3.3. COMMUNITY NOISE EQUIVALENT LEVEL (CNEL)

The community noise equivalent level is a measure of the noise environment over a 24-hour annual average day. It is the 24-hour A-weighted sound level) with a 5 dB weighting applied to the evening (1900 to 2200) levels and a 10 dB weighting applied to the nighttime levels,

The CNEL is used in California. The CNEL is similar to the day-night average sound level except for the 5 dB weighting for evening levels. air base noise environments the CNEL and day-night average sound level values will agree within a fraction of a dB.

2-2.3.4 EQUIVALENT SOUND LEVEL (L_{eq})

The equivalent sound level, or L_{eq} may be obtained by averaging (on an energy basis) the A-weighted sound levels over a selected time period. This level is the continuous noise level that would be equivalent, on an energy basis, with the fluctuating noise signal under consideration. In contrast with the CNR and NEF measures, L_{eq} is applicable to all the noise sources, not just aircraft.

The typical averaging time for the equivalent sound level is a period of one hour. However, by averaging over an 8-hour work period, for example, a measure of the equivalent sound level a worker is exposed to during a work day can be obtained.

For noise sources which are not in continuous operation, the equivalent sound level may be obtained by decibel summing (i.e., summing on an energy basis) the individual SEL values and dividing by the appropriate time period.

2-2.3.5 DAY-NIGHT AVERAGE SOUND LEVEL (L_{dn})

The day-night average sound level is obtained by energy-averaging noise levels over a 24-hour period, with a 10 dB penalty to nighttime noise levels. As with L_{eq}, the day-night average sound level can be applied to all sources of noise. With regard to aircraft noise, the L_{dn} process does not incorporate a special penalty for ground runup operations as with the CNR and NEF measures. For discrete event noise sources, such as aircraft operations, L_{dn} is analogous to NEF: it may be computed by decibel summation of noise levels (in terms of SEL rather than EPNL) occurring during daytime and nighttime periods (with the nighttime penalty).

2-2.3-6 C-WEIGHTED EQUIVALENT SOUND LEVEL (L_{Ceq})

The C-weighted equivalent sound level is the level of the time-weighted mean square C-weighted sound pressure. The C-weighted equivalent level is determined in a manner similar to that of the equivalent sound level (L_{eq}) except that the C-weighting is substituted for the A-weighting,

2-2.3.7 C-WEIGHTED DAY-NIGHT AVERAGE SOUND LEVEL (L_{Cdn})

While the noise impact of impulsive sounds may be quantified using the (A-weighted) day-night average sound level, L_{dn}, the additional annoyance of structural vibration must also be taken into account. The C-weighted day-night average sound level is an appropriate measure of this annoyance (see Reference 2-4).

Similar to L_{dn}, L_{Cdn} is computed by decibel summation of noise levels (in terms of SEL_C) occurring during daytime and nighttime periods, with a nighttime penalty included.

Future studies may result in changing the treatment of impulse noise, however, this use is appropriate as the best approximation now available.

CHAPTER 3 NOISE ASSESSMENT TECHNIQUES

3-1 GENERAL INFORMATION

The planner must be able to estimate the noise exposure produced by individual noise sources, as well as the total exposure resulting from a combination of noise sources. Knowing the cumulative noise exposure at potential development sites permits selection of the most appropriate site for a particular land use. (Refer to Chapter 6 for a more detailed discussion of the noise planning methodology.)

The purpose of this chapter is to describe the tools the planner may use to estimate the noise exposure at potentially developable sites. These tools include computer-generated noise exposure contours provided by DOD agencies (see Appendix A) and manual evaluation procedures which the planner may use to estimate noise exposure.

3-1.1 NOISE EXPOSURE PREDICTION TOOLS

Major noise sources on an installation may include aircraft operations (on the ground and in the air), weapon operations, traffic (including motor and rail vehicles), and operations of fixed noise sources (including power plants, testing facilities and ground support' equipment).

It would be ideal if installation planning could be based on an installation wide noise exposure contour map, incorporating the contributions of all major noise sources. At the present time such contours are not available; it is therefore necessary to describe the noise environment using a variety of tools.

Because of their impact on a majority of military installations, as well as in the civil environment, aircraft and impulse noise have been studied considerably over the past several years. The complexity of estimating the noise exposure from these sources has resulted in the development of computer models. Consequently, several agencies within the military departments have acquired computer capabilities for generating noise exposure contours for these sources.

The complexity of the prediction procedure is a result of the large number of parameters required for an accurate estimation. For aircraft noise, for example, there is a wide range of aircraft types, variations in missions, flight paths, and operational procedures which must be incorporated within the evaluation procedures. The necessary calculations can be performed by hand but the computer can analytically predict noise exposure more quickly and efficiently. Manual estimation procedures are provided in this chapter for aircraft noise sources.

For sources other than aircraft and impulsive noise, the reduced number of relevant variables permits the use of much less complex predictive procedures, For example, highway noise is predicated on a fixed path and a limited number of vehicle types; thus, generalized evaluation procedures are simplified enough to obviate the need for computers. Manual evaluation procedures for these sources are presented in this chapter.

3-1.1.1 NOISE ASSESSMENT SERVICE PROVIDED BY JOINT SERVICES AGENCIES

Services provided by the DOD agencies listed in Appendix A include both on-site measurement of existing noise conditions and generation of noise contours. Because of the availability of sophisticated acoustical equipment and special computer programs, contours provided by DOD agencies are more accurate than the manual procedures listed in this manual. Computer-developed noise exposure contours are available for ground and air operations of both fixed and rotary wing aircraft and for artillery firing and blasting operations. (Social research is being undertaken for the purpose of validating the methodology for artillery fire contours.)

Eventually, all computer contours will be, generated in L_{dn} units drawn at 5 dB intervals. To facilitate analysis contours should be generated at the same scale as installation maps. The input data required for various computer programs is presented in this chapter and in Appendix A.

The accuracy of computer-generated contours depends on the accuracy of the data supplied by individual installations. As an upper limit, the computer-generated noise contours should be accurate to within ±5dB, depending on the noise source and accuracy of the operational data. For many evaluations, accuracy to within ±2dB is possible.

3-1.1.2 MANUAL EVALUATION PROCEDURES

Although not as accurate as the computer-generated estimates of noise exposure, the generalized evaluation procedures presented in this chapter are sufficiently accurate for screening purposes.

The noise sources to be considered in this chapter can be classified as either <u>intermittent</u> or <u>continuous</u>. Intermittent sources are those involving single, easily-identified discrete events: the noise level rises with time, reaches a maximum value, and then decays to the background level. The noise exposure from this type of source is assessed in terms of the <u>sound exposure level</u> and-the <u>number</u> of such events which occur throughout the day.

In contrast, continuous noise sources are those in which the noise level rises to a particular value, and then remains at that level for a specified period of time. These sources are assessed in terms of the maximum level and the duration of such occurrences.

These concepts are expressed explicitly in the following two equations:

Intermittent source

$$L_{dn} = SEL + 10 \log (N_d + 10 N_n) - 49.4 \qquad (3\text{-}1)$$

where: SEL = maximum sound exposure level occurring during a single event

N_d = number of individual events occurring during the daytime (0700-2200 hours)

N_n = number of individual events occurring during the nighttime (2200-0700 hours)

Continuous source

$$L_{dn} = AL + 10 \log (D_d + 10 D_n) - 49.4 \qquad (3\text{-}2)$$

where: AL = the maximum A-level occurring during the continuous event

D_d = the event duration in seconds during the daytime

D_n = the event duration in seconds during the nighttime-

Equations 3-1 and 3-2 are illustrated in graphic form in Figures 3-1.1.2a and b. In Figure 3-1.1.2a, the difference between SEL and and L_{dn} is plotted as a function of total number of operations (N_d + N_n) and the percentage of nighttime operations. In Figure 3-1.1.2b, the difference between the A-level and L_{dn} is in terms of the total duration of operations and the percentage of that total occurring at nighttime (note that in this figure,' the duration scale is shown in units of minutes). For each figure, the insert illustrates use of the chart. (See Appendix 6 for references containing noise level data.)

This type of evaluation for either intermittent or continuous events can only be performed for similar operations of the same noise source, that is, where the maximum level is the same for each event. For example, for the following series of aircraft operations: 30 with SEL of 80 dB, 50 with SEL of 85 dB, and 20 with SEL of 90 dB, a separate evaluation would be required for each of the three sets of

FIGURE 3-1.1.2a

L_{dn} CHART FOR SINGLE EVENTS

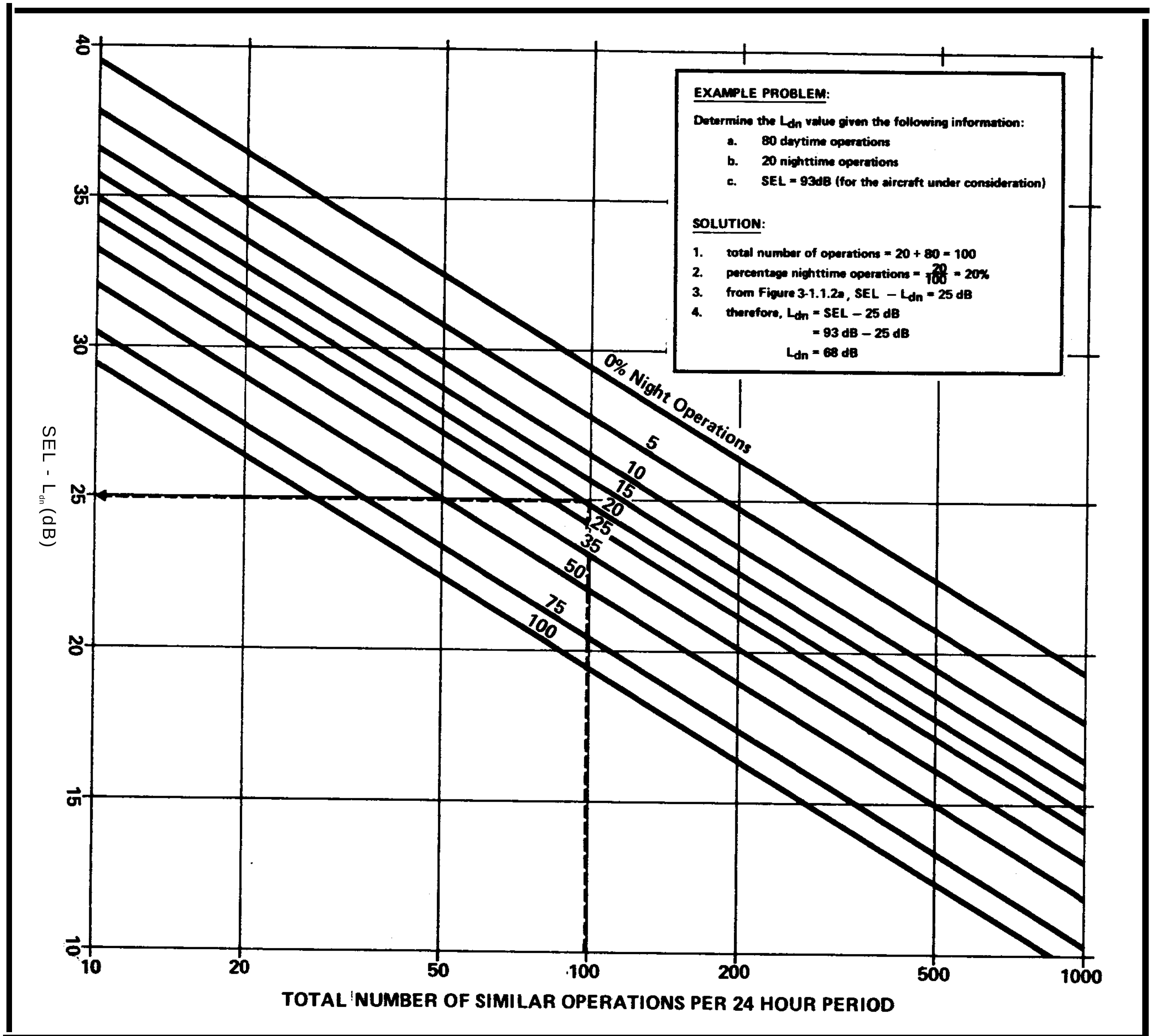
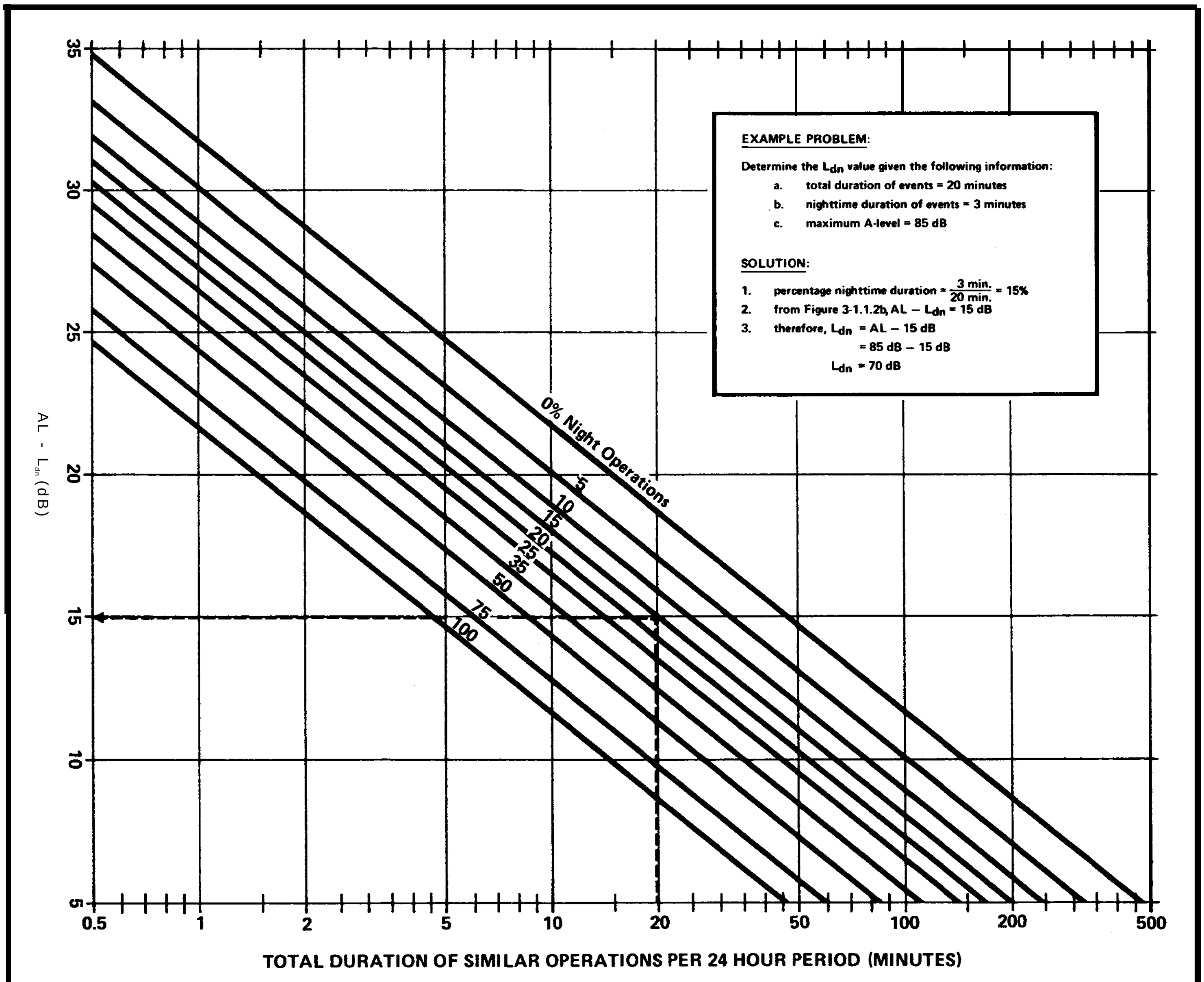


FIGURE 3-1.1.2b

L_{dn} CHART FOR CONTINUOUS EVENTS



operations. The total day-night sound level would be obtained by summing, on an energy basis, the L_{dn} values computed separately. Similarly, this is the case for a series of ground runups where different aircraft produce different maximum A-levels.

Because of the daily and monthly variability of aircraft activities, operational information should be based on the average "busy day".* This is obtained by computing a workday average over a monthly period for each month, and then averaging the twelve values. (The use of other than average "busy day" operational levels may be appropriate where analysis indicates that peak or seasonal operations are such that long term averaging techniques would not properly reflect the noise environment. For example, if the average of any quarter of the year if greater than this yearly average by a factor of two or more, it may be appropriate to assess the noise environment resulting from these operations separately,)

To utilize the charts presented in this section, the planner must have the SEL or AL value for the noise sources being considered. Acquisition of this data is outlined in Appendix B.

The noise evaluation procedure may be summarized as follows:

(1) Determine the SEL (for intermittent sources) or AL (for continuous sources) at the location of interest for each different type of operation. (Note: This step is carried out according to the procedures discussed in succeeding sections for each noise source.)

(2) Tabulate the number of operations (for intermittent sources) or duration of operations (for continuous sources) for each different type of operation.

(3) Determine L_{dn} for each type of operation, using Figure 3-1.1.2a (for intermittent sources) or 3-1.1.2b (for continuous sources). (Note: Equations 3-1 or 3-2 may be used instead of the figures.)

(4) Determine the total L_{dn} for all operations by energy summing the individual L_{dn} values using Figure 3-1.1.2c.

This procedure is illustrated in Example 3-1.1.2 for a series of aircraft flyovers.

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* The average busy day concept is appropriate for on-installation purposes. However if an evaluation of noise exposure of off-installation is performed in compliance with specific civil regulations, the use of different operational data may be required. Frequently, use of <u>annual average</u> number of operations is specified.

FIGURE 3-1.1.2c

METHOD FOR ADDITION OF SOUND LEVELS

When Two Decibel Values Differ By	Add the Following To The Higher Value
0 or 1 dB	3
2 or 3 dB	2
4 to 9 dB	1
10 or more dB	0

NOTE: To add more than two levels. start with lowest value.

PROBLEM:

Determine total L_{dn} at location X which is exposed to 30 takeoffs of aircraft A, 50 takeoffs of aircraft B and 20 takeoffs of aircraft C. Nighttime operations are 10% of total activity.

SOLUTION:

1. From altitude profiles and SEL curves for aircraft A, B and C, the SEL's at location X from these aircraft are 80, 85 and 90 dB respectively. (See Section 3-2.2.2, Figures 3-2.2.2a and b, and Example 3-2.2.2)

2. Number of Operations

Aircraft	SEL,dB	Daytime	Nighttime	Total	Night %
A	80	27	3	30	10
B	85	45	5	50	10
C	90	18	2	20	10

3. From Figure 3-1.1.2a

$SEL - L_{dn} = 32.0 \therefore$ $L_{dn} = 48.0$ for aircraft A

$SEL - L_{dn} = 29.5 \therefore$ $L_{dn} = 55.5$ for aircraft B

$SEL - L_{dn} = 33.5 \therefore$ $L_{dn} = 58.5$ for aircraft C

Alternately, using Equation 3-1 (rounding to nearest one-half dB),

$L_{dn} = 80 + 10 \log ((27 + (10)(3))) - 49.4 - 48.0$ for aircraft A

$L_{dn} = 85 + 10 \log ((45 + (10)(5))) - 49.4 = 55.5$ for aircraft B

$L_{dn} = 99 + 10 \log ((18 + (10)(2))) - 49.4 = 58.5$ for aircraft C

4. From Figure 3-1.1c

48.0 + 55.5 = 56.5

56.5 + 56.5 = 59.5

Total L_{dn} at location X is 59.5 dB.

This procedure applies to all noise sources except motor vehicle traffic. Since roadway noise is often continuous (over a 24-hour period), the assessment procedure involves determination of the equivalent sound level during a particular hour, with application of an adjustment to this L_{eq} based upon the total traffic during the day to yield the day-night average sound level. Computations of roadway noise are presented in section 3.6.

The evaluation procedures presented in this chapter do not take into account the effects of shielding of ground-based noise sources by walls, land forms, buildings or other barriers located between the source and observer. Simplified procedures for assessing the magnitude of these shielding effects is presented in Section 5-2.1.4.

3-1.2 ORGANIZATION OF CHAPTER 3

The next several sections are devoted to the individual sources of noise, listed in Figure 3-1.2. Each section is initiated with background information defining noise source characteristics and the importance of operational parameters on the noise environment. Where computer-generated contours are available, information concerning the necessary input data is provided. Where appropriate, manual procedures for estimating noise exposure (including simplified contours) are presented, with examples.

In the last section of this chapter, the total noise environment resulting from multiple noise sources is discussed in terms of site screening.

Figure 3-1.2 a guide to the types of analyses presented in this manual. Note that computer and manual evaluation procedures are not presented for each noise source. As explained in the final section, the planner may have to utilize contours and site-specific analyses together in the site selection process'.

FIGURE 3-1.2

ASSESSMENT TOOLS DISCUSSED

Noise Source	Type of Source	Computer-Generated Contours	Manual Evaluation	Refer to Section	Page
Aircraft Noise					
Fixed Wing	Intermittent	Yes	Yes	3-2	3-12
Rotary Wing	Intermittent	Yes	Yes	3-3	3-21
Ground Operations (Fixed and Rotary Wing)	Continuous	Yes	Yes	3-4	3-24
Impulse Noise	Intermittent	Yes	No*	3-5	3-27
Traffic Noise					
Motor Vehicles	Continuous	No	Yes	3-6	3-33
Railway Vehicles	Intermittent	No	Yes	3-7	3-55
Fixed Noise Sources	Continuous	No	Yes	3-8	3-60

*Under Development

3-2 AIRCRAFT NOISE, FIXED WING

3-2.1 BACKGROUND INFORMATION

3-2.1.1 AIRCRAFT NOISE SOURCES

Fixed wing aircraft may be divided into'& and propeller driven categories. Figure 3-2.1.1a illustrates the major noise sources in various aircraft engines.

Jet Aircraft

Two major noise sources common to ail jet aircraft, are jet exhaust noise and turbo-machinery noise. The roar of the jet exhaust results from the turbulent mixing of the high velocity exhaust gases with the ambient air. This noise is broadband (i.e., the acoustic energy is spread throughout the audible spectrum) and varies with the eighth power of flow velocity. Turbo-machinery noise results from turbulence produced by rotating blades in the engine. This source consists of strong discrete frequency components, sometimes called pure tones, superimposed upon the broadband spectrum. These pure tones are associated with the blade passage frequency and its harmonics and typically occur in the 2000 to 4000 Hz region.

In the turbojet engine the main noise source is the jet exhaust. Only for low thrust settings, such as on approach, is the compressor "whine" detectable. On afterburner-equipped aircraft, the increased flow velocity through the afterburner creates significantly more noise than any other power setting because of the eighth power relationship.

By contrast, in the turbofan engine a significant portion of the air bypasses the combustion chamber and primary exhaust; this results in a lower exhaust velocity and thereby reduced jet noise. In this engine, however, the large rotating fan at the front of the engine produces strong pure tones which are dominant at ail thrust settings.

Propeller Aircraft

Propeller aircraft, either piston or turbine powered, generate noise by the formation and shedding of vortices in the flow past the propeller blades. This noise is also broadband, with discrete frequencies superimposed on the spectrum at the blade passage frequency due to the oscillating pressure field on the air. In contrast with jet aircraft, the major components of the propeller noise spectrum occur in the lower frequency bands.

FIGURE 3-2.1.1a MAJOR NOISE SOURCES IN AIRCRAFT ENGINES

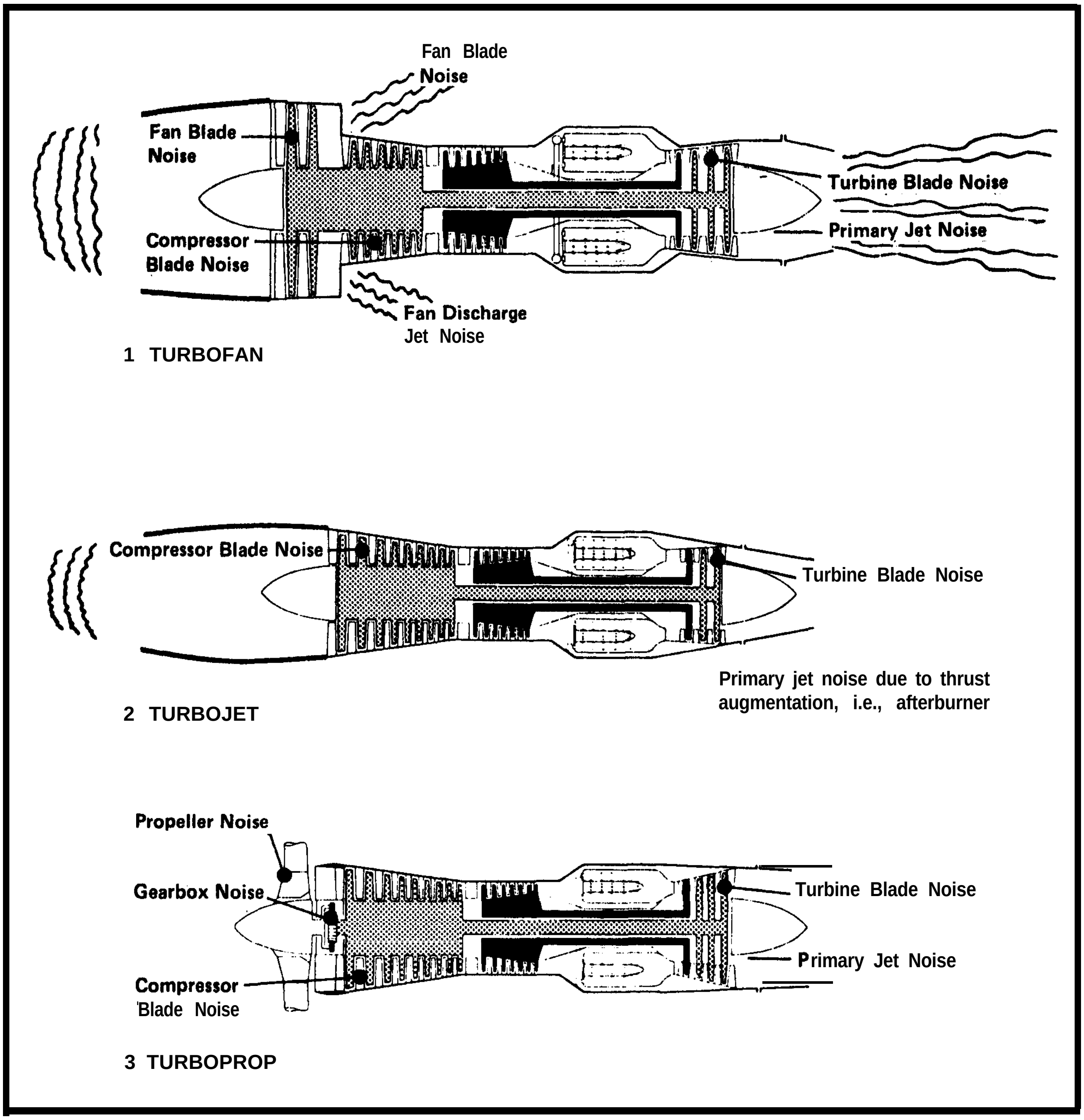
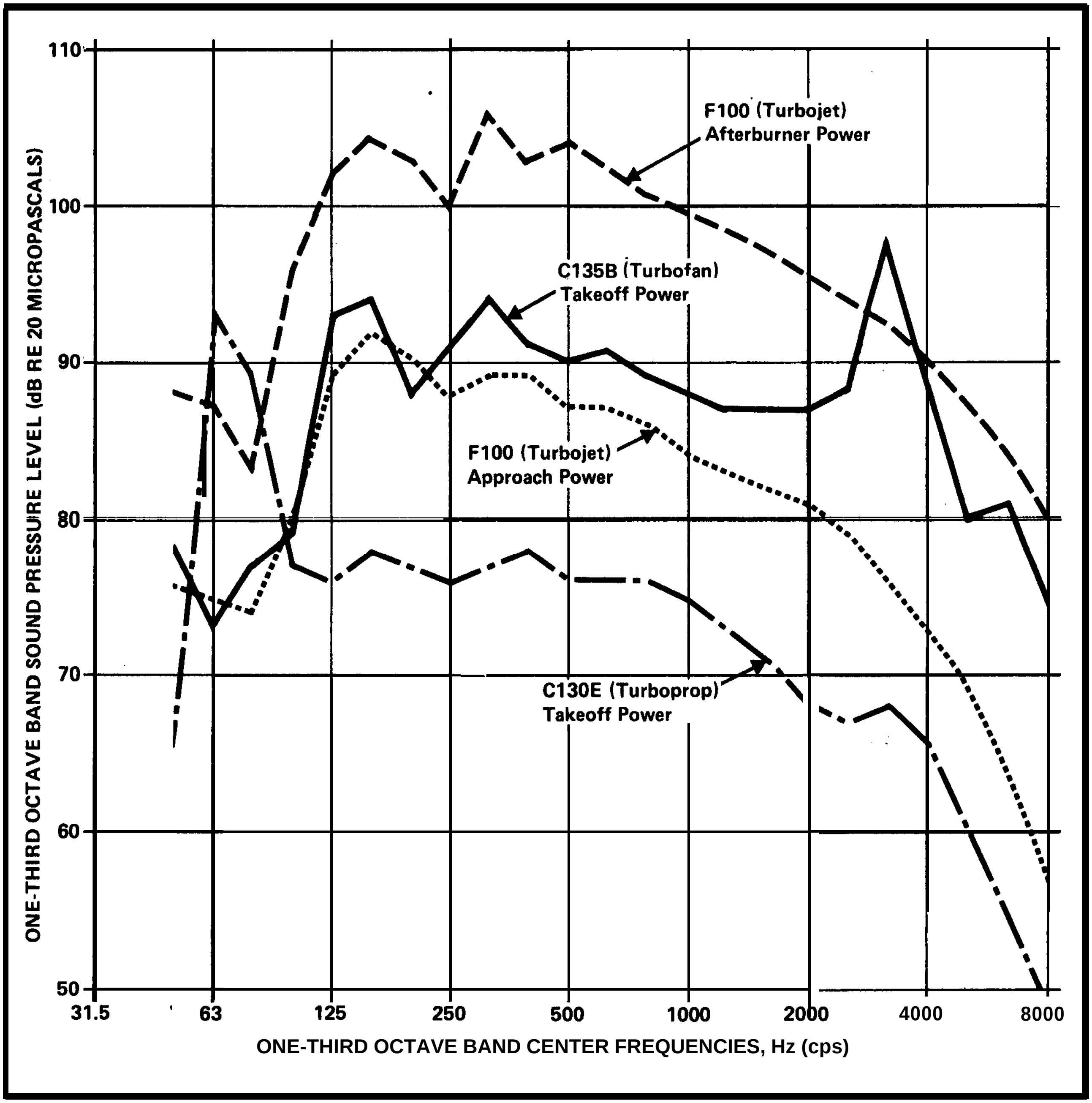


FIGURE 3-2.1.1b TYPICAL AIRCRAFT SPECTRA AT 1000 FT



Secondary to propeller noise is that of the aircraft engine. At typical takeoff power, the piston-powered aircraft produces greater exhaust noise than its turbine-powered counterpart. However, on approach, the compressor of the turbine-powered aircraft generates distinct pure tones.

Representative noise spectra for various aircraft are presented in Figure 3-2.1.1b.

3-2.1.2 OPERATIONAL CONSIDERATIONS

The noise exposure at a ground location resulting from aircraft flight operations is a function-of the sound exposure levels produced by individual aircraft, and the numbers of such aircraft operating during daytime and nighttime periods.

Typically, the noise levels associated with a particular operation of a specific aircraft (or class of aircraft) at a given thrust are defined as a generalized function of the slant distance between the aircraft and the observer (refer to Figure 3-2.2.2b). The noise level versus distance data is used to determine the sound exposure level at a specific ground location. The path of the aircraft in space is defined, so that the slant distance between the aircraft and observer is known. This is accomplished by specifying the flight track and altitude profile (refer to Example 3-2.2.2). The flight track is the projection onto the ground plane of the three dimensional flight path of the aircraft; the-altitude profile defines the performance characteristics of the aircraft in terms of altitude versus distance from the start of takeoff roll.

The total aircraft noise exposure is the summation of the noise exposure from ail operations of all aircraft on ail flight paths. This information should be specified in terms of the number of “busy day” operations on each flight path (see p. 3-6 for discussion of the “busy day” concept).

In summary, the following operational data, in conjunction with sound exposure level versus distance data, will yield the total aircraft noise exposure:

- Flight track locations
- Altitude profile for each aircraft operation
- Thrust schedule along each profile
- Average “busy day” number of each aircraft operation, by daytime (0700-2200 hrs.) and nighttime (2200-0700, hrs.) periods on each flight track.

3-2.2 EVALUATION PROCEDURES

3-2.2.1 COMPUTER-GENERATED NOISE CONTOURS

The calculation of L_{dn} values for even a few ground locations can be a tedious and time-consuming operation, considering the myriad of aircraft and types of operations that can occur at an installation. The planner should, therefore, utilize available computer programs to perform the noise exposure computations. Appendix A contains directions for obtaining contours.

Noise level data for both military and civil aircraft (SEL vs. distance curves) are contained in the files of the computer program. Installation specific information needed for the generation of contours includes such items as:

- o Altitude profiles
- o Thrust/power schedules
- o Flight track locations
- o Number operations on each flight track
- o Schedule of restrictions and limitations
- o Runway utilization schedule
- o Departure procedures
- o Special mission descriptions
- o Touch and go/FMLP*descrlption

3-2.2.2 MANUAL EVALUATION

Occasions may arise when it will be convenient to have L_{dn} hand calculation capabilities, thus permitting quick evaluation of the effects of operational changes on the noise environment. This is accomplished in the following manner:

(1) Refer to appropriate altitude profile and SEL vs. distance curve. (These profiles may also be specified in tabular form. See Appendix B.) (Typical curves are illustrated in Figures 3-2.2.2a and b.)

(2) Determine the ground level SEL in manner shown in Example 3-2.2.2.

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* FMLP is abbreviation for Fleet Mirror Landing Pattern, a Naval aircraft procedure used in practice landings simulating aircraft carrier operations.

FIGURE 3-2.2.2a ALTITUDE PROFILE FOR F-100 JET

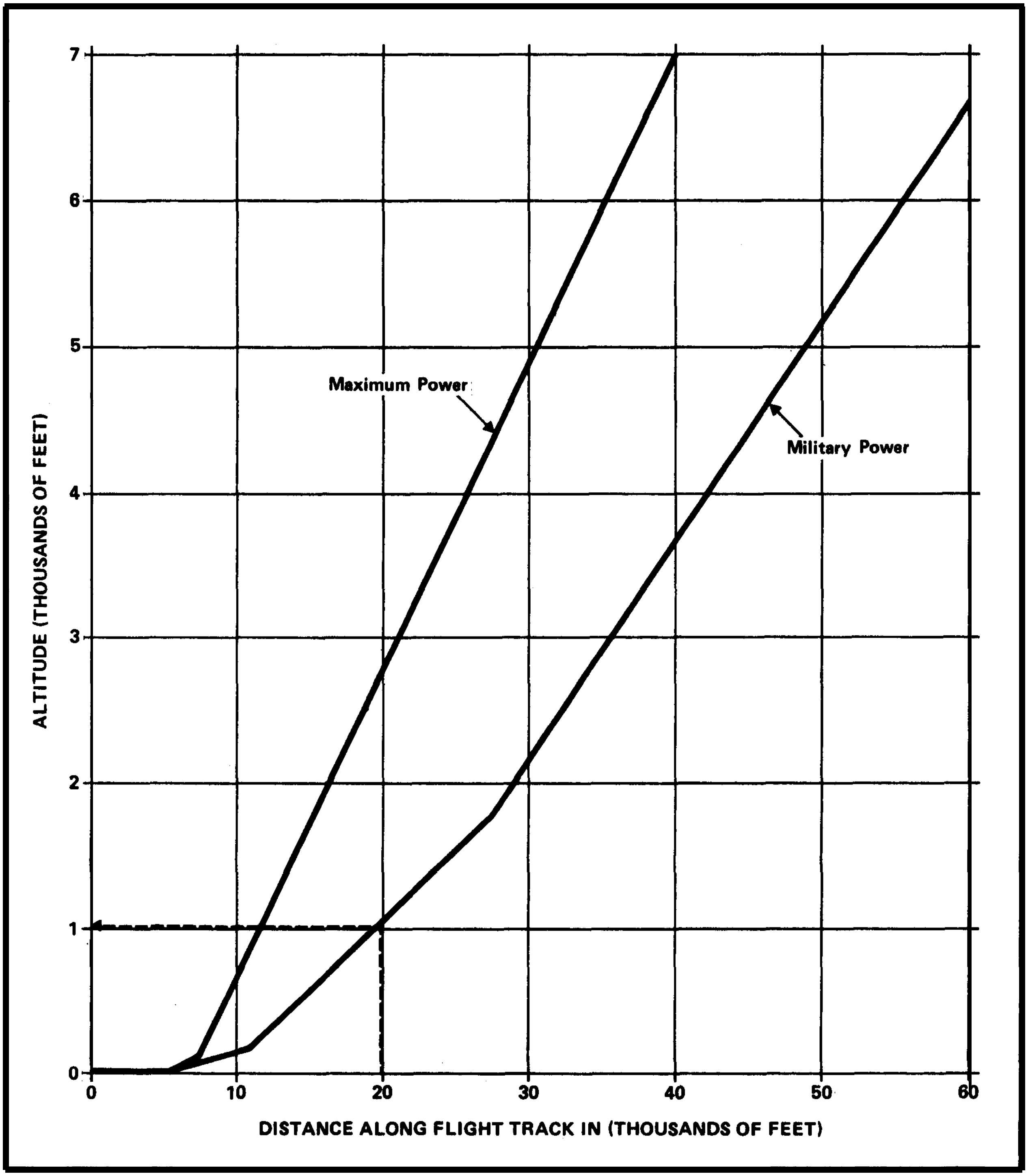
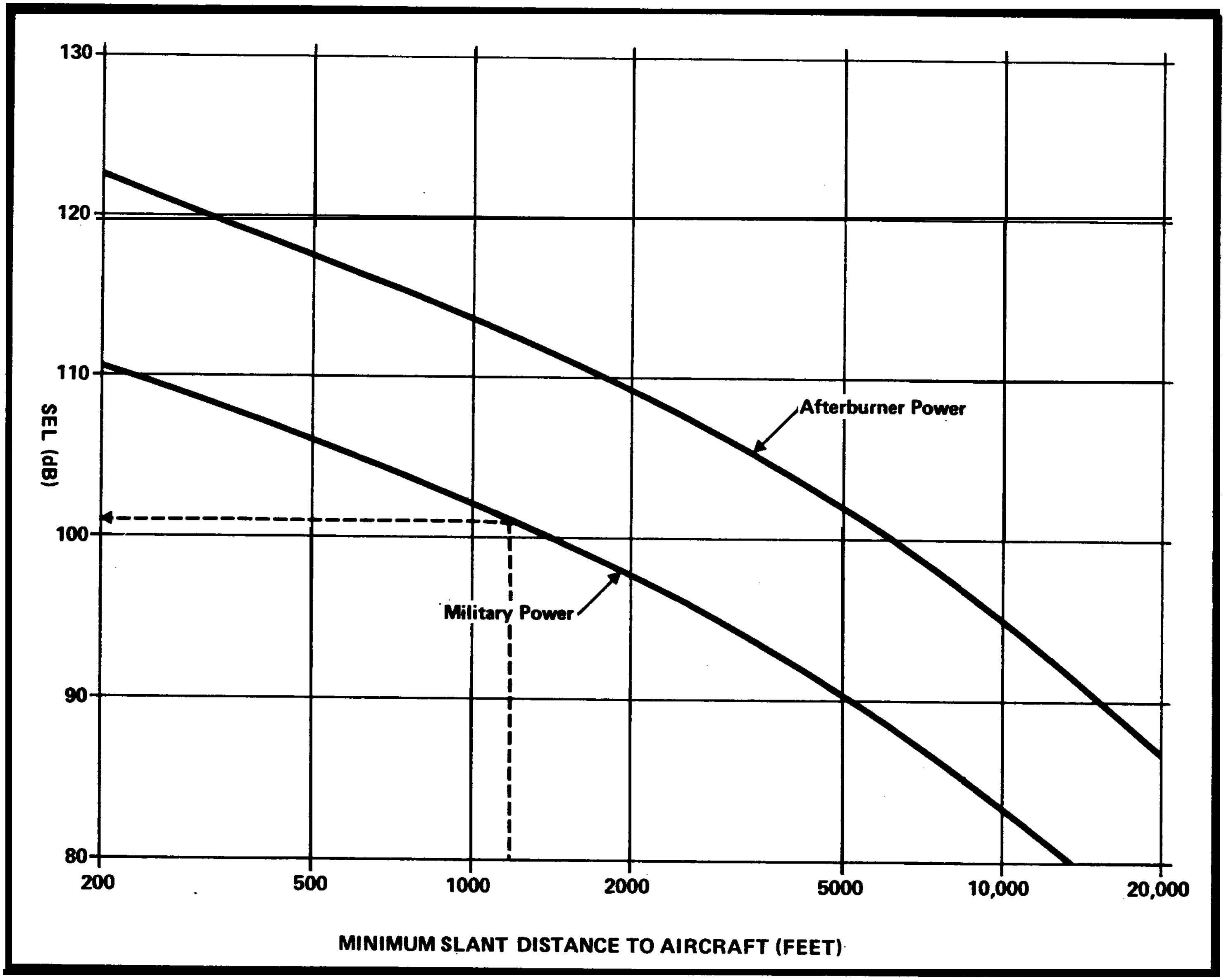
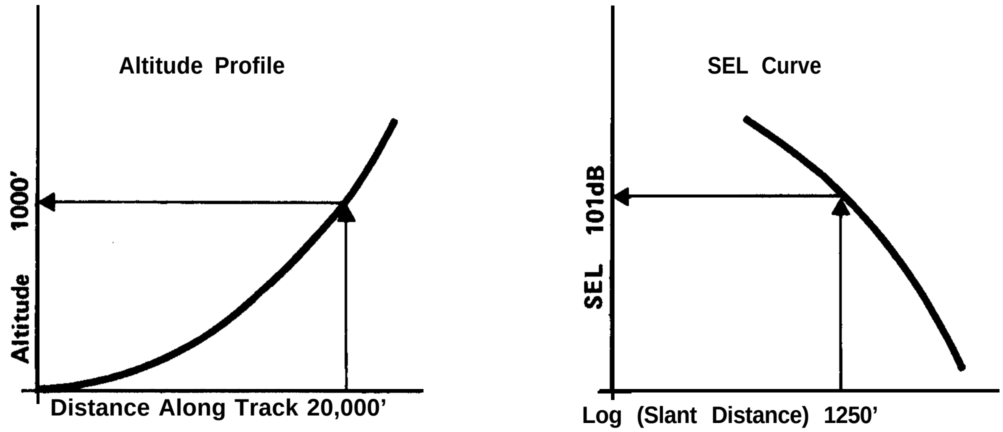


FIGURE 3-2.2.2b

VARIATION OF SEL WITH DISTANCE FOR TAKEOFF OF F-100 JET



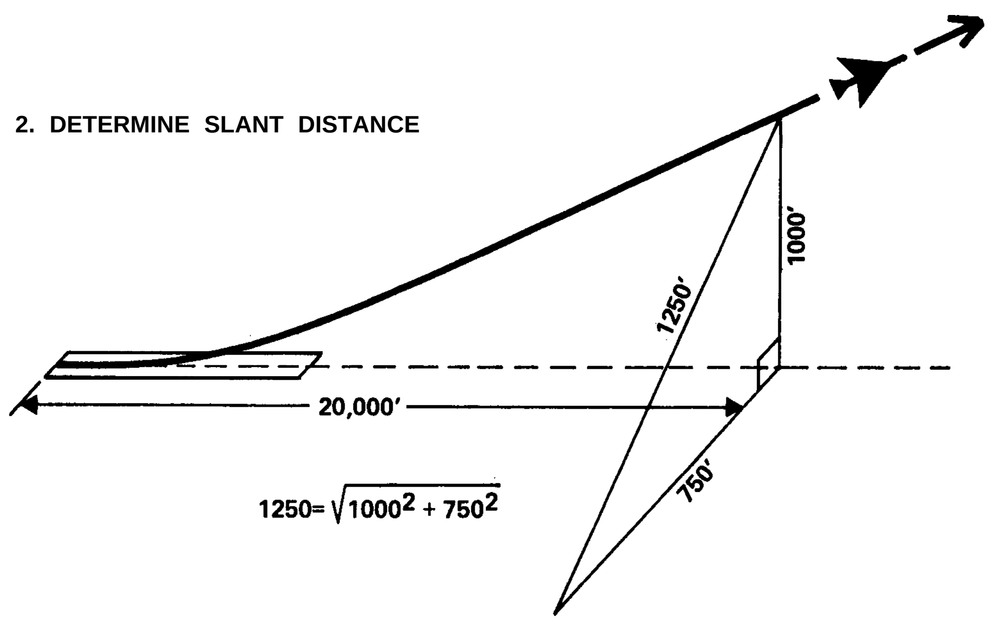
Determine the SEL at a location 750 feet lateral from a point 20,000 feet down the flight track of an F-100 jet at military power.



1. DETERMINE AIRCRAFT ALTITUDE (FROM FIGURE 3-2.2.2a)

3. DETERMINE SEL (FROM FIGURE 3-2.2.2b)

2. DETERMINE SLANT DISTANCE



The L_{dn} at a prescribed point may be determined following the steps below.'

(1) Use equation 3-1 or Figure 3-1.1.2a to solve for the L_{dn} Of One set of similar operations.

(2) Use energy addition (Figure 3-1.1.2c) to calculate L_{dn} for all sets of aircraft operations. (Refer to Example 3-1.1.2.)

NOTE:
This is a simplified evaluation omitting several complicating factors built into the computer program. For example, this procedure does not properly assess noise exposure resulting from operations during ground roll, turn operations, or from flight operations for which the angle of observation above the horizon is less than 7 degrees; nor does it account for airspeeds or power settings different from the measured data.

<u>The manual procedure is most useful in comparing different sets of operations. It should not be used to determine the absolute L_{dn} for a single set of operational conditions.</u>

3-3 AIRCRAFT NOISE, ROTARY-WING

3-3.1 BACKGROUND INFORMATION

3-3.1.1 AIRCRAFT NOISE SOURCES

The rotor system, in addition to the engine, is a principal noise source. Specifically the major noise sources are as follows:

Rotor blade slap

Tail rotor rotational noise

Main rotor broad band and rotational noise

Turbine engine noise

Transmission noise

The dominant noise produced by helicopters consists of a broadband spectrum generated by vortex formation and shedding in the flow past the helicopter blade. in addition to the discrete frequency noises at harmonics of the blade passage frequency, superimposed on the broadband spectrum for helicopters is a rotational noise known as blade slap. This is high amplitude periodic noise plus highly modulated vortex noise caused by fluctuating forces on the blade due to the cutting of one blade's tip vortices by another blade and transonic shock. Blade slap is a distinctive, low frequency throbbing sound which increases during certain descent, maneuvering and high-speed cruise operations.

(Refer to Appendix A for sources of information on blade slap corrections.)

A representative helicopter frequency spectrum is shown in Figure 3-3.1.1. The spectrum in this figure was obtained using a series of filters 6 Hz in width so that the narrowband fine structure of the signal (due to the many harmonic tones) would be apparent. Note that these occur primarily in the low frequency portion of the spectrum.

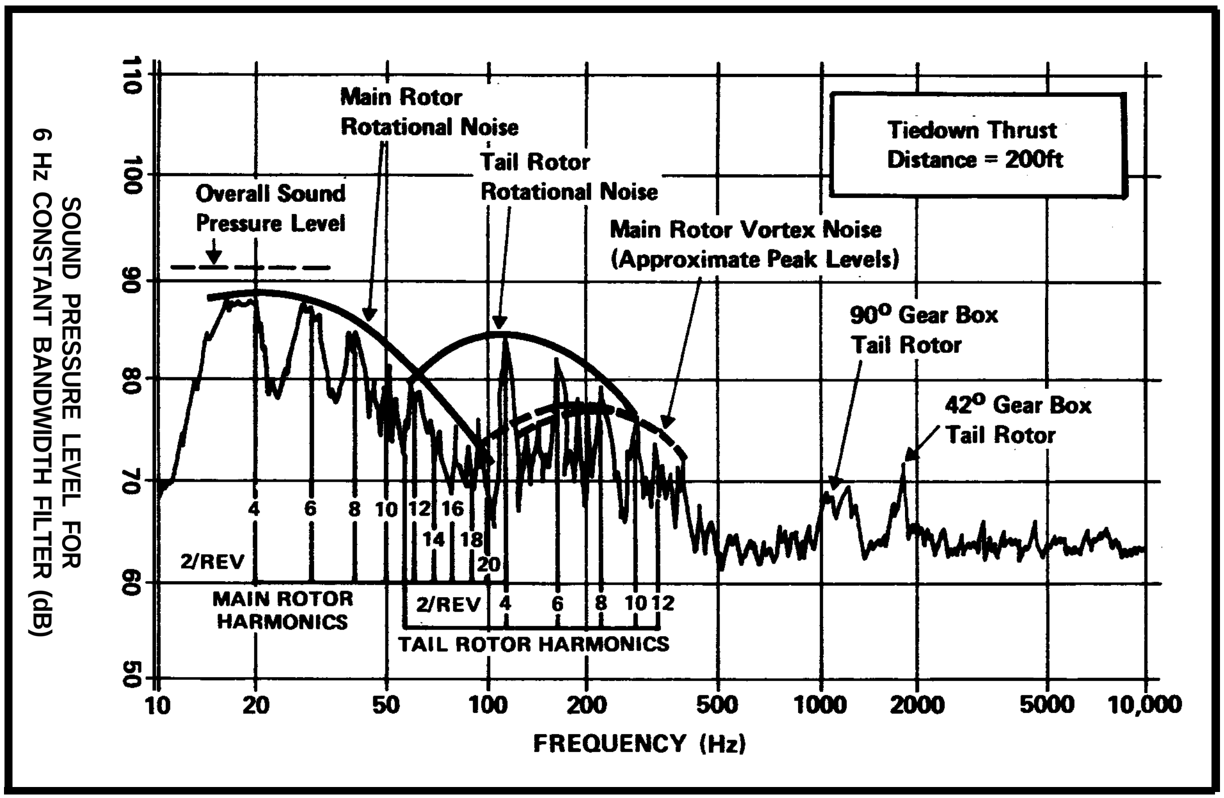
3-3.1.2. OPERATIONAL CONSIDERATIONS

The evaluations of rotary-wing noise exposure requires the same operational information as required for fixed-wing aircraft. See Section 3-2.1.2.

- o Flight track locations
- o Altitude profile for each helicopter operation
- o Phase of flight (takeoff, cruise, landing)
- o Average "busy day" number of each aircraft operation, by daytime (2200-0700 hrs and nighttime 2200-0700 hrs) periods on each flight track."

FIGURE 3-3.1.1

UH-1A EXTERNAL NOISE SPECTRUM (STUCKEY AND GODDARD, 1967)



REF. 3-2

3-3.2 EVALUATION PROCEDURES

Assessment of the cumulative noise exposure from rotary-wing aircraft operations parallels that of fixed-wing aircraft operations.

The fixed-wing aircraft computer program discussed previously may also be applied to rotary wing operations. Refer to Section 3-2.2.1 for discussion of input requirements and to Appendix A for enumeration of the agencies responsible for noise contours.

A simplified evaluation of rotary-wing aircraft noise exposure, like fixed-wing exposure, may be undertaken manually using the procedures illustrated in Figures 3-1.1.2a and b and Example 3-1.1.2. Append ix B provides references to detailed noise and performance data for rotary-wing aircraft. The previous warning note (Section 3-2.2.2, page 3-19) concerning the use of the manual procedures also applies here.

For planning purposes and a meaningful prediction of noise, due to the great maneuverability of helicopters, it is necessary to constrain significant numbers of operations into zones and/or corridors. in this fashion, impacted and nonimpacted land can be set aside.

3-4 GROUND OPERATIONS, FIXED AND ROTARY WING

3-4.1 BACKGROUND INFORMATION

3-4.1.1 AIRCRAFT NOISE SOURCES

The noise of aircraft flight and ground operations differ in level and temporal characteristics. For the same aircraft to observer distance, the maximum (peak) noise levels produced during a ground operation will typically be lower than during a flight operation because of ground absorption. The presence of intervening buildings and other barriers may further attenuate the noise level.

However, a runup operation may produce a much higher integrated noise level. This is because a runup is a continuous operation which may last for several minutes as opposed to a flyover noise signal which is intermittent in nature and usually lasts for several seconds.

Case studies of community response to aircraft noise have generally shown that ground runup noise response is judged less acceptable than the noise exposure of flyovers of the same average level of acoustic energy. This may be based in part on the feeling that runup operations are more controllable than flyovers, and thus the noise impact of runups could be more readily controlled as well.

For runup operations, consideration must also be given to the directional characteristics of the noise source. Figure 3-4.1.1 shows the noise levels of an F-100 aircraft at power settings of military power and afterburner, illustrating the highly directional nature of sound propogation from aircraft engine ground runups. Due to this factor, the orientation of aircraft runup pads and engine test stands has a major impact upon the noise exposure nearby.

3-4.1.2 OPERATIONAL CONSIDERATIONS

The cumulative noise exposure from ground operations is based upon peak noise levels and average "busy day" durations of daytime and nighttime operations. Thus, L_{dn} contours for runup operations are a function of the location and orientation of the runup pads, the time of day and duration of use.

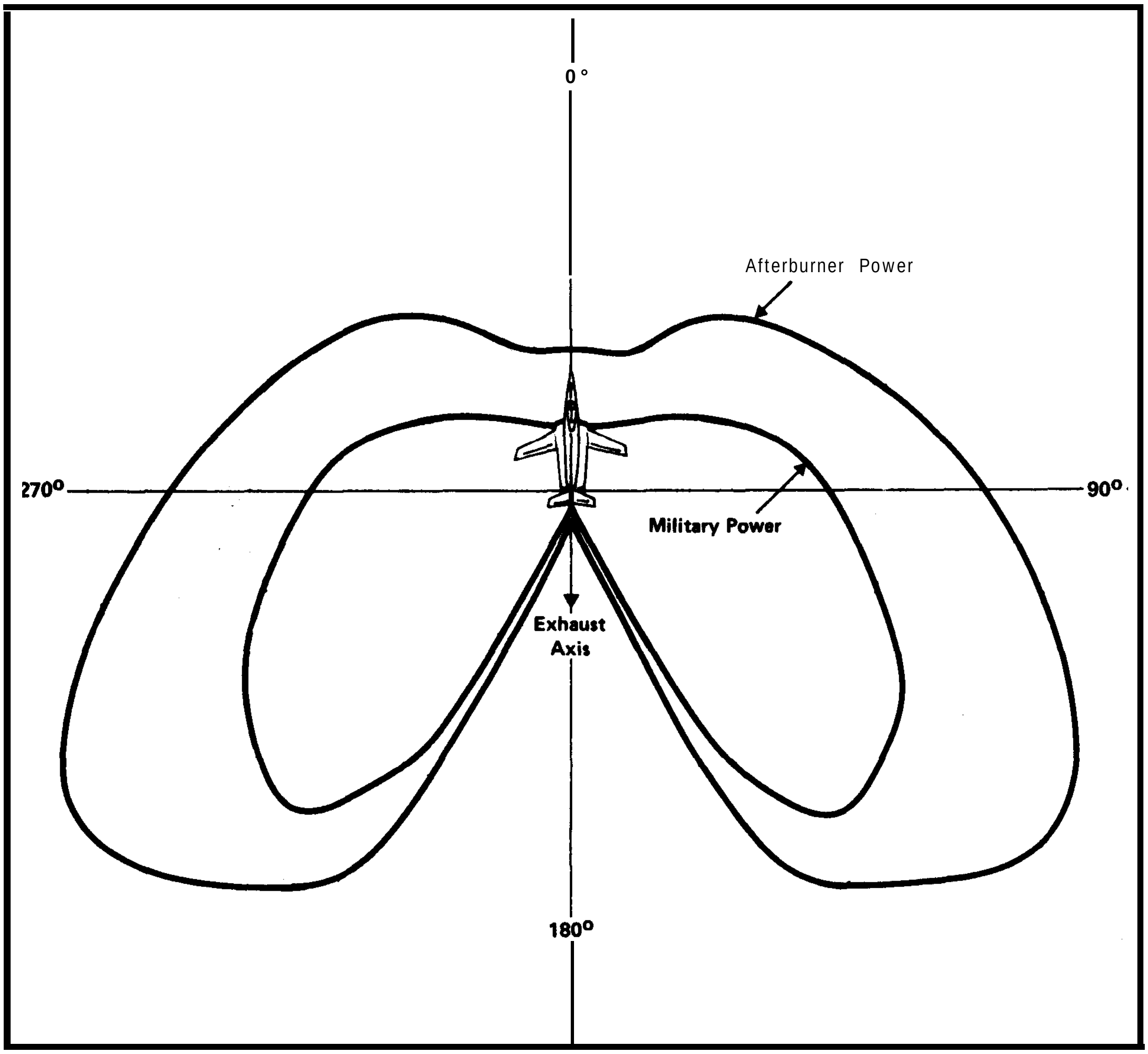
3-4.2 EVALUATION PROCEDURES

3-4.2.1 COMPUTER-GENERATED NOISE CONTOURS

The computer program discussed in Sections 3-2 and 3-3 for flight operations also incorporates runup operations. The data required for contour generation includes the following:

FIGURE 3-4.1.1

TYPICAL DIRECTIVITY PATTERN OF F-100D RUNUP



(1) Runup pad location and orientation

(2) Runup pad utilization

(3) Aircraft/engine types and test schedule

(4) Type and use of suppression devices

As with flight operations, the program produces L_{dn} contours at 5 dB intervals.' These contours are usually combined with the flight contours when contours are generated for military installation operations; however, they may be produced separately if desired. (Refer to Appendix A.)

3-4.2.2 MANUAL EVALUATION

The L_{dn} at a site of interest is determined in the manner outlined for continuous sources in Section 3-1.1.2, using Figures 3-1.1.2b and c. Reference to AL versus radiation angle and propagation distance data is provided in Appendix B for both fixed and rotary wing aircraft.

3-5 IMPULSE NOISE

3-5.1 BLAST NOISE

3-5.1.1 BACKGROUND INFORMATION

Aircraft noise tends to rise and fall slowly with time (in a matter of several seconds). In contrast, "blast noise" is impulsive in nature and generally less than a second in duration. Frequently encountered blast sounds are:

- o Artillery fire
- o Shell bursts (at or above, ground level)
- o Surface blasting
- o Cratering blasts

Although the duration of individual blasts is short (approximately 0.5 second), the rapid onset of such sounds is a source of discomfort for many persons. In addition, the vibration of buildings and other structures induced by the noise impulse is a source of increased annoyance. This vibration and the rapid onset produce "startle" effects and may cause rattling of dishes and other loose objects within the building. For this reason both the noise and vibration impact of blast noises must be assessed.

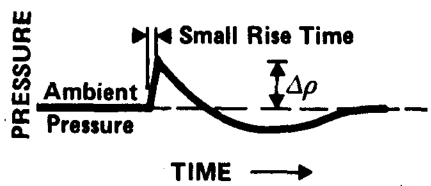
Important factors regarding people's subjective evaluation of blast noise exposure are:

- o Peak overpressure of individual blasts
- o Number of occurrences per day
- o Time of day the blasts occur

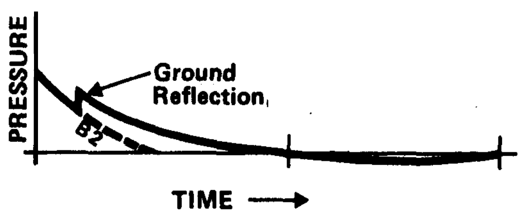
3-5.1.1.1 BLAST NOISE SOURCES

The noise produced by blasts results from the generation of shock waves, with peak overpressure (i.e., the pressure increase above ambient) often greater than 1 psi. Figure 3-5.1.1.1a depicts a typical blast impulse, which consists of an abrupt compression (characterized by an extremely short "rise time") followed by a gradual pressure reduction to below ambient pressure, and then finally a recovery to ambient. The overpressure (and therefore the noise level) is a function of the source strength (charge weight), meteorological conditions, and distance to observer.

FIGURE 3-5.1.1.1a TYPICAL BLAST IMPULSES



1. "PURE" BLAST



2. BLAST INCLUDING GROUND REFLECTION

REF. 5-20

Noise radiates in an omnidirectional pattern from most blast sources. Thus, their location (and not their orientation) with respect to an observer is important; however artillery fire is directional in nature and both the location and the direction of firing are important.

These sources usually produce extremely high sound pressure levels of predominantly low frequency content which can propagate long distances (Figure 3-5.1.1.1b presents typical spectra). Site selection should therefore include evaluation of blast noise sources up to distances of three miles or more. Where large numbers are involved, as with an Armor Division, distances of concern may extend to seven or ten miles.

3-5.1.1.2 OPERATIONAL CONSIDERATIONS

As with aircraft noise exposure, the two major factors used to determine blast noise exposure are sound exposure level and number of events during daytime and nighttime periods. However, determination of blast noise level is complicated by many operational factors. In particular, the height of the blast above or below ground is important. For blasts below the surface, the transmissivity through the soil affects the noise level. Propagation above ground is influenced by wind and temperature gradients which can create focusing effects. Furthermore, for blasts occurring near the ground, reflections can increase pressure by 50 percent or about 3 dB.

3-5.1.2 EVALUATION PROCEDURES

Computer-generated contours may be obtained for blast noise exposure (see Appendix A for references).. Contours to be used in the evaluation of impact noise are C-weighted L_{dn} (L_{Cdn}). (A hand calculation method is being developed and will be added to this manual when it becomes available.)

Requisite program information required for daytime and nighttime periods is as follows:

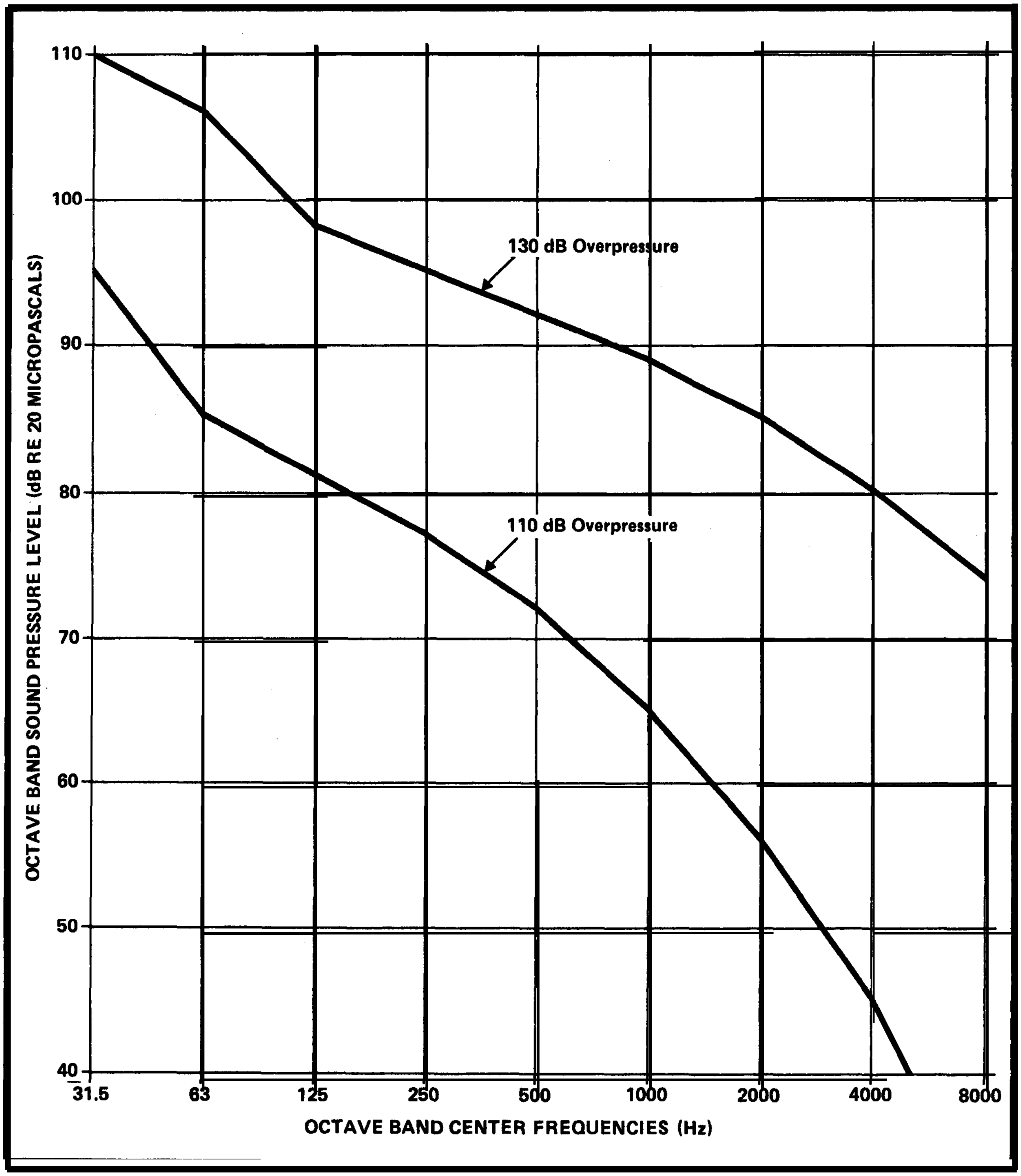
(1) Artillery

- o Type of weapon
- o Location and muzzle direction of weapon
- o Average number of rounds fired during the day/night

(2) Shell Bursts

- o Type of shell

FIGURE 3-5.1.1.1b TYPICAL SPECTRA FOR 10 TO 100 LB TNT BLAST



- o Location of bursts
- o Average number of bursts during the day/night

(3) Surface/Above-surface Blasts

- o Type of blasting device
- o Location of blast
- o Height above ground level
- o Average number of blasts during the day/night

(4) Cratering blasts

- o Type of blasting device
- o Location of blast
- o Depth of charge below surface
- o Average number of blasts during the day/night

3-5.2 SONIC BOOMS

3-5.2.1 BACKGROUND INFORMATION

A sonic boom is a conical shaped impulse (pressure wave) generated as an aircraft travels at speeds which exceed the speed of sound. The aircraft Is at the apex of the cone and the flight path is the axis. Contrary to the prevalent misconception booms do not occur just once as an aircraft breaks the sound barrier but instead are generated continuously the entire time the speed of sound is exceeded. The area affected by a boom can be calculated by multiplying the length of a supersonic flight by the width of the boom path, which may vary from twenty to eighty miles depending on aircraft altitude and a number of other operational factors. As with other large amplitude impulsive noises, annoyance results from both the noise impact and the noise-induced vibrations of buildings and structures.

3-5.2.1.1 SONIC BOOM SOURCES

Supersonic flights are either short bursts or sustained operations. The latter account for five percent of the flights but fifty percent of the distance traveled. It is estimated that the average sustained mission affects 175,000 square miles. The flights are ground dependent, that is they must fly over specific ground installations. The former variety of operations, which includes brief supersonic sprints and training maneuvers, is ground independent and therefore can be executed avoiding populated areas.

3-5.2.1.2 OPERATIONAL CONSIDERATIONS

The' three factors that effect the severity and extent of sonic booms are aircraft design, aircraft operation, and atmospheric conditions. in the first category aircraft size, weight, volume distribution, and lift distribution-are critical factors. Of similar importance are altitude, Mach number, flight path, acceleration affects, and maneuvering effects. Important atmospheric effects include temperature, turbulence patterns, atmospheric pressure and wind gradient. The variability of sound transmission in air has been demonstrated in field tests where sequential measurements taken every 200 feet along flight tracks have illustrated 12 dB differentials within 600 feet.

3-5.2.2 EVALUATION PROCEDURE

Because of the geographically widespread effects of sonic booms and the variations in impact due to operational and atmospheric factors, it is not practical for site selection purposes to evaluate the effects of booms because it affects all potential sites in a comparable manner.

3-6 MOTOR VEHICLES

3-6.1 BACKGROUND INFORMATION

Motor vehicles are grouped into street and combat categories. Because of different source characteristics, they are further subdivided into automobile and truck classes of street vehicles and transport and weapons classes of combat vehicles. The noise exposure at a given distance from a roadway will depend upon traffic flow and roadway characteristics. Traffic will consist of a mixture of vehicles, randomly located relative to one another, travelling at a variety of speeds. The noise exposure of a roadway can be determined from the volume flow (in vehicles per hour) and the average speed (in miles per hour) for each class of vehicle on the roadway.

Analysis of roadway characteristics to yield an accurate measure of noise exposure should take into consideration a wide variety of parameters including roadway gradient, type of pavement, roadway cross-section configuration, roadway curves, vertical alignment, and roadside structures or land forms.

3-6.1.1 NOISE SOURCES

3-6.1.1.1 STREET VEHICLES

The maximum noise emitted by an automobile increases approximately with the third power of vehicle speed. This is due primarily to tire noise created by the tire-roadway interaction. (Figure 3-6.1.1.1a illustrates automobile noise spectra at different speeds.)

The noise output of trucks is a more complicated phenomenon. First, trucks should be considered in three distinct classes according to their noise emission characteristics: light, medium, and heavy trucks. Light trucks are two axle, four wheel vehicles such as panel and pick-up trucks; their noise characteristics are similar to those of automobiles. Medium trucks are typically gasoline-powered two axle, six wheel vehicles, such as city trucks without a vertical exhaust muffler. The noise generation characteristics of these vehicles are also similar to those of automobiles. However, medium trucks are usually 10 dB noisier than automobiles for the same flow and speed.

Heavy trucks are a more complex noise source. These diesel powered, three or more axle vehicles have a multitude of noise mechanisms, i.e., tire noise, exhaust noise, intake noise, engine noise, and gear noise. Shown in Figure 3-6.1.1.1b is a typical truck noise spectrum for the three major component sources: tires, engine and exhaust.

FIGURE 3-6.1.1.1a

TYPICAL AUTOMOBILE SPECTRA FOR TWO AVERAGE SPEEDS

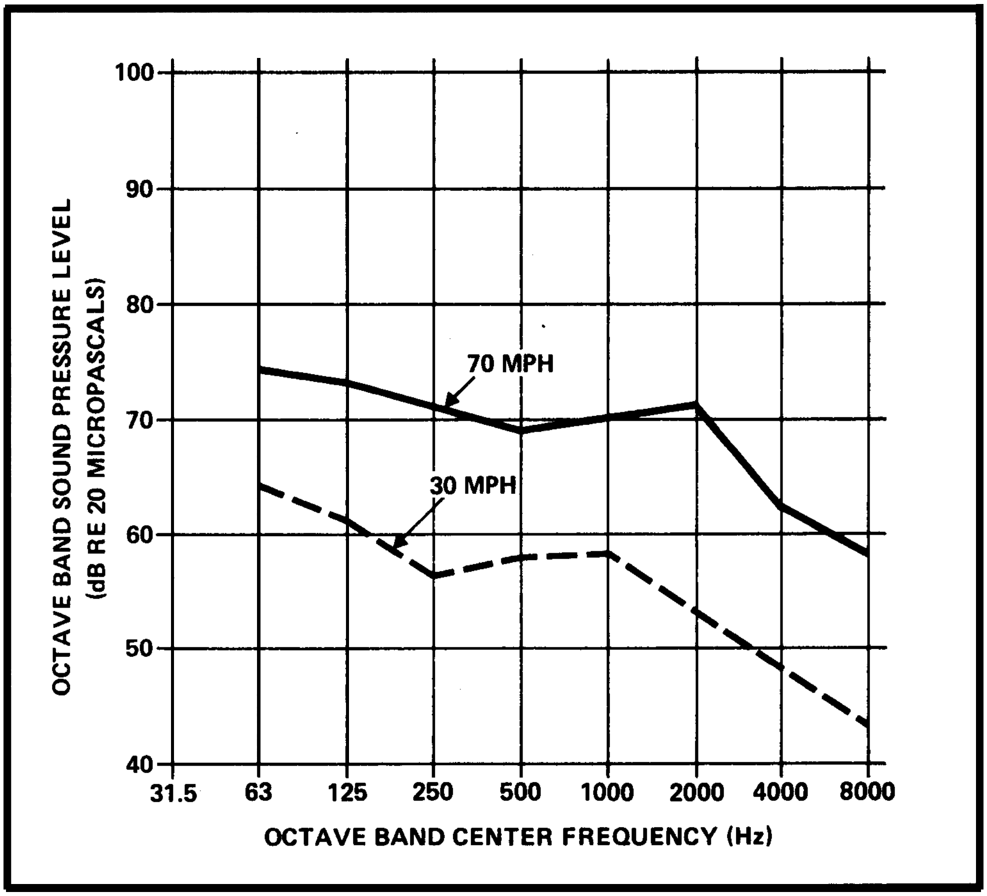
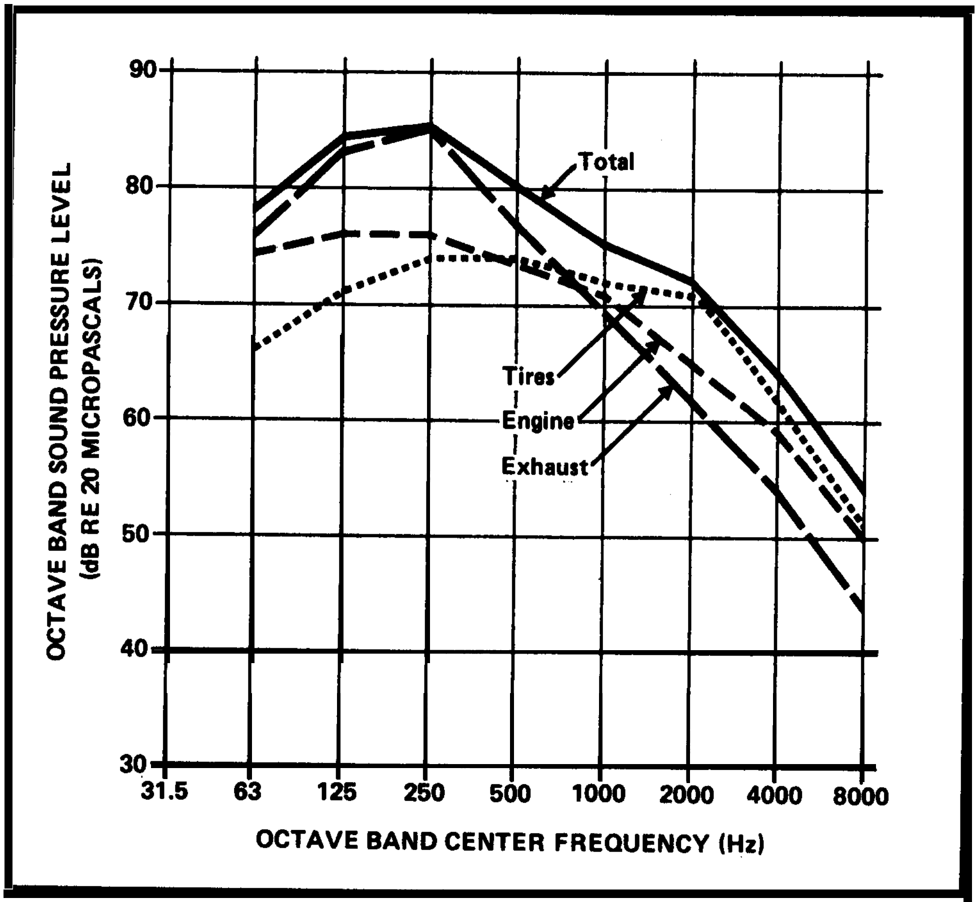


FIGURE 3-6.1.1.1b

TYPICAL SPECTRA FOR DIESEL TRUCK AND COMPONENT SOURCES



Tire-roadway interaction, the major noise source for automobiles and light and medium trucks, occurs at ground level. For heavy trucks an additional noise source, the exhaust stack opening, is nominally located eight feet above the ground. Heavy truck noise does not exhibit great variability. While tire noise varies with speed, the engine noise sources generally show little dependence upon road speed. Furthermore, drivers tend to maintain relatively constant engine speed for all road speeds.

3-6.1.1.2 COMBAT VEHICLES

Transport and weapons vehicles operate at speeds well below that of street traffic. The main use of transport vehicles is to move troops; the vehicles are either wheeled or a combination of wheeled and tracked. Weapons vehicles which serve as mobile weapons are usually tracked.

Measurements have shown that transport and weapons vehicles are up to 10 dB noisier than heavy trucks. The major noise sources of these vehicles are the engine, drive gears and track. Track noise is dominant on those vehicles so equipped.

3-6.1.2 OPERATIONAL CONSIDERATIONS

As previously discussed, roadway noise exposure is a function of the traffic flow parameters of the classes of vehicles using the roadway. automobiles (including light trucks), medium trucks, heavy trucks, transport vehicles and/or weapons vehicles. Where vehicles are uniformly distributed along a single lane roadway that is straight, infinitely long, at grade on flat level terrain, the noise exposure is a function of the volume flow and average speed of each group of vehicles. These conditions will rarely exist, especially for weapons vehicles which are not usually operated on conventional asphalt or concrete road, but rather on dirt roads..

In practice roadway factors will affect noise levels. Noise exposure is <u>increased</u> by uphill grades (for heavy trucks and transport vehicles) and by very rough and/or broken pavement surfaces (for wheeled vehicles). The noise exposure is decreased by buildings, land forms or other barriers located between the roadway and the observer.

The drop-off of noise levels with distance from a roadway will typically range from 4 to 5 dB per doubling of distance. This drop-off rate is affected substantially by ground cover. Beyond two to three thousand feet, the drop-off can increase to about 6 dB per doubling of distance, due to the additional effect of atmospheric attenuation. However, the noise levels from roadway traffic will rarely be high enough to be of concern at these larger distances.

3-6.2 EVALUATION PROCEDURES

The use of a computer greatly facilitates the incorporation of traffic and roadway variables' into the derivation of contours. For the purpose of evaluating prospective sites, the simplified manual approach presented below is adequate.

This section is organized into five subsections. The first four relate to determining the L_{dn} of a specified location. They are as follows:

(1) Determining L_{eq} for a simplified roadway (3-6.2.1)

(2) L_{eq} adjustments for roadway variables (3-6.2.2)

(3) Solving for L_{dn} (3-6.2.3)

(4) Process review (3-6.2.4)

Presented in the fifth subsection (3-6.2.5) is a simplified procedure for determining contours.

3-6.2.1 DETERMINING L_{eq} FOR A SIMPLIFIED ROADWAY

The peak hour equivalent level (L) at a location of interest near a roadway that is flat and infinitely long, with no acoustic shielding, can be determined using the nomographs in Figure 3-6.2.1a (street vehicles) and Figure 3-6.2.1b (combat vehicles). (The peak hour is used because volume flow information is usually readily available for this period, particularly for civil street vehicles. The peak hour L_{eq} is ultimately converted to L_{dn}.)

The following is the information required for use of the nomographs:

(1) The peak hour number of vehicles for each vehicle class.

(2) Average speed of each class of vehicle.

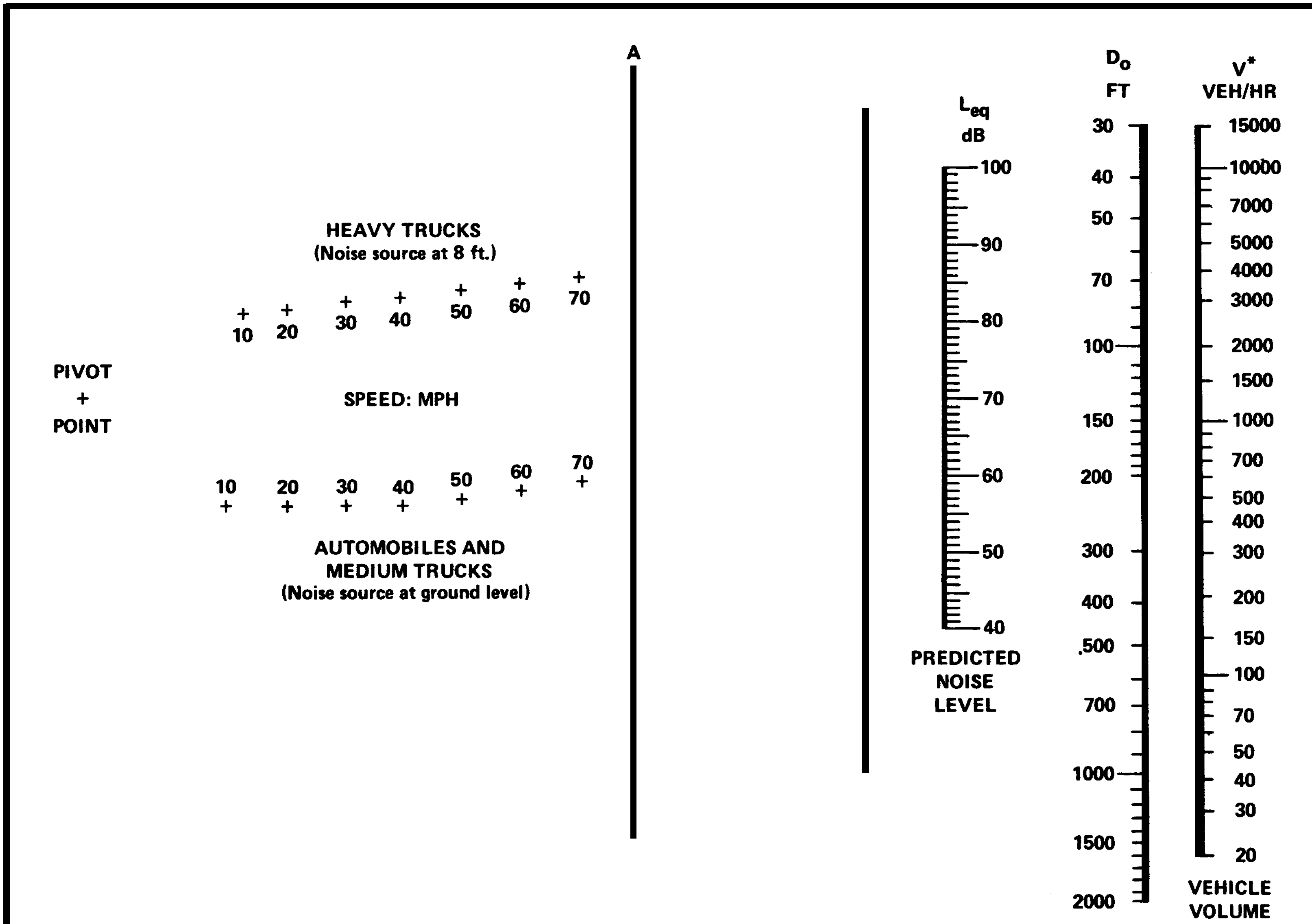
(3) Distance from the site to the centerline of the roadway.

<u>Use of the Nomograph, Basic Information</u>

- o Nomographs are used separately for each vehicle class.

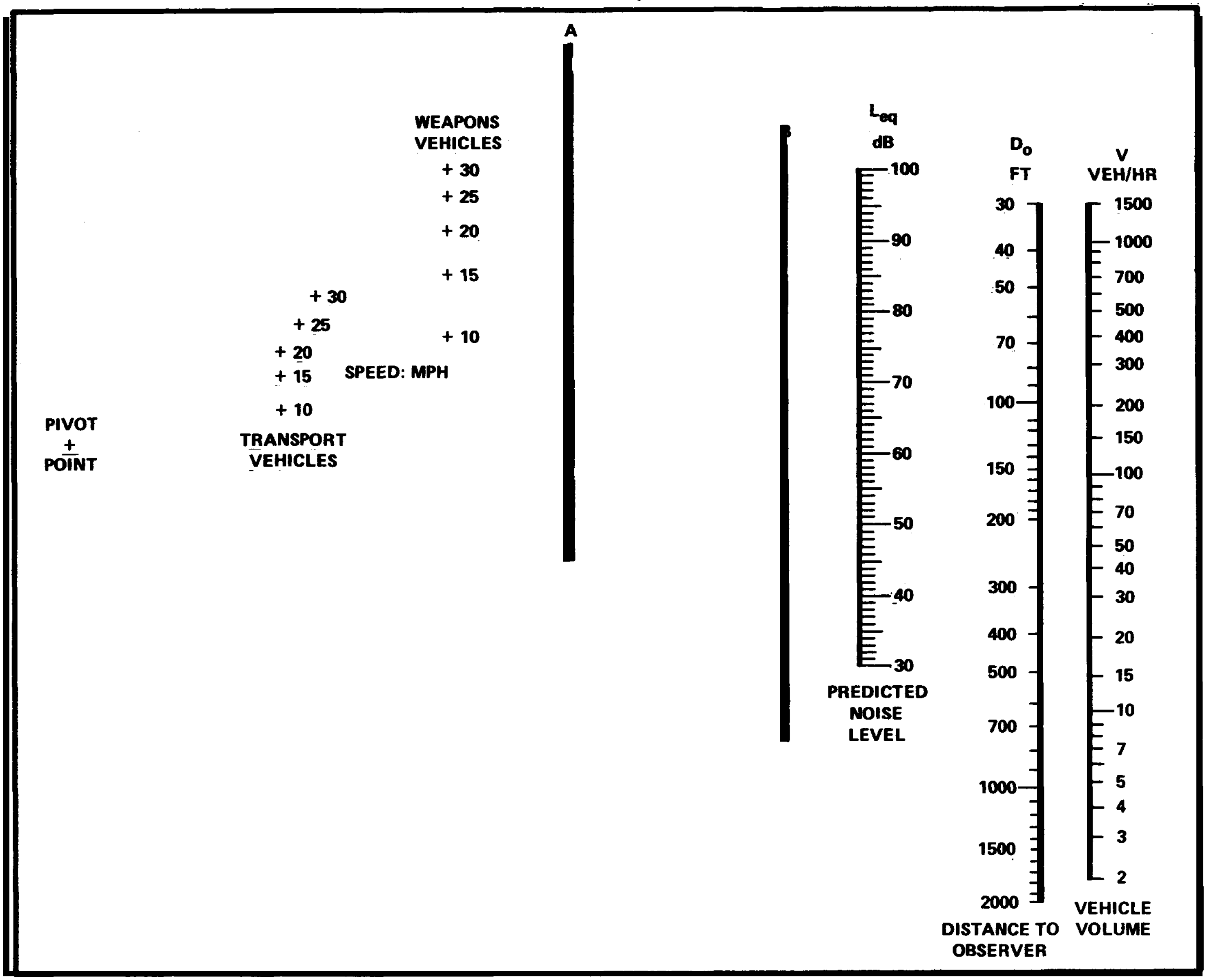
FIGURE 3-6.2.1a

L_{eq} NOMOGRAPH FOR STREET VEHICLE ROADWAY NOISE



*Multiply medium truck traffic volume by ten before using.

FIGURE 3-6.2.1b L_{eq} NOMOGRAPH FOR COMBAT VEHICLE ROADWAY NOISE



- Figure 3-6.2.1a

  - Light trucks are equivalent to automobiles
  - The top row of speed crosses are used for heavy trucks
  - The bottom row of speed crosses are used for automobiles and medium trucks
  - The traffic volume of medium trucks is multiplied by ten before nomograph analysis is made
  - Nominal noise source heights; heavy trucks 8 feet and automobiles ground level (0 feet)

- Figure 3-6.2. lb

  - The left hand column of speed crosses are used for transport vehicles
  - The right hand column of speed crosses are used for weapon vehicles

<u>Use of the Nomograph, Procedural Steps</u>

Refer to Example 3-6.2.1

(1) Draw a line from the pivot point through the correct average speed scale to line A.

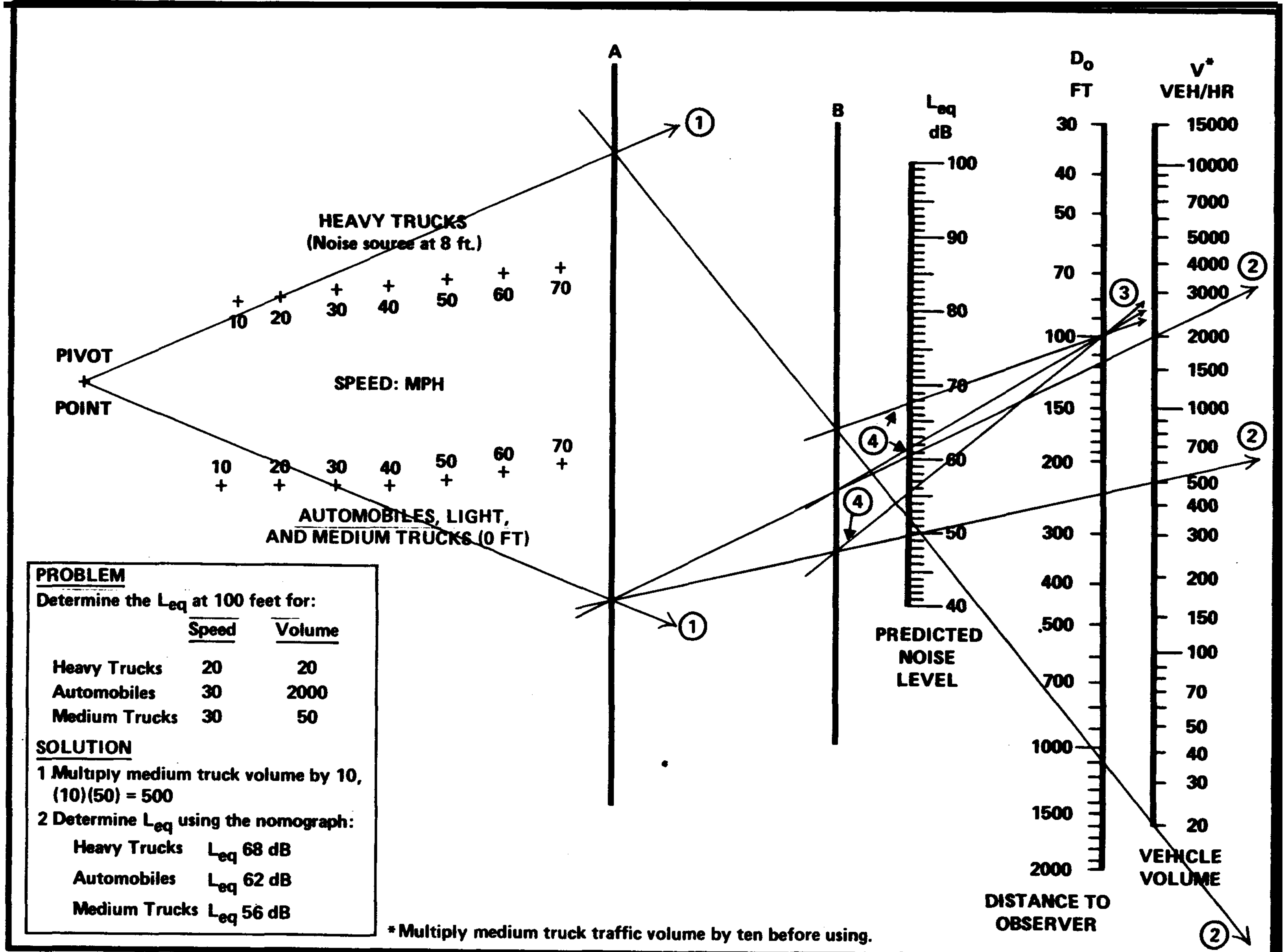
(2) From the intersection point on line A draw a line to the peak hour vehicle volume scale, V, located on the far right of the nomograph. (Use 10 times the volume for medium trucks.)

(3) From the intersection of this line with line B draw a line to the distance to observer scale, D_o, at the appropriate distance.

(4) At the intersection of this line with the L_{eq} scale, read the L_{eq} value.

EXAMPLE 3-6.2.1

L_{eq} NOMOGRAPH FOR STREET VEHICLE ROADWAY NOISE



PROBLEM

Determine the L_{eq} at 100 feet for:

	Speed	Volume
Heavy Trucks	20	20
Automobiles	30	2000
Medium Trucks	30	50

SOLUTION

1 Multiply medium truck volume by 10, (10)(50) = 500

2 Determine L_{eq} using the nomograph:

Heavy Trucks	L_{eq} 68 dB
Automobiles	L_{eq} 62 dB
Medium Trucks	L_{eq} 56 dB

*Multiply medium truck traffic volume by ten before using.

3-6.2.2 L_{eq} ADJUSTMENTS FOR ROADWAY VARIABLES

Gradient Adjustment

Several adjustments to the L_{eq} values determined from the nomographs may be necessary to account for realistic roadway situations. The first is the gradient adjustment. Listed in Figure 3-6.2.2a are the appropriate adjustments as a function of vehicle speed and percent grade. Note that these adjustments apply only to heavy trucks and transport vehicles and are added directly to the equivalent level for the particular class of vehicles.

Shielding Adjustment

A second adjustment is for shielding effects. There may be a variety of obstacles between the roadway and the observer, including buildings, landforms, walls, and portions of the roadway itself (in the case of elevated or depressed roadways). Section 5-2.1.4 in Chapter 5 provides guidelines and techniques for evaluating the shielding effects of these obstacles.

Roadway Surface Adjustment

A third adjustment is appropriate for wheeled vehicles (all street vehicles and transport vehicles) when the roadway surface is unusually rough. When pavement is broken, or when there are large voids or grooves in the surface, 5 dB should be added to the equivalent level for each applicable vehicle class.

Roadway Segment Adjustment

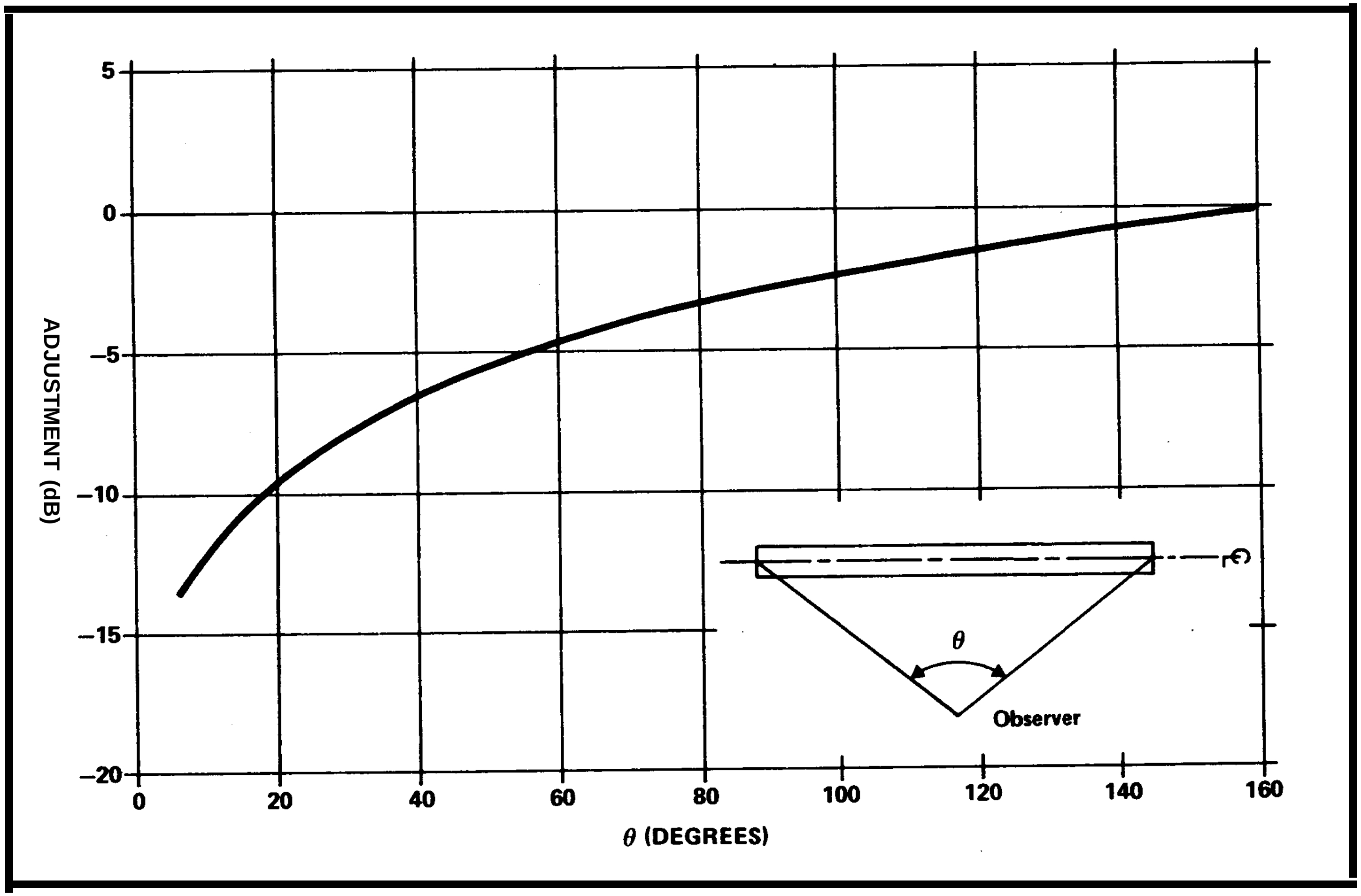
Although many roadways are not infinitely long and straight, it is usually preferable (and sufficiently accurate for screening purposes) to perform the noise evaluation as if they were. However, where roadway conditions vary near a site being evaluated, it may be desirable to evaluate the roadway in sections. For example, consider a roadway with a 3% grade over half its length: dividing the roadway into a level section and a section of constant 3% grade would improve the accuracy of the noise estimation.

The L_{eq} for a section of roadway is obtained by first determining the L_{eq} for the roadway as if it were infinite (i.e., by using the appropriate nomograph) and then applying an adjustment to account for the finite length of the section. The proper adjustment as a function of the angle of observation is shown in Figure 3-6.2.2b. Note that the observer need not be in the center of the segment for this adjustment to be applicable. (For angles greater than 160°, the adjustment is 0 dB.)

FIGURE 3-6.2.2a ROADWAY GRADE ADJUSTMENT FOR HEAVY TRUCKS AND TRANSPORT VEHICLES

Percent Grade	Average Speed, mph		
	≤15	20-35	≥40
1	4	3	2
2	5	4	3
3	6	5	4
4	7	6	5
5	8	7	6

FIGURE 3-6.2.2b ADJUSTMENT TO ACCOUNT FOR FINITE LENGTH OF ROADWAY SEGMENT



3-6.2.3 SOLVING FOR L_{dn}

Once the equivalent levels for a class of vehicles has been determined for all roadway sections, they may be energy added using Figure 3-1.1.2c. The individual L_{eq} values for each vehicle class can then be added together again using Figure 3-1.1.2c to yield the total L_{eq} for the roadway.

L_{dn} can then be determined by using the following equation:

$$L_{dn} = L_{eq} + \Delta \qquad (3\text{-}3)$$

where :

Δ (delta) = a function of the percentage of nighttime traffic (Refer to Figure 3-6.2.3)

3-6.2.4 PROCESS REVIEW

The calculation of motor vehicle L_{dn} can be summarized as follows:

(1) Determine the average speed and peak hour number of vehicles for each vehicle class.

(2) Use the appropriate L_{eq} nomograph (Figure 3-6.2.1a or 3-6.2.1b) for each vehicle class to determine the L_{eq} for an infinite roadway.

(3) If appropriate, divide the roadway into finite segments.

(4) Adjust the L_{eq} values for finite segments using Figure 3-6.2.2b.

(5) Apply adjustments from Figure 3-6.2.2a to heavy trucks and transport vehicle noise for those segments with gradients.

(6) Apply adjustments from Section 5-2.1.4 for those segments shielded from the observer.

(7) Apply a 5 dB adjustment to wheeled vehicles for those segments with very rough pavements.

(8) in each segment arithmetically sum the L_{eq} values and adjustments for each vehicle class.

FIGURE 3-6.2.3

ADJUSTMENT TO CONVERT L_{eq} TO L_{dn} FOR ROADWAY TRAFFIC NOISE

% Day	% Night	ΔdB
62.5	37.5	3
75	25	2
85	15	1
90	10	0
95	5	-1
100	0	-3

(9) Sum the adjusted L_{eq} values for each vehicle class to obtain an Leq value for each segment (use Figure 3-1.1.2c)

(10) Sum the segment L_{eq} values to obtain L_{eq} for the entire roadway (use Figure 3-1.1.2c).

(11) Adjust the L_{eq} to yield L_{dn}, using Figure 3-6.2.3.

To facilitate analysis, this ten step process is presented in matrices depicted in Figure 3-6.2.4a and b and illustrated in Example 3-6.2.4.

3-6.2.5 DETERMINATION OF CONTOURS OF EQUIVALENT NOISE EXPOSURE

The procedure outlined in 3-6.2.4 can be used to develop approximate L_{dn} contours, with the following specific restrictions: the roadway must be considered as a single segment, must be considered infinitely long and shielding effects must be ignored. Within these constraints, approximate L_{dn} contours may be derived as follows:

1. Determine L_{dn} value for a 100 foot distance between observer and roadway centerline.

2. Use Figure 3-6.2.5 to calculate the distance from centerline to the desired L_{dn} contour value using the L_{dn} value at 100 feet as a reference point. (Example shown in Figure 3-6.2.5.)

3. Draw contour lines at the appropriate distances from the centerline, parallel to the sections of the roadway under study.

FIGURE 3-6.2.4a

STREET VEHICLE ANALYSIS MATRIX

		Equivalent Levels (L_{eq}) for Segment No.____			
		Heavy Trucks	Medium Trucks	Automobiles	Source
	Average speed (mph)				Field data
	Peak hour traffic (vph)		x 10 =		Field data
1.	L_{eq} (dB)				Figure 3-6.2.1a
2.	θ = ____, segment adjustment				Figure 3-6.2.2b
3.	Grade = ____, gradient adj.				Figure 3-6.2.2a
4.	Barrier adjustment				Section 5-2.1.4
5.	Rough roadway adjustment				Section 3-6.2.2
6.	Adjusted L_{eq}				Total of rows 1 through 5
	Segment L_{eq}				Energy addition of row 6 (Figure 3-1.1.2c)

FIGURE 3-6.2.4b COMBAT VEHICLE ANALYSIS MATRIX

Equivalent Levels (L_{eq}) for Segment No.__				
		Transport Vehicles	Weapons Vehicles	Source
	Average speed (mph)			Field data
	Peak hour traffic (vph)			Field data
1.	L_{eq} (dB)			Figure 3-6.2.1 b
2.	θ =____, segment adj.			Figure 3-6.2.2b
3.	Grade =__ gradient adj.			Figure 3-6.2.2a
4.	Barrier adjustment			Section 5-2.1.4
5.	Rough roadway adj.			Section 3-6.2.2
6.	Adjusted L_{eq}			Total of rows 1 through 5
	Segment L_{eq}			Energy addition of row 6 (Fig. 3-1.1.2c)

FIGURE 3-6.2.4c ANALYSIS OF ROADWAY DAY/NIGHT LEVEL (L_{dn})

1. % of nighttime traffic __%
2. Nighttime adjustment _____ (Δ from Figure 3-6.
3. Roadway segment L_{eq}'s ___ ___ ___ ___ ___
4. Total Roadway L_{eq} ___ (total of all roadway segment L_{eq}'S)
5. Roadway L_{dn} at point of analysis ___ (add nos. 2 and 4)

PROBLEM:

Determine the L_{dn} value at location X (100 feet from roadway) given the following information :

- a. **Traffic flow situation in Figure 3-6.2.1**
- b. **One half of roadway flat, one half at 2% grade**
- c. **Median point in change of grade (0 to 2%) occurs directly opposite of site, i.e., line drawn through median point in change of grade and middle of site is perpendicular to centerline of road.**
- d. **15% of traffic flow at night.**

SOLUTION:

FIGURE 3-6.2.4a STREET VEHICLE ANALYSIS MATRIX

		Equivalent Levels (L_{dn}) for Segment No. 1			
		Heavy Trucks	Medium Trucks	Automobiles	Source
	Average speed (mph)	20	30	30	Field data
	Peak hour traffic (vph)	20	50 x 10 = 500	2000	Field data
1.	L_{eq} (dB)	68	56	62	Figure 3-6.2.1a
2.	θ = 80°, segment adjustment	-3	-3	-3	Figure 3-6.2.2b
3.	Grade = 2, gradient adj.	+4			Figure 3-6.2.2a
4.	Barrier adjustment	0	0	0	Section 5-2.1.4
5.	Rough roadway adjustment	0	0	0	Section 3-6.2.2
6.	Adjusted L_{eq}	69 dB	53 dB	59 dB	Total of rows 1 through 5
	Segment L_{eq}	70 dB			Energy addition of row 6 (Fig. 3-1.1.2a)

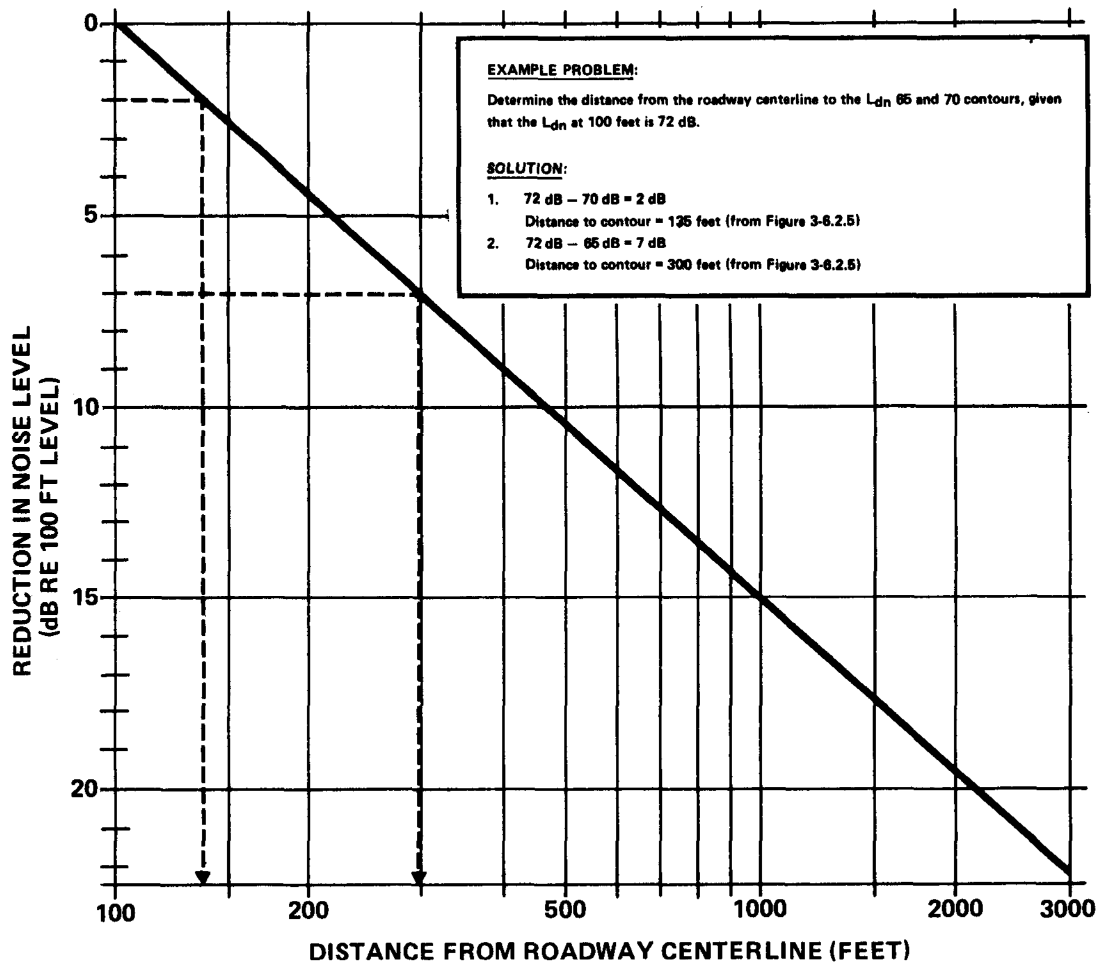
		Equivalent Levels (L_{eq}) for Segment No. 2			
		Heavy Trucks	Medium Trucks	Automobiles	Source
	Average speed (mph)				Field data
	Peak hour traffic (vph)		x 10 =		Field data
1.	L_{eq} (dB)	68	56	62	Figure 3-6.2.1a
2.	θ = 80°, segment adjustment	-3	-3	-3	Figure 3-6.2.2b
3.	Grade = 0, gradient adj.	0			Figure 3-6.2.2a
4.	Barrier adjustment	0	0	0	Section 5-2.1.4
5.	Rough roadway adjustment	0	0	0	Section 3-6.2.2
6.	Adjusted L_{eq}	65 dB	53 dB	59 dB	Total of rows 1 through 5
	Segment L_{eq}	66 dB			Energy addition of row 6 (Fig. 3-1.1.2a)

FIGURE 3-6.2.4c ANALYSIS OF ROADWAY DAY/NIGHT LEVEL L_{dn}

1. % of nighttime traffic 15 %
2. Nighttime adjustment +1 (from Figure 3-6.2.3)
3. Roadway segment L_{eq}'s 70 66 ___ ___ ___
4. Total Roadway L_{eq} 71 (total of all roadway segment L_{eq}'s)
5. Roadway L_{dn} at point of analysis 72dB (add nos. 2 and 4)

FIGURE 3-6.2.5

REDUCTION IN ROADWAY NOISE LEVEL WITH DISTANCE



3-7 RAILROAD NOISE

3-7.1 BACKGROUND INFORMATION

There are two distinct types of railroad noise: noise from line operations, which involves a train moving from one point to another, and noise from yard and siding operations, which also includes car loading and unloading, switching, storage, and maintenance.

3-7.1.1 NOISE SOURCES

3-7.1.1.1 LINE OPERATIONS

Railroad line noise has an engine and car component.

Engine noise includes exhaust, casing, intake and fan noise. Both engine casing and fan noise levels are typically lower than exhaust levels, and intake noise, which is muffled by the air filter, usually cannot be individually identified. The exhaust noise increases with increased horsepower, and non-turbocharged engines are about 6 dB quieter than turbocharged engines. Casing noise is also dependent upon the horsepower rating. An additional significant, but periodic, noise source is the train horn.

Car noise is created by the interaction of steel wheels and rails and increases markedly with train speed. In addition to normal interaction noise, there is wheel squeal, a high pitched pure tone, which occurs when a train traverses a tight curve. There is also impact noise, which is produced when wheels pass over a joint, frog, or signal junction.

3-7.1.1.2 YARD AND SIDING OPERATIONS

Retarders are the principal noise source in a typical railroad yard. Retarders are mechanical devices used to control the velocity of individual cars as a train is being assembled. A retarding beam is clamped against the wheels of a car to slow it down and the resultant noise normally peaks at a frequency of 2000 to 4000 Hz. Noise levels are dependent on retarder location and frequency of use.

Another noise source in railroad yards and sidings is car impacts. When a car is being coupled to a string of cars or when a locomotive with a number of cars is starting to move, several impacts may occur. Impacts add little to L_{dn} because: a) the signal is of very short generation; b) the signal has a low amplitude; and c) typically the number of impacts is not significant. In contrast, the noise of an idling engine may be significant; although not of high level It may occur for extended periods of time.

3-7.1.2 OPERATIONAL CONSIDERATIONS

3-7.1.2.1 LINE OPERATIONS

The power of a train is controlled by a throttle with eight equal incremental settings.. On line runs, the engine is at the eighth setting (full throttle) about fifty percent of the time. The noise level difference between idle and full throttle is about 15 dB; however, engine noise is not a function of speed.

Conversely, the effect of speed on car noise is most important. The noise levels for a typical car increases with the third power of speed.

The noise exposure from railroad operations is thus a function of both the noise level and the duration of passby (which, in turn, is dependent upon train speed and length).

3-7.1.2.2 YARD AND SIDING OPERATIONS

Railroad yard and siding noise levels are highly dependent upon operations. The more cars to be moved around, the more noise there will be.

Most installation yard type activities are loading and unloading, rather than switching, coupling and decoupling of cars. Therefore, the important noise sources are low speed movement and idling. Although maximum noise levels may not be high, the duration of these operations will significantly affect the noise exposure.

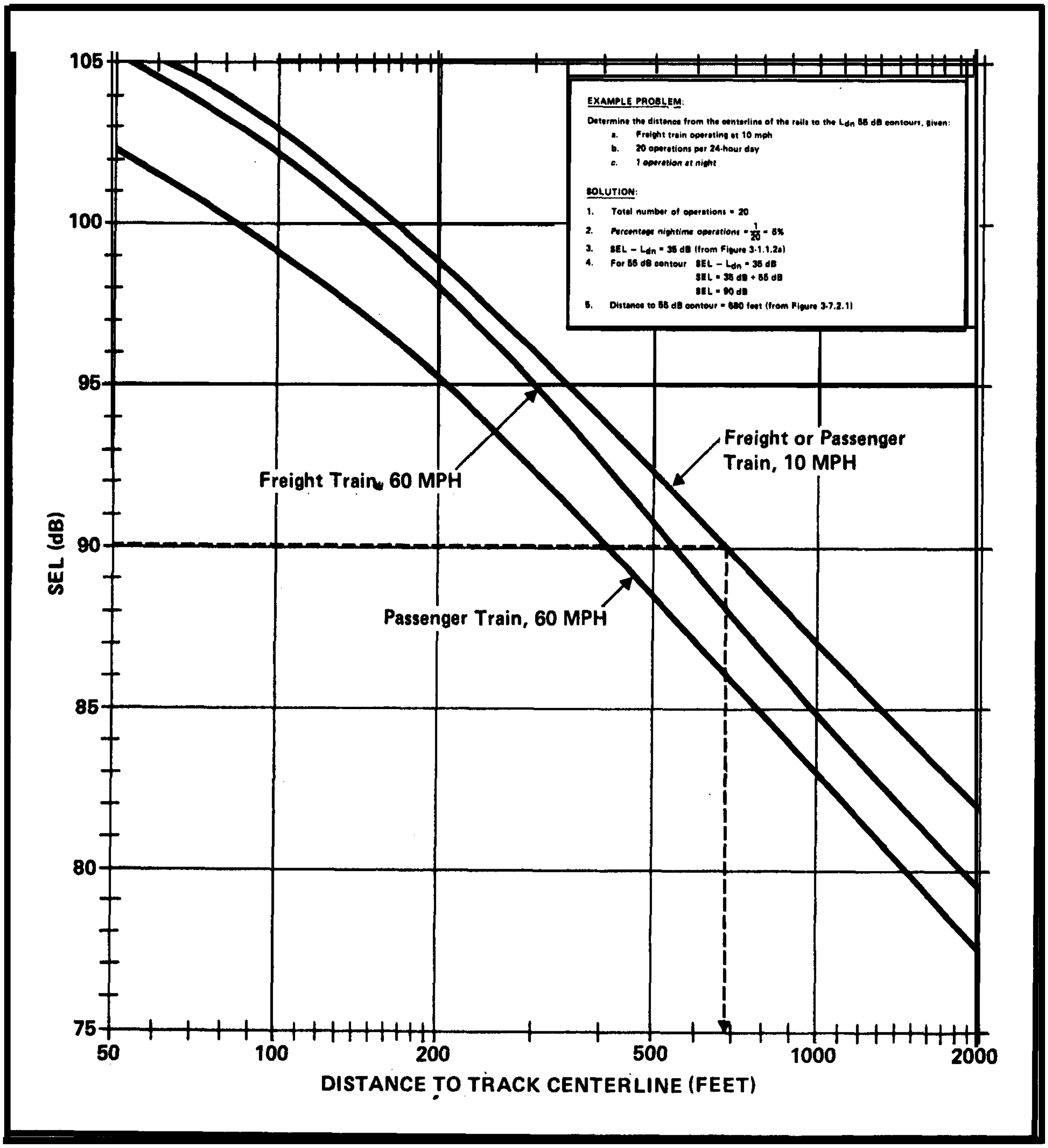
3-7.2 EVALUATION PROCEDURES

The procedure discussed below is based on several simplifying assumptions concerning the type, length and speed of trains which may be encountered.

3-7.2.1 LINE OPERATIONS

This analysis is valid for railroad operations on level grade, with no shielding by buildings or other structures between the train and the location of interest.

The variation of SEL with distance for typical train operations is shown in Figure 3-7.2.1. The SEL is a measure of duration as well as noise level. Since the duration of the noise signal increases with decreasing speed, and the noise of the engine is independent of speed, the SEL decreases with increasing speed. For a given distance


EXAMPLE PROBLEM:
Determine the distance from the centerline of the rails to the L_{dn} 55 dB contours, given:
a. Freight train operating at 10 mph
b. 20 operations per 24-hour day
c. 1 operation at night
SOLUTION:
1. Total number of operations = 20
2. Percentage nighttime operations = $\frac{1}{20}$ = 5%
3. SEL − L_{dn} = 35 dB (from Figure 3-1.1.2a)
4. For 55 dB contour SEL − L_{dn} = 35 dB
SEL = 35 dB + 55 dB
SEL = 90 dB
5. Distance to 55 dB contour = 680 feet (from Figure 3-7.2.1)
Freight or Passenger Train, 10 MPH
Freight Train, 60 MPH
Passenger Train, 60 MPH
SEL (dB)
105
100
95
90
85
80
75
50
100
200
500
1000
2000
DISTANCE TO TRACK CENTERLINE (FEET)

and percentage of nighttime operations, the SEL determined from this figure may be used to obtain the L_{dn} by referring to Figure 3-1.1.2a. If several different trains utilize a particular track, the L_{dn} values determined for each may be added together using Figure 3-1.1.2c. L_{dn} contours may be derived by proceeding in the reverse order; refer to Figure 3-7.2.1.

The curves in Figure 3-7.2.1 illustrate that the maximum SEL difference among types of trains is only 4 dB. This small value permits further simplification in deriving contours where there are different types of railroad operations. First, determine the major noise-contributing class of operations. This is done by selecting an arbitrary distance and determining the L_{dn} value for each type of train. The highest L_{dn} determines the major contributor. Then use the SEL value for the major contributor with the total number of Operations for all train types to determine L_{dn} contours.

Train noise contours, like highway contours, are prepared by drawing lines along and parallel to the rails at the appropriate distances from the center of the tracks.

3-7.2.2 YARD AND SIDING OPERATIONS

For screening purposes, the noise exposure of yard operations (primarily loading and unloading activities) may be approximated by using the top curve (freight or ‘passenger train, 10 mph) in Figure 3-7.2.1. Each single train movement to a yard area or siding should be counted as though it were one passby of a freight train at 10 mph. The duration effects of idling are approximated in the SEL curve, therefore an identical procedure to that illustrated for line operations may be used to approximate the noise from yard operations.

3-8 FIXED NOISE SOURCES

3-8.1 BACKGROUND INFORMATION

Fixed noise sources include a variety of equipment which can generally be found in and around testing facilities, power plants, maintenance facilities and other buildings. Such equipment is typically operated in a fixed position (either permanently or temporarily over an extended time period) and typically produces noise levels that are constant over the period of operation.

The noise exposure is dependent upon the way in which the equipment is installed, the use of mufflers or enclosures, and operating schedule. Because of the variety of machines in use and the wide variance in operating parameters for machinery, an all-inclusive generalized evaluation procedure is impractical. Thus, the procedure to be taken with fixed sources is as follows:

(1) Acquire noise information about the particular machine under consideration (this may require in-field measurements) and

(2) Apply operational considerations to determine an L_{dn} value.

3-8.1.1 NOISE SOURCES

Frequently encountered noise sources are compressors, generators, blowers and pumps. Noise produced by these machines exhibit a wide range in both frequency, content and level; however the A-weighted level (AL) is an appropriate measure of the noise produced during routine operations. The noise exposure may be assessed by considering the maximum A-level and the period of time over which it occurs.

3-8.1.2 OPERATION CONSIDERATIONS

The manner of installation and the location of a piece of equipment will have a significant effect on the noise levels produced. Noisy compressors and generators in the basement of a building may have little noise impact outside the building itself; however, an unenclosed compressor on the flight line can radiate excessively high noise levels for hundreds of feet in all directions. Mufflers, enclosures, and barriers modify the directional characteristics and absolute noise levels of fixed sources.

3-8.2 EVALUATION PROCEDURES

Equipment noise, like aircraft ground runup noise, is nearly constant with time. Thus, noise exposure evaluation is similar.

(1) Determine AL

(2) Establish daytime and nighttime duration

(3) Use Figure 3-1.1.2b to obtain the L_{dn} for all major operating modes

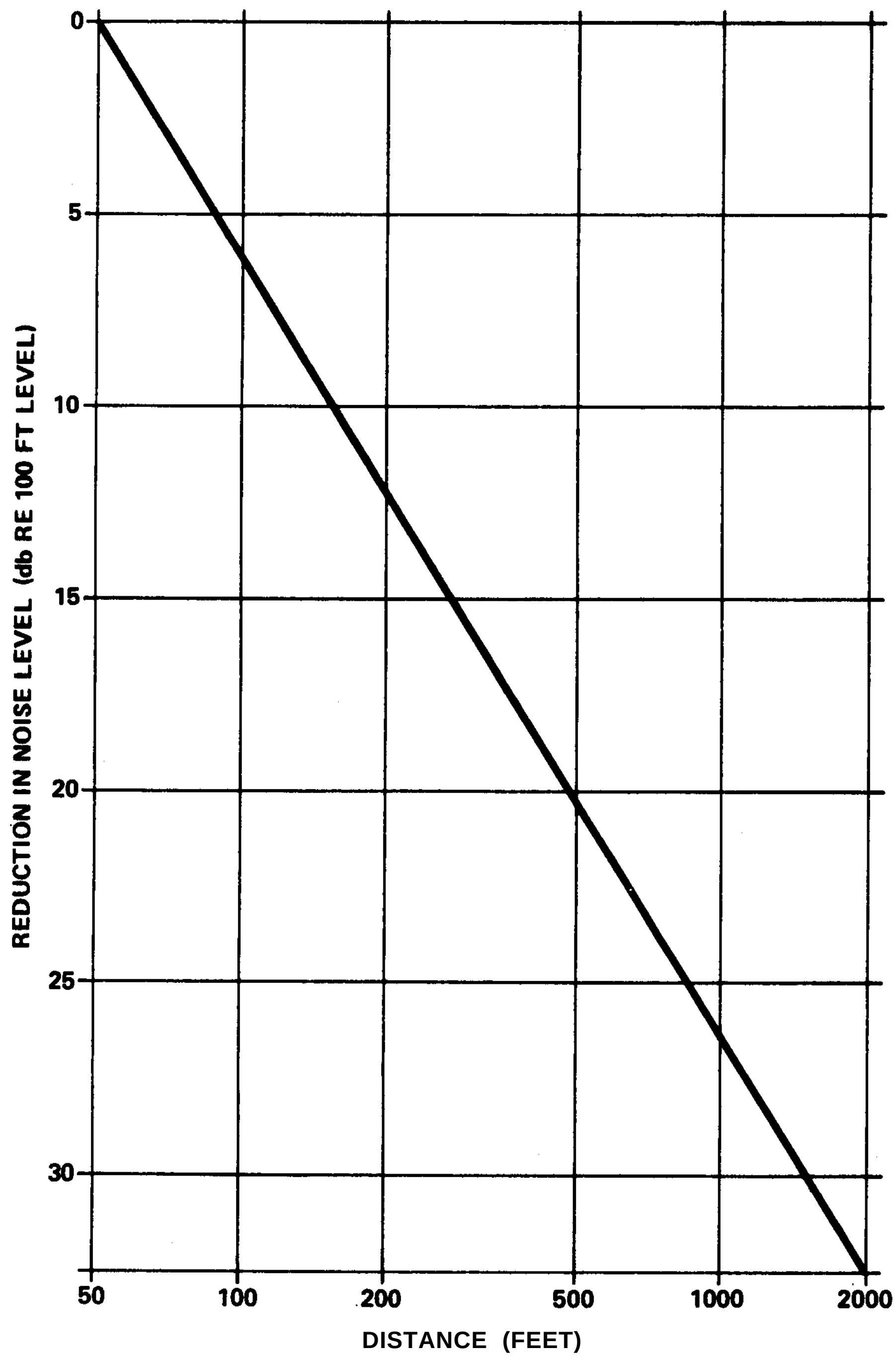
The A-levels for much equipment have been measured and are available In the reference listed in Appendix B. When not available elsewhere, AL can be determined with field measurements. This approach will generally be more accurate. Measurements may be made by the installation Bioenvironmental Engineer or Health and Environment Officer.

When the AL cannot be obtained at the point of interest, but is known for another point, the L_{dn} can be determined from Figure 3-8.2. Contours can be developed through a reversal of that process. For example, if the L_{dn} at 50 feet were 66 dB, the 60 dB contours would be located 100 feet from the source.

If a source is omnidirectional, i.e., if the noise radiates equally in all directions, as for an unobstructed point source, contours will consist of concentric circles with radii equal to the distances derived for prescribed L_{dn} values. For sources with distinct directionality characteristics, development of contours is much more complex and should not be undertaken; instead, utilize available assistance listed in Appendix A.

FIGURE 3-8.2

REDUCTION IN NOISE LEVEL WITH DISTANCE FROM A POINT SOURCE



NOTE: This figure is based on inverse-square spreading from the noise source, and does not incorporate atmospheric and ground absorption affects. These effects may be significant at distances of 1000 feet and beyond.

3-9 COMBINED NOISE EXPOSURE FROM ALL SOURCES

The purpose of the preliminary screening is to quickly determine and eliminate those areas where it is undesirable to locate the facility of interest. Specific potential sites may then be selected in the remaining areas. The second phase screening involves evaluating the noise exposure at each site by considering the combined effect of all noise sources.

3-9.1 PRELIMINARY SCREENING

Procedurally, the planner should first determine the maximum acceptable noise exposure for the facility (refer to Figure 4-5). For each noise source for which L_{dn} contours are available (either computer-generated or manually-derived), the contours should be overlayed, one at a time, on a map of the installation. Noise contours for aircraft operations (both air and ground) and blast/impulse noise sources may be obtained through the agencies listed in Appendix A. For other sources, methods are provided in this volume for manually deriving approximate noise contours. Where the noise exposure from any source exceeds the maximum acceptable limit, the exposed area should be eliminated from further consideration. Note that, when feasible, the application of attenuative measures (refer to Chapter 5) can render marginally unacceptable sites suitable for development.

This process will not screen out all areas with excessive noise exposure as the cumulative effect of all sources is not evaluated.

3-9.2 FINAL SITE SCREENING

After the specific locations of potential sites have been identified on a single map, the L_{dn} values of contributing sources are added, using Figure 3-1.1.2c to determine the total noise exposure.

The L_{dn} value for a prescribed point may be obtained directly from manual evaluations or interpolated from computer-produced or manually-derived contours. When computer-produced contours are available, the approximate L_{dn} value at the location of interest may be determined by overlaying the contours on the installation map, and reading the L_{dn} value by visual interpolation between the contour lines surrounding the site.

The L_{dn} values for each source should be determined to the nearest decibel and then energy added (using Figure 3-1.1.2c, starting with the lowest levels first). The following sections describe this procedure in detail.

After the total L_{dn} at each potential site has been determined, the planner can proceed with the planning process presented in Chapter 6. This will enable the planner to logically compare sites and incorporate appropriate noise abatement measures.

3-9.2.1 DETERMINATION OF INTERMEDIATE CONTOURS

Computer-produced contours are usually described in 5 dB increments from L_{dn} 80 to L_{dn} 65, although the L_{dn} 85 and L_{dn} 60 contours are sometimes plotted. The following procedure may be used to determine one dB incremental contours between the computer-plotted contour lines. The following steps are illustrated in Example 3-9.2.1:

<u>Step 1</u>: At several points on the 5 dB contour lines, establish lines which are perpendicular to the inner contours and extend them outward toward the outer contours. Insofar as possible, these lines should be perpendicular to all the contour lines which they intersect.

<u>Step 2</u>: Divide these lines into equal segments between each 5 dB contour line.

<u>Step 3</u>: Draw in contours through the points established in Step 2 following the general curvature of the nearest 5 dB contour line.

3-9.2.2 DETERMINATION OF L_{dn} 60 CONTOUR

Available computer-generated contours for aircraft and/or blast noise may not have L_{dn} 60 contours plotted. Ideally, at locations where noise from both aircraft and blast/artillery operations both contribute to the noise environment, computer-generated contours for both operations should be requested through the agencies listed in Appendix A. contours down to L_{dn} 60 should be explicitly specified in the request. However, if contours with L_{dn} 60 plotted are not available and a siting determination is necessary for an area which falls outside, but near both the L_{dn} 65 contours for aircraft and blast/artillery operations, then the procedure described in this section may be used to determine a conservative estimate of the position of the L_{dn} 60 contour. Once this has been done for both noise sources, the unit contours between L_{dn} 60 and L_{dn} 65 may be drawn in using the procedure described in 3-9.2.1 The following steps are illustrated in Example 3-9.2.2.

<u>Step 1</u>: Select several points along the 5dB contours where a perpendicular line can be drawn through all the contours (80, 75, 70, 65) and remain essentially perpendicular to all of them.

<u>Step 2</u>: Measure the distance between the contours on these perpendicular lines and plot the distances against the L_{dn} contour values.

<u>Step 3</u>: Using a French curve, establish a curve which fits these plotted points for each perpendicular line drawn through the contours. Extend the curve until it crosses the L_{dn} 60 line on the plot of distances versus L_{dn} values. Read off the distance to the L_{dn} 60 contour line.

Step 4: Draw the L_{dn} 60 contour through the points established in Step 3 following the same general curvature as the L_{dn}65 contour.

3-9.2.3 DEVELOPMENT OF COMBINED NOISE CONTOURS

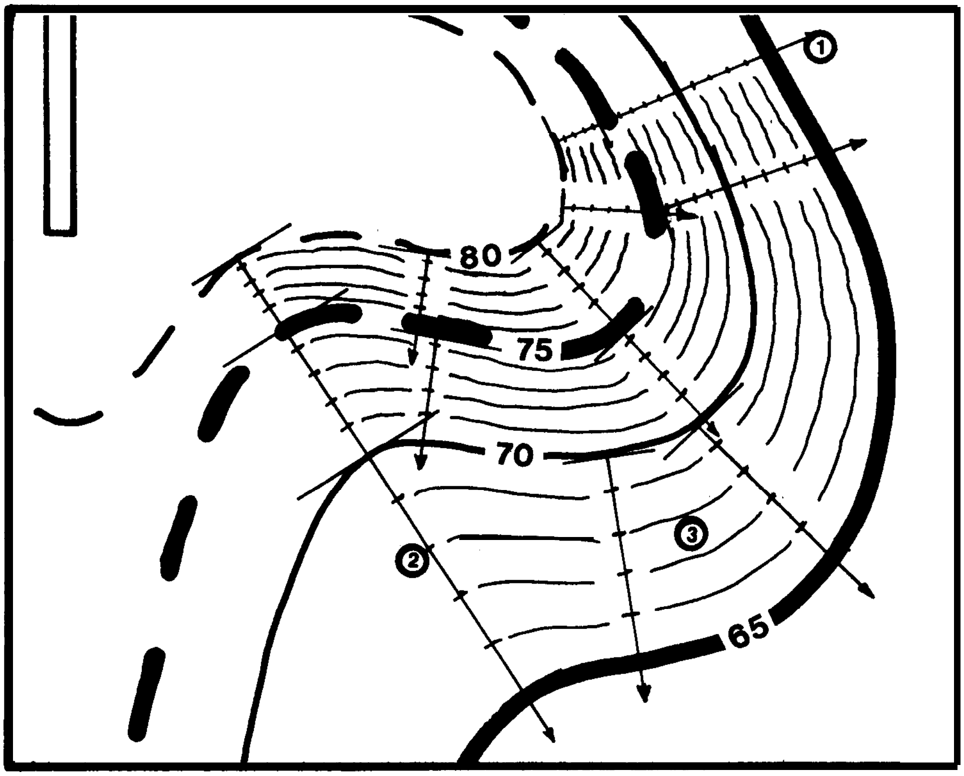
If computer-produced contours combining all relevant noise sources are not available, then the procedure described in this section may be used to combine L_{dn} and/or L_{Cdn} contours from various noise sources (see example 3-9.2.3).

Step 1: Obtain unit contours for the noise sources impacting the potential sites in question and overlay them upon one another by use of tracing paper or other appropriate means locate the intersections of contours in the areas of interest. (Refer to 3-9.2.1 and 3-9.2.2 for determining the location of unit contours if those available are in increments of more than one decibel.)

Step 2: Using Figure 3-1.1.2c, determine the decibel increment to add to the higher contour value to equal the combined value of the two sources at that point. Repeat this procedure for a sufficient number of points to enable manual contouring.

Step 3: Connect points of equal noise exposure to produce combined contours.

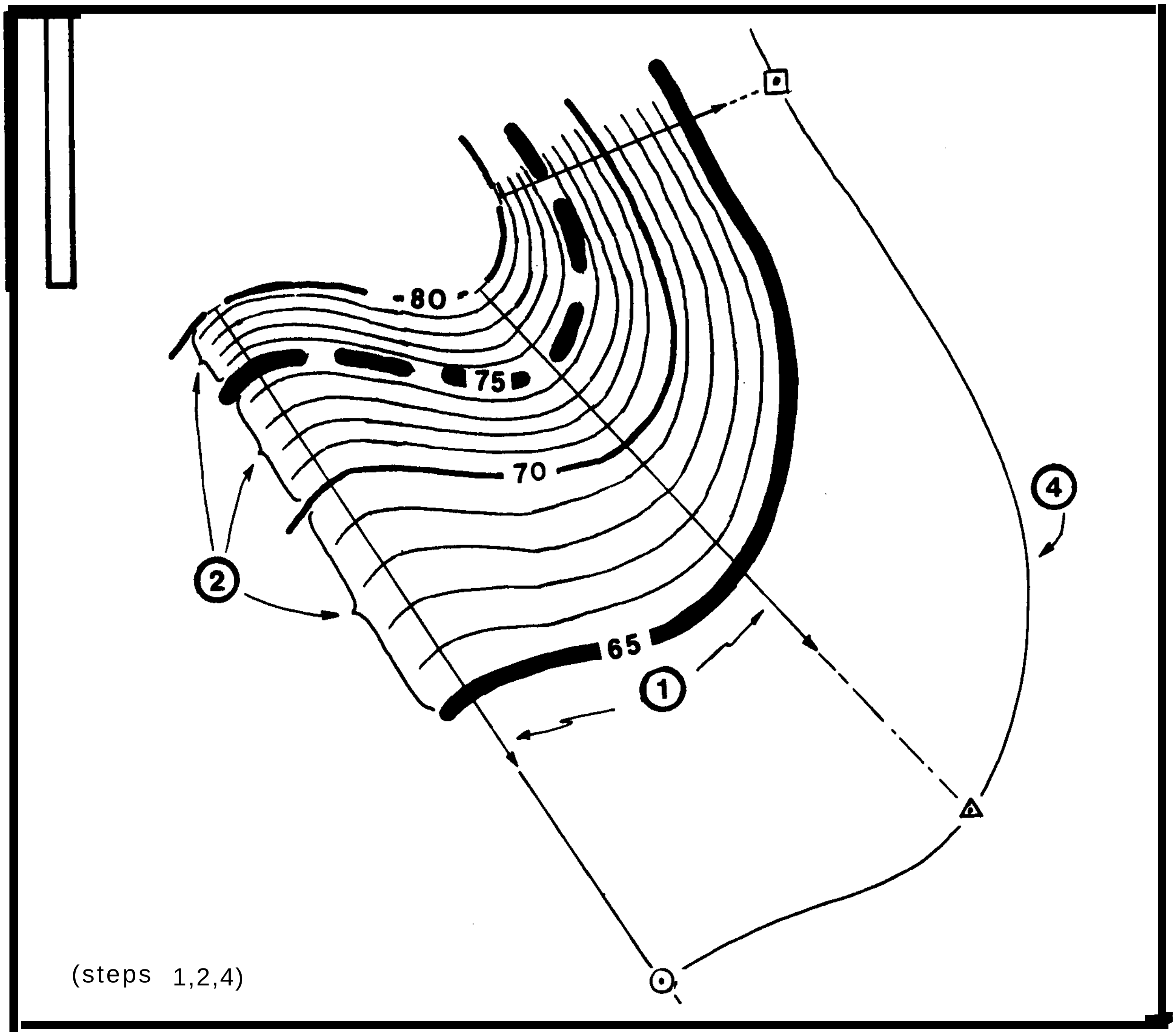
EXAMPLE 3-9.2.1 DEVELOPMENT OF INTERMEDIATE CON TOURS



①	ESTABLISH PERPENDICULAR LINES
②	DIVIDE INTO EQUAL SEGMENTS
③	DRAW INTERMEDIATE CONTOURS

EXAMPLE 3-9.2.2

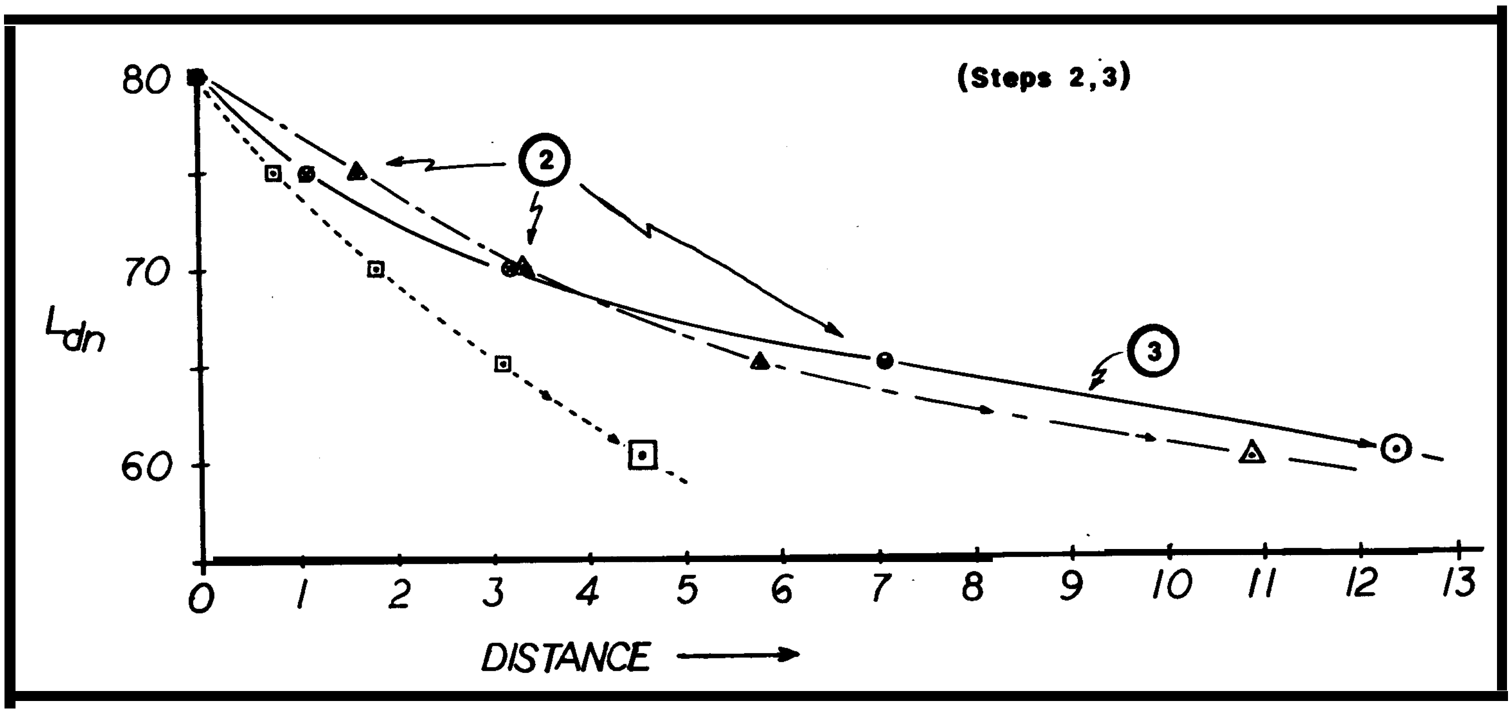
DETERMINATION OF L_{dn} 60 CONTOUR

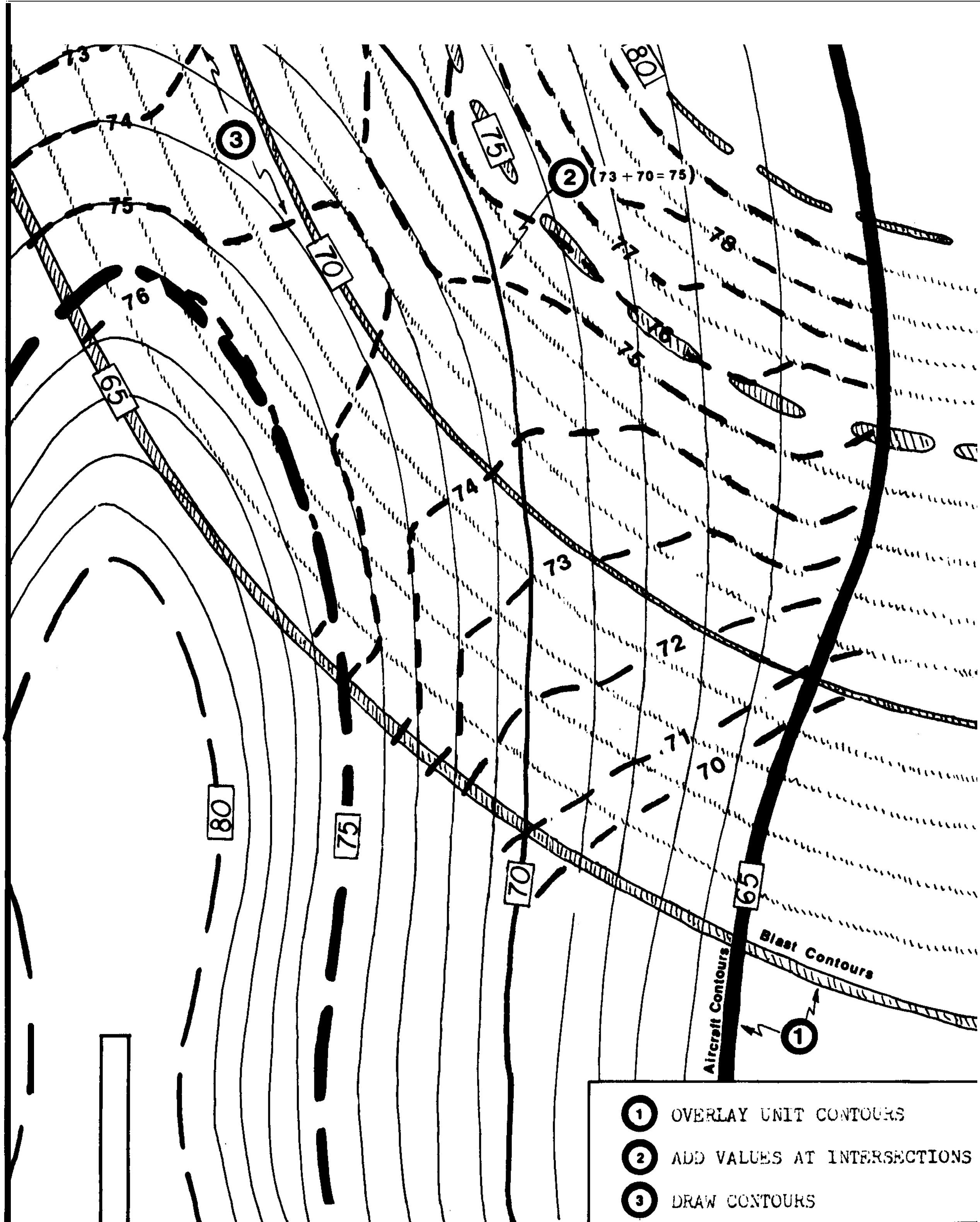


1. ESTABLISH PERPENDICULAR LINES
2. MEASURE DISTANCES & PLOT vs CONTOUR VALUE
3. FIT CURVE THROUGH POINTS & EXTEND
4. DRAW L_{dn} 60 CONTOUR

EXAMPLE 3-9.2.2 (Continued)

DETERMINATION OF L_{dn} 60 CONTOUR




73
74
75
76
77
78
70
65
80
72
71
(73 + 70 = 75)
Blast Contours
Aircraft Contours
1 OVERLAY UNIT CONTOURS
2 ADD VALUES AT INTERSECTIONS
3 DRAW CONTOURS

CHAPTER 4 RECOMMENDED NOISE LEVELS

4-1 BACKGROUND IN SELECTING LEVELS

4-1.1 BASIS FOR SELECTION

Recommended design noise levels for planning purposes are provided in this chapter. The background for selection of noise levels is reviewed to provide a basis of understanding of the recommended levels.

Man is an adaptable organism and can function effectively for short time periods despite high noise levels and exposures, Thus, in selection of planning levels both short and long term effects of noise must be considered. In the past, undesirably high noise levels have often been tolerated because of the lack of apparent short term ill effects.

The effects of noise can be characterized in several impact areas:

(1) The effects on individuals (particulary physiological and psychological).

(2) The impact on the ability of people to perform effectively.

(3) The effects on communities and group actions and attitudes.

The effects of noise may also be viewed in terms of three interrelated factors :

(1) Physiological effects, either temporary (e.g., startle reactions and temporary hearing threshold shifts) or enduring (e.g., permanent hearing damage or the cumulative physiological effects of prolonged sleep loss).

(2) Behavioral effects involving interference with activities such as speech, sleep or the performance of work tasks.

(3) Subjective effects described by such words as “annoyance”, “nuisance”, “dissatisfaction”, etc., which result from combinations of behavioral and physiological effects over perhaps extended time periods.

Different effects of noise, depending on the type of environment, are the basis for setting design noise levels.

The higher noise levels specified for industrial areas are set primarily to avoid long term physiological effects, particularly hearing damage. The major consideration in office type work areas is the impact of noise on speech communication. For residential and recreational non-work activities, the effects of noise on speech, communication, sleep and feelings of annoyance and dissatisfaction are important.

4-1.2 SPEECH COMMUNICATION CONSIDERATIONS

Because of the importance of speech communication in many human activities, the impact of noise on speech communication must be carefully considered in specifying noise levels. The chief effect of intruding noise on speech is to mask (hide) the speech sounds and thus reduce speech intelligibility. The most important speech sounds, from the standpoint of intelligibility, cover a range in frequency from about 200 to 6,000 Hz, and at each frequency, a dynamic range of about 30 dB. The intelligibility of speech would be nearly perfect if all these contributions could be heard by the listener. To the extent that intruding noise masks out some of these contributions, intelligibility deteriorates.

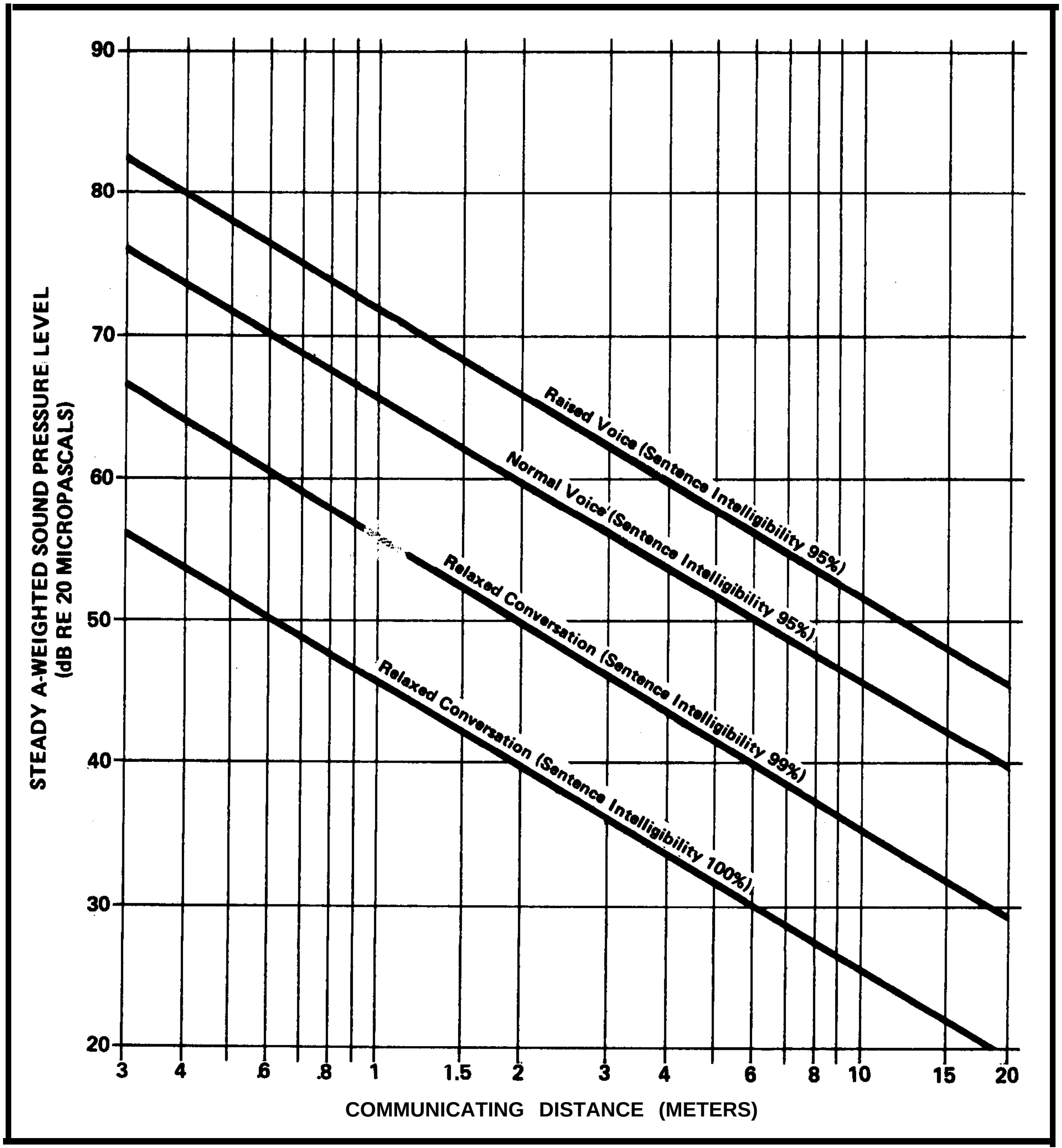
Human hearing is most sensitive in the frequency range most important for the understanding of speech. Therefore, the A-weighting, originally designed to reflect the frequency sensitivity of the human ear in terms of loudness, is also a useful measure of the speech interference potential of intruding noise.

There are many variables other than the background noise level that affect a person's understanding of speech. The speaker's enunciation, the familiarity of the listener with the speaker's language and vocabulary, the listener's motivation, and the normality of the listener's hearing also influence intelligibility. There is also a wide range in sound power output of different speakers. Hence, in a given "marginal" noise environment, one speaker may be much more understandable than another.

The effects of noise on speech out of doors are summarized In Figure 4-1.2a. This figure shows the distances between speaker and listener for satisfactory outdoor conversations for different steady A-weighted noise levels. Curves are shown for three levels of vocal effort. Outdoors, the voice levels at the listener's ear decreases at a predictable rate (6 dB per doubling of distance) as the distance between speaker and listener is Increased. Thus, for a steady background noise, there is a point, as the speaker and listener increase their separation, where the decreasing speech signal is masked by noise.

FIGURE 4-1.2a

MAXIMUM DISTANCES OUTDOORS OVER WHICH CONVERSATION IS CONSIDERED TO BE SATISFACTORILY INTELLIGIBLE IN STEADY NOISE



References 4-10 and 4-14

The curves for normal and raised voice are labeled "satisfactory conversation-sentence intelligibility 95%", meaning that 95% of the key words in a group of 'sentences would be correctly understood. At this percentage of sentence intelligibility, communication is usually reliable because of normal redundancy, In many situations understanding is aided by the restriction in vocabulary. Therefore, 95% sentence intelligibility is satisfactory in most situations.

In critical situations and activities, a higher sentence intelligibility may be required. However, in many situations which demand accuracy in verbal communication, a highly restricted vocabulary is used, for example, air traffic communications. Where restricted vocabulary is employed, the 95% intelligibility criteria will permit reliable communication.

The effects of noise on speech indoors are summarized in Figure 4-1.2b. This figure shows sentence intelligibility as a function of the steady state background level (A-weighted) at distances greater than about one meter for a speaker in a moderately large office or typical classroom. A reverberant field is assumed to exist in the room, the result of reflections of sound from walls and other boundaries of the room. These reflections enhance speech sounds so that the decrease of speech level distance found outdoors occurs only for distances close to the speaker. Thus, at distances greater than about one meter from the speaker, the level of speech is nearly constant throughout the room.

The distance from the speaker to the point where the level of the speech decreases to a constant level in the room is a function of the amount of sound absorption in the room. The greater the amount of absorption, the greater the distance over which the speech will decrease and the lower the level in the reverberant field for a given vocal effort. As shown in the figure, the maximum sound level that will permit communicating with 95% sentence intelligibility throughout the room is approximately 64 dB.

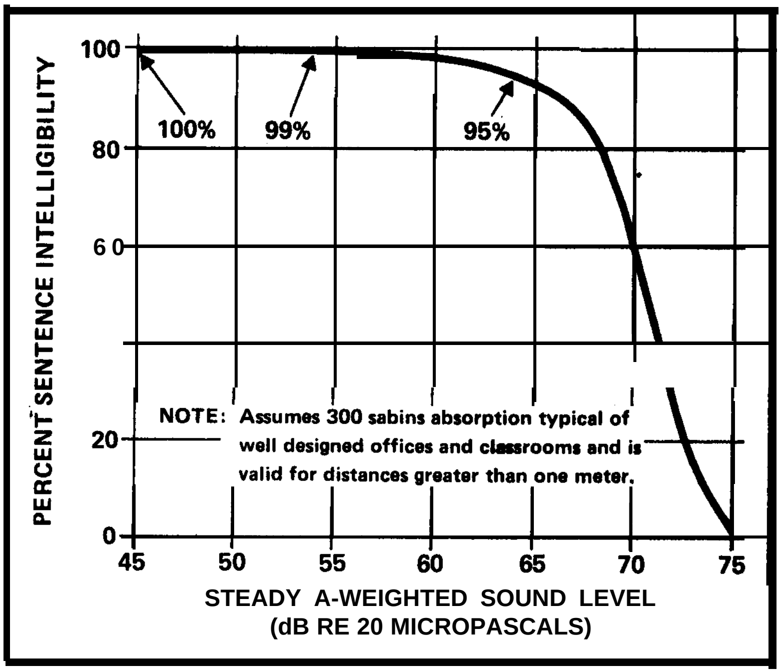
In Figures 4-1.2a and b, a steady state noise level has been assumed. In the more practical case of fluctuating levels, laboratory tests and calculations show that the percentage of speech interference for a fixed L_{dn} is greater for steady noise than foralmost all types of time varying noise. Thus, the figures will provide conservative estimates of the effect of noise in most actual cases.

4-1.3 COMMUNITY REACTION CONSIDERATIONS

The introduction of many new types of noise sources in suburban and residential areas in the last 25 years has created numerous community problems. These problems have provided significant

FIGURE 4-1.2b

NORMAL VOICE SENTENCE INTELLIGIBILITY AS A FUNCTION OF THE STEADY BACKGROUND SOUND LEVEL IN AN INDOOR SITUATION



References 4-10 and 4-14

data and insight into community reaction and annoyance. Various governmental agencies began to investigate the relationships between aircraft noise and its effect on people in communities in the early 1950's; studies have continued since that period.

The planning levels established for residential land use are based largely upon field evidence obtained in two ways. The reactions of individuals or groups of individuals to specific noise levels have been studied with the use of: (a) social surveys; and (b) documentation of actions taken (e.g., complaints, legal actions, etc.).

Community case history experience can be presented in terms of the correlation of noise levels versus various degrees of community reaction ranging from no reaction to vigorous legal actions. However, community reaction is not determined solely on noise level; other community and noise source factors must be taken into account to obtain a consistent correlation.

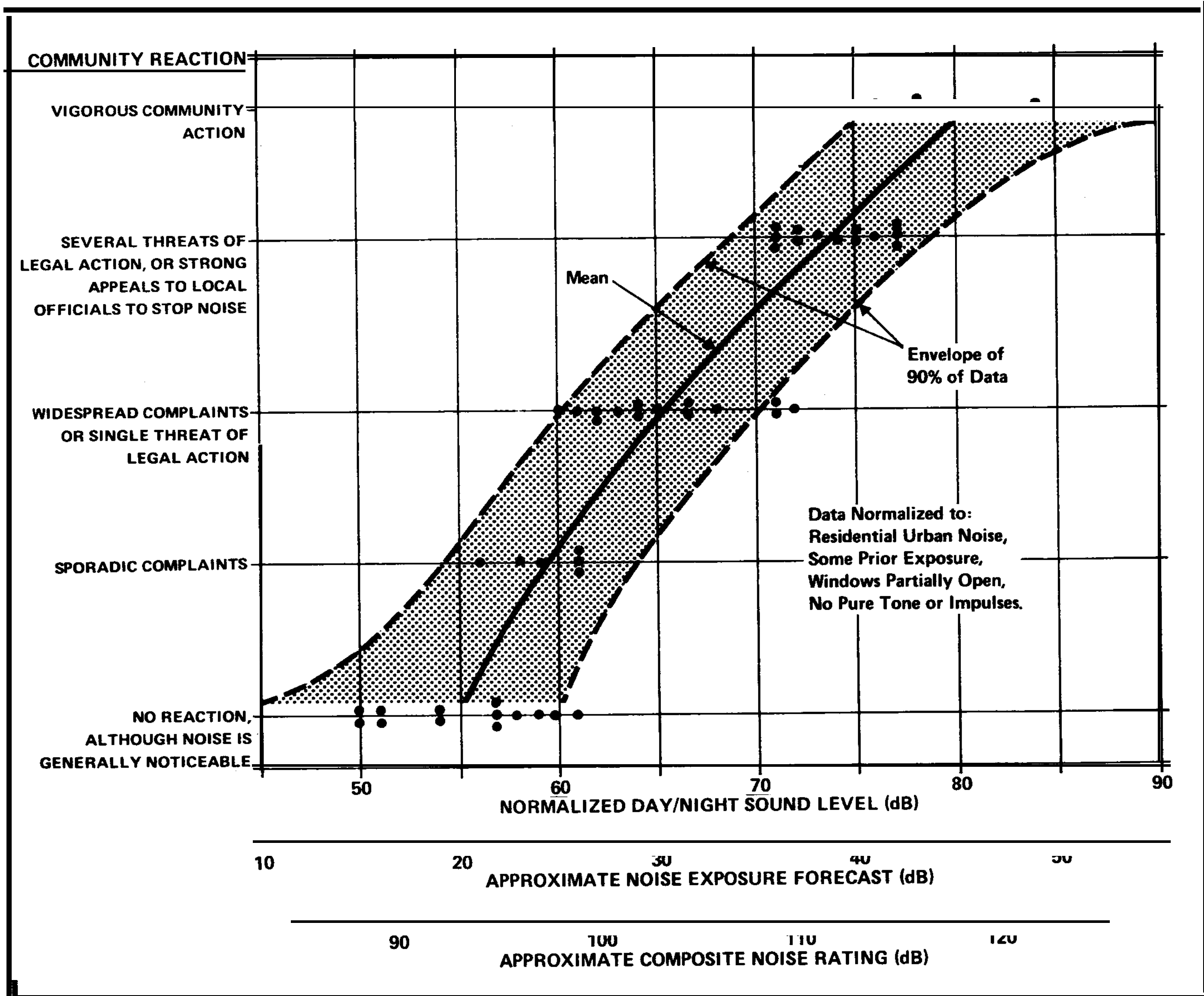
The results of a study of 55 community noise case histories are illustrated in Figure 4-1.3a. The L_{dn} values are "normalized"; that is, adjusted for community and noise source characteristics (refer to Figure 4-1.3b). In Figure 4-1.3a the "no reaction" response corresponds to a normalized outdoor day-night sound level ranging from about 50 to 61 dB with a mean of 55 dB. For a normalized day-night outdoor level of 65 dB, widespread complaints or single threats of legal action can be expected.

Sociological surveys intended to determine longer-term integrated adverse responses of people to environmental noise have been conducted in several countries, including the United States. The results of such surveys are generally stated in terms of the percentage of respondents expressing differing degrees of disturbance or dissatisfaction. Each social survey is related to some measurement of noise exposure (usually from aircraft operations), thus enabling correlation between annoyance and outdoor noise levels in residential areas.

The results of social surveys show that for a given noise level, individual responses vary widely. Studies have also shown that these variances are reduced substantially when individuals are considered according to similar attitudes about "fear" of aircraft crashes and "misfeasance" of authorities. Almost identical functional relationships between human response and noise levels are obtained from averaged responses of a whole surveyed population and from the groups of individuals having neutral attitudinal responses. Therefore, in deriving relationships between reported annoyance and day-night sound level, it is reasonable to use the average overall group responses, recognizing that individuals may vary considerably from the average, both positively and negatively depending upon particular attitudinal biases.

FIGURE 4.1.3a

COMMUNITY REACTION TO MANY TYPES OF INTRUSIVE NOISE AS A FUNCTION OF NORMALIZED DAY/NIGHT SOUND EQUIVALENT LEVEL



References 4-4 and 4-10

FIGURE 4-1.3b

CORRECTIONS TO BE ADDED TO THE DAY/NIGHT AVERAGE SOUND LEVEL (L_{dn}) TO OBTAIN NORMALIZED L_{dn}

Type of Correction	Description	Correction Added to Measured L_{dn} in dB
Seasonal Correction	Summer (or year-round operation)	0
	Winter only (or windows always closed)	- 5
Correction for Outdoor Residual Noise Level	Quiet suburban or rural community (away from large cities, industrial activity, and trucking)	+10
	Normal suburban community (away from industrial activity)	+5
	Urban residential community (not near heavily traveled roads or industrial areas)	0
	Noisy urban residential community (near relatively busy roads or industrial areas)	- 5
	Very noisy urban residential community	-10
Correction for Previous Exposure and Community Attitudes	No prior experience with intruding noise	+5
	Community has had some exposure to intruding noise; little effort is being made to control noise. This correction may also be applied to a community which has not been exposed previously to noise, but the people are aware that bona fide efforts are being made to control it.	0
	Community has had considerable exposure to intruding noise; noise maker's relations with community are good.	- 5
	Community aware that operation causing noise is necessary but will not continue indefinitely. This correction may be applied on a limited basis and under emergency conditions.	-10
Pure Tone	No pure tone or impulsive character	0
or Impulse	Pure tone or impulsive character present	+5

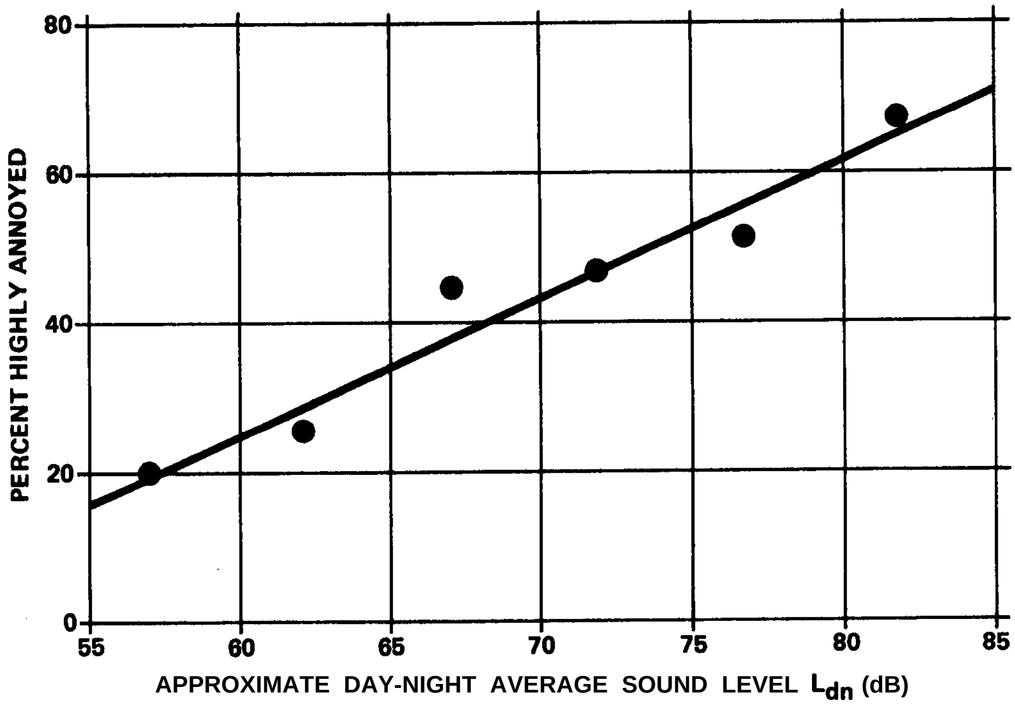
Reference 4-4 and 4-10

Social survey data obtained from questionnaires in eight communities near civil airports in this country and around Heathrow Airport in London are shown in Figure 4-1.3c. This figure shows the percentage of the populace that is highly annoyed as a function of the day-night sound level. The figure indicates that for a L_{dn} of 65 dB, over 30% of the people exposed will be highly annoyed.

The percent of people who will actively complain to authorities about noise will be much less than the number of people annoyed. The approximate relationship between those annoyed and those complaining is shown in Figure 4-1.3d, which is based upon social data gathered in this country. The figure indicates that when 1% of the people complain, 17% report being highly annoyed, and when 10% of the people complain, 43% are likely to be highly annoyed.

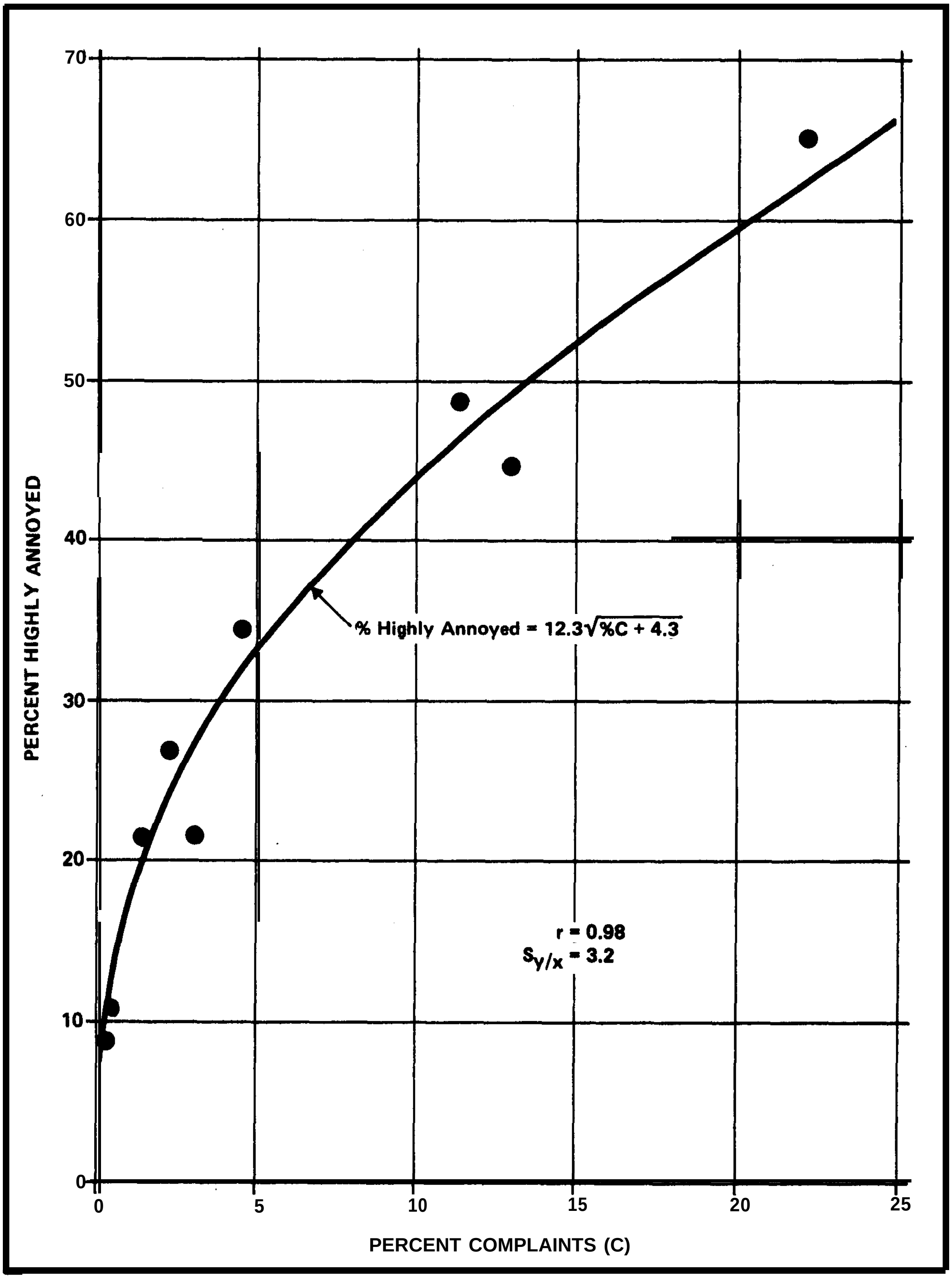
A summary of the relationship between the day-night sound level and the percent likely to complain and be highly annoyed is shown in Figure 4-1.3e. This figure is based upon the results of the several surveys mentioned. Also indicated are the average community reaction (derived from the community case histories studies) and a scale of the relative importance of aircraft noise as a factor in disliking an area or wanting to move. When the outdoor L_{dn} is 60 dB, approximately 2% of the household might be expected to complain, although 23% of the people might respond as highly annoyed when questioned, and some reaction would be expected from a typical community. If the levels increase over 65 dB, more than 5% may be expected to complain and over 33% would respond as highly annoyed. At higher levels, increasingly vigorous community reaction would be expected and noise would become a dominant factor In disliking an area.

FIGURE 4-1.3c PERCENTAGE OF PEOPLE HIGHLY ANNOYED AS A FUNCTION OF DAY/NIGHT AVERAGE SOUND LEVEL



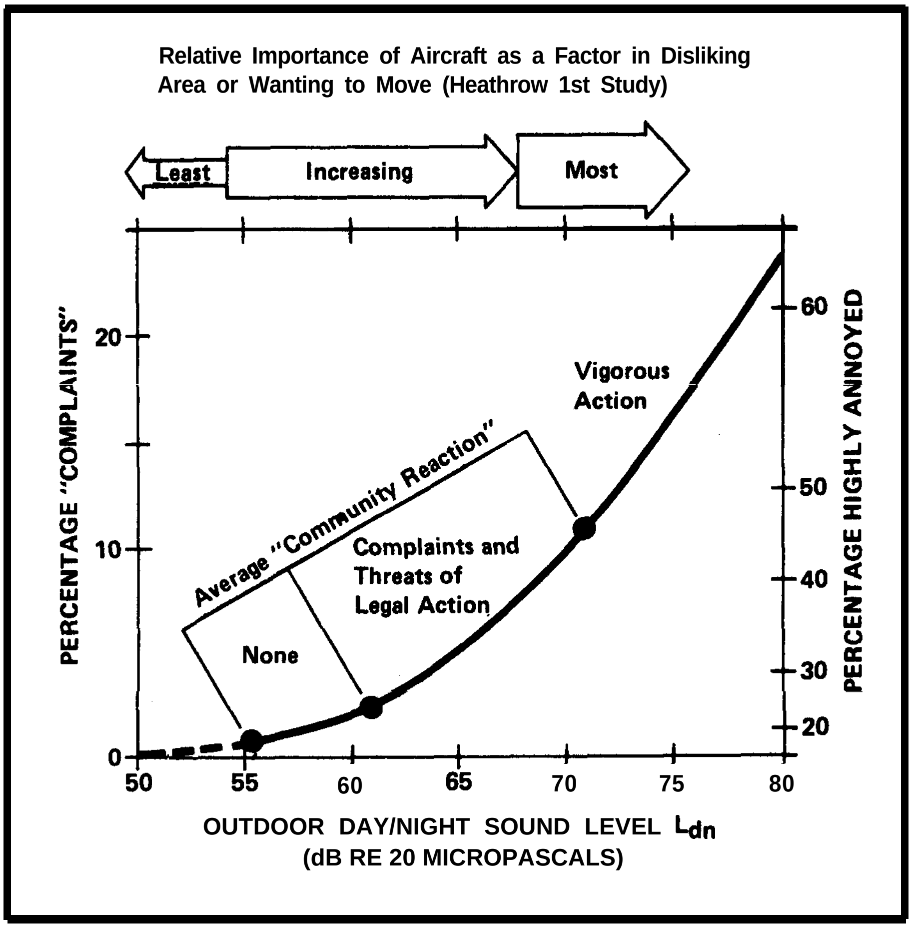
References 4.3, 4-6, 4-7, 4-8 and 4-12

FIGURE 4-1.3d SOCIAL SURVEY ESTIMATE OF THE PERCENTAGE OF HIGHLY ANNOYED AS A FUNCTION OF PERCENT OF COMPLAINTS



Reference 4-9

FIGURE 4-1.36 SUMMARY OF ANNOYANCE SURVEY AND COMMUNITY REACTION RESULTS



Reference 4-10

4-2 CHOICE OF NOISE MEASURES FOR SCREENING PURPOSES

Installation environments may encompass a range of noise sources with widely varying characteristics. As stated in Chapter 2, not all noises can be evaluated equally well (in terms of impact on people) with the same noise measure or noise scale. For site screening and initial design purposes, the basic equivalent level, A-weighted, is satisfactory, with a few exceptions.

The exceptions are large amplitude impulse type sounds: typically sonic booms, explosive blasts or artillery fire. Such sounds are discrete noises (or series of such noises) of short duration (less than a second) in which the sound pressure level rises very rapidly to a high peak before decaying to the level of the background noise. These large amplitude impulsive sounds can excite noticeable vibration of buildings and other structures. The induced vibrations may generate additional annoyance to people beyond that due to audibility of the impulse because of "house rattling" and "startle," as well as additional contributions to interference with speech or sleep. For these exceptions, criteria in terms of A-weighted L_{eq} values must be augmented with noise criteria based on consideration of the C-weighted equivalent levels.

4-2.1 NOISE MEASURES AND CRITERIA FOR LARGE AMPLITUDE IMPULSE SOURCES

For screening purposes, the impulse sounds which would be considered separately are those for which the wide band peak sound pressure level is over 110 dB (100 dB nighttime),* For such impulse sounds, the C-weighted equivalent levels or C-weight day-night average levels should be determined. When the wide band peak sound pressure levels for impulse sounds exceed 140 dB, evaluations of effects such as hearing loss, window breakage and other structural damage should be undertaken. This may require use of special analysis procedures not covered in this planning guide. For quarry blasts, ground borne vibration and window breakage potential should also be assessed even for impulse sounds where the wide band peak sound level falls below 140 dB.

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* An approximate evaluation of the threshold requirements for impulse sounds may be made using a standard Type 1 sound level meter employing the C-weighting and the "slow" meter characteristic. An impulse sound would be one that produces a maximum meter reading in excess of 82 dB in daytime or 72 dB at night.

C-weighted day-night levels for impulse noise can be interpreted in terms of annoyance in residential areas by use of Figure 4-1.3c. The same noise level scale applies for the C-weighted day-night level for impulse noise.

Acceptable A-weighted day-night average levels, as shown in Figure 4-5, also apply to C-weighted day-night average levels of impulse noise for exposure up to the level where special building construction requirements are needed (i.e., where the word "yes" occurs).

Detailed criteria for interpreting the C-weighted equivalent level (or day-night level) in terms of impact on other land uses have not been fully developed. Therefore, the building noise level reduction (NLR) requirements discussed in the following sub-sections for non-impulse sounds should not be directly applied to noise environments dominated by impulse sounds,

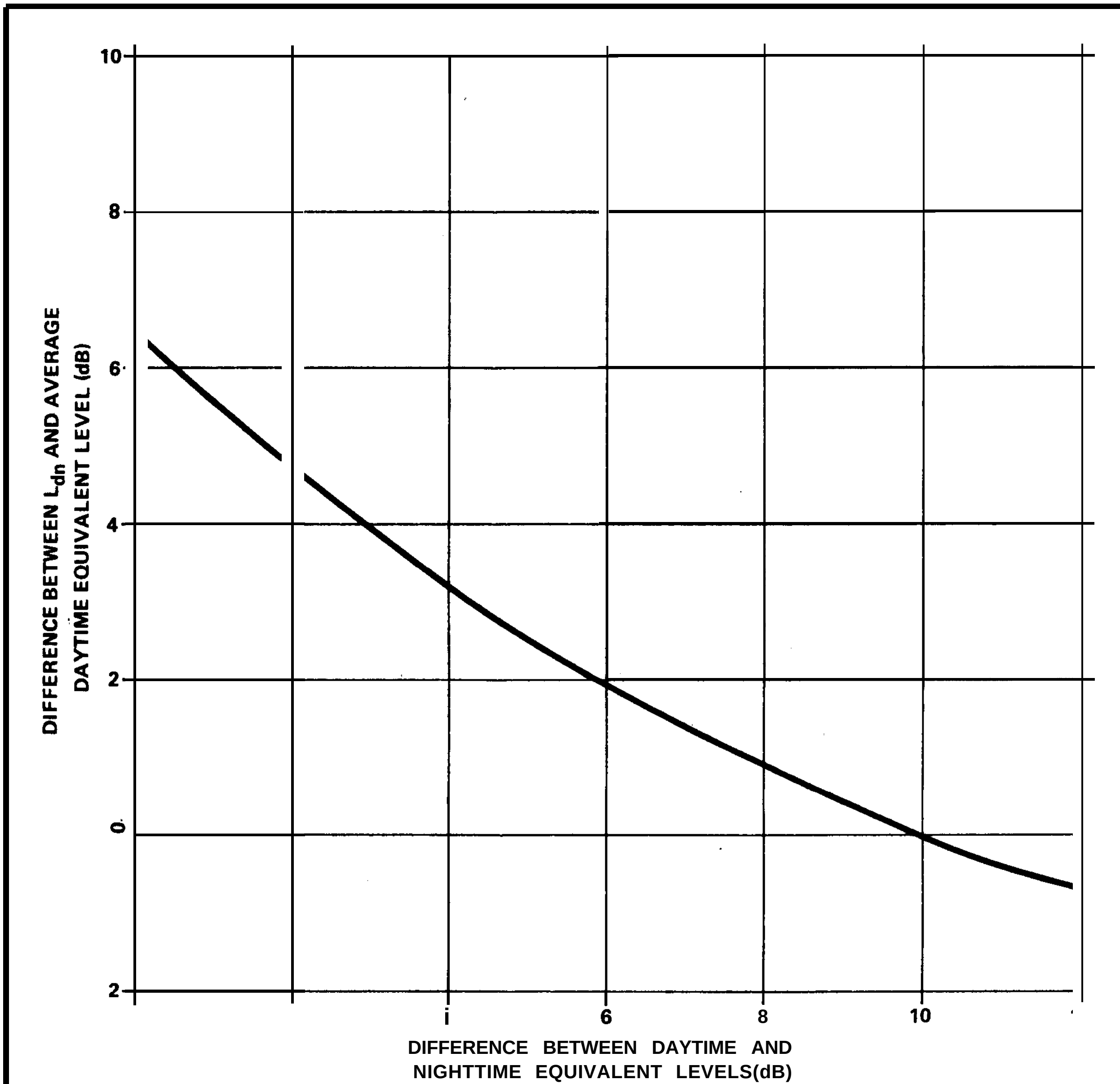
4-2.2 NOISE MEASURES FOR NON-IMPULSE SOUNDS

The following sections present criteria for non-impulse sounds in terms of L_{dn}. For some land uses or activities the noise exposure over the entire 24-hour period is essential (especially in residential or other living spaces). In most work areas, exposure over a shorter period, perhaps an 8 to 10 hour period, is important. Thus, the L_{dn} measure, which represents the noise environment over a 24-hour period, may not be entirely accurate in depicting the noise environment for shorter periods. Since the L_{dn} measure may be one that is most easily available, it can satisfactorily serve as an appropriate measure for screening purposes for most all activities or land uses. The L_{dn} will usually provide a conservative noise estimate (or overestimation) of the noise exposure during shorter periods of the day.

For detailed design purposes, the noise exposure may be determined for the appropriate period of the day. When complete information about daytime and nighttime levels is not available, Figure 4-2.2 may be used. It illustrates the relationship between the L_{dn} value and the difference between daytime and nighttime equivalent levels. It provides a way of correcting the L_{dn} value to obtain the daytime equivalent level when the difference between daytime and nighttime equivalent levels can be estimated. Refer also to Example 4.2.2.

FIGURE 4-2.2

VARIATION OF L_{dn} AS A FUNCTION OF DAYTIME AND NIGHTTIME EXPOSURE



Larger differences between day and night Leq values usually exist in quiet neighborhoods than in noisier dense urban areas. When the day-night average level is 55 dB or less, the typical decrease from day to night equivalent levels will be 10 dB; similarly, when L_{dn} is 70 dB the decrease may be 4 dB or less.

EXAMPLE 4-2.2

SOLVING FOR APPROXIMATE DAYTIME AND NIGHTTIME L_{eq}

PROBLEM:

Determine the approximate daytime and nighttime L_{eq}, given that L_{dn} is 70 dB.

SOLUTION:

1. If L_{dn} = 70 dB, then assume the difference between day and nighttime L_{eq} = 4 dB.
2. The difference between L_{dn} and daytime $L_{eq} \cong$ 3 dB (from Figure 4-2.2)
3. Daytime L_{eq} = 70 dB - 3 dB
   Daytime L_{eq} = 67 dB
4. Nighttime L_{eq} = 67dB - 4dB
   Nighttime L_{eq} = <u>63 dB</u>

4-3 EXISTING NOISE LEVELS

The typical range of L_{dn} values for various outdoor environments is shown in Figure 4-3a. Note that the noise levels increase with population density (and motor vehicle density).

The number of people in this country exposed to different day-night levels is illustrated in Figure 4-3b. The figure shows the increment in noise exposure due to the most intense urban noise sources, aircraft and freeway noise. Even excluding those living near airports, considerable numbers of residents live In relatively noisy areas. This is illustrated in Figure 4-3c.

FIGURE 4-3a

TYPICAL RANGE OF OUTDOOR COMMUNITY NOISE EXPOSURE LEVELS

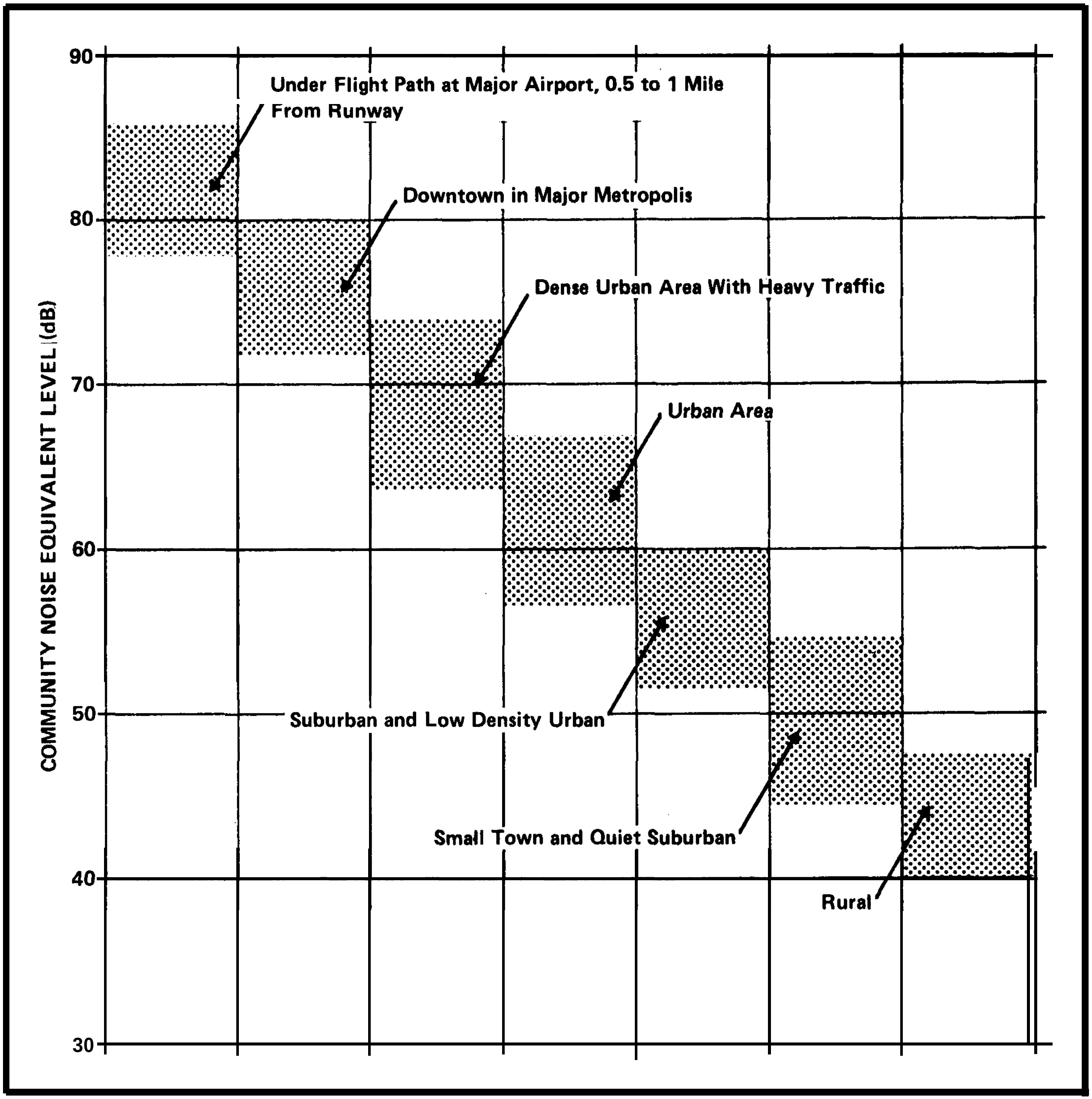
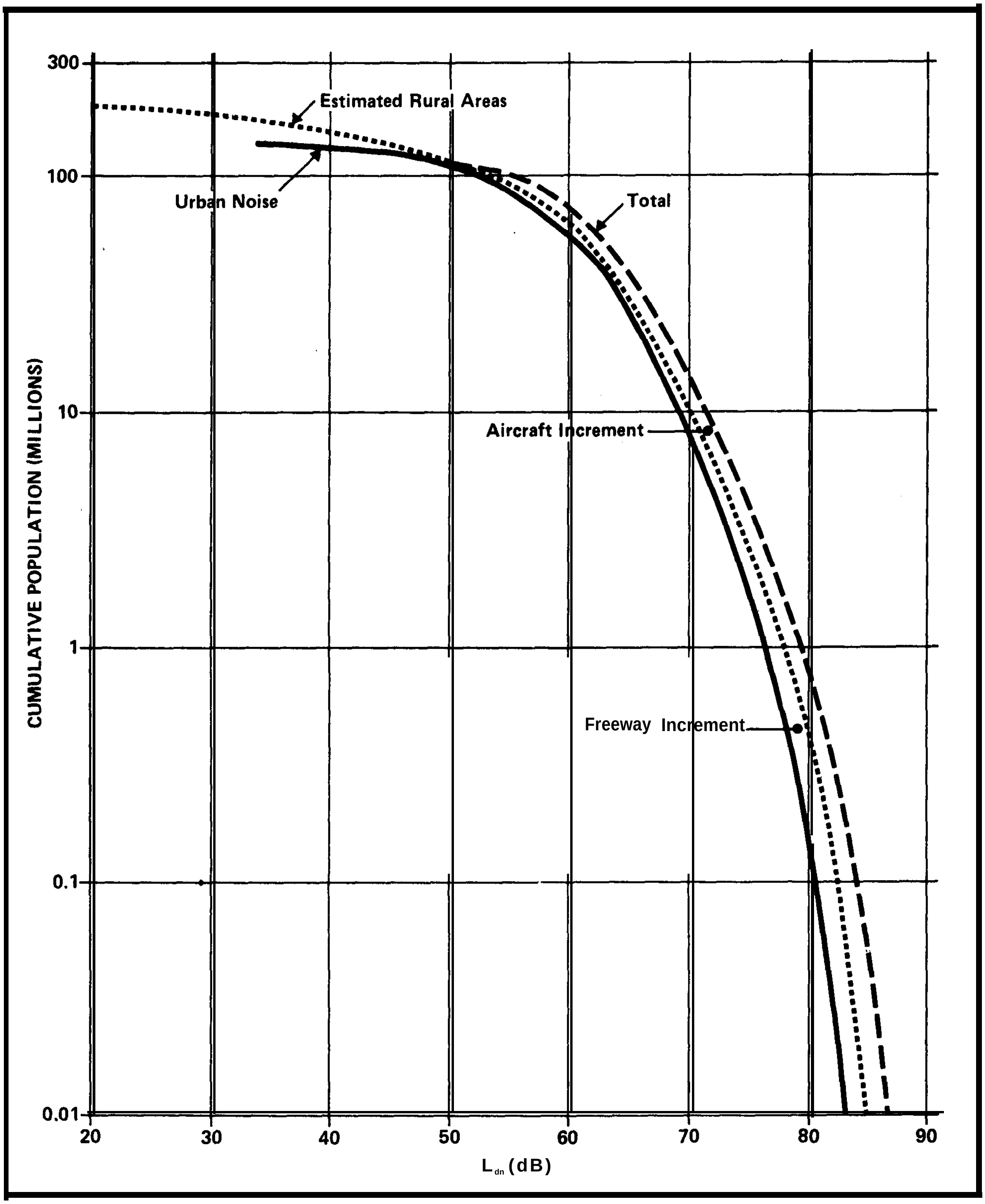


FIGURE 4-3b

RESIDENTIAL NOISE ENVIRONMENT OF THE NATIONAL POPULATION AS A FUNCTION OF EXTERIOR DAY/NIGHT AVERAGE SOUND LEVEL



Reference 4-10

FIGURE 4-3c **URBAN POPULATION EXPOSED TO NOISE ABOVE 60 dB**

L_{dn} Exceeds	Number of People	Percent of Total Urban Population*
60dB	62.1 million	46
65 dB	26.8 million	20
70 dB	8.8 million	6.6
75 dB	2.2 million	1.6

*Estimated as 134 million.

4-4 PLANNING LEVELS VERSUS OTHER NOISE CRITERIA

The planning levels presented in this chapter should be considered as "design levels" which will assure noise environments that will not interfere with activities, that is, will not reduce work efficiency, not interfere with the speech communication appropriate to the activity, and not interfere with rest or recreational activities. Higher noise levels can be tolerated and will frequently exist at installations and developments, civil and military. In many cases, the design levels are below the maximum levels incorporated in existing military and industrial regulations.

The design levels specified are based upon experience and judgment, consideration of current urban noise levels, and basic technical and economic factors. Primary factors relating the design levels to other noise standards are considered below.

The Department of Housing and Urban Development's current policy statement on noise abatement and control, HUD Circular 1390.2, states "noise is a major source of environmental pollution which represents a threat to the serenity and quality of life in population centers." (Ref. 4-9). In establishing noise exposure policies and standards to be observed in the approval or disapproval of ail HUD projects*, noise environments are categorized as: (1) acceptable, (2) discretionary - normally acceptable, (3) discretionary - normally unacceptable, and (4) unacceptable. The planning levels presented in this manual would define the boundary between categories (1) and (2): acceptable and discretionary - normally acceptable.

For many activities and land uses, the range in noise levels between categories (2) and (3), discretionary - normally acceptable and discretionary - normally unacceptable, is 5 to 10 dB. Thus, exceeding the planning levels presented in this chapter by 5 to 10 dB would usually result in a noise environment that would be classified as normally unacceptable.

The planning noise levels in this manual may be higher than those that have been specified without consideration of technical feasibility or economic impact. For example, the EPA has identified levels for different situations requisite to protect public health and welfare with an adequate margin of safety (Ref. 4-10). The EPA

* HUD-assisted projects cover a wide range of land uses, in addition to residential.

recommendations do not generally incorporate technical feasibility, economic impact, nor the fact that a large proportion of the current population may be exposed to levels well in excess of the EPA-identified levels. The EPA recommendations include margins of safety on the order of 5 to 10 dB.

The planning levels specified in this manual take into consideration the existing noise environments found in many communities. Because of economic impact considerations the specified planning levels do not include large margins of safety. Margins of safety on the order of 5 to 10 dB would, in many cases, impose severe restrictions on land use and drastic increases in construction costs. The resulting higher design levels would also drastically reduce flexibility in land planning, without necessarily achieving a marked increase in the judged acceptability of the noise environment.

The EPA recommendations should be regarded as ultimate goals for attaining a quiet noise environment. However, it should be noted that consistent application of the planning noise criteria given in this manual will generally result in noise environments that are quieter than those encountered in many existing military and civil communities.

4-5 EXTERIOR PLANNING LEVELS

The acceptable outdoor noise environments are 1 is ted in Figure 4-5 for major military and civil land uses. Appropriate design levels for facilities not listed in the table can be inferred by relating the types of human activities and reliance upon speech communication to parallel land uses or facilities in the table.

Planning levels are in terms of L_{dn} values. As discussed previously (Sec 4-2.2), however, the Leq over the period of usage is preferable for detailed design when occupancy or usage does not extend over 24-hour periods.

In the table, the outdoor noise environment is considered in 5 dB wide "zones". For each zone acceptability is noted by one of the four following entries: (1) "yes", (2) noise level reduction (NLR) number, (3) "no", or (4) one of these and a footnote number.

"Yes" Designation

Where "yes" is indicated, no special noise control restrictions are necessary and normal construction appropriate to the activity may be used.

"NLR" Designation

For many land uses, higher levels of exterior noise exposure are acceptable provided there is a proper degree of building noise insulation. Such trade-offs are possible for land uses where indoor activities predominate. When such trade-offs are appropriate, the amount of noise insulation required is enumerated in the table in units of NLR. (NLR in dB, is the difference in A-weighted noise levels, measured outside and inside a facility.)*

* Refer to Section 5-2.2 for further information. It should be noted that the NLR is dependent not only upon the transmission loss characteristics of the building surfaces exposed to the exterior noise, but is also dependent upon the particular characteristics of the exterior noise source and the acoustic properties of the designated room in the building. An outside noise spectrum to be used for design calculations is suggested in Reference 4-2. This spectrum will generally be suitable for estimating NLR values for facilities exposed to surface vehicle and aircraft noise.

FIGURE 4-5

Facility	SLUCM Code	Outdoor Noise Environment (L_{dn}/L_{eq} in dB) 85-89	80-84	75-79	70-74	65-69
Family Housing	**1100**	**No**	**No**	**No**	**NLR 30(4)**	**NLR 25 (4**
Bachelor Housing	**1100**	**No**	**No**	**NLR 35 (4)**	**NLR 30 (4)**	**NLR 25 (**
Transient Lodging - Hotel, Motel, etc.	**15**	**No**	**No**	**NLR 35(4)**	**NLR 30 (4)**	**NLR 25 (**
***Classrooms, Libraries, Churches**	**68,711**	**No**	**No**	**No**	**NLR 30**	**NLR 25**
***Offices & Administration Buildings - Military**		**NLR 40**	**NLR 35**	**NLR 30**	**NLR 25**	**Yes**
*Offices - Business & Professional	61, 62, 63, 65	No	No	NLR 30	NLR 25	Yes
Hospitals, Medical Facilities, Nursing Homes (24-hour Occupancy)	651	No	No	No	NLR 30	NLR 25
*Dental Clinic, Medical Dispensaries	651	No	No	NLR 30	NLR 25	Yes
*Outdoor Music Shells	7211	No	No	No	No	No
*Commercial & Retail Stores, Exchanges, Movie Theaters, Restaurants & Cafeterias, Banks, Credit Unions, EM/Officer Clubs	53, 54, 56, 57, 59	No	No	NLR 30	NLR 25	Yes
*Flight Line Operations Maintenance & Training		**NLR 35** 35 (5)	**NLR 30** 30 (5)	Yes	**Yes**	**Yes**
*Industrial, Manufacturing & Laboratories	21-29, 31-35, 39 41-49, 51, 52, 64	**No**	**NLR 35 (5)** 35 (5)	**NLR 30 (5)** 30 (5)	**NLR 25(5)** 25 (5)	**Yes**
*Outdoor Sports Arenas, Outdoor Spectator Sports	722	**No**	**No**	**No**	**Yes(1)** (1)	**Yes(1)** (1)
*Playgrounds, Active Sport Recreational Areas	7610	**No**	**No**	**No**	**Yes**	**Yes**
*Neighborhood Parks	7610	**No**	**No**	**No**	**Yes**	**Yes**
*Gymnasiums, Indoor Pools	7425, 7432	**No**	**NLR 30** 30	**NLR 25** 25	**Yes**	**Yes**
*Outdoor - Frequent Speech Communication		No(2,3)	No(2,3)	No(2)	No(2)	No(2)
***Outdoor** - Infrequent Speech Communication		No(2,3)	No(2,3)	**Yes**	**Yes**	**Yes**
Livestock Farming, Animal Breeding	815-817	**No**	**No**	**No**	**Yes**	**Yes**
*Agricultural (except Livestock)	81	Yes(3)	Yes(31)	**Yes**	**Yes**	**Yes**

*For detailed design, the L_{eq} for the appropriate peroid of usage is the preferred measure of the noise environment. See 4-2.2 for L_{eq} estimation from L_{dn}.

Yes - Land use compatible with noise environment. **No** spatial noise control restriction. Normal construction appropriate.

NLR - Appropriate noise level reduction where indoor activities predominate.

No - Land use not compatible with noise environment, even if special building noise insulation provided.

Refer to text for further explanations of Yes, NLR, and **No** designations.

FOOTNOTES:

1. Land use is acceptable provided special sound reinforcement systems are installed.
2. Land use may be acceptable provided special speech communication systems are used.
3. Land use may be acceptable provided hearing protection devices are worn by personnel. Check applicable hearing damage regulations.
4. Although it is recognized that local conditions may require residential uses in these areas, this use is strongly discouraged in L_{dn} 70-74 and L_{dn} 75-79 75-79 and discouraged in L_{dn} 65-69. The absence of viable alternative development options should be determined. **NLR** criteria will not eliminate outdoor environment noise problems and, as a result, site planning and design should include measures to minimize this impact particularly where the noise is from ground level sources.
5. The **NLR** must only be incorporated into the design and construction of portions of these buildings where the public is received, office areas, and noise sensitive work areas or where the normal noise level is low.

The NLR values given in Figure 4-5 represent a conservative estimate of required building insulation. NLR estimates should be reviewed during detailed design, taking into account the noise spectra of the most predominant outside noise sources and the desired interior noise levels (see Section 4-6). From design analysis, it may be found that the actual NLR requirements can be relaxed from those given in this table. However, such relaxation of building requirements should be accepted only after a detailed analysis has been undertaken.

Due to high and geographically widespread noise exposures, it will not often be possible to locate facilities without considering building insulation requirements. It should be recognized that increasing noise insulation increases flexibility in locating facilities, but also increases construction costs.

"No" Designation

A "no" indication in Figure 4-5 means that the noise environment is not suitable for the designated activity or facility, even if special building noise insulation is provided. Table footnotes indicate exceptions where special conditions apply.

Comparative Levels

For residential areas, Figure 4-5 indicates that no special noise insulation is required in residential areas exposed to L_{dn} values of less than 65 dB. Similarly, no special insulation is required for classrooms, libraries, churches, hospitals and nursing homes. It should be noted that a noise environment having an L_{dn} value of 65 dB is 10 dB above the L_{dn} value recommended by the EPA (Reference 4-10) as the maximum outdoor level to avoid any interference with outdoor activities. Conversely, a noise environment having an L_{dn} of 65* dB defines the HUD boundary between "acceptable" and "discretionary -- normally unacceptable" zones (Reference 4-9).

For offices and administrative facilities, outdoor equivalent levels may reach 70 dB before special building noise insulation is required.

For outdoor work activities not requiring frequent speech communication, the acceptable noise environment range extends up to 80 dB. For outdoor work activities in noise environments of greater than L_{dn} 80, the following factors should be considered:

(1) Speech communication needs (including availability of special communication systems)

* Assuming NEF 30 is equivalent to an L_{dn} of 65.

(2) Hearing damage risks (specifically considering applicable military regulations concerning hearing loss protection).

It should be noted that the EPA has identified a 24-hour L_{eq} of 70 dB as the desirable level for protecting against hearing loss 8or long term exposure (40 years). Contrarily, both current military and civil regulations set considerably higher limits for work-related noise exposure.

Military vs Civil Use

For offices and administration buildings, military usage, with appropriate NLR requirements, is permitted (but not encouraged) in higher noise exposure than recommended for civil offices. This differentiation recognizes occasional overriding operational needs to locate administration offices close to flight lines or ground runup locations.

4-6 INTERIOR DESIGN LEVELS

Figure 4-6 contains a list of planning levels for activities conducted in interior spaces. The planning levels for exterior noise and for interior equipment that is not continuously operated are given in terms of L_{eq} values. Continuous noise sources, for example ventilating systems or other mechanical equipment, emit steady state noise which is measured in terms of L_s.* The sources must be considered separately. As indicated in the right hand column of Figure 4-6, permissible L_s values are 5 to 10 dB less than L_{eq} values for the same activity.

Interior steady state noise levels more than 5-10 dB below the levels specified in Figure 4-6 are not desirable. Annoyance will actually increase with the lowered background noise levels because individuals will hear intruding sounds that normally would be masked by the steady state noise. Occasionally, where adequate noise insulation cannot be provided, increasing the continuous background noise levels over the values shown in Figure 4-6 will provide better masking of intruding intermittent sounds. For such occasions, the characteristics of both in the intruding noises and the background noise should be considered during the design of the facility. (Refer to Section 5-3.2.1, Noise Masking,)

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*L_s is the A-weighted noise level produced by the ventilation or mechanical systems (or other interior noise sources) which operate more or less continuously. The L_s value for design should be the noise level produced in the space during the time of occupancy while the equipment is at the typical mode of operation.

FIGURE 4-6

INTERIOR NOISE ENVIRONMENT PLANNING LEVELS

ACTIVITY	All Noise Sources L_{eq} (dB)	Continuous Interior Sources * L_s(dB)**
Sleeping	45	40
Other Residential Activities (Conversations, Radio, T.V. Listening, etc.)	50	40
Classrooms, Libraries, Churches Hospitals	50	40
Offices - Private, Conference	45	40
Offices/Work Spaces, Telephone Use Satisfactory	55	45
Work Spaces - Occasional, Speech Communication or Telephone Use	60	55
Work Spaces - Infrequent Speech Communication, Telephone Use Infrequent	70	60

*Typically, ventilation systems and mechanical equipment in near-continuous operations.

**The L_s value is given in terms of A-weighted noise level. The approximate noise criteria (NC) curve values are 8 dB less than the A-level values (references 4-13 and 4-14).

CHAPTER 5 REDUCING NOISE CONFLICT

This portion of the manual is laid out in three sections according to the point where an abatement technique is applied: the noise source, the noise path, and the noise receiver. The abatement techniques presented in this chapter are' enumerated below.

Outline of Noise Abatement Strategies

5-1 NOISE SOURCE MODIFICATIONS

Generally, noise can be abated more effectively at the source than at the numerous places of reception. Noise reduction at the source is typically of three types:

(1) Technological change. A design modification which actually reduces the "amount" of noise emanating from a source.

(2) Operational change. A change in the operation of the source which does not necessarily reduce the absolute level of the noise created, but reduces the level perceived by the receiver.

(3) Locational change. A separation of the source and the receiver which will reduce the level of noise perceived but not the level created.

The planner will be involved with each approach but more frequently with the third. The opportunity for relocation of existing noise sources will generally be limited because of cost and possible mission degradation. Locational modifications are stronger possibilities in expansion and initial construct ion programs. Methodologically, noise source siting is the same as site selection for non-noise source facilities.

Traditional land planning tools will not always be sufficient to solve a noise problem. The following discussions on operational and technological approaches illustrate other possibilities for abatement. These sections will broaden the planner's perspective on a complex problem which cannot be successfully treated through any single narrow approach.

5-1.1 AIRCRAFT NOISE - FIXED WING

There are two classifications of fixed wing aircraft: propeller and turbine powered. The comments in this section pertain primarily to the latter.

Because of the intensity and prevalence of aircraft noise, it is a major noise problem and, as a result has been extensively researched. The following comments reflect abatement philosophies rather than state-of-the-art solutions which are evolving too rapidly to be published as current.

5-1.1.1 OPERATIONAL MODIFICATIONS

The opportunity to employ operational modifications is limited. The goal of the air installation planner is to create an environment that will support aircraft operations; thus extensive operational modifications will normally be unacceptable. However, such alternatives should not be ignored as possible methods of reducing noise conflict. The following brief descriptions of operational modifications are included to augment the planners' general knowledge of abatement techniques.

The potential feasibility of the following techniques is dependent on installation mission, safety, and approved air traffic control procedures. Specific variables which will alter the effectiveness of the techniques include aircraft type, mission, aircraft load, runway length, traffic load, meteorologic and topographic conditions, pilot capability, approach/takeoff patterns, etc.

5-1.1.1.1 APPROACH PROCEDURES

Holding and Maneuvering Altitudes

Sufficiently high holding and maneuvering altitudes can reduce noise around air fields.

Traffic Control

A steady flow of traffic, which minimizes waiting time to take-off or land, can reduce noise at and around airfields.

Approach Glide Angle

By increasing the approach glide angle to the maximum practicable, noise can be reduced (but to a constantly diminishing degree) in areas under runway approach. Noise reduction is due to increased altitudes and reduced engine power. (Refer to Figure 5-1.1.1.1.)

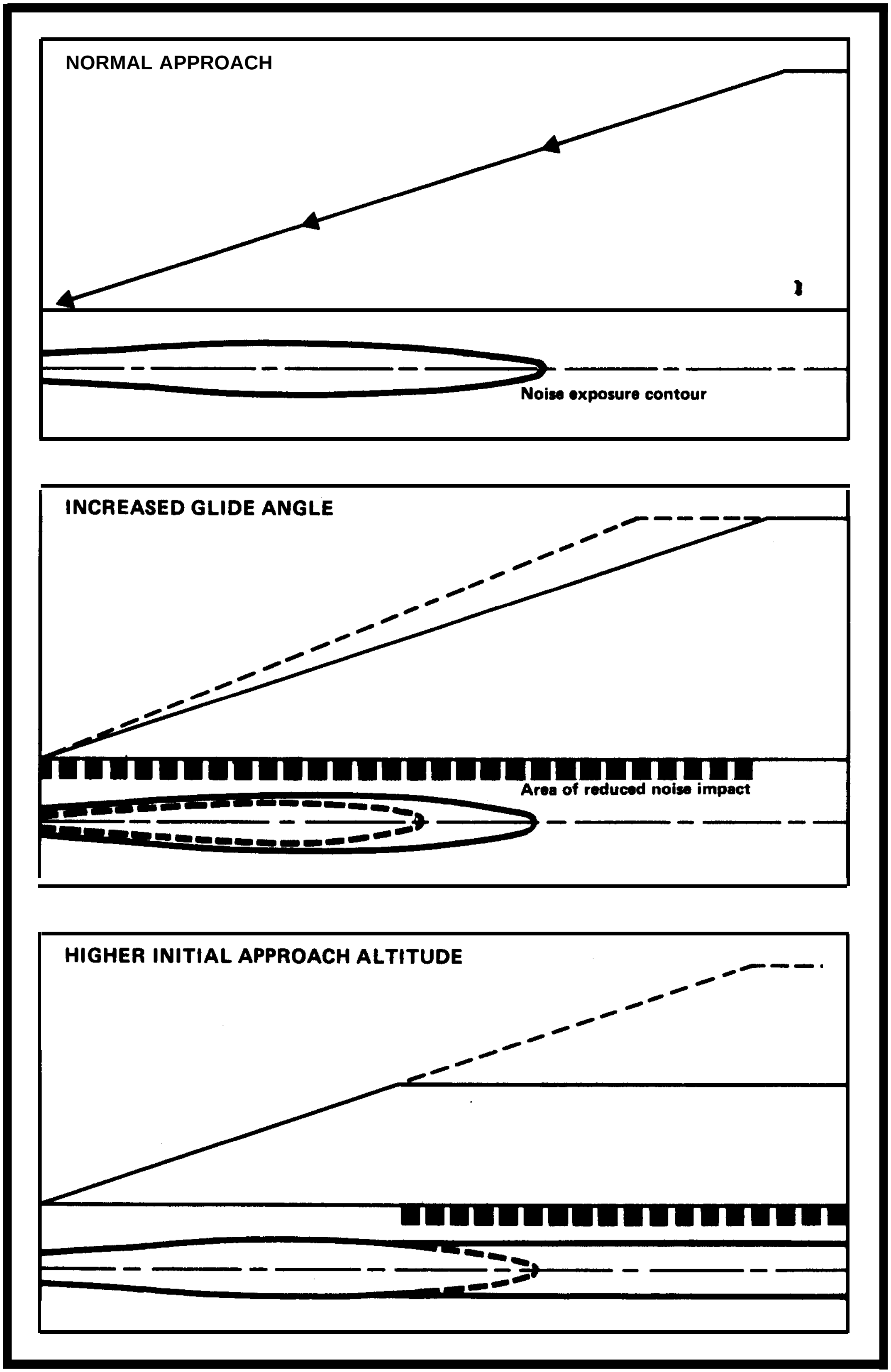
Initial Approach Altitude

Sufficiently high initial approach altitudes can reduce noise in outlying regions. (Refer to Figure 5-1.1.1.1)

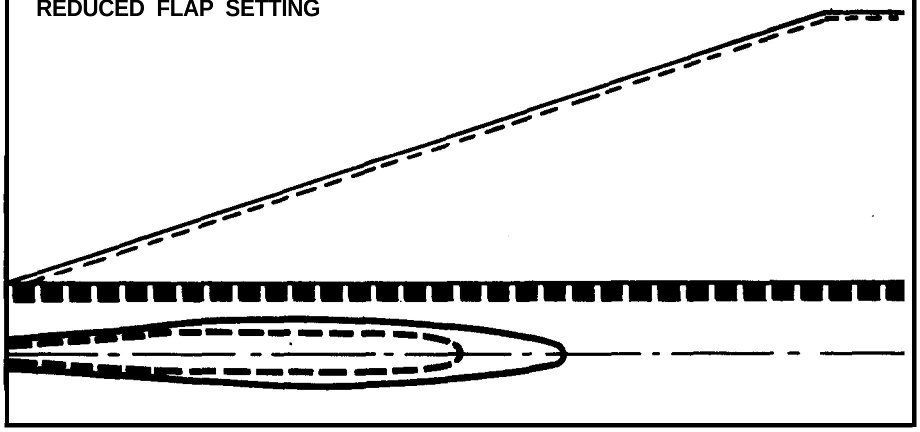
Flap Setting

Reducing flap setting reduces airframe drag, thus decreasing the amount of engine power required and increasing speed. The net result is decreased noise in outlying areas. (Refer to Figure 5-1.1.1.1)

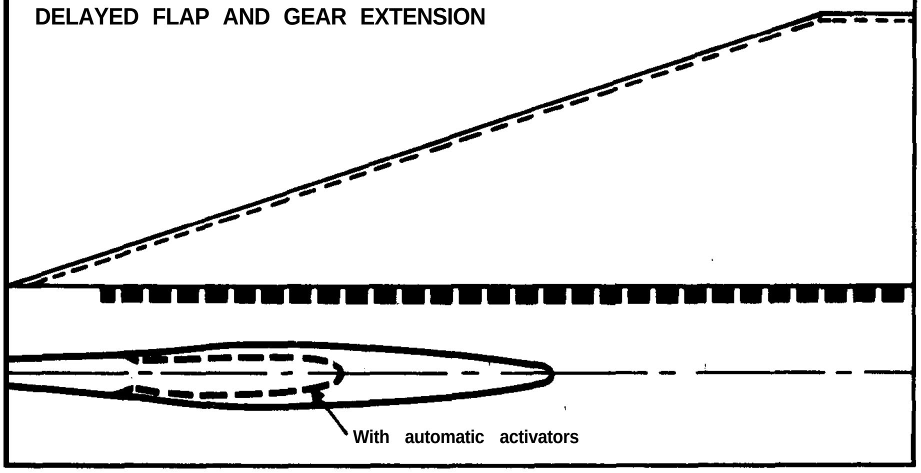
FIGURE 5-1.1.1.1 NOISE ABATEMENT APPROACH PROCEDURES



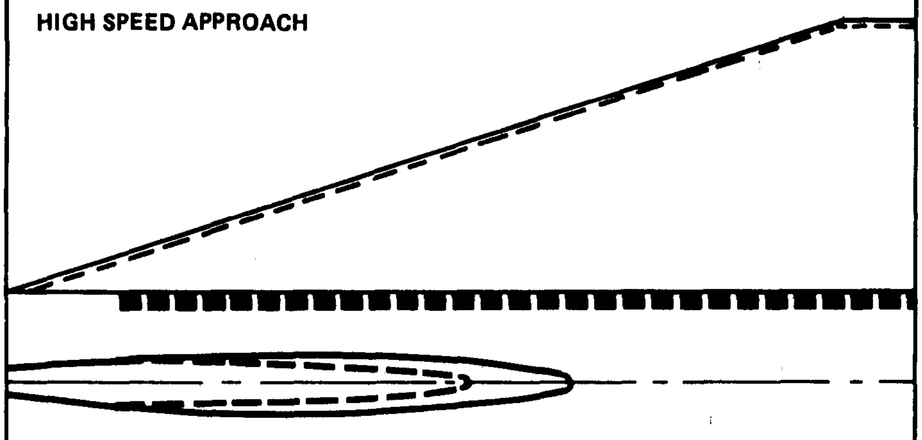
REDUCED FLAP SETTING



DELAYED FLAP AND GEAR EXTENSION



HIGH SPEED APPROACH



NOTE: DIAGRAMS ARE GENERALIZATIONS FOR ILLUSTRATIVE PURPOSES ONLY:

- No scale
- In practice the shapes of the contours will differ with aircraft type and operating conditions
- In practice the differences between the solid and dashed contours will differ from those illustrated. That is, the relative merits of any one technique may be more or less than depicted.

Delayed Flap and Gear Extension

Delayed flap and gear extension will also reduce airframe drag, engine power required, and thus noise in outlying areas. (Refer to Figure 5-1.1.1.1.)

High Speed Approach

A high speed approach can reduce noise in outlying areas. Aircraft descent is at a high speed with reduced thrust, utilizing aerodynamic drag and flap and landing gear adjustments to control speed. The procedure adds to pilot workload and is best suited for aircraft equipped with automatic landing systems. (Refer to Figure 5-1.1.1.1.)

Regulation of Thrust Reversals

Some aircraft employ thrust reversals for added braking power when landing. Such reversals cause objectionable sideline noise near the runways. The restriction of thrust reversals is possible when runway lengths permit. There is a trade off between reducing reversals and increasing taxi time.

Combined Techniques

Greater noise reductions are possible through combinations of techniques, but results are not entirely additive. Furthermore, not all techniques are compatible with each other.

Propeller Driven Aircraft

Noise mitigating techniques for propeller driven aircraft are similar to those outlined for jet aircraft. The typically lower noise output of prop-aircraft and the steep descent capabilities of lighter weight varieties facilitate noise mitigation. in general, the objective,, as with jet aircraft, is to keep the aircraft high.

5-1.1.1.2 TAKEOFF PROCEDURES

Associated with takeoffs are two types of noise; sideline and climbout. Sideline noise is characterized by engine noise and the effects of noise reflection caused by structures near runways. Sideline noise occurs when an aircraft is on or close to the ground. Climbout noise is dominated by engine noise and occurs when an aircraft is above building height, Controlled aircraft thrust is paramount in abating both types of noise.

Most of the following takeoff procedures will result in decreased noise in one area and increased noise in another. This tradeoff must be weighed with the patterns of sensitive and non-sensitive land uses to minimize detrimental noise impact. Again, maintenance of the flying mission and safety must take precedence. Reducing thrust under some circumstances is unsafe.

Reduced Thrust

Reducing thrust, or lowering the power setting, decreases noise. Reducing thrust at takeoff is the primary method of reducing sideline noise and is one of several methods of reducing climbout noise. The potential benefits of this are offset, however, by the, greater distances required to achieve a “noise free” altitude. (Refer to Figure 5-1.1.1.2)

Full Throttle

The use of full throttle or full power throughout takeoff will permit a maximum climbout angle. More noise will be created near the runways but further down the flight track noise will be reduced because of increased altitude. (Refer to Figure 5-1.1.1.2)

Flap Setting

A steeper ascension angle and reduced thrust are possible if the flap angle is reduced after a prescribed velocity is attained. Both higher altitude and lower power setting will reduce noise impact. (Refer to Figure 5-1.1.1.2)

Power Cutback

A normal liftoff with a power reduction at a selected point down range will decrease near range noise and increase far range noise. (Refer to Figure 5-1.1.1.2)

Afterburner Use Modification

Noise emissions during afterburner use are significantly higher than when the afterburner is not used. Cessation of afterburner use as soon as possible may result in lower exposure levels beneath the flight path. The reduction may however, be offset by the greater distance required to achieve a “noise free” altitude.

Propeller Driven Aircraft

In concept, the techniques for jet aircraft apply to propeller driven aircraft. Power cutbacks are not as effective, though, because of lower engine noise levels.

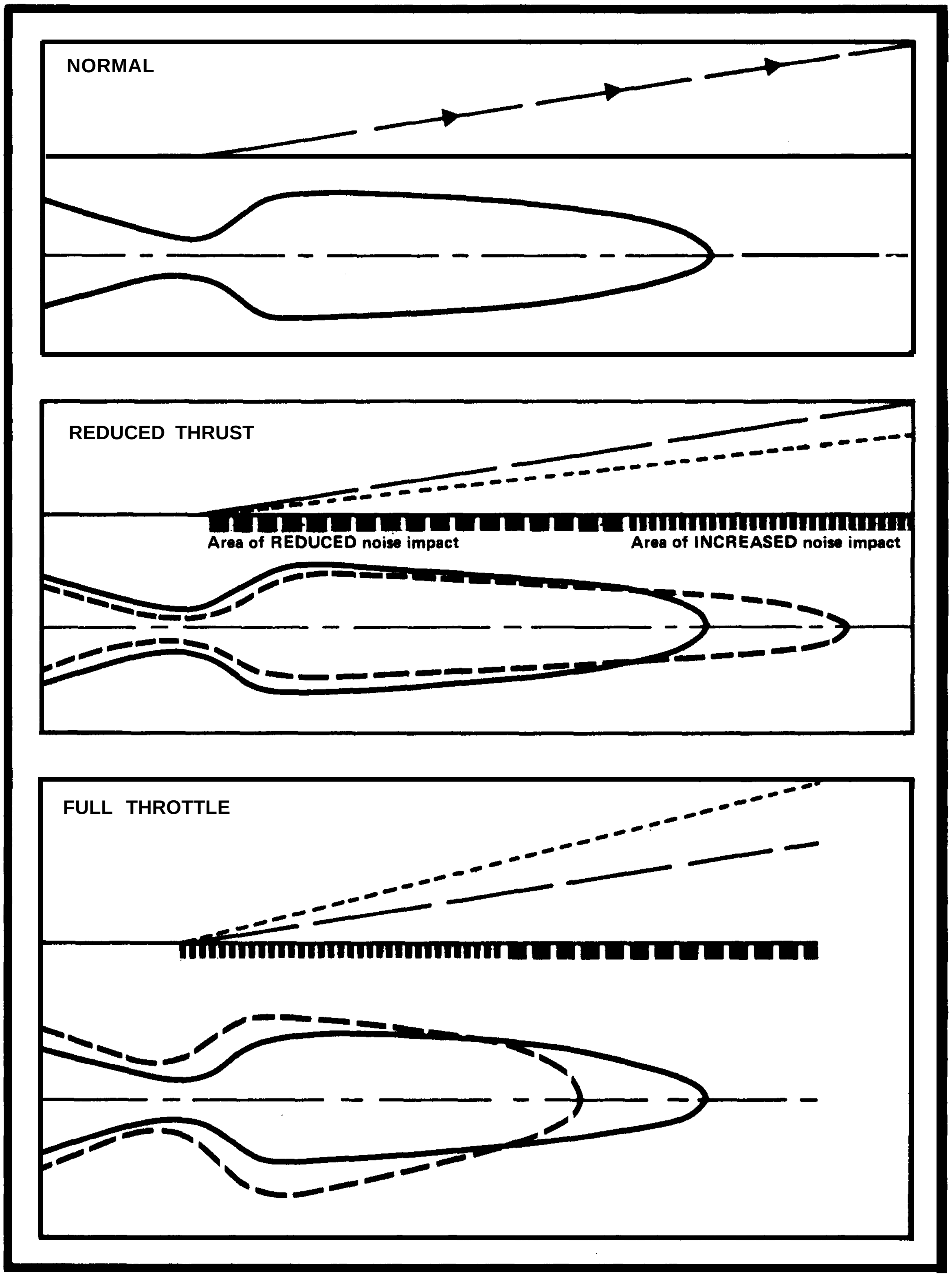
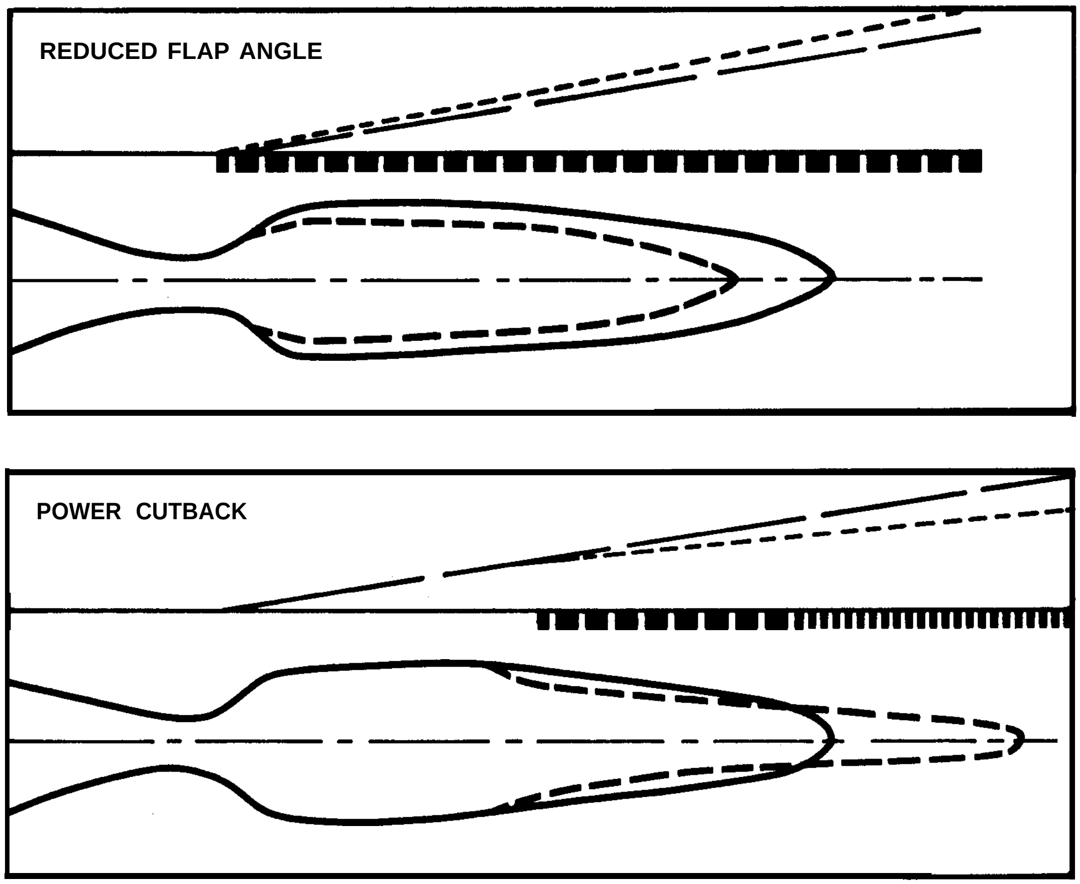

NORMAL
REDUCED THRUST
Area of REDUCED noise impact
Area of INCREASED noise impact
FULL THROTTLE

FIGURE 5-1.1.1.2 (CONTINUED)



NOTE: DIAGRAMS ARE GENERALIZATIONS FOR ILLUSTRATIVE PURPOSES ONLY.

- No scale
- In practice the shapes of the contours will differ with aircraft type and operating conditions
- In practice the differences between the solid and dashed contours will differ from thoses illustrated. That is, the relative merits of any one technique may be more or less than depicted.

5-1.1.1.3 ROUTING AND RUNWAY USAGE

The location of flight corridors or routes, especially near runways when aircraft are closer to the ground, is a controlling factor in noise pollution. By dispersing corridors, the amount of area subject to noise and crash potential will increase but the severity of the noise impact will diminish. Conversely, flight paths can be concentrated into a singlecorridor, thus decreasing the amount of land affected while increasing the severity of impact. (Refer to Figure 5-1.1.1.3)

This approach can be varied to handle problems in a particular area or during a specified time. Flights can be concentrated into a route which avoids noise sensitive areas. Corridors can be changed according to the time of day so that night flights are routed over areas not used during the night. Similarly, changes can be made seasonally to reduce the effects on facilities which may be used only during certain times of the year.

Routing has the advantages of being flexible, comparatively inexpensive, and potentially very effective. Two factors critical to route changes are as follows:

(1) The location of noise sensitive areas; and

(2) The constraints to route changes.

Constraints may include mission requirements, other air traffic, pilot and aircraft capabilities, and FAA approval.

Preferential runway usage is not as flexible as route changes but can be equally cost effective. Prevailing winds determine the layout and usage of runways. When winds are not a factor or there is more than one runway, then it may be possible to utilize that runway or runway direction which minimizes adverse impacts on surrounding environs.

5-1.1.1.4 OPERATION SCHEDULING

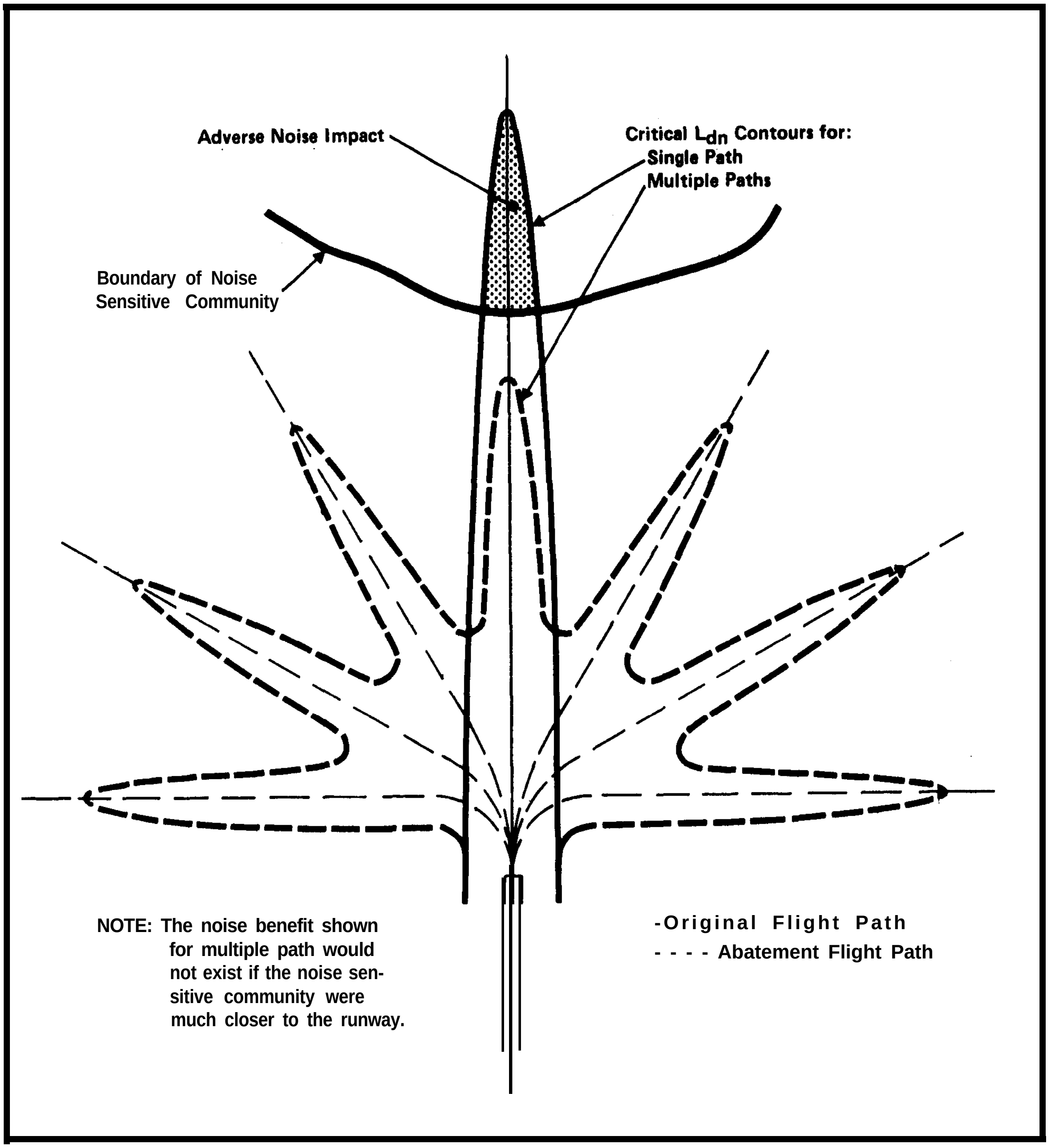
Noise abatement can be achieved with the distribution of aircraft operations in a prescribed manner over a defined time period. The two approaches are as follows:

(1) Scheduling to restrict the number of night flights;

(2) Scheduling to distribute the number of operations "evenly" over a time period.

People are more sensitive to night noise; this is reflected in Figure 5-1.1.1.4a (reprint of Figure 3-1.1.2a). This graph can be used to calculate the reduction in noise which results from a reduction in the percentage of night flights.

FIGURE 5-1.1.1.3



Reference 5-35

FIGURE 5-1.1.1.4a

L_{dn} CHART FOR SINGLE EVENTS

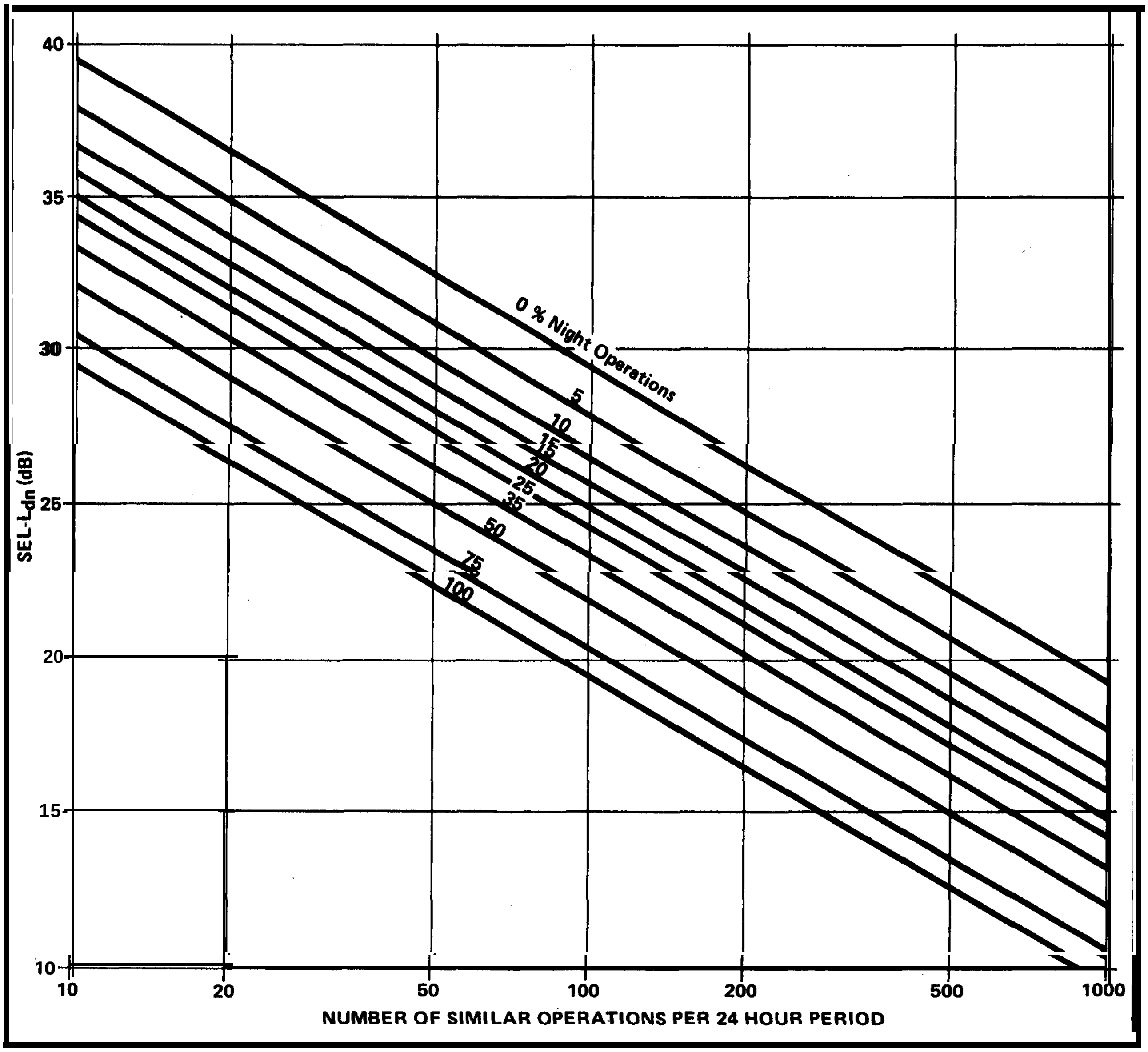
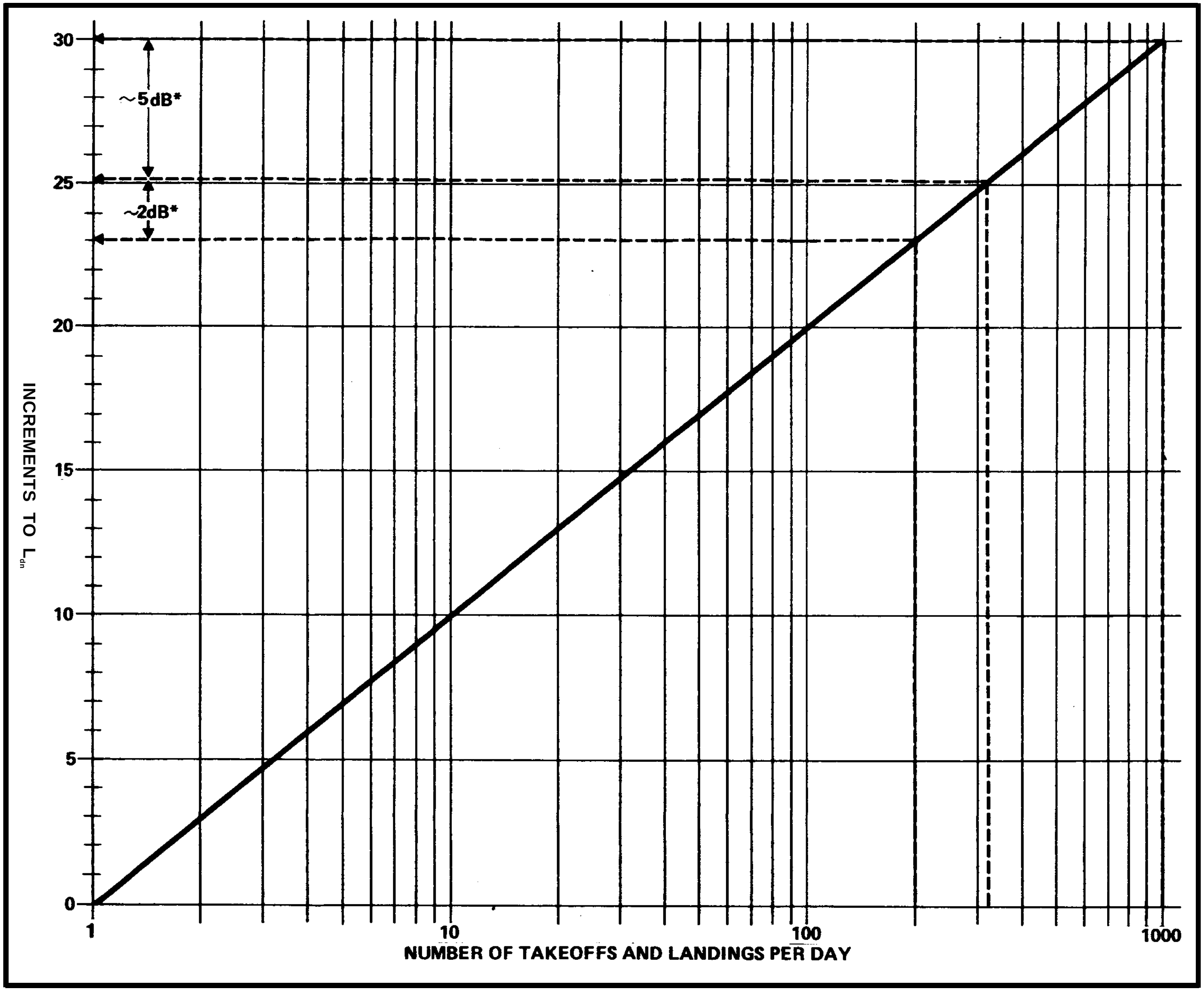


FIGURE 5-1.1.1.4b EFFECT OF NUMBER OF FLIGHTS ON CUMULATIVE NOISE EXPOSURE



Reference 5-34
*Refer to example in Section 5-1.1.1.4

For example, if for a given aircraft type there is a reduction in night operations from 50 percent to 10 percent (regardless of the number of total operations), the reduction in L_{dn}, which is calculated by subtracting the two corresponding numbers on the ordinate ($SEL-L_{dn}$) axis, is 4.5 dB. For more than one aircraft type, the total noise reduction can be calculated using decibel addition. (Refer to Figure 3-1.1.2c.)

The purpose of the second scheduling approach is to minimize traffic peaks which result in higher noise levels. For example, at an installation when there are 10,000 operations per month, there may be 200 operations one day, 1,000 the next, and so on. If the number of take-offs and landings were dispersed evenly over each of the 30 days in a month, then there should be 333 per day. As demonstrated in Figure 5-1.1.1.4b, the L_{dn} on a 333 operations day would be approximately 5 dB less than on a 1,000 operations day, but would also be approximately 2 dB <u>greater</u> than on a 200 operations day. This approach can reduce peaks but <u>will not</u> alter the total monthly noise exposure.

Inflexible scheduling restrictions, i.e., blanket curfews, hourly or daily quotas, etc., can in effect mandate a reduction in total operations and otherwise interfere with mission accomplishment. For these reasons, scheduling constraints must be planned with respect to mission requirements.

5-1.1.1.5 AIRCRAFT OPERATION REGULATIONS

Aircraft operation regulations include limiting aircraft loads and prohibiting the use of certain types of aircraft. Invoking such constraints to abate noise will generally conflict with air installation mission.

For some of the noisier transport aircraft, steeper climbout angles or reduced thrust may be possible if loads, including fuel, are limited. Reduced loads and fuel may require greater numbers of flights (and thus more noise, Figure 5-1.1.1.4b) which can offset the benefits of reduced thrust. Because L_{dn} has a logarithmic base, levels are strongly affected by the noisiest aircraft. Consequently, reassigning the offending aircraft can bring noise relief.

5-1.1.1.6 FLIGHT SIMULATORS

Much military flying time is for training. Some training flights can be eliminated with the use of flight simulators. There are many simulators in operation and current development trends are toward more sophisticated and useful designs. Regardless, the training situation requires extensive air time. The planner should be aware that such devices exist and that their use has a bearing on the noise environment.

5-1.1.1.7 OPERATOR CONTROL

The aircraft operators are an integral part of any abatement program. They must fully understand operational abatement techniques - the rationales as well as operating procedures. They should always be aware of the location of noise sensitive areas.

5-1.1.2 TECHNOLOGICAL CHANGES

Such technological innovations as quieter engines, more powerful engines (for steeper and faster climbouts), or new types of aircraft (like fixed-wing vertical take-off aircraft) can bring relief to noise affected environments. Within the next decade civil type transport aircraft will have quieter engines due to an aggressive research and development program. High performance military combat aircraft are not always suited to this "quiet technology", because degradation in performance is usually a by-product of quieting.

There are presently no short range (five to ten years) technological modifications (other than the gradual replacement of current turbojet aircraft with quieter fanjet aircraft) which are likely to significantly improve the air installation noise environment. Long range innovations are probable but cannot be incorporated into current planning.

5-1.1.3 AIR INSTALLATION PLANNING

Beyond operational modifications and technological changes, noise can be "reduced" at the source by relocating the source away from the receiver. In practice this is not always a viable alternative. The locations of airfields are limited by topographic, meteorologic, and other considerations. In addition, such facilities represent large capital investments. For these reasons the planner should rely on receiver location alternatives (Refer to Section 5,-3.1, Receiver Location) rather than source location alternatives.

5-1.1.4 IMPLEMENTATION

The planner has the responsibility for achieving an environment which will support aircraft operations; therefore, extensive operational alterations to abate noise may not be feasible. However, operational modifications should always be considered where practicable.

As part of their larger responsibility, planners are to assess existing and potential areas of adverse noise impact, When in their judgment a problem is severe enough to warrant consideration of

FIGURE 5-1.1.4

SUMMARY OF FIXED WING AIRCRAFT SOURCE MODIFICATIONS
Potential benefits and Costs

	PROCEDURE	POTENTIAL BENEFITS	POTENTIAL** COSTS
APPROACH	Holding and Maneuvering Altitudes	Reduced noise up to descent	No direct costs
	Traffic Control	Reduced noise in areas around runway Reduced fuel consumption	Administration
	Approach Glide Angle	Reduced noise up to touchdown	Optional automatic guidance systems
	Initial Approach Altitude	Reduced noise up to descant	No direct costs
	Flap Setting	Reduced noise up to touchdown Reduced fuel consumption	No direct costs
	Flap and Gear Extension	Reduced noise up to point of extension	Optional automatic extension equipment
	High Speed.	Reduced noise up to landing field	Automatic landing systems
	Regulated Thrust Reversals	Reduced noise in runway area	Runway lengthening More taxi time
TAKEOFF	Reduced Thrust	Reduce noise in runway area and close downrange+ Decreased fuel consumption	Increased noise far downrange*
	Full Throttle	Reduced noise far downrange*	Increased noise close downrange* Increased fuel consumption
	Flap Setting	Reduced noise throughout takeoff Decreased fuel consumption	No direct costs
	Power Cutback	Reduced noise after cutback	Increased noise far downrange*
OTHER	Routing	Reduced noise (up to 100%)	Increased noise in some areas
	Runway Usage	Reduced noise near runway A	Increased noise near runway B
	Operation Scheduling	Reduced noise at certain times of the day	Increased noise at certain times
	Aircraft Operation Regulations	Reduced noise in all areas	Greater number of operations
	Installation Planning	Reduction of noise in all areas	Airfield modifications
	Training Simulators	Reduction of noise in all areas	Cost of simulator

* Close and far downrange are relative terms referring to the proximity of the areas under the flight path to the runway. Close-downrange is the area nearest the runway and far-downrange is the area beyond (Refer to Figure B-1.1.1.2).

** There are any number of potential coats fend banefits) for each procedure. Costs might also include technique development, staff time, pilot training, mission interference, etc.

aircraft operations modification (summarized in Figure 5-1.1.4), they should present a statement of the problem and their recommendations for abatement to their commanding officer, who will forward it through appropriate channels for resolution. Variables which should be appraised in determining problem severity include the following:

- number of persons adversely affected
- degree to which standards are exceeded
- probable cost of solving/avoiding problem
- potential short and long term costs of inaction
- possible mitigating measures (pros and cons)

This general procedure can be used for each noise source mentioned hereafter: rotary-wing aircraft, aircraft ground operations, impulse noise sources, motor vehicles, railroads, and fixed sources.

5-1.2 AIRCRAFT NOISE - ROTARY-WING

The methods of abating rotary-wing aircraft noise are similar to those for fixed-wing aircraft. The primary distinctions between rotary-and fixed-wing noise are the source of the noise and the noise level. The techniques presented below are summarized in Figure 5-1.2.

The rotor system and the engine are principal rotary wing aircraft noise sources. Although absolute noise levels are approximately one-half those generated by jet transport, the throbbing of blade slap and rotor rotational noise increase annoyance.

5-1.2.1 OPERATIONAL MODIFICATIONS

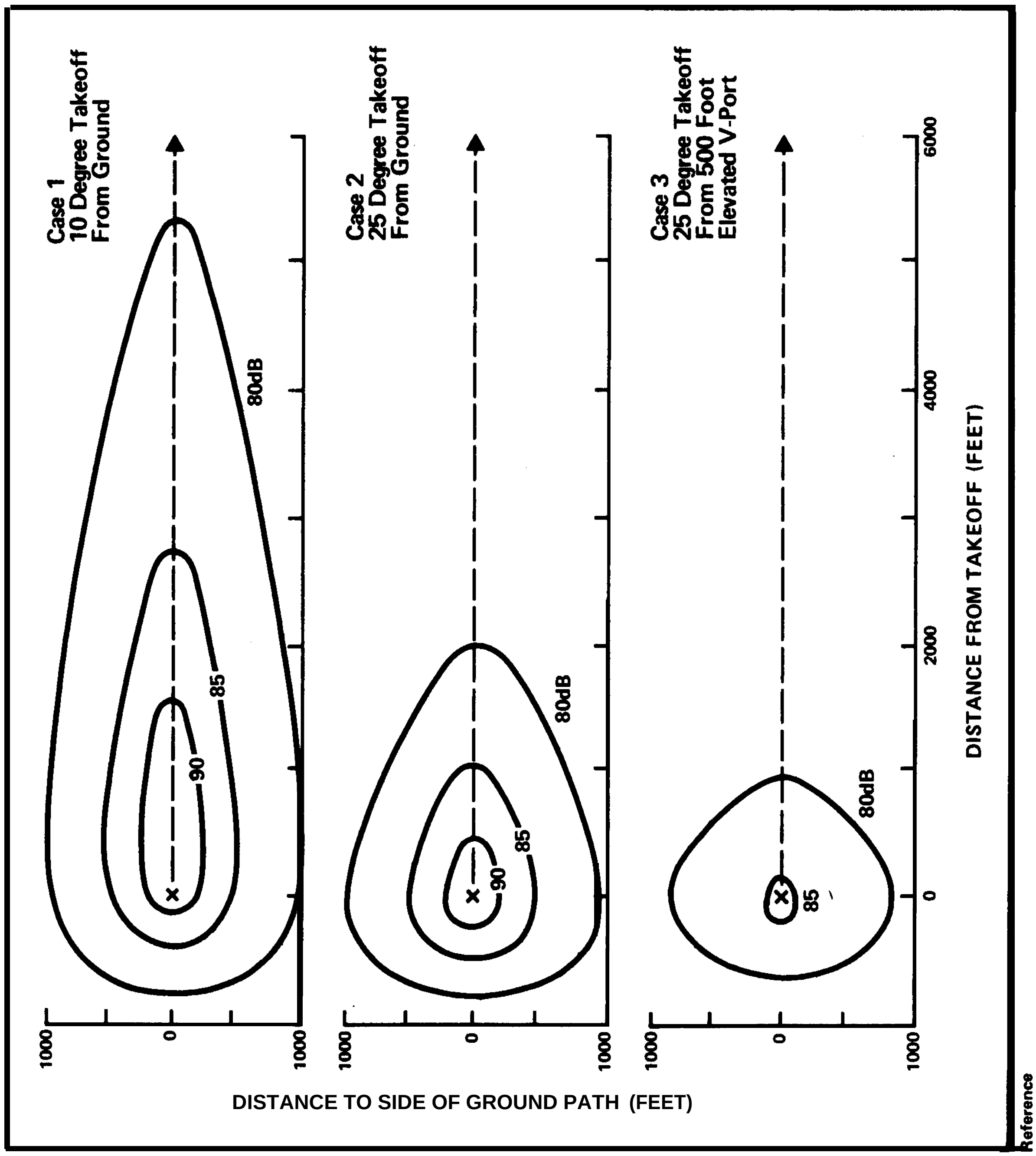
The maneuverability, vertical flight, takeoff and landing capabilities of rotary-wing aircraft permit greater flexibility than fixed-winged aircraft; the opportunity to employ operational modifications is limited. The objective of the installation planner is to create an environment that will support aircraft operations. Degradation of mission or safety is not permissible. The following brief descriptions of operational modifications are included to augment the planner's general knowledge of abatement techniques.

5-1.2.1.1 TAKEOFF AND APPROACH PROCEDURES

At takeoff, noise can be mitigated by maximizing the climbout angle. The sample case depicted in Figure 5-1.2.1.1 exemplifies the results obtainable for one type of aircraft under various takeoff conditions. Unlike fixed-wing aircraft, power cutbacks at takeoff are not feasible.

FIGURE 5-1.2.1.1

NOISE EXPOSURE CONTOURS FOR TRANSPORT PROPROTOR VTOL



During descent, annoying blade slap noise from the large rotor is at a maximum for a narrow range of airspeeds and descent rates. The blade slap regime can be avoided by an approach which combines the best approach angle, speed and blade loading condition for the specific helicopter model involved,

5-1.2.1.2 AIRCRAFT OPERATION REGULATIONS

There are several aircraft operation regulations which can mitigate noises. These include: avoidance of sharp turns, utilization of optimum cruise speeds and motor rpm, utilization of high altitude localizer flight for instrument training, and restricted utilization of the noisiest aircraft. Maintenance of a high altitude is the best in-flight abatement procedure. (It is recommended that rotary and fixed winged aircraft flying Visual Flight Rules keep at a minimum of 2,000 feet above noise sensitive areas - FAA Advisory Circular 91-36.) Other regulations include limiting aircraft load and prohibiting the use of certain types of aircraft. Refer to Section 5-1.1.1.5, Aircraft Operation Regulations (Fixed Wing Aircraft) for further discussion.

5-1.2.1.3 ROUTING AND RUNWAY USAGE

When low altitude flights are integral to mission accomplishment, then route modification should be investigated. Where possible, flight corridors should avoid or, at a minimum, be down wind of sensitive areas. The use of runways, particularly the location of the takeoff and touchdown points, should be based on this latter criteria. The comments in Section 5-1.1.1.3 Routing and Runway Usage (Fixed Wing Aircraft) apply.

5-1.2.1.4 OPERATION SCHEDULING

Refer to Section 5-1.1.1.4, Operating Scheduling (Fixed Wing), for discussion of night operation and scheduling.

5-1.2.1.5 FLIGHT SIMULATORS

Rotary wing flight simulators have been developed and are in use. These devices can result in reduced noise levels by obviating the need for some flights.

5-1.2.1.6 OPERATOR CONTROL

The comments in Section 5-1.1.1.7 Operator Control (Fixed Wing Aircraft) apply.

5-1.2.2 TECHNOLOGICAL CHANGES

There are several significant rotary-wing aircraft technological innovations in the research and design phase which could have an impact on noise environments. There are likely to be changes in conventional aircraft and the introduction of new types of aircraft.

Two predominant noise sources of rotary-wing aircraft are blade slap and rotor rotational noise. Blade slap is caused by the compressibility phenomena occurring on the advancing rotor blade during high forward speeds. During hover and at low speeds the sound is created by an interaction of the vortices of the preceding blades with the oncoming blades. (Refer to Section 3-3.1.1 Aircraft Noise Sources, Rotary-Wing.) Decreased rotor tip speeds together with specially designed blades can suppress slap. Increasing the number of blades will provide the same lift capabilities at reduced rotor speeds, thus reducing slap. Main and tail rotor rotational noise is similar to blade slap and, therefore, can be diminished in the same manner. Quieter rotor systems have been designed and are undergoing further development and testing.

<u>Increased blade tip speed</u> results in <u>increased forward speed</u> and <u>increased helicopter noise</u>. Thus, there is a trade-off between helicopter performance and economics and noise. However, compound helicopters, which have auxiliary engines for forward flight (alleviating the dependence on the rotor for such capability) are not subject to this tradeoff. The compound configuration permits greater forward speeds and more efficient lift and without great increases in noise output. Greater application of this vehicle could be a partial aid in reducing noise problems.

Vertical take-off and landing (VTOL) technology is advancing. One of the most promising developments has been the tilt rotor vehicle which combines the best characteristics of the rotary and fixed wing aircraft. The eventual widespread utilization of such vehicles could radically alter installation noise signatures.

Also of potential importance are short take-off and landing (STOL) aircraft. In addition, quiet engines are being tested for possible use in light weight helicopters. These innovations are at varying states of development.

After new aircraft becomes operational, there are delays, sometimes lengthy, before significant changes are realized in the noise environment because of final modification and production times and phased replacement of older aircraft. The planner should be aware of what is being developed for middle and long-range planning purposes. (Refer to Figure 5-1.2.2.)

FIGURE 5-1.2.2 ESTIMATED NOISE REDUCTION POTENTIAL FOR HELICOPTERS

Time Period	Noise Reduction (dB)*		
	Heavy Transport Helicopters	Light and Medium Turbine-Powered Helicopters	Light-Piston-Powered Helicopters
Potential in 1977 Utilizing Available Production Methods	0	5	10
Potential by 1985 Utilizing Current Industry Trends	10	15	10
Potential by 1980 to 1985 Utilizing Demonstrated or Advanced Technology	10	17	20

Reference 5-36

* Noise reduction relative to typical 1973 noise levels in dBA at 1000 feet

FIGURE 5-1.2

SUMMARY OF ROTARY WING SOURCE MODIFICATIONS
Potential Benefits and Costs

PROCEDURE	POTENTIAL BENEFITS	POTENTIAL COSTS*
Climbout Angle	Reduced noise in all areas	No direct cost
Flight Altitude	Reduced noise up to descent	No direct cost
Route Modifications	Reduced noise in area A	Increased noise in area B
Noise Abatement Approach Trajectory	Reduced blade slap	No direct cost Increase pilot workload
Operation Scheduling	Reduced noise at certain times	Increased noise at certain times
Installation Planning	Reduced noise in all areas	Airfield modifications, cost of new hardware, safety, convenience

*There are any number of potential costs (and benefits) for each procedure. Costs might also include technique development, staff time, pilot training, mission interference, etc.

5-1.2.3 AIR INSTALLATION PLANNING

Besides operational modifications and technological changes, perceived noise. levels can be reduced by separating the source from the recipient. Generally, as with fixed wing aircraft, it will be best to consider noise receiver rather than the noise source locational alternatives. However, since rotary wing aircraft require little space for touchdown and takeoff there is a degree of locational flexibility for operations, but safety and operational efficiency conditions must be considered. Many military helicopters are single engine type which require unrestricted ingress and egress conforming to established helipad criteria. In addition, there is a tradeoff between the inconvenience created by separating the site of operations from support facilities and the resultant reduction in noise.

5-1.3 AIRCRAFT NOISE-GROUND OPERATIONS

Aircraft ground operations consist of maintenance activities, where engines may be installed in or "free" from aircraft, and pre-takeoff operations. For equal noise exposure (in terms of SEL), noise from ground operations is generally more annoying than the noise of aircraft in flight. It has been theorized that individuals believe air installation officials have greater control over ground operations and that much of the noise is unnecessary, and therefore, is more annoying. The situation is aggravated by nighttime ground runup noise.

The duration and type of engine runup will vary widely during maintenance operations. Typical operations may consist of two or three runups at military power lasting from 5 to 10 minutes each. Afterburner operations may last from a few seconds up to a minute or more.

To reduce the impact from ground runup noise, the first factors to be considered are:

(1) Engine runup test schedules; and

(2) The location and orientation of powercheck pads and engine test stands.

Engine runup schedules should be reviewed to insure that operations, especially nocturnal, occur at those sites which have the least impact on noise sensitive areas or activities. Because of the pronounced directionality of runup noise (refer to Figure 3-4.1.1.a) orientation as well as location of runup sites must be considered when noise is to be reduced in a particular area.

If orientation, siting, and scheduling cannot be used to reduce noise impact, then consideration should be given to an effective but generally more expensive solution: noise suppressors. There are three varieties of ground maintenance noise suppressors:

(1) Portable. Portable noise suppression equipment can be used with some engines not equipped with afterburners.

(2) Demountable (semi-permanent). All components of these units, with possible exception of the intake mufflers, are constructed in sections and designed for assembly on site. Depending on the specific requirements, the intake mufflers may be either demountable or portable.

(3) Permanent (Typically concrete construction.) Permanent installations may consist of a fixed muffler system, with aircraft exposed, or a muffler system combined with a total enclosure for the aircraft or engine.

Typical demountable noise suppression equipment consists of an exhaust noise muffler, secondary air intake and enclosure, primary air intake system, cooling water system and controls, control house, and aircraft tiedown system. Generally, ground runup noise suppression equipment is cooled by aspirated air at all engine power settings up through military power, Water is typically required for cooling the exhaust muffler of noise suppressor systems during afterburner power operations. For discussion within this manual, ground suppression equipment is classified according to three grades of acoustical performance:

Grade	Approximate Maximum A-Levels* (along 250 ft. measurement circle)
I	77 dB
II	89
III	99

*Actual criteria are specified in terms of octave band SPL's.

Usually, Grade I performance is only possible with permanent construction. Current demountable equipment provides Grade II performance. Portable equipment for single engine non-afterburner aircraft provides Grade II performance. Portable equipment anchored by direct attachment to multi-engine aircraft (C-135, C-141, B-52 and C-5A type aircraft) provides Grade III performance.

The effectiveness of portable and demountable suppressors is mitigated by leakage in the seals between the suppressor and the airframe exhaust and intake openings. Unless acoustical leaks can be eliminated, suppressor design goals cannot be achieved. Total aircraft enclosures eliminate the need for close coupling of suppressor systems to the airframe. However, enclosures are expensive ($1.5 to 3 million) due to their size and special construction requirements.

The use of noise suppression equipment for engine runups will increase the time and number of maintenance personnel required. Time is required to tow and tie-down aircraft and attach the silencing system.

Additional information on suppressors is contained in References 5-28, & 5-6.

5-1.4 IMPULSE NOISE

Impulse or blast noise is characterized by a sound pressure wave which abruptly peaks and then slowly decays and, in the case of a sonic boom, peaks once again. There are two primary impulse noise sources: supersonic aircraft and weapons The nature of the noise and potential abatement techniques or each source vary widely.

Sonic booms are of lower intensity than weapon noise, which has broad spectral characteristics. While each source can cause disconcerting vibration and startling, noise from weapons, due to the spectral differences, is more annoying.

5-1.4.1 SON I C BOOMS

Sonic booms result from supersonic overflights occurring in designated supersonic corridors/areas. From a source modification standpoint, the planners should concern themselves with the location of such corridors/areas, the possibilities for rerouting, and/or increasing flight altitude.

5-1.4.2 WEAPONS

Opportunities for abating explosive noise at the source are limited. Blast noise cannot be reduced and muffling artillery pieces reduces range and accuracy. The most effective approaches to reducing weapon noise are:

(1) Regulating operating hours: To reduce noise intrusion during noise sensitive hours, e.g., nighttime in resident i al areas, class time in instructional areas, etc., a temporal analysis should be made of potentially

affected noise sensitive activities and mission requirements. This analysis will indicate when there are noise conflicts and where operation times of the noise source and/or receiver might be altered.

(2) Remote range locations: Separating the noise source from the receiver is a possible attenuation technique where space permits. In addition to land requirements, consideration must be given to the cost of moving operations, possible added cost of operating at a less convenient site, possible mission degradation, and new noise problems relative to existing development and potential development needs near the new range.

(3) Restrictions during worse focusing conditions: A temperature inversion layer and certain other conditions of temperature gradients and wind velocity and gradients will cause sound waves to be focused back toward the ground. These local conditions should be identified and monitored and operations modified accordingly, where possible.

5-1.5 VEHICULAR TRAFFIC NOISE

Although generally not as intense, vehicle noise is more prevalent than aircraft and impulse noise. This section is subdivided according to the two classifications of motor vehicles: street and combat. Vehicles normally operated on paved roadways are defined as street vehicles. Automobiles, pickups, jeeps, and diesel trucks whether they are privately or military owned fall into this category. Combat vehicles are defined as vehicles which are operated by the military and function off of roadways. This includes military street vehicles when operating off of roadways and all-terrain vehicles.

The noise source abatement techniques discussed below are primarily vehicle or roadway related and vary within each vehicle class. These techniques include:

(1) Vehicle design, operation and maintenance; and

(2) Route design, maintenance, and location.

These techniques are summarized in Figure 5-1.5.

5-1.5.1 STREET VEHICLES

As stated in Section 3-6.1.1 Noise Sources (Motor Vehicles), street vehicles can be divided into three distinct classes: light trucks and automobiles, medium trucks, and heavy trucks. The vehicles in each class generate the same approximate noise levels, but deviant vehicles (those that are especially noisy because of poor maintenance, poor muffling, etc.) strongly impact the roadside noise environment.

5-1.5.1.1 VEHICLE NOISE CONTROL

Noise generated by vehicles can be abated to a degree. Military vehicles can be maintained to insure that engines are well tuned, that exhaust system components are operating efficiently, and that quieter style tires are installed and well maintained. Privately owned vehicles which are blatant noise sources can be controlled with police type regulations, such as citations for faulty muffler systems. The noise from improperly maintained vehicles can be controlled, but there is little that can be done to reduce the composite effect of many vehicles in optimal operating condition. For this reason roadway related abatement techniques, as well as vehicle related techniques, must be utilized.

5-1.5.1.2 NOISE CONTROL ALONG THE ROADWAY

Roadway Gradient

Grades can cause significant increase in heavy truck noise (up to 8 dB), as indicated in Figure 3-6.2.2a.

Stop-and-Go Traffic

The effects of stop-and-go traffic are a function of truck-automobile traffic mix. A slight percentage of slow moving commercial vehicles will increase the noise of stop-and-go traffic. It is generally felt by experts that where there is a typical mix of heavy trucks (2 to 4 percent), moderate and steady speed freeflow traffic will be quieter than stop-and-go traffic. The means to calculate the noise level reduction has not yet been developed. Freeflow can be facilitated through the use of any number of typical engineering modifications, e.g., computerized signals, elimination of unnecessary arterial stops, road widening to prevent bottlenecks, one-way streets, etc.

Traffic Volume and Speed

Vehicle noise is a function of traffic volume and speed. The L_{eq} nomograph for street vehicles (Figure 3-6.2.1a) illustrates the following relationships:

- For all vehicle types, noise levels increase as vehicle volume increases;
- For heavy trucks, noise levels decrease slightly as vehicle speed increases; and
- For automobiles and medium trucks, noise levels increase as vehicle speed increases.

Considering traffic volume, if roads are constructed or modified to accommodate less traffic, then sideline noise will decrease, but this reduction must be weighed against the added expenditure of constructing a greater number of roads and the possibility of exposing a greater number of persons to traffic noise. Limiting traffic speeds can also reduce noise (depending on the truck-auto mix).

Routing

Routing or rerouting traffic to avoid a noise sensitive land use can be an effective abatement technique. Rerouting may consist of constructing a new roadway or rechanneling traffic on existing roadways. Heavy trucks deserve individual attention in terms of special routes including alternate night routes.

Roadway Configuration

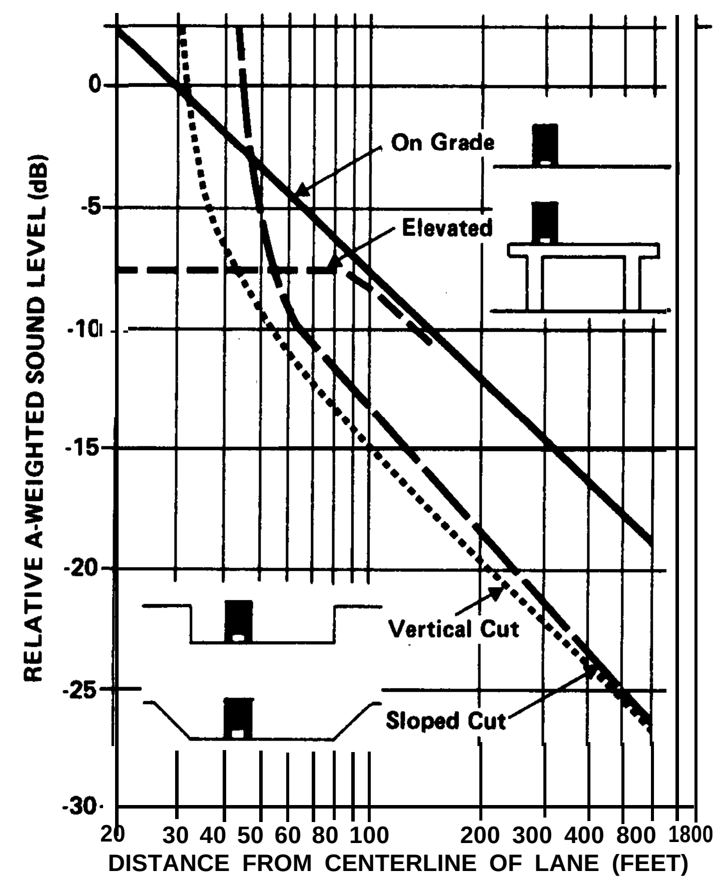
Noise can be abated by elevating or depressing a highway. The net effect is the same as that of a noise barrier. (The method for calculating noise reduction by either technique is presented in Section 5-2.1.4.) Figure 5-1.5.1.2 is a generalized illustration of the benefits that can be derived from various typical highway configurations. (This figure should not be used for abatement evaluation..) For the example shown, in comparison with a roadway at grade, at distances in excess of 100 feet, the depressed roadway will be approximately 5 to 7 dB quieter, and within the shadow of the elevated roadway it will be from 0 to 7 dB quieter.

Roadway Surface

As stated in Section 3-6.2.2, a roadway which Is unusually rough due to broken pavement or large voids or transverse grooves will cause a noise level increase of about 5 dB.

FIGURE 5-1.5.1.2

NOISE REDUCTION PRODUCED BY VARIOUS HIGHWAY CONFIGURATIONS *



Reference 5-33

* Generalized figure; do not use for noise reduction calculations (Refer to Section 5-2.1.4)

5-1.5.1.3 SCHEDULING

Roadway vehicle noise levels are directly related to peak hour vehicle volume; the lower the volume, the lower the noise. This relationship is illustrated in the nomographs for manual noise level calculation in Section 3-6.2.1, Determining L_{eq} for a Simplified Roadway. Peak volume can be manipulated through routing (described previously) or scheduling. A temporal analysis of noise sensitive functions and periods of noise peaking will illustrate where scheduling changes may be useful. Major peaks typically occur before and after work hours. These can be “flattened out” by staggering work hours.

5-1.5.1.4 IMPLEMENTATION

To minimize costs and the detrimental effects of noise, abatement planning should occur on the drawing board before a problem is created. Implementation of the following procedures will help in achieving this end.

(1) Roadway designers and traffic engineers should understand the noise ramifications of roadway design and traffic flow. They should know where noise sensitive areas are, how to determine noise impact, and how to mitigate the effects of noise.

(2) The potential noise impact of all alternate designs should be calculated (refer to Section 3-6.2).

(3) The costs (dollar and otherwise) of ameliorating adverse impacts should be determined.

(4) The above information should be incorporated into the final design selection process.

(5) The planner should monitor this process to insure that the noise environment receives proper consideration.

In the case of an existing problem, studies should be made to ascertain the feasibility of rerouting, resurfacing, and/or reducing stop-and-go traffic, traffic speed, and traffic volume. Implementation strategies should be investigated concurrently. Often these types of abatement techniques can be implemented at moderate expense. For example, resurfacing can be coordinated with routine maintenance resurfacing. Modifying grades and roadway configurations and constructing roadways in new routes are costly and normally will not be viable approaches to ameliorating an existing problem. Abatement analysis should address not only direct costs but delay time costs, effects on fuel consumption, and other factors typical to engineering cost-benefit analyses.

5-1.5.2 COMBAT VEHICLES

Combat vehicles are classified as transport and weapon types. Tracked and wheeled vehicles in either class are generally noisier than heavy trucks.

5-1.5.2.1 VEHICLE NOISE CONTROL

The noisiest vehicles are likely to be those that have poorly maintained engines and running components. At a minimum, muffler and intake systems should be checked and engines tuned. Beyond typical maintenance, noise can be reduced by utilizing sound absorbing material in engine compartments and additional exhaust and intake mufflers or baffles.

Several types of vehicles are equipped with auxiliary equipment such as pumps and compressors. These noise sources should be treated as fixed sources. Quiet motors, enclosures, and other measures outlined in Section 5-1.7 are applicable.

5-1.5.2.2 NOISE CONTROL IN THE FIELD

There are four areas of opportunity for operational modifications ions to reduce noise exposure:

(1) vehicle speed and volume;

(2) scheduling;

(3) routing; and

(4) operator awareness.

As illustrated in Figure 3-6.2.1b, for both transport and weapons vehicles, noise exposure increases as either vehicle speed or volume increases. Thus, speed restrictions and scheduling modifications, to reduce “peaks” in traffic volume, can reduce noise. Additional scheduling modifications might include regulating operations in noise sensitive areas during “sensitive” hours of the day.

In some cases, noise abatement can be achieved through relocation of routes and maneuver areas that create a noise nuisance. In all cases, operators of noisy equipment should be made aware of problems (or potential problems) so they can modify their actions accordingly as practicable.

FIGURE 5-1.5

SUMMARY OF VEHICLE SOURCE MODIFICATIONS
Potential Costs and Noise Reductions

TECHNIQUES	POTENTIAL NOISE REDUCTION	POTENTIAL COSTS*
Reduced Roadway Gradient	0-8dB (Fig. 3-6.2.2a)	Increased construction costs
Stop-and-Go Traffic	0-20dB	Computerized signals Rerouting on existing roadways Street widening
Reduced Traffic Volume	(Fig's. 3-6.2.1a & b)	More noise elsewhere Road underutilization Road investments elsewhere
Reduced Speed	(Fig's, 3-6.2.1a & b)	Delay time
Roadway Surface	0-5dB	Resurfacing
Routing	Reduced noise in area A	New circulation on existing roads--signing and strip costs Increased noise in area B
Depressed Roadways	0-10dBA	Increased construction costs
Elevated Roadways	0-10dBA	Concrete structure $60 - $100 sq.ft.
Vehicle Maintenance	Variable	Added maintenance labor&material
Ancillary Equipment Noise	0-15dB	Absorptive material Damping material Barriers Enclosures Quiet engines
Scheduling Regulations	Variable	Administration Possible delay time
Remote Operation	Reduced noise in one area	New support facilities Increased noise in another area

*There are a number of potential costs (and benefits) for each procedure. Costs might also include mission interference, decreased production, staff time, etc.

5-1.6 RAILROAD NOISE

There are two main types of railroad operations: line and yard. The noise from these operations consists of a locomotive component and a car component. Reviewing briefly Section 3-7, Railroad Noise:

(1) Locomotive line noise is affected primarily by grades;

(2) Car line noise is affected by velocity, curves, bridge structures, rail discontinuities, and wide and/or uneven rail joints;

(3) Locomotive yard noise is a function of idling time;

(4) Car yard noise consists of coupler impacts and wheel-rail interact ion noise.

Axle differentials, improved car brakes, rubber wheel webs, engine modifications and other rolling stock improvements will reduce source noise, but the planner is likely to have more control over abatement and obtain better results by ensuring that tracks are constructed in the best manner and are well maintained and that operations do not occur during noise sensitive hours.

Specifically, welded rails can reduce noise up to 8 dB. An additional 1 to 2 dB can be achieved by grinding rails flat and smooth. Vibration noise can be reduced several decibels by coating the rail web with an appropriate vibration damping compound or by-using rail fasteners to reduce transmission to structures. Concrete track beds are slightly quieter than wooden ties and ballast. The lost significant reduction in noise, 5 to 25 dB, can be obtained by eliminating tight radius curves. (Refer to summary Figure 5-1.6.)

In addition to modifying track systems, or optimally, insuring noise criteria are incorporated in initial design, the potential benefits of scheduling should be investigated. Siding and spur operations will usually be more adaptable to scheduling controls than line operations. (See Reference 5-25.)

5-1.7 FIXED NOISE SOURCE

Noise sources operated at a stationary site, commonly within a structure, are defined as fixed sources. Power plants, maintenance shops, machine shops, and wind tunnels, are noise generators in this category.

In the discussion of source modifications which follows, machinery and the structure in which it is housed are treated as the source. The source is so described because the planner has noise environment

FIGURE 5-1.6

SUMMARY OF RAILROAD SOURCE MODIFICATIONS
Costs and Potential Noise Reduction

TECHNIQUES	NOISE REDUCTION (at 100 feet)	MAJOR COSTS (1976 dollars)
(Typical Railroad Construction)		Main line (wooden ties, jointed rail - without grading) $25 - 40/LF
(Turnouts)		$4,500 - $8,000 each
(Crossings1		Major street $40,000 Minor street $30,000
Welded Rails	4-8dB	$4 - 7/LF (plus above construction costs)
Concrete Ties	0-2dB	$20/LF (plus above construction
Eliminating Tight Radius Curves	5-25dB	$3 - 5/LF (plus above construction costs)
Rail Grinding	1-2dB	Grinding
Scheduling	Reduced noise at certain times	Administration Possible delay time Increased noise at certain times

responsibility when fixed sources impact areas beyond their immediate confines, e.g., shop or plant walls. The health and welfare of equipment operators and other workers within a noise source structure are primarily the responsibility of the medical services.

Stationary Engine Design

Proper initial design is the most effective approach to eliminating machinery noise at the source. There are a limited number of measures that can be taken with existing machinery. Where engines are the dominant noise source, a specially designed air in-take muffler or a "motor mute" can reduce noise levels up to 10 dB at the operator position. The installation of a new quieter engine would be an effective but more expensive solution.

Vibration Isolation

Vibration of large, thin metal machinery guards is a common noise source. This effect can sometimes be checked by:

(1) Moving the points of panel attachment from vibrating elements of the machine to other, more stable points of the frame; or

(2) Replacing solid metal sheets with perforated ones which will not radiate noise as readily.

Machinery rigidly attached to floors or walls can create a loudspeaker effect which can be mitigated with the installation of rubber or other resilient type mounting blocks. Up to 15 dB. reduction at the operator position is possible.

Energy Absorption

Indoor reverberant noise can be reduced to a limited degree (3 to 5 dB at removed locations) with the use of "acoustical treatment" or absorbent materials on walls and ceilings. Several decibels reduction can be achieved by affixing dampening materials to vibrating surfaces such as large pipes or equipment housing walls, etc. These materials convert vibratory energy to heat.

Barriers and Enclosures

Dramatic noise reductions are possible with sound barriers and equipment enclosures. These devices best reduce high frequency noise (above 500 Hz). Where a slight reduction in noise is required a sheet of laminated glass or plastic may be sufficient. Barriers several feet wide and high may provide 10 to 15 dB attenuation.

Although noise may be reduced on one side of a barrier, it may be amplified on the other side due to reflection. Absorbent material on the noise source side of the barrier will partially dissipate sound energy and reduce reflective qualities.

Elaborate and expensive total enclosures can reduce machinery noise by 30 to 50 dB. This reduces access to machinery and, therefore, will rarely be viable. Access openings usually lessen effectiveness to a 10 to 20 dB reduction. In some instances, it may be possible to enclose both equipment and operator. While this has positive effects on the overall noise environment, the worker inside will not benefit. Small machines can be enclosed in a "glove box" container which has openings for a worker's hands. Depending on the size of the opening, noise reduction may be 5 to 15 dB. (Refer to summary Figure 5-1.7.)

5-1.7.1 CONCLUSION - IMPLEMENTATION

The potential reductions in noise cited previously do not incorporate the reductions afforded by a structure in which the noise source may be located. Refer to Section 5-2.2, Soundproofing, and consider the effects of "inverse soundproofing", that is containing noise inside a building rather than keeping it out.

As with other abatement techniques, a combination of measures will often bring the maximum results, but the potential noise reductions of each separate technique are not directly additive.

Procedurally, after a problem is identified, the installation Bio-environmental Engineer or Health and Environment Officer should measure the noise environment. The planner should then assess the problem and recommend a solution or solutions for appraisal and implementation. The determination and installation of appropriate abatement devices must be done by acoustical experts: persons who are experienced in acoustics and familiar with the hundreds of fixed source abatement apparatus available. The planner's role is to assess the problem, recommend solutions and assure that the desired results are achieved.

Various abatement techniques should be compared on the basis of decibel reduction versus direct monetary outlays and costs of reduced productivity. Barriers and enclosures will be obstacles to workers. At first, operators will be unaccustomed to them and productivity will be reduced. With time, it will rise, perhaps never to its former level or perhaps surpassing it because of the improved work environment. Losses in productivity may also result from shut down time during the installation of noise mitigating devices.

FIGURE 5-1.7 SUMMARY OF FIXED SOURCE MODIFICATIONS

TECHNIQUE	POTENTIAL NOISE REDUCTION	MAJOR COSTS (1976)	
		UNIT COSTS	PRODUCTIVITY
Absorption	3-5 dB**	$ .50-2.50/sq. ft.	0
Damping	3-10dB *	.20-4.50/sq. ft.	0
Barriers (inside structure)	5-15dB *	2.00.3.50/sq. ft.	up to 15%
"Glove Box" Booths	3-15dB *	250.00-450.00/ea.	up to 20%
Equipment Enclosures	5-50 dB *	4.00.9.00/sq. ft.	up to 25%

Reference 5-40

* at operator position
** at "removed" distances within structure housing noise source

5-2 NOISE PATH MODIFICATIONS

Thus far, the discussion in this chapter has centered about noise abatement at the source. Recognizing that abatement at the source may not be sufficient or even possible, one must look to the next logical place in the noise system for intervention. That place is along the noise path.

Abating noise along the noise path consists basically of placing a physical barrier between the noise source and receiver. Just as it is most effective to deal with noise at the source before it disperses, it is generally more efficient to block noise near the source than near the receiver.

This section deals with the two approaches to noise path modifications: changes near the noise source; barriers and shields, and changes near the noise receiver; soundproofing.

5-2.1 BARRIERS

Walls, earth berms, buildings, natural terrain, and foliage are commonly utilized as noise barriers. To varying extents each reduces noise by partially absorbing it and reflecting it away from receivers. Barriers, which are most effective against higher frequency sounds, must be located in the line-of-sight between the source and the receiver. Barrier effectiveness increases with height, width, and proximity to either the source or the receiver. If there are gaps in a barrier, the potential benefits of acoustical shielding will be substantially reduced. Furthermore, the effects of all barriers are lessened by atmospheric sound scattering and by noise "spilling" effects around barrier limits. Besides acoustic advantages, barriers visually obscure the noise source and thus also benefit the noise recipient psychologically.

The discussion following focuses on the use of barriers to mitigate aircraft, surface vehicle, and impulse noise. The method for calculating barrier height and effectiveness is presented in the concluding sect ion. A final summary chart (Figure 5-2.1) enumerates typical costs and benefits of several types of barriers.

5-2.1.1 AIRCRAFT NOISE

Barriers are not utilized extensively to abate aircraft noise because they can be effective only when aircraft are operating on or near the ground.

The sideline noise of fixed-wing aircraft which is generated during taxiing, takeoff, and landing can be reduced by properly positioned barriers. During takeoff the maximum effects of a barrier will occur when an aircraft is still on the ground and approximately 45° beyond the point being shielded. (The 45º is measured from an axis drawn through the shielded point and perpendicular to the flight track.) For landing aircraft, barriers will reduce sideline noise to the front and rear after touchdown. Barriers are useful in abating thrust reversal noise.

The effectiveness of barriers in reducing sideline noise is not well established, in part because of limited application. Buildings along runways afford partial shielding and landscaped earth berms are the least expensive and can be the most aesthetic barrier mode.

Field measurements at the Minneapolis-St. Paul Airport barrier (a one mile long, 15 feet high earth berm with 25 foot high trees planted 60 to 100 feet deep) affirm a 5 dB minimum noise reduction in selected areas.

A barrier with a smooth solid surface may reflect noise into regions beyond the barrier. (Refer to figure 5-2.1.1.) This effect can be mitigated with the use of surface treatment or vegetation which provides absorptive and dispersive properties,

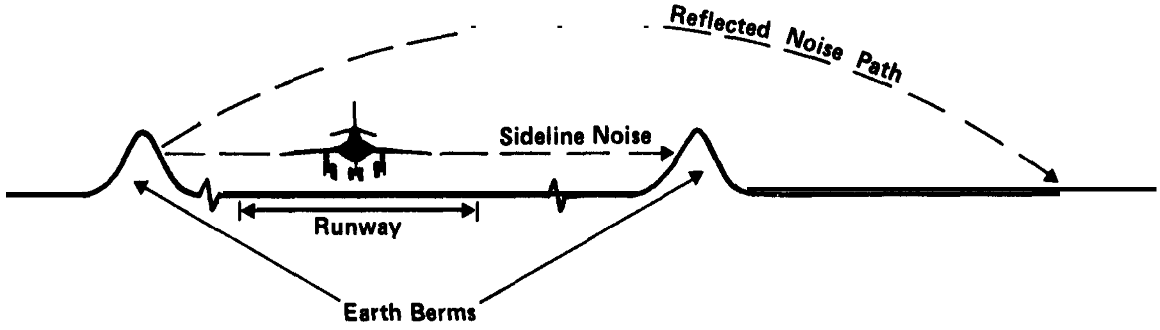
Barriers offer little relief from rotary wing operations because of the rapid vertical ascent capabilities of the aircraft. However. for rotary or fixed winged ground operations noise barriers can be effective.

5-2.1.2 MOTOR VEHICLE AND RAILROAD NOISE

Barriers are capable of reducing the noise of railway, street, and combat vehicles in areas around fixed guideways or paths. Where combat vehicles are executing field maneuvers, the use of barriers for abatement is less feasible. In this case, barriers should be erected as close as possible to the noise receiver, not the noise source.

Several types of barriers have been used extensively along highways. The most common are wooden, block, and concrete walls and earth berms, These obstructions approach a maximum effectiveness of 22 dB. Rows of buildings will also provide noise attenuation if the source is completely. shielded by the structures, both vertically and horizontally. A single row of structures, with less than 20% open area between structures, will provide 5 dB attenuation. Succeeding rows will provide an additional 2 to 3 dB each, up to a maximum attenuation of 10 dB for all rows.

FIGURE 5-2.1.1 **BARRIER REFLECTED NOISE**



0 SCALE

Landscaping, although aesthetically pleasing, is not highly effective in abating noise unless it is dense, thick and tall. If vegetation is not dense enough to obscure the sight of the noise source, its effect will be inconsequential. A reduction of 5 dB for every 100 feet of dense landscaping at least 15 feet high is appropriate. The maximum degree of reduction that can usually be expected is 10 dB.

Natural terrain and roadway configuration also can help reduce noise. As indicated in Section 5-1.5.1.2, Noise Control Along the Roadway, elevated or depressed roadways have built-in noise barriers. The potential noise reduction in these cases is presented in the following section.

The types of barriers appropriate for highways are applicable to railways too. Since line operation noise is predominately wheel and track related, low walls (about car floor height) are adequate. Such parapets are capable of reducing wayside noise 10 dB (at 100 feet). With yard and siding type operations, where predominant engine noise is augmented by the impacts of couplers, more extensive walls are required.

Besides mitigating noise, barriers can reduce glare, dust, and fumes, and can improve aesthetics. To avoid the adverse effects of barriers, design considerations should include maintenance, noise reflection, shadow effects, drifting sand or snow, and related factors.

5-2.1.3 IMPULSE NOISE

Barriers are normally effective for small arms ranges but their use with heavier weapons is not recommended. It is not uncommon for sound waves from explosions to be transmitted upwards and focused downwards miles away. This phenomena renders ground terrain, earth berms, and other barriers ineffectual. Where sound waves are transmitted along the ground, a barrier would have to be located close to the blast to be effective. Without a total enclosure, there is a high probability of reflecting noise to other points.

5-2.1.4 EVALUATION OF SHIELDING

For most ground based point and line noise sources, an obstruction between the source and the receiver can provide significant attenuation of noise.

A simplified assessment of the benefits of shielding may be performed, using the path length difference parameter. This quantity, usually symbolized by δ (delta), is the difference in distance travelled by the sound wave going over the obstruction rather than directly through it (along the line-of-sight to the observer if the obstacle were not present). Figure 5-2.1.4a illustrates the geometry of acoustic shielding, and defines δ for a generalized obstruction or barrier. (Note that obstructions of finite width are approximated by a "knife-edge" barrier.)

Barrier attenuation as a function of 6 is depicted in Figure 5-2.1.4b. The upper curve is to be used for point sources, while the lower applies to roadways or railroads.

After establishing the location of the observer (or site), the location of the source, and desired degree of noise reduction, the following procedure should be used to solve for barrier height.

(1) Establish the location of the proposed barrier. (Generally the closer a barrier is to either the source or the receiver the more efficient it will be.)

(2) Estimate the required barrier height.

(3) Compute δ using Figure 5-2.1.4a and barrier attenuation using Figure 5-2.1.4b.

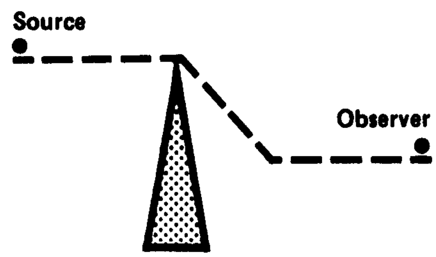
(4) Compare the barrier attenuation value obtained to the desired value of noise reduction.

(5) Adjust the estimated wall height either up or down according to the above difference and solve for barrier attenuation again. Reiterate until the discrepancy under Step 4 above is acceptably small. (See Example 5-2.1.4a)

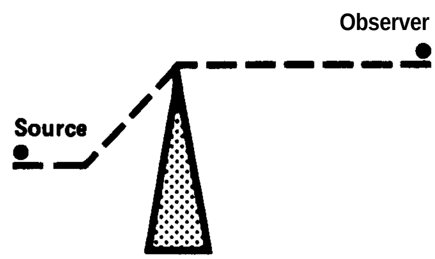
To be an effective noise barrier, an obstruction must be solid (no gaps or leaks), moderately dense (minimum surface weight of 2 to 4 lb./sq.ft.), high enough to significantly break the 'line-of-sight (i.e., the greater the δ value the greater the attenuation) and sufficiently long to prevent sound from defracting around the edges.

For line sources, the attenuation indicated in Figure 5-2.1.4b will be realized only if the barrier is sufficiently long to cover an <u>angle of observation</u> (α) greater than 160 degrees. Barrier attenuation for shorter barriers can be calculated using Figure 5-2.1.4c, which indicates barrier attenuation as a function of <u>shielding ratio</u> α/θ (alpha/theta) and infinite barrier performance. Barrier performance is seriously degraded by insufficient length. Noise from around the barrier edges creates an additive effect to that which spills over the top. For example, from Figure 5-2.1.4c, if the shielding ratio for a barrier with "infinite performance" of 15 dB decreases from 0.9 to 0.8, the attenuation drops 30%, from 10 dB to 7 dB.

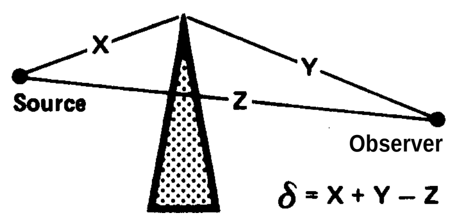
FIGURE 5-2.1.4a ACOUSTIC SHIELDING GEOMETRY



SCHEMATIC OF ELEVATED HIGHWAY



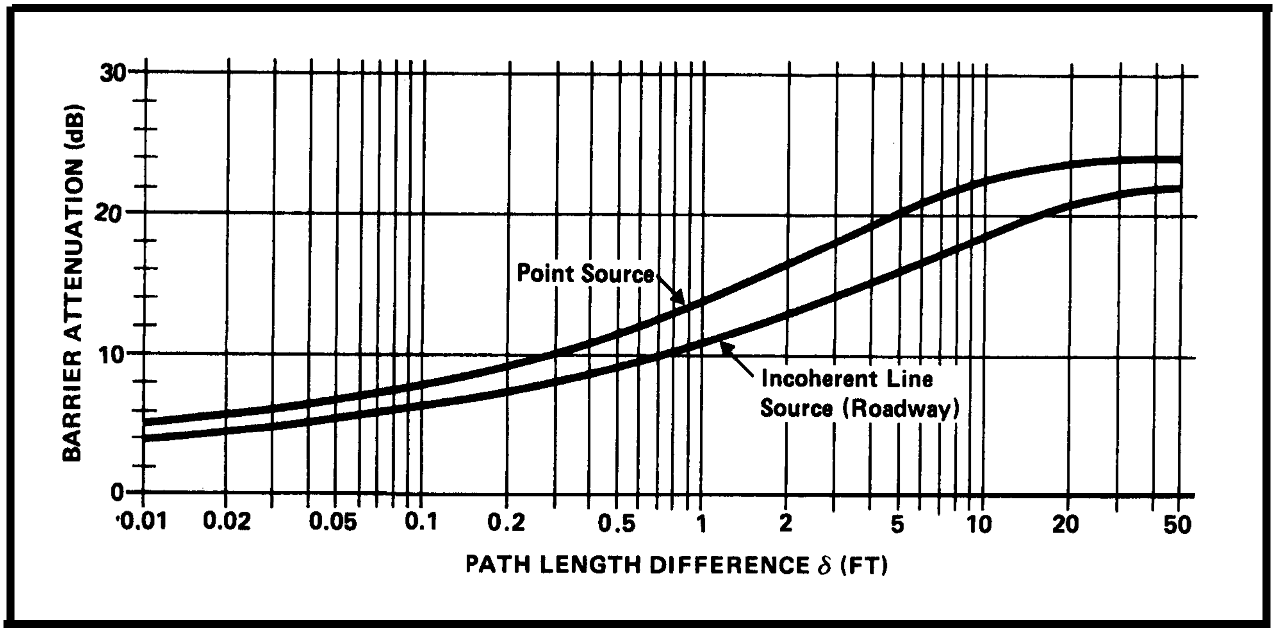
SCHEMATIC OF DEPRESSED HIGHWAY



GENERALIZED GEOMETRY OF ACOUSTIC BARRIER

FIGURE 5-2.1.4b

ATTENUATION OF AN INFINITE BARRIER FOR POINT SOURCES AND ROADWAYS



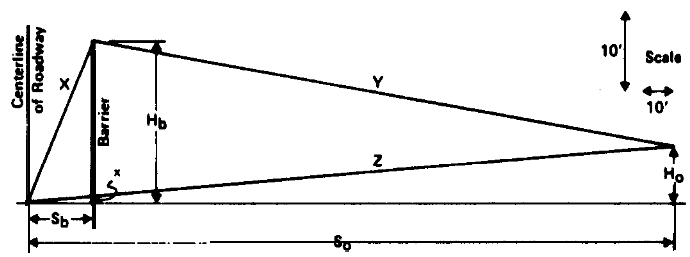
EXAMPLE 5-2.1.4a CALCULATION OF BARRIER HEIGHT

PROBLEM:

Determine the barrier height required to reduce the noise levels in a residential backyard by 12dB. The only noise source is automobile traffic on a roadway 200 feet distant. The terrain is flat. The angle of observation of the road (()) will be greater than 160° Assume an infinite barrier length.

SOLUTION:

1. Select a suitable location for the barrier in this case at the edge of the sidewalk: 20 fact from the centerline of the roadway.
2. Estimated barrier height (H_b) = 10 feet.
3. Prepare a diagram of the wall, source, and receiver relationship where:
   a. source height (H_s) = 0 (for automobiles. Section 3.6.1.1.11
   b. observer height (H_o) = 5.0 feet (typical case assumption)



   c. Setback. roadway to barrier (S_b) = 20 feet
   d. Setback, roadway to observer (S_o) = 200 feet

4. Calculate path length difference (δ)

   $\delta = X + Y - Z$ (Figure 5-2.1.4a)

   $X = \sqrt{S_b^2 + H_b^2} = \sqrt{(20)^2 + (10)^2} = 22.36$ (Pythagorean theorem)

   $Y = \sqrt{(S_o - S_b)^2 + (H_b - H_o)^2} = \sqrt{(180)^2 + (5)^2} = 180.07$ (Pythagorean theorem)

   $Z \approx 200$

   $\delta = 2.4$

5. Determine barrier attenuation (A_b)

   A_b = 14dB (Figure 5.2.1.4b)

   This is more than the desired 12dB, so assume a shorter barrier height and recalculate A_b.

6. Estimate barrier height (H_b) = 6 feet
7. $\delta = 0.9$
8. A_b = 10.5dB
   = 10 dB (round off to nearest dB)

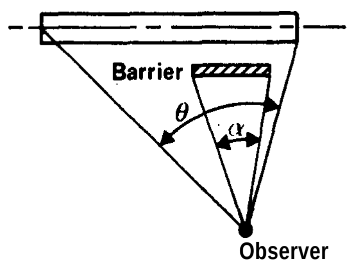
   A_b too low, assume an H_b less than 10 feet, but greater than 6 feet
9. H_b = 8 feet
10. $\delta = 1.6$
11. A_b = 12dB ∴ the barrier should be 8 feet in height

    Note: Because of field uncertainties, for example the actual average height of observer, and assumptions made in the calculation of X, Y, and Z, a safety factor can be introduced, and a greater barrier height selected.

FIGURE 5-2.1.4c

FINITE BARRIER ATTENUATION FOR ROADWAYS

		Finite Barrier Attenuation										
Shielding Ratio, α/Θ		0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
Infinite Barrier Performance	-5dB	0	0	-1	-1	-1	-2	-2	-3	-4	-4	-5
	-10dB	0	0	-1	-1	-2	-3	-3	-4	-6	-7	-10
	≤ -15dB	0	0	-1	-2	-2	-3	-4	-5	-7	-10	-15



EXAMPLE PROBLEM:

Calculate barrier attenuation on an infinite roadway (Θ = 180°) for a barrier which subtends an angle of 125% (α = 125°). The same barrier, but of infinite length ($\alpha \geq 160°$) affords 15 dB attenuation.

SOLUTION:

1. **Calculate $\frac{\alpha}{\Theta}$**

$$\frac{\alpha}{\Theta} = \frac{125^{o}}{180^{o}} = 0.69 \simeq 0.7$$

2. Barrier attenuation = -5 dB (from Figure 5-2.1.4c)

To apply the aforementioned process to the procedure for calculating barrier dimensions for a line source, it is necessary to execute three additional steps:

(1) Select the desired barrier height (Hb) and calculate the shielding ratio (α/θ).

(2) Calculate α .

(3) Calculate the barrier length (using trigonometry). (Refer to Example 5-2.1.4b.)

5-2.1.5 IMPLEMENTATION

Barriers are powerful abatement tools, but they can be costly and can cause many non-acoustical deleterious effects. A barrier cost-benefit analysis should include the following:

(1) Benefits

- o Noise reduction (and related benefits)
- o Privacy
- o Less dirt, glare, and exhaust

(2) costs

- o Mission degradation
- o Direct (design and construction)
- o Maintenance (landscaping, cleaning, repairing, etc.)
- o Safety (to motorists, pilots, etc.)
- o Visual (ugly, block view, etc.)

For further information on design considerations refer to the following publications:

(1) "Location, Selection and Maintenance of Highway Traffic Barriers", NCHRP Report #118, 1971.

(2) AASHTO, Guide on Evaluation and Attenuation of Traffic Noise, 1974.

(3) AASHTO, Highway Design and Occupational Practices Related to Highway Safety, 1974.

PROBLEM:

Determine the length of a barrier assuming the conditions in Example 5-2.1.4a, where $\theta = 150^{\circ}$ (due to topography) and the desired attenuation (A_b) is 12 dB.

SOLUTION:

1. Select the desired barrier height (H_b) and calculate the shielding ratio $\frac{\alpha}{\theta}$. For Example, with respect to Example 5-2.1.4a, one could select a barrier with H_b = 8 feet, A_b = 12dB and "infinite" length ($\alpha = \theta$) or with H_b = 10 feet, A_b = 15dB and a shorter length. In each case the shielding ratio would differ, the resultant barrier length (Lb) would differ, but the desired attenuation (12dB) would be the same. For an H_b of 10 feet, L_b is calculatedas follows.

2. Calculate the shielding ratio.

   Infinite barrier performance = 15dB (Example 5-2.1.4a)

   Desired performance = 12dB

   $\frac{\alpha}{\theta}$ is between .9 and 1.0 (Figure 5.2.1.4c), interpolate by ratios:

$$\frac{\left(\frac{\alpha}{\Theta}\right)_{15dB} - \left(\frac{\alpha}{\Theta}\right)_{10dB}}{\left(\frac{\alpha}{\Theta}\right)_{A_b} - \left(\frac{\alpha}{\Theta}\right)_{10dB}} = \frac{15\text{ dB} - 10\text{ dB}}{A_b - 10\text{ dB}}$$

$$\frac{1.0 - 0.9}{\left(\frac{\alpha}{\Theta}\right)_{A_b} - 0.9} = \frac{15\text{ dB} - 10\text{ dB}}{12\text{ dB} - 10\text{ dB}}$$

$$\left(\frac{\alpha}{\Theta}\right)_{A_b} = 0.94$$

3. Calculate α

$$\alpha = (.94)\theta = 141^{\circ}$$

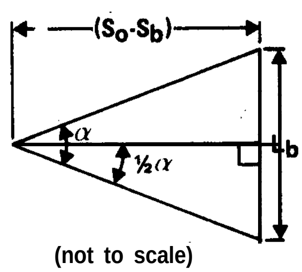
4. Calculate L_b

$$\tfrac{1}{2} L_b = (\tan \tfrac{1}{2}\alpha)(S_o - S_b)$$

$\frac{1}{2} L_b$ = (2.82)(180)

$\frac{1}{2} L_b$ = 508

L_b = 1016 feet



(not to scale)

SUMMARY OF BARRIER TYPES: Potential Benefits and Costs

FIGURE 5-2.1

TYPE	MAXIMUM POTENTIAL NOISE REDUCTION	CONSTRUCTION COSTS* (1976)
Construction Block Wall** 5 feet (parapet) 10 feet 20 feet	 15 dB 15 dB 15 dB	 $ 4.00/LF - $ 9.00 8.00/LF - 18.00 16.00/LF - 37.00
Earth Berm (10 feet high 10 feet wide no landscaping)	15 dB	$12.00/L F
Foliage (Strip 100 feet wide)	5dB	$40.00/LF

*Does not include maintenance.

** As walls increase in height the base width and subsurface foundation must also increase in size. As a result, cost per square foot also increases with height.

5-2.2 ACOUSTIC DESIGN

Acoustic design includes modifications to site design, architectural design, and construction to achieve noise reduction.

5-2.2.1 ACOUSTIC SITE DESIGN

Acoustic site design is defined as the practice of positioning structures and other land uses within the confines of a site for the purpose of reducing noise levels. The primary techniques are shielding, reflection reduction, and land use.

5-2.2.1.1 SHIELDING

Structures and natural variations in topography may serve as barriers to shield noise sensitive portions of a site.

(1) A small hill or earth mound can be as effective as a man made earth berm. A depressed area may be a good location for a structure or noise sensitive exterior use.

(2) Due to site limitations, it is most likely that shielding can best be provided by structures.

- o Buildings housing non-sensitive uses are ideal for shielding. The garage or parking structure can serve this function.

- o Buildings with uses less sensitive to noise than those being protected are also potential shields; in such cases the shielding structure will usually require acoustic architectural design and/or construction. Retailing and administrative buildings can be used to shield residential structures.

(3) Although the topography of a site may not offer much opportunity for shielding, properly placed structures can exploit natural site characteristics. Earth-mounds between buildings can further enhance shielding characteristics.

5-2.2.1.2 REFLECTION REDUCTION

Noise reflected off buildings and ground surfaces can be a significant problem, especially in highrises and exterior spaces.

(1) A street bounded by buildings is a noise canyon. This effect can be mitigated by maximizing, building setbacks.

Building reflection can also be reduced by varying building heights, reducing building density? use of open space), and avoiding parallel wall canyons.

(2) Setbacks can be doubly functional because they present the opportunity to utilize landscaping and other noise absorbic surface treatments which are effective in reducing the impact of terrestrial noise sources. Hard surfaces, such as parking lots, will reflect noise, and may even amplify it.

(3) Structures should be oriented to focus reflected noise into non-sensitive areas.

5-2.2.1.3 ATTENUATION WITH DISTANCE

Land uses can be manipulated not only to create shielding and reduce reflection, but to capitalize upon noise attenuation with distance (4.5 dB reduction for every doubling of distance for line sources). Recreation areas, parking and other land uses can be situated to increase the distance between a noise source and the primary land use.

Another facet of attenuation with distance (buffering) is on site noise source location. Streets, parking areas, and fixed noise sources should be situated to reduce unnecessary noise exposures.

Note that buffering land uses, e.g., an outdoor recreation area, may be more sensitive than the use being protected. Thus, abatement priorities must be assessed at the outset. A comparison of the periods of a day during which a noise level is unacceptable, and during which a facility is used, may suggest optimal noise reducing land use patterns.

5-2.2.1.4 MINIMIZATION OF EXPOSED SURFACES

Noise can be reduced by minimizing the surface area of that portion of a structure exposed to, or facing, a noise source. In the case of a line source, such as a roadway, the noise may be more annoying in rooms with an exterior wall perpendicular to the roadway (and facing oncoming traffic) than in rooms with an exterior wall parallel to the roadway. This is because of the following:

(1) The directional characteristics of the noise.

(2) Noise levels rise and drop off quickly as vehicles pass the corner of a building, rather than rise and decay slowly as perceived in a parallel surface room.

5-2.2.2 ACOUSTIC ARCHITECTURAL DESIGN

Architectural techniques which can be used to reduce noise include room layout, window sizing, wall opening (doors, windows, ducts, etc.) treatment, etc. Architectural techniques are not to be confused with construction measures like wall insulation and heavy roof construction which are treated in the following section. Architectural techniques to reduce noise, like site design techniques, are usually less expensive than acoustic construction.

5-2.2.2.1 SHIELDING

Shielding consists of physically blocking or impeding sound waves. Architecturally, there are two general approaches: reduction of wall opening surface area and utilization, of external architectural elements, e.g., overhangs, balconies, etc.

(1) Wall openings. The wall of a structure is a sound barrier. Abatement effectiveness is greatly diminished, though, if there are passages through which sound energy can penetrate. The three common weak links 'in walls are ventilation ducts, windows, and doors. Methods to reduce sound transmission for each are as follows:

- Ventilation ducts:
  - Minimize the number needed on walls and roofs exposed to noise sources. This can be facilitated through room arrangement (refer to Section 5-2.2.2.3, Space Utilization).
  - Use ventilation noise traps.
  - Locate ducts in areas not exposed to noise.
- Windows:
  - Minimize the window surface area (to zero if possible) on walls exposed to noise sources.
  - Locate windows in areas not exposed to noise.
  - Reduce the need to open windows exposed to noise sources by providing mechanical ventilation or natural ventilation through windows or ducts at unexposed locations. (Note, mechanical ventilation in itself requires wall openings.)

- o Doors:
  - . Locate entries in areas not exposed to noise.

(2) Architectural elements. Elements which are a normal part of a structure can be designed to provide a shielding effect. As implied by the previous discussion, shielding is most effective near acoustically weak elements such as wall openings. Enumerated below are some of the elements which should be considered in mitigating noise.

- o Balconies:
  - . Depending on topography and room arrangement, balconies can shield noise from below or above.
  - . Balconies may reflect noise into a building.
  - . Because a balcony is often a place of relaxation, it may not be fitting to locate it in an exposed area. An analysis of times of use and of periods of unacceptable noise levels could reveal the appropriateness of balcony shielding.
- o Overhangs and soffits can impede noise from above, but can al so have reflective characteristics.
- o Shielding can also be achieved by recessing a building into the ground or backfilling earth around lower floors.
- o Noise exposure is reduced in recess areas, e.g., a patio or entry recessed into the surface of a structure.
- o Other potentially protective elements are architectural embellishments such as decorative walls, protrusions, or facades.

5-2.2.2.2 REFLECTION REDUCTION

Most building surfaces are excellent sound energy reflectors. Built-in noise problems can be avoided by utilizing techniques parallel to those outlined in Section 5-2.2.1.1 covering site design shielding. There are three approaches:

(1) Surface treatment is the use of materials which partially absorb, thus reducing, reflected sound energy. Noise levels at absorbently coated walls are less than at reflective walls, but there is an upper limit to the effectiveness of absorption. Ivy or other absorbent materials can be useful.

(2) Reflection can be reduced by promoting the scattering or dispersion of sound waves. Surface design, or the use of rough materials, variegated surfaces, screening, etc. can achieve this end.

(3) As indicated previously, balconies and other appurtenances can be the source of unwanted reflections. By properly locating reflective surfaces, reflected noise intrusion can be avoided. The designer should also be cognizant of all large flat surfaces, potential reflection into outdoor spaces, and potential mini-canyons where noise might be reflected back and forth.

5-2.2.2.3 SPACE UTILIZATION

The manner in which space is utilized, vertically and horizontally, can have a significant effect on the amount of noise to which a room is exposed. The abatement principles for space utilization are similar to the land use principles of acoustic site design.

In the case of space utilization, the primary goal is to minimize noise in sensitive portions of a structure by maximizing the shieldins and/or barrier benefits afforded by the structure itself.

This is done by locating rooms housing noise sensitive functions and rooms with wall openings away from a noise source.

(1) In the former case it is necessary to first classify rooms according to sensitivity. In a residential structure there might be three categories:

- o Most sensitive: bedroom and den
- o Sensitive: living room and dining room
- o Least sensitive: kitchen, bathroom, utility rooms, halls, and closets.

(2) Similarly, rooms with wall openings should be class/fled according to their propensity to permit the passage of sound. The more vulnerable places are outdoor patios

and rooms with a large window area, outside doors that are used frequently, and windows which provide ventilation. The least sensitive rooms, as in the residential example above, are usually the rooms least requiring wall openings.

Areas needing protection should be located away from the noise source, buffered by non-sensitive uses and walls. With inflight airplane noise it is desirable to locate sensitive uses away 'from the flight track horizontally and vertically, i.e., on the lower floors of a multi-story structure. Illustrated in Figure 5-2.2.2.3 are several layouts designed to mitigate noise from a predominant direction. As indicated in the same figure, outdoor spaces can be sheltered by arranging other uses around them in a courtyard fashion, not unlike the method of creating recessed areas.

As an extension of the above approach, a structure can be designed to "turn its back" on the noise source and focus elsewhere, e.g., into an interior court. Accordingly, the space between the noise source and the structure can be minimized to maximize the amount of protected areas on a site.

5-2.2.3 ACOUSTIC CONSTRUCTION

Acoustic construction is the use of structural elements to impede sound transmission. Elements such as windows, walls, and roofs will mitigate noise to a degree, but greater abatement is possible with acoustic construction. Noise i's best mitigated by impeding the passage of the soundwave and by facilitating the absorption of sound energy.

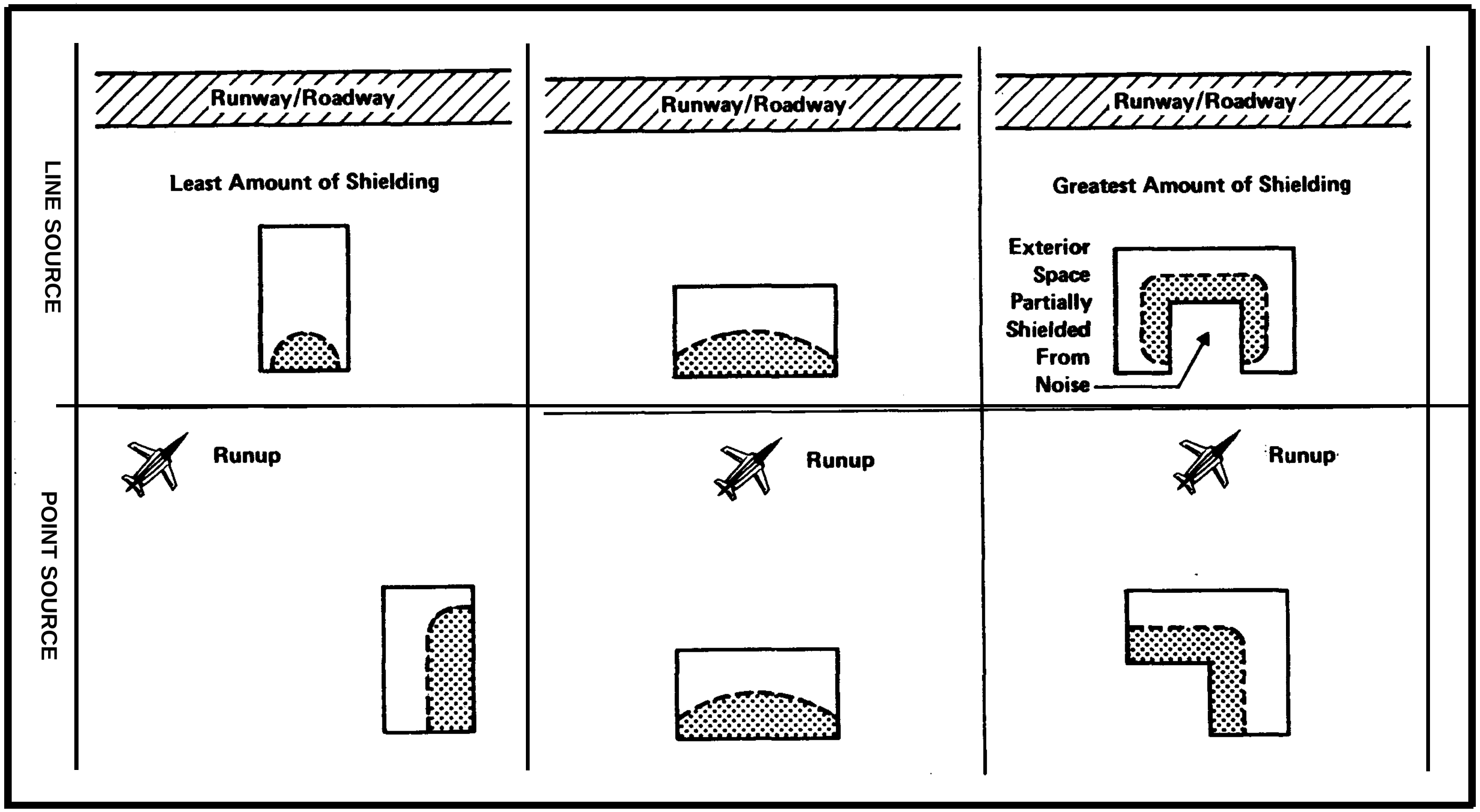
5-2.2.3.1 ACOUSTIC CONSIDERATIONS

Acoustic construction has been demonstrated to be a technically feasible means to reduce noise up to 50 dB, but only indoor environments can be improved. An acceptable outdoor environment is especially important in residential areas and the more moderate the climate, the more often the outdoor environment is used. In a Los Angeles study it was found that in areas where outdoor noise exceeded 87 dB, owners regarded the environment to be unsuited for residential use, regardless of the effectiveness of indoor soundproofing (Reference 5-39). Acoustic construction can be a viable solution for churches. schools. off ices, retailing facilities, etc.

Those land uses where noise insulation should be considered are enumerated in Figure 4-5. For some land uses (for example, classrooms, libraries, and hospitals), soundproofing may be effective only under

FIGURE 5-2.2.2.3

LOCATION OF "NOISY" AND "QUIET" AREAS IN A HOUSE EXPOSED TO NOISE FROM AIRCRAFT ON THE GROUND



Noise levels in shaded areas will be less than those in unshaded areas, if rooms in shaded areas are separated from unshaded areas by walls.

certain conditions. For instance, in structures housing training programs where outdoor activities are not required, soundproofing is appropriate. Where outdoor activities are an integral part of a training program the potential value of insulation is lessened The acceptable noise level reductions (NLR) for outdoor L_{dn} or L_{eq} values are also presented in the aforementioned figure.

There are numerous means to reduce sound levels. Several techniques are listed below. The quantified sound reductions afforded by several typical construction measures are presented in Figure 5-2.2.3.1. More specific data on acoustic construction can be acquired from the references listed in Appendix D.

(1) Walls

- o Increase mass.
- o Use "dead" air spaces.
- o Increase airspace width (between walls).
- o Increase airspace length (space between studs).
- o Use staggered studs.
- o Seal cracks and edges.
- o Use insulation blankets.
- o Give special attention to openings; electrical outlets, medicine cabinets, etc.
- o Use resilient materials to hold studs and panels together.
- o Use acoustic coating.

(2) Roofs

- o increase mass.
- o Seal cracks and edges.

(3) Ceilings

- o Use insulation blankets.
- o Use non-fixed suspension methods.
- o Use acoustic coatings.

(4) Floors

- o Increase mass.
- o Block off all joists (prevents noise from traveling over or under walls).
- o Use resilient supports between joists and floor.

(5) Windows

- o Use sealed windows.
- o Increase glass thickness.
- o Use double glazed windows.
- o Increase volume of "dead" airspace in double glazed windows.

(6) Doors

- o Use solid core doors (not sliding or hollow core).
- o Use doorframe gaskets.

(7) Interior Design

- o Use heavy drapes.
- o Use heavy carpets.
- o Use acoustic ceiling treatment.

The sound level reductions in Figure 5-2.2.3.1 are specified in decibel ranges because of the variance in noise sources and types and quality of construction. Designed noise reduction levels cannot be achieved if acoustic elements are not constructed or installed with proper care.

Reference 4-2 provides conservative building construction specifications required to attain NLR values of 20, 25, and 30 dB in buildings exposed to surface vehicle and aircraft noise. If NLR values greater than 25 dB are specified, then a detailed acoustical analysis should be undertaken because the NLR values in Figure 4-5 are conservative.

FIGURE 5-2.2.3.1 TYPICAL BUILDING CONSTRUCTION NOISE LEVEL REDUCTION VALUE%

TYPE OF CONSTRUCTION	NLR in dB AIRCRAFT AND VEHICULAR NOISE
Conventional wood frame - windows open	15 - 20
Conventional wood frame - windows closed	25 - 30
Conventional wood frame - no windows, or ¼" glass windows sealed in place	30-35
1/8" glass windows, sealed in place*	20 - 25
1/4" glass windows, sealed in place*	25 - 30
Walls and roof - weighing 20 to 40 Ibs/sq.ft., no windows*	35-40
Walls and roof - weighing 40 to 80 Ibs/sq.ft., no windows*	40 - 45
Heavy walls and roof - weighing over 80 Ibs/sq.ft., no windows*	45 - 50

*Assuming a surface area consisting of only this element.

5-2.2.3.2 NON-ACOUSTIC CONSIDERATIONS

Provision of acoustic construction can increase initial construction costs,

Most acoustic construction techniques involve wall openings, especially windows; either closing, sealing, or removing them. These modifications can necessitate the installation of a ventilation, or air conditioning system. With respect to these systems, the following should be considered:

(1) Window hung air conditioners normally do not impede exterior noise penetration.

(2) Ventilation systems are, in themselves, noise sources.

(3) Air ventilation and conditioner systems are costly.

Acoustic construction provides thermal insulation as well as acoustic. This benefit can be equated to long term monetary savings through reduced energy consumption and should be incorporated into cost benefit analyses. Note too, that the provision of a ventilation system will, conversely, increase energy consumption.

5-2.2.4 IMPLEMENTATION

A typical acoustic design program will entail the following:

(1) Determining the degree of noise reduction needed.

(2) Establishing which design techniques are appropriate and their probable effectiveness.

(3) Establishing preliminary implementation program.

(4) Estimating cost of program and cost of not executing program.

(5) Estimating the value of acoustic and non-acoustic benefits.

(6) Submitting program for approval.

(7) Executing program

a. Establish design specifications.

b. Develop construction plans.

c. Obtain quarters for displaced persons and functions (if altering existing structures).

d. Make building modifications.

e. Verify effectiveness of program.

To follow this acoustical design program, the planner will require the expertise of acousticians and architects. The former should be consulted in areas 1, 2, and 7a above. Architects will take part in areas 4, 5, 7a, b, and e.

The approval of new construction in noise impacted zones must be contingent upon the provision of adequate noise insulation, The planner should advise those responsible for design and construction of the need for adequate noise insulation.

5-3 NOISE RECEIVER MODIFICATIONS

Noise can be abated at the source, along the path, or, as is considered here, at the point of perception. The two basic receiver oriented approaches are: 1) insuring that individuals are not located or cannot locate in impacted areas; and 2) helping individuals in impacted areas to become more tolerant of noise. The former approach, receiver locational considerations, is a primary planning tool.

5-3.1 RECEIVER LOCATIONAL CONSIDERATIONS

5-3.1.1 ON-INSTALLATION

5-3.1.1.1 SOLVING EXISTING PROBLEMS

In the case of an existing problem, that is, where built up areas are adversely affected by noise, there are basically three locational approaches for use by the planner if noise abatement cannot be economically accomplished at the source or along the path:

(1) If noise levels are unacceptable for one type of use but not another, and the building in question can be modified accordingly, then relocate the impacted activity and alter the structure to accommodate the less sensitive use. For example, an administrative building might be used as a work shop or storage area.

(2) Physically relocate the structure to a site with acceptable noise environment.

(3) Abandon the structure and relocate the activity else-

5-3.1.1.2 AVOIDING FUTURE PROBLEMS

To avoid on-installation noise problems, noise planning criteria must be incorporated into the site selection process. This procedure is explained in Section 6-4.1, Site Selection. The major points are as follows :

(1) Gather background data.

(2) Identify acceptable sites (compare noise exposure with land use sensitivity).

(3) Consider abatement techniques (to increase the range of acceptable sites).

(4) Select a site.

FIGURE 5-3.1.1.1 SUMMARY OF RECEIVER CHANGES

ON-INSTALLATION	
PROCEDURE	**COSTS**
Change function of building	Building alterations Moving furniture, etc. Temporary shutdown
Move structure	Building moving Site preparation Moving furniture, etc. Temporary shutdown
Demolition	Demolition costs

5-3.1.2 OFF-INSTALLATION

The effect of installation operations on the off-installation environment must be considered in all planning programs. When such effects are unavoidable, attention shifts from noise receiver location changes to noise source and path modifications. The noise maker has potential legal liability and depending on the circumstances, may be sued for depreciating property values.

For the purpose of assessing potential impacts, planners should refer to the Air Installation Compatible Use Zone (AICUZ) program. There they will find a description of existing and proposed off-installation land uses and other pertinent data on local communities and installation air operations. In addition, planners should refer to local general plans, zoning ordinances and maps, specific plans, economic reports, and other documents which relate to the existing and proposed use of land around the installation. They should also enter their name on the environmental impact statement circulation list of local agencies. If an AICUZ report is not available, planners will have to rely on the latter. sources for information about the off-installation environment

5-3-2 CHANGE IN RECEIVER SENSITIVITY

The two approaches to modifying receiver sensitivity discussed below, noise masking and public relations, will reduce the amount of annoyance an individual experiences without actually reducing noise levels. This effect is achieved by altering one's perception of noise.

5-3.2.1 NOISE MASKING

Noise masking is the use of homogenous background noise to “soften” unwanted sounds. It is not a positive relief measure, but a cosmetic device that dulls perception of intruding noise. This technique is used in telephone booths where the "whirr" of the fan dampens obtrusive outside noise. In open plan offices, masking is critical and is provided by controlled levels of ventilation noise (or music). Masking is generally used only in public spaces and work environments. Its application inside residences is not recommended, although exterior environments can benefit from the sounds of cascading water and rustling leaves. Sound masking is only effective where noise intrusions are not extreme, within 5 to 10 dB of background noise levels, and where total noise levels (masking plus background levels) do not exceed concentration, sleep, and conversation interference levels.

It should be noted that various unwanted sounds serve to mask each other. In some office situations where structures have been soundproofed to such an extent that outside noise is imperceptible, indoor noise becomes dominant and unacceptable. Allowing slight encroachment of external noise for masking has been found to create good working environments. It is advisable to consult with acoustical experts when noise masking appears appropriate. (See also Section 4-6.).

5-3.2.2 PUBLIC RELATIONS

The more negative an individual's attitude toward a noise producer, the more intolerable the noise itself is likely to be. The reduction of ill feelings can decrease the incidence of complaints and will have positive spinoffs in other dealings with the on- and off-installation public. The responsibility for enhancing an installation's public image lies with all personnel who deal with the public, and in the case of noise problems, it lies primarily with the Public Information Officer, the installation planner, and those who respond to specific noise complaints.

Beyond the usual courtesies extended to persons making inquiries and registering complaints, installation personnel should be as informative as possible. Helpful information might include explanations of why operations have to occur when they do or why they must occur at a particular installation or why operating the noise source is necessary. Although such information <u>will not-lessen the adverse effects</u> experienced during a particular incident, it will hopefully reduce further alienation and resultant intolerance. Disseminating information about the execution of specific abatement techniques or any other positive measures is particularly important. In essence, people want to know if there is a prevailing reason why they must be subjected to noise and what is being done about the noise situation. Furthermore, they do not want to be ignored.

Personnel who operate noise producers deal with the public in a secondary fashion, but still have a responsibility for maintaining an installation's public image. Operators (gunnery officers, pilots, etc.) must avoid creating undue and unnecessary noise. One unusual, "bad", noise incident, such as an offtrack low overflight, does irreparable harm. It draws attention to an installation and heightens public awareness of noise. Events such as these will often induce complacent endurors to act.

<u>Implementation</u>

A positive public relations program should be instigated regardless of the manner in which noise abatement is approached. Towards the creation of such a program, the planner should endeavor to:

(1) Prepare selected individuals to deal with the public. Inform personnel who handle complaints and inquiries about noise and its abatement. This manual contains the background information they will need.

(2) Set up a standard procedure for receiving and responding to inquiries and complaints. This procedure should insure that letters are answered promptly and that complete information about incidents is collected. A checklist for telephone complaints will facilitate data collection.

(3) Have all noise related grievances and questions channeled to the specially prepared personnel.

(4) Insure that those who operate and work with noise producing devices are informed of their responsibilities and about special problems (including those revealed through complaints). This is a matter of course for critical problems but should also be done as a preventative measure.

(5) Provide, on an ongoing basis, information on operations and noise abatement efforts to interested citizen groups and public agencies.

CHAPTER 6 NOISE PLANNING STRATEGIES AND THEIR APPLICATION

The previous chapters in this manual contain background information on the noise problem:

Chapter 2 - the nature of noise

Chapter 3 - the assessment of noise

Chapter 4 - recommended acceptable noise levels

Chapter 5 - methods to reduce noise

This information is utilized in the execution of noise abatement programs. How such programs are developed and implemented is explained in this Chapter.

Figure 6, Noise Abatement System, illustrates how to implement noise abatement techniques and, correspondingly, illustrates the relation of the elements in this Chapter. The Chapter is divided into three sections according to the three subject areas depicted:

(6-1) Define Problem

(6-2) Analyze and Implement Solutions

(6-3) Monitor

These sections are followed by three example problems.

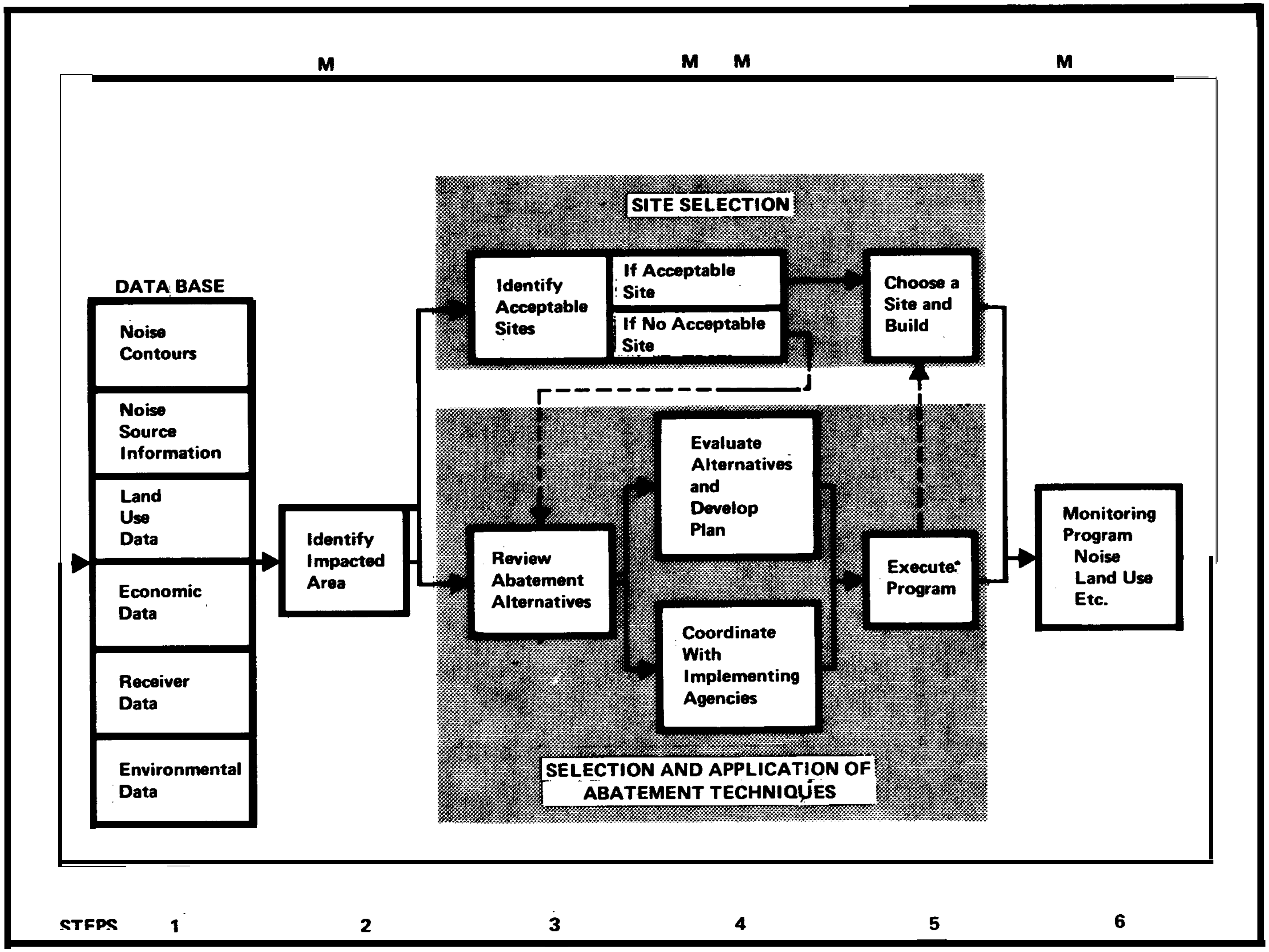
Define Problem

Referring to Figure 6, to define the problem one must have the information afforded by the Data Base (Section 6-1.1). With this basic data one can Identify the Impacted Areas (Section 6-1.2).

Analyze and Implement Solutions

When the noise problem has been identified, one can then analyze and implement solutions. When attempting to mitigate an existing or unavoidable noise problem, the planner should follow the Selection and Application of Abatement Techniques process (Section 6-2.2), but whensearching for an acceptable site for a new structure, the Site Selection process should be executed (Section 6-2.1). If during site selection an ideal site cannot be found, then an investigation should be made of those abatement techniques which will rectify the situation or expand the number of potential sites. (This relationship is indicated by the dashed lines leading to and from the Selection and Application of Abatement Techniques process.)

FIGURE 6 **NOISE ABATEMENT SYSTEM**



Monitor

After a site is chosen or an abatement program is executed, a Monitoring Program (Section 6-3) should be implemented. Changes in land use, the environment, the noise environment, and other data base elements should be recorded into the Data Base for subsequent verification that no new noise problems have resulted. In addition, when abatement techniques have been applied, field noise measurements should be taken to substantiate their adequacy. This checking mechanism is indicated by the return arrow at the bottom of Figure 6.

SUMMARY Of SECTION 6

6-1 DEFINE PROBLEM

Determining where a problem or potential problem exists requires the development of a data base.

6-1.1 DATA BASE

The first task performed in a planning program is the development of a data base. Problem solving is greatly facilitated if the problem is accurately and completely identified. Gathering data should not be a one time function. Processes should be set up which will supply information on an ongoing basis, so that changes may be detected when they occur.

6-1.1.1 NOISE ENVIRONMENT INFORMATION

The bases for defining a noise problem are noise contours and site noise analysis. The planner will develop and acquire this information using the procedures set forth in Chapter 3, Noise Assessment Techniques.

Noise levels will not remain constant over time; missions change, technology changes, vehicular (ground and air) traffic levels change, etc. When noise level changes are suspected, they may be verified by in-field noise measurements, and when necessary installation personnel can calculate adjustments in noise exposures. Where significant noise level changes are suspected, a new analysis (including computer contour runs) should be initiated. Significant changes might include cases where acceptable noise zones with builtup facilities become unacceptable, or where areas slated for future use are adversely Impacted.

6-1.1.2 NOISE SOURCE INFORMATION

In addition to noise levels, relevant information on factors which will affect noise levels should also be gathered. The list below includes several of the important variables which are applicable to most sources. The list of relevant variables should be expanded to include other specific points of importance.

- Number of operations
- Projected number of operations
- Duration of operations
- Changes in operational procedures
- Time of operations

- Constraints to operational changes
- Mission requirements
- Time schedules for technological changes
- Present abatement procedures
- Meteorological conditions which effect noise levels and limit operational flexibility
- Other projected noise source changes

6-1.1.3 LAND USE DATA

Land use and noise data are the most important elements in the data base. Land use can be directly correlated with activities; e.g., sleep, study, play, etc., and noise interference is a function of activities. Thus, land use is a substitute measure of noise sensitivity. It is also a convenient measure.

Land use information should be broken down into the classifications presented in Chapter 4 and it should be recorded structure by structure. The data should be mapped at the same scale as the noise contours to facilitate overlay comparison. The choice of scale is predicated upon the degree of accuracy required. At a minimum, building footprints and site boundaries should be clearly discernible.

Comprehensive, up to date information on land use often does not exist. It can be readily obtained, though, from the installation master plan and analysis of current aerial photographs (with field verification). Information on proposed land uses, including land use conversions, should also be gathered. Civil planning staff personnel can identify future off-installations land use changes.

6-1.1.4 ECONOMIC DATA

Economic data, including building values (replacement costs), land values, construction costs, refurbishing costs, economic lifespan, etc., are required for siting and abatement alternative analyses. The accuracy of cost/benefit studies is dependent upon the utilization of current and precise economic data. In addition, economic data is useful for estimating the likelihood of off-installation development and thus, aids in identifying priority areas for land development and potential land use incompatibility. Economic reports drawn up by local governments and large land owners can be useful.

6-1.1.5 RECEIVER DATA

Noise receivers are an invaluable data resource, capable of providing first hand information in the noise environment. In addition, demographic data is primary problem solving input.

<u>Collecting Receiver Data</u>

A noise abatement program by nature must be geared toward the noise receiver. To facilitate this the planner must rely upon census type information and information gathered directly from the noise receiver.

Information about the number of people in noise impacted areas is useful in establishing costs and benefits for noise abatement programs. Total population and population variables can be estimated from installation census or housing data, from the U.S. Census, or from land use data.

As stated in Section 5-3.2.2, Public Relations, planners should establish a standardized procedure for receiving and compiling noise complaints. This will open lines of communication and benefit the planner and complainant. The planner needs the first hand data that noise receivers can supply and those affected by noise need to air their complaints to responsive individuals. Specifically, complaint data can be useful in:

(1) Substantiating the greatest noise nuisances and the most objectionable hours of operation.

(2) Gauging the severity of a problem and the public and individual actions that are likely to be taken.

(3) Locating hyper-sensitive individuals and activities.

(4) Substantiating noise contours.

(5) Measuring the success of abatement programs.

<u>Sensitive Activities</u>

Some land use related activities are especially noise sensitive and therefore should be identified for special consideration. These would include outdoor areas for passive recreation, theatrical performances, etc. During moderate weather there are likely to be greater numbers of outdoor activities susceptible to noise interference.

Sensitive Groups

Each community will react differently to noise. While it is not fully understood why react ions vary, several variables have been identified which are useful in assessing special problems. Although all population groups are treated alike, for the purposes of analyzing complaint data, the planner should be aware of those characteristics related to noise sensitivity.

Older people are more sensitive to sleep disturbance and less able to return to sleep once sleep has been interrupted. They are also more likely to register complaints. Higher income groups are more sensitive to environmental quality and are also more likely to be annoyed by noise (Reference 5-28). Fear of a noise source, such as fear of aircraft crashes, will also lead to increased sensitivity.

6-1.1.6 ENVIRONMENTAL DATA

An awareness of environmental limitations is especially necessary in the site selection process. Factors such as soil conditions and unique animal habitats should be considered along with noise in site selection. The weight of each factor is an installation policy issue. Relevant environmental factors may include the following:

- slope
- soil characteristics
- geologic substructure characteristics
- ground water resources
- surface water resources
- water quality
- marine environment
- endangered species habitats
- unique plant and animal habitats
- historic landmarks
- air quality
- meteorologic conditions

Furthermore, when significant noise abatement programs are needed, they, like new construction, may require Environmental Impact Statements (EIS's) or Environmental Assessments (EA's). The preparation of these reports demand analysis of a wide variety of environmental factors.

Planners should give a sustained effort to collecting and familiarizing themselves with environmental data so that they can assess the impact on probable sites and the effects of abatement programs. Environmental factors must be considered as part of the analytic process, not after a site or abatement program has been selected.

A library of useful documents should be assembled, and should include relevant military and civil EIS's, EA's, environmental inventories, background reports, etc. Civil documents can be obtained from local federal agency officials (Soil Conservation Service, USGS, etc.) and non-federal governmental entities.

6-1.2 IDENTIFY IMPACTED AREAS

After being assembled, the data base information is used to identify existing or potential adverse impacts. As explained below, this process is greatly simplified where there is a single noise source described by contours. Where there is more than one noise source and overlapping noise exposures there is no simple graphical means to identify composite exposures.

in cases where there is a single noise source depicted by contours, adversely impacted areas can be identified by overlaying a map of contours with a map of land uses. Those land uses which are unfavorably impacted can be identified by visually scanning the composite map. Depending on the basis of the contours, either existing or potential conflicts may be identified in this manner (refer to Figure 6-1.2).

Identifying impacted areas is more complex where exposure is due to more than one type of noise source. The additive effects of noise must be taken into account by computing spot checks where excessive noise exposures are suspected. Exposure derived by manual procedures and contour interpolation can be combined through decibel addition to obtain single point exposures. Such points might include the following:

- where contours overlap;
- where noise sources, not described by contours, *are* located;
- where there is a nearby area of unacceptable noise exposure; and
- where there have been noise complaints.

This intuitive approach will become more precise as the planner gains experience in identifying potential and existing trouble spots and in calculating noise exposures.

As described in Section 3-9, Cumulative Noise Exposure for All Sources, there are two phases to site selection: preliminary screening and site screening. Initially, contours (and the aforementioned spot checks) are used to identify unacceptable areas, which can then be excluded from further analysis. Next, potential sites can be identified, and noise levels can be calculated at these specific points.

FIGURE 6-1.2 IDENTIFYING NOISE CONFLICT AREAS

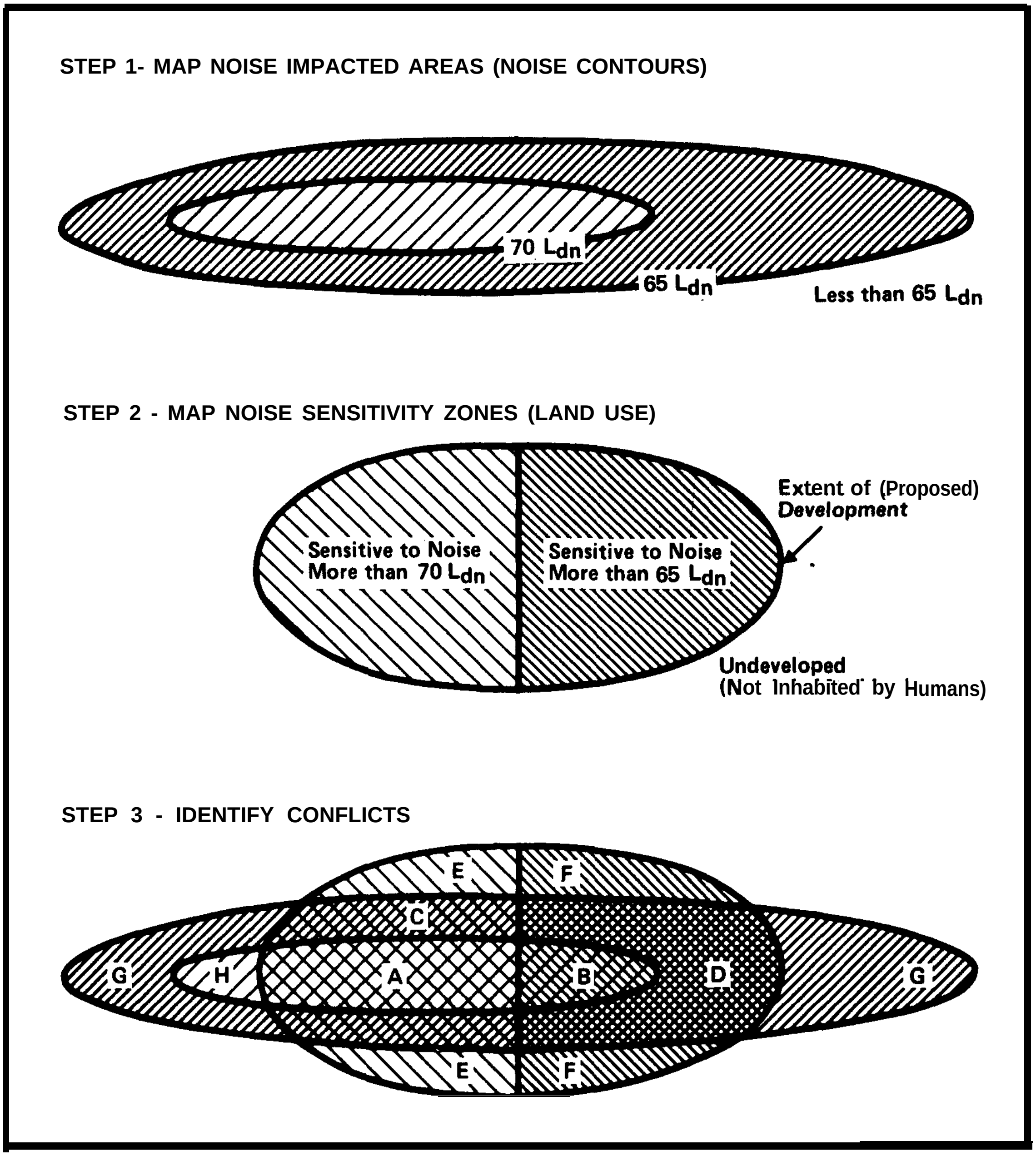


FIGURE 6-1.2 (CONTINUED)

DESIGNATION	PATTERN	NOISE EXPOSURE *	SENSITIVITY TO NOISE *	COMPATIBLE
A		$\geq$ 75 L_{dn}	> 70 L_{dn}	No
B		$\geq$ 70 L_{dn}	> 65 L_{dn}	No
C		65-69 L_{dn}	> 70 L_{dn}	Yes
D		65-69 L_{dn}	> 65 L_{dn}	No
E		< 65 L_{dn}	> 70 L_{dn}	Yes
F		< 65 L_{dn}	> 65 L_{dn}	Yes
G		6 5 -	6 9 L_{dn}	- -
H		$\geq$ 70 L_{dn}	—	—

* >, Means GREATER THAN

< Means LESS THAN

> Means GREATER THAN OR EQUAL TO

6-2 ANALYZE AND IMPLEMENT SOLUTIONS

With respect to controlling the noise environment, the planner will typically be involved in one of three sets of circumstances. First, for future facility site selection the planner will seek to avoid noise problems. Next, in cases where there are no sites free of unacceptably high noise levels, it will be necessary to incorporate abatement techniques into the initial design process to preclude noise problems. Finally, where there is an existing noise problem, techniques should be selected and applied to ameliorate that problem.

6-2.1 SITE SELECTION

Site selection is a fundamental and effective means to avoid adverse noise impacts. The process consists of four main steps.

(1) Gather Background Data

Problem solving first requires definition of the problem and associated factors (refer to Section 6-1, Define Problem). It is important to understand the existing state of affairs, and in the case of siting, an added emphasis must be placed on anticipating future conditions. This pertains to each Data Base factor (Section 6-1.1) especially the following:

- o Noise - the expected noise levels (including noise levels to be generated by the proposed facility, e.g., increased traffic) over the life span of the proposed facility
- o Land use - future requirements which may have ramifications on current land use decisions
- o Noise source - technological, mission and other possible changes which may effect the future noise environment.

Physical facilities are costly, permanent investments and those things which may lessen their usefulness must be anticipated.

(2) Identify and Describe Acceptable Sites

Land use relationships and project requirements must be the main consideration in the choice of building sites. However, site selection also involves many other factors:

- Noise
- Topography
- Access
- Availability of utility services
- Various hazards:
  - Geologic
  - Seismic
  - Erosion
  - Flood
  - Soil shrink/swell
  - Ordance safety zones
  - Aircraft accident potential zones
  - Airfield safety clearance criteria
- Soil bearing capacity
- Soil limitations for septic tank filter field
- Unique vegetation or wildlife habitat
- Mineral resources
- Aquatic resources (river, lake, watershed, etc.)
- Historic or archaeologic site

Projects which are “infill” between existing developments will usually not require extensive evaluation beyond a noise assessment. However, master planning efforts involving future land use configurations and site identification in undeveloped areas of an installation will require a more in-depth analysis of a greater number of factors.

Maps are convenient for storing and manipulating data. The following graphic processes can be used to screen and/or select sites:

(a) Map all pertinent data (see above) on separate sheets of clear acetate.

(b) Use experience and intuition to establish potential sites and identify each of those sites on a base map.

(c) Overlay each data map on the base map and annotate problems and drawbacks; e.g., adverse noise environment, geologic hazards, etc.

For ease of analysis, each data map should be shaded according to the severity of impact or limitation. For example, the areas with slight soil bearing capacity limitations should be depicted with light shades of color, areas with more severe limitations should be darker, and areas completely unacceptable under any circumstances nearly opaque. Other site select ion criteria, such as proximity to domestic water supply and seismic hazard, can also be mapped in this manner. The number of gradations delineated on the maps will be a function of the available base data and the requirements of the planner.

The map comparison approach can be used for initial siting in lieu of step "b" above, After the shaded data maps have been prepared, the maps depicting criteria relevant to the proposed land use should be simultaneously overlayed on an unmarked base map. All acceptable sites will be revealed as clear spots, and the darker the composite shading the less desirable the location will be. (For further information and examples see Reference 5-13.)

(3) Consider Abatement Techniques

It may not be possible to obtain a site that will satisfy all criteria. Therefore, it may be necessary to consider modifications which will render a site acceptable. Utilization of the procedure outlined in Section 6-2.2, Selection and Application of Abatement Techniques, should reveal viable noise ameliorating solutions. These can be compared with non-noise design and site modifications to determine the best method of creating a suitable site.

(4) Choose a Site

As a result of the previous steps the planner should have a list of one or more sites and the noise abatement measures and site modifications that will make them acceptable for use. The costs and benefits of each site should be assessed in the manner outlined under Evaluate Alternatives, in the following section. The planner and others involved in site selection can thus arrive at a recommendation to be acted upon by the approving authority.

6-2.2 SELECTION AND APPLICATION OF ABATEMENT TECHNIQUES

When it is determined that noise abatement is needed and the existing or potential noise problem has been identified and assessed, the analysis and implementation phase of noise abatement can be initiated.

This procedure contains five steps: (1) review/analyze abatement alternatives, (2) evaluate alternatives, (3) develop plan, (4) identify and coordinate with implementing agencies, and (5) execute plan.

(1) Review/Analyze Abatement Alternatives

First the planner should review the abatement alternatives presented in Section 5. Experts should be consulted as needed to obtain further details. Through this process a set of potentially feasible techniques should be chosen for additional study. A wide range of possible approaches should be considered because: 1) noise problems normally require more than a single means of abatement; and 2) during the selection process many approaches will be dropped from consideration, and those which appear infeasible at the outset may become practicable.

(2) Evaluate Alternatives

Procedurally the evaluation of noise abatement alternatives is the same as any project evaluation process. In this case, the planner develops a list of alternatives. This list is modified by experts and technicians in the field of concern. The recommendations are submitted to the approving authority for review, modification, and approval.

The basis of evaluating alternative plans is the comparison of the magnitude and distribution of costs and benefits resulting from implementation of the plans. Noise abatement strategies do not lend themselves to analysis by formal cost/benefit analysis because key variables, such as benefits of reducing noise, are not easily quantified. Values or costs can be assigned, but only for comparative purposes.

Costs to be considered should include the following:

(a) Costs of implementation (e.g., capital improvements, staff time, consultant fees, operational changes, etc.).

(b) Long-run costs (fuel consumption, maintenance, etc.).

(c) Costs of affecting the natural environment (e.g., degradation of air quality, alteration of wildlife habitat, etc.).

(d) Costs of foregoing the use of installation land (where abatement in one place shifts noise impact to another place).

(e) Costs of restricting off-installation land use (e.g., foregone taxes, probable dampening effect on development, etc.).

(f) Costs of permitting noise impact (e.g., litigation, physiological and psychological costs, reduction in usable land, poor public image, depressed land values, reduced economic activity, etc.).

The benefit of abating noise is basically the reduction of the costs of permitting it to exist.

To facilitate comparative analysis, values can be given to non-quantified costs and benefits. Assigned values or costs will vary depending on who assigns them. Therefore, care must be taken not to incorrectly weight a variable as this will distort results. Value decisions made by an interdisciplinary group are likely to be the least biased.

The particular costs and benefits to be measured and the value they are given will differ from situation to situation, There will be a substantial difference between the on- and off-installation situations. A solely military problem will involve the welfare of impacted individuals and cost and benefits to the federal government. An analysis of off-installation impacts must, in addition, take into account the viewpoints of: the resident, who is concerned about his welfare and monetary costs he may have to bear; the businessman, who wants to promote a healthy economy; and the local government, which is advocating the interests of residents and businessmen on the environmental, social, political, and economic fronts.

(3) Develop Plan

The next step in the noise abatement procedure Is the development of an abatement plan. Such a plan will be instrumental in avoiding the pitfalls of a piecemeal approach to noise reduction, A cohesive and well defined plan will serve as the backbone of an abatement program and will assure program consistency despite personnel changes,

After the relative costs and benefits of the abatement techniques have been compared and the optimum techniques chosen, then a set of implementation priorities should be set. In instances where abatement programs conflict, it is best to develop priorities during the initial evaluation procedure.

The basis of the priorities should be agreed upon at the outset. Some of the considerations that should be resolved are as follows:

(a) Should undeveloped areas have priority over areas where development is established?

(b) Should federal resources be the primary basis for decision making?

(c) Should the most "severely" impacted areas be given top priority regardless of the costs of abatement?

An abatement program will be based on established priorities. Through coordination with other involved individuals and agencies (enumerated later) priorities can be developed into a realistic implementation program. The availability of funding must be balanced against abatement needs and operative constraints to arrive at a timetable of affirmative action. The abatement plan should describe:

(a) What is to be done.

(b) Where it is to be done.

(c) When it is to be done.

(d) How it is to be done (resource allocation).

(e) Who i's to do it.

Major plans should enumerate the specific measure to be accomplished over a five year period. In the mid range (5 to 10 years) and long range (10 years and on), the plan should state in decreasing specificity the general types of things that should be achieved. For example, if there is a long-range projection that aircraft operations will increase by a prescribed amount, then a long-term abatement measure should be sketched out, such as insulating, converting, or removing "x" number of structures in certain areas. As time passes and the long range becomes the short range, plans should be made more explicit; i.e., they should cover the five points listed above. The abatement plan should be updated annually, and progress on implementation should be checked quarterly.

Whether an abatement plan is relatively simple (e.g., the utilization of acoustic construction) or complex (e.g., affording protection to a single area by utilizing aircraft operations modifications within the context of changing aircraft types and missions) planners should develop a specific strategy of execution before setting out. They should assemble their data base, identify individuals who will take part in the program, and set up a procedure by which a plan can be developed.

(4) Identify and Coordinate with Implementing Entities

Concurrent with the evaluation of alternatives and plan development, the planner should identify those agencies, military and civilian, that will be involved in, or affected by, the implementation of proposed noise abatement plans. While coordination with some agencies will not be required, a broad base of contacts will generally aid in data gathering and information dissemination and help elicit support. For the same reasons it is important to coordinate with other entities as early in the process as possible.

This is critical when dealing with the off-installation environment. Early coordination with local agencies should prevent unnecessary problems. When there is a potential off-installation impact, it can be anticipated that an environmental impact statement will be needed and that the regional A-95 clearinghouse will become involved. Planners should familiarize themselves with local regulations and OMB Circular A-95.

Funding is likely to be the controlling factor in an abatement program and, therefore, the availability of funding should be investigated as soon as feasible. If personnel responsible for requesting (and persons responsible for granting) funds are fully informed of the nature, extent, and severity of the problem, the chances for receiving adequate funding will be enhanced.

(5) <u>Execute Plan</u>

Once the what, where, when, how and who of an abatement program has been defined, subsequent approval will initiate the actual program. At this juncture the planner may assume a variety of roles ranging from passive, where direct implementation is to be executed by others, to active, where on-going coordination and supervision is required.

6-3 MONITOR

The final step in the noise abatement procedure is monitoring, which consists of two parts: 1) monitoring noise levels; and 2) monitoring Data Base information.

Monitoring and plan review should not be done at random. Formalized procedures should be established and assigned to staff members. The amount of time that must be devoted to these functions will be a function of the severity of an installation's noise problem. Monitoring of blast noise and other extremely random and unusual sources require special planning, equipment and techniques,

Siting and abatement plans are based on today's information of tomorrow's situation. The noise environment is not static, Technology changes, as do missions and operational procedures. Thus, the planner is required to accommodate the unknown. Maintaining open lines of communication with personnel directly responsible for noise sources and other key decision makers is imperative.

Even with the best information, though, one cannot anticipate all the short range decisions which may alter the environment. It is, therefore, advisable to take a conservative approach to noise planning, Protective safety factors should be built in every abatement strategy. In practice this may require, for example, "over designing" barriers or providing more than adequate buffer space between noise sources and built up areas.

6-3.1 MONITORING NOISE LEVELS

After a site has been selected for a proposed facility, if it is geographically near an area of unacceptable noise exposure, then an in-field spot check using a noise level meter should be made. Similarly, after implementation, an abatement program or measure should be field checked to insure that the desired results have been achieved. The precautions to be taken in analyzing short term noise measurements are enumerated in Chapter 2.

Long term continuous monitoring may be appropriate in specialized cases; to gather data for cases involving litigation or to resolve noise exposure questions at sites having controversial land uses. Because of operational and reasonal weather changes , even 90 days of continuous monitoring may be insufficient. In extreme conditions, a one year time period may be required.

All monitoring requirements should be referred to the installation bio-environmental engineer or health and environment officer.

NOTE: Monitoring systems for blast noise, rifle fire, rotary-wing aircraft, and other noise sources with a high crest factor require instrumentation that computes the "true" integral as specified in the definition of L_{dn} and L_{Cdn}. Normal sound level meter detectors are unacceptable for this purpose.

Noise Monitoring Systems

There are numerous noise monitoring systems on the market. They range in complexity (and price) from the simple sound level meter to sophisticated systems with microphones (receivers) linked to computers which automatically analyze, compute, and record the daily noise exposure and analyze number and types of noise events. The monitoring systems within this range can be described as either portable or fixed point (for continuous monitoring). For the most commonly required types of measurements, namely short term or spot check, portable systems (as described below) are appropriate.

Direct observat ion of standard sound level meter readings is satisfactory for the simplest noise monitoring tasks. Such cases may arise when the noise is relatively constant and where one is concerned about noise levels at a certain time of day or where noise levels can be predicted from measurements taken over a limited period. There are observation techniques for making systematic meter readings at periodic intervals. From the data the statistical precision of the measurements can be calculated. This approach could be used to monitor traffic noise during peak periods of the day.

More complex portable monitoring systems consist of a noise metering device with recording capability, The recording output can be graphic; showing the variation in noise levels with time. From graphical records the noise environment level can be calculated manually. This can be a cumbersome process, particularly where large variations in noise levels are observed. The typical cost of such a system is on the order of $1,000 to $2,000.

When significant variations in noise levels occur in short time periods, such as aircraft flyover noise, systems which provide automatic analysis of noise data and storage capabilities are desirable. A number of cities have opted for these types of systems. The major components may be as follows:

- A sound level meter.
- A “receiver” which records the sound level meter data on magnetic tape (usually in digital form).
- A standard programmable calculator which analyzes the magnetic tape data to calculate L_{dn} or desired statistics of the noise measures.

A system of this nature costs about $10,000. If an installation possesses a programmable calculator, it can be used directly, thus reducing the above cost by about one half. When it is necessary to monitor several sites simultaneously, the use of tape recorders can avoid duplication of expensive equipment. Tape recordings can be played back into a sound level meter - programmable calculator system for analysis. An alternate type of instrumentation involves:

- A sound level meter.

- A small self-contained digital micro-programing unit to calculate the desired L_{eq} or L_{dn}.

- A printout device which prints the desired value at hourly or daily intervals.

This approach eliminates the need for a separate programmable calculator. Typical costs per unit run from $8,000 to $10,000.

6-3.2 MONITORING DATA BASE INFORMATION

Describing a noise problem involves more than defining the noise environment. An understanding of the factors outlined in Section 6-1.1, Data Base, is critical to the noise abatement process. In addition, this information must be continually updated.

Monitoring Data Base information helps to define the existing environment, and aids in defining the future environment and potential problems.

Noise Source Information

Modification of a noise source or its operation can affect noise levels. With thorough information about projected changes the planner can anticipate and avoid possible problems. information on the modification or operation of noise sources will usually be obtained from activity commanders. Planners should sensitize commanders to their needs and obtain formal authorization to secure appropriate data.

Land Use Data

Vacant land can be developed with intense uses on short notice. Therefore, the planner must keep informed of proposed changes. For off-installation land, this will require the following:

(1) Reviewing environmental impact statements for local development.

(2) Staying abreast of important zoning changes, general plan changes, public facility improvements (road and utility extensions).

(3) Reviewing local jurisdiction policies and plans.

(4) Updating land use information with the use of aerial photographs and in-field observation.

Economic Data

Economic data will most likely be derived from special studies performed by lending institutions, the military, cities, counties, and large land owners. The planner will have to take the initiative to secure these reports. City planners, installation architects, civil engineers, and public works officers should be aware of the presence and availability of such reports.

Receiver Data

Information on noise receivers can be kept current by utilizing the standardized procedure for receiving and compiling noise complaints specified in Section 6-1.1.5, Receiver Data, and reviewing census data as necessary.

Environmental Data

As with economic data, planners will have to rely mainly on studies performed by others to acquire information. Because of the range of environmental factors, planners should compile a list of those that are appropriate to their needs and then list all the possible sources for that information. For example, 1) the state of ground water resources could be found in reports prepared by the U.S. Army Corps of Engineers, the U.S. Geologic Survey, or installation engineers and 2) unique animal habitats might be located with the aid of special installation studies such as those prepared by the Waterways Experiment Station (U.S. Army Corps of Engineers) as well as those performed by scientists and students from local colleges. The updating process requires acquainting information disseminating agencies of planning needs so that relevant materials might be forwarded as they become available.

PROBLEM:

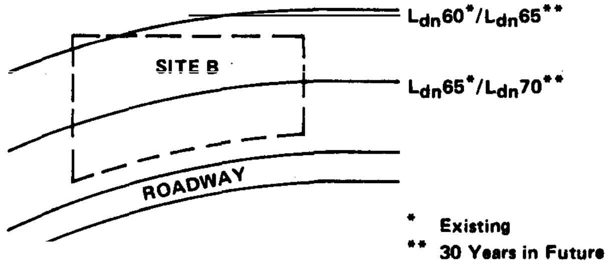
Locate a suitable on-installation site for x units of family housing. It has been determined that the housing must occupy a single site of y acres and be within a prescribed distance of selected support facilities.

SOLUTION:

1. Gather background data (Section 6-2.1, No. 1). Data Base information, Section 6-1.1, has been assembled and mapped and is current.

2. Identify and describe acceptable sites (Section 6-2.1, No. 2)

   a. Based on experience and personal knowledge of the installation, the planner identifies sites A and B which meet selection criteria.
   b. Sites A and B are delineated on a base map.
   c. Clear sheets of plastic denoting Data Base information are overlayed separately on the base map to indicate site assets and limitations.
      1) Site A is found to be in a flood plain and is subject to two feet of flooding once every ten years and five feet of flooding once every 60 years. Site A also has soil bearing capacity limitations.
      2) Site B is located near a major installation roadway and according to the noise impact map (Section 6-1.2) one half of the site has an existing adverse noise exposure (with respect to the family housing noise criteria, Figure 5-4). An estimate is made of the future noise environment over the period of the life of the project: 30 years. Future traffic levels, including those resulting from the project, indicate that in the future the entire site will be adversely impacted.



3. Consider abatement techniques (Section 6-2.1, No. 3). Both sites will require modifications before either will be suitable for family housing. The possible costs and benefits of these modifications should be enumerated for subsequent quantification and cost-benefit analyses. The most practicable modifications/abatement techniques are presented below. (See Matrix, next page. The lists of modifications, costs, and benefits are examples and are not meant to be exhaustive.)

4. Evaluate alternatives (Section 6-2.2, No. 2)
   At this juncture the possible alternatives are investigated in further depth. Although not done below, costs and benefits en quantified and assigned specific monetary values, if possible.

   a. Alternative 1: Engineers have calculated that the weight of the fill material might cause ground failure because of the soil bearing capacity limitations to high loads: therefore, this alternative is rejected.
   b. Alternative 2: Preliminary cost estimates indicate that a levee will cost more then guidelines for this project permit, and this altarnative is tentatively rejected (pending demonstration of a better alternative).
   (The evaluation of Alternatives 3, 4, and 5--the Site B alternatives--cannot be performad without a conceptual site plan layout, because the acoustic environment is dependent upon the physical layout of buildings and land uses. Therefore, a site plan is developed which incorporates as many techniques as possible to mitigate noise; e.g., the active recreation area Is located adjacent to the roadway, the first tier of homes is buffered by carports, the first tier of homes is oriented to lessen noise impact on patio areas, etc. The following alternatives are evaluated in light of the acoustic improvements afforded by the conceptual site plan.)
   c. Alternative 3: It has been determined that 60% of the traffic traveling by Site B is going to and from Locations P and Q. An alternative, but longer, route between these points can be utilized but will require the construction of one light signal before it can be used. The costs and benefits of this alternative (as listed in Step 3) are quantified and compared in ı cost/benefit analysis.
   d. Alternative 4: Preliminary acoustical analysis indicates that a 6 foot wall would be required to abate the current noise levels, and a 9 foot wall would be required to abate the levels that are likely to exist in 30 years (the life of the project). Because of space and cost considerations, a 5 foot wall supported by a 4 foot earth berm is selected for preliminary analysis purposes. The costs and benefits of this alternative (as listed in Step 3) are quantified and compared in a cost/benefit analysis.
   e. Alternative 5: Referring to the previous sketch and Figure 4-6, it can be seen that protection from future (30 years hence) noise levels will require that approximately one-half of the homes have an NLR of 25 and one-half an NLR of 30. The costs and benefits of this alternative (as listed in Step 3) are quantified and compared in a cost/benefit analysis.

5. Choose a site (Section 6-2.1, No. 4). The planner rank orders the alternatives according to the results of the cost/benefit analyses and other factors deemed important for ultimate site selection. Site B Alternative 5 is chosen.

6. Develop abatement implementation plan (Section 6-2.2, No. 3). A short range (direct implementation) plan is developed to facilitate the execution of acoustical construction.
   a. What is to be done:
      1) An NLR 25 is to be achieved in certain designated structures.
      2) An NLR 30 is to be achieved in certain designated structures.
   b. Where it is to be done: Site B
   c. When it is to be done:
      1) Design drawings are to be completed by (date).
      2) Construction is to be completed by (date).
      3) Post construction monitoring is to occur by (date).
   d. How it is to be done: An additional allocation of x dollars is to be acquired for acoustical treatment.
   e. Who is to do it:
      1) An architect/engineer (A/E) with soundproofing expertise will be hired to develop construction drawings.
      2) Construction inspection is to be performed by individuals familiar with acoustical construction.
      3) Post construction monitoring will be performed by installation personnel.

7. Identify and coordinate with implementing entities (Section 6-2.2, No. 4) and execute plan (Section 6-2.2, No. 5).

   a. Planner assures that requests for A/E proposals outline acoustical requirements.
   b. Planner assures that NLR performance criteria are included in contract with A/E.
   c. Planner assures that NLR performance criteria are included in contract with construction contractor.
   d. Planner assures that post construction acoustic performance is performed and criteria are met.

ALTERNATIVE NO.	SITE	MODIFICATION	POTENTIAL ADVANTAGES	POTENTIAL DISADVANTAGES/COSTS
1	A	Raise the grade of the site 5 ft.	a. Reduce severity of flooding	a. Cost of fill material and placement b. Not foolproof (flooding could be greater than 5 ft.) c. Potential property loss in flood d. Potentially unsightly
2	A	Construct levee along stream	a. Reduce severity of flooding on site and in adjacent areas	a. Cost of levee (design and construction) b. Not foolproof c. Potential property loss in flood d. Unsightly e. Maintenance of levee
3	B	Reroute a portion of the traffic to another road	a. Reduce noise at site b. Reduce dust, air pollution and other localized effects of the roadway	a. Cost of additional signalization b. Future traffic noise will rise to an unacceptable level in 15 years c. More traffic noise adjacent to new route d. Roadway users costs related to longer new route (delay time, fuel consumption, etc.)
4	B	Construct noise barrier	a. (as 3a above) b. (as 3b above)	a. Cost of barrier b. Maintenance of barrier c. Unsightly
5	B	Acoustic construction	a. (as 3a above) b. Reduce heating and cooling costs	a. Cost of acoustic construction b. No acoustic advantages to exterior environment

PROBLEM:

Aircraft operations have been altered significantly because of a mission change. Identify the acoustic problems that may have resulted from this change and develop means to solve them, if needed.

SOLUTION:

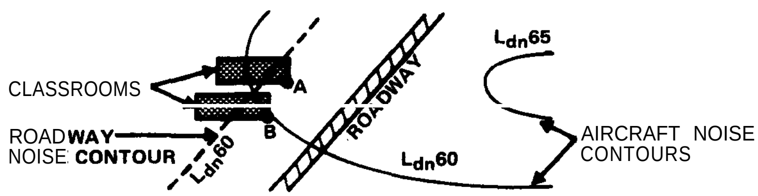
1. The Data Base information (Section 6-1.1) has been assembled and mapped and, before analysis, it is verified that all information is current. The noise environment information (Section 6-1.1.1) portion of the Data Base is updated through the generation of new contours. (Future noise levels are not available.)

2. Identify impacted areas (Section 6-1.2).

   a. The new aviation noise contour map is overlayed on the land use map (as demonstrated in Figure 6-1.2) to identify areas of noise conflict, and none are found.

   b. The noise contour map for major roadways is then overlayed on the land use and aviation contour maps to see if there are areas where the composite noise levels might be at an unacceptable level. A potential problem is detected where two classroom structures are impacted by roadway and aviation noise.

   c. Determine the composite noise levels.



      (1) Select the most severely impacted points or areas near the classrooms. There are no exterior land uses so a window on each structure is chosen (A and B).

      (2) L_{dn} at A = Roadway L_{dn} + Aircraft L_{dn}
      = 61 dB (calculated using Figure 3-6.2.1a)
      + 61 dB (interpolated from contours)
      L_{dn} 64 dB (decibel addition, Figure 2-1.2a)

      (3) L_{dn} at B = 61 dB+60dB
      = 64dB

   d. Based upon the noise criteria (Figure 4-5), neither structure is adversely impacted.

   e. No immediate action required, but potential problem area noted for periodic re-examination.

PROBLEM:

It is learned that artillery operations at one firing range may be shifted to another range.. Identify potential noise environment problems.

SOLUTION:

1. The Data Base information (Section 6-1.1) has been assembled and mapped and, before analysis, it is verified that all information is current. The probable noise environment change resulting from the proposed change in operations is quantified by the generation of future case contours.
2. Identify potentially impacted areas (Section 6-1.2). The new noise contour map is overlayed on the land use map (as demonstrated in Figure 6-1.2) and it is discovered that 20 acres of housing and administrative structures will be adversely impacted.
3. Select possible abatement techniques (Section 6-2.2).
   a. Review/analyze abatement alternatives (Section 6-2.2, No. 1) in the manner illustrated in Step 3 of Example 6a.
   b. Evaluate alternatives (Section 6-2.2, No. 2) in the manner illustrated in Step 4 of Example 6b.
   C. Present a statement of the potential problem, the means by which it can be solved, and the monetary and non-monetary cost and benefits of each possible solution to the approving authority, so that the decision to modify operations can be weighted in light of the acoustic ramifications.

BY ORDER OF THE SECRETARIES OF THE AIR FORCE, THE ARMY, AND THE NAVY

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SUMMARY OF CHANGES

This revision replaces AFM 86-5; TM 5-365; NAVDOCKS P-98 in its entirety, updating the aircraft noise assessment and prediction methodology. Added features include the provision of comprehensive guidance for installation planning with respect to noise produced by all major noise sources, including aircraft noise (fixed-wing and rotary-wing flight and ground operations), impulse noise (blast and sonic boom), motor vehicle noise (street and combat vehicles), railroad noise, and significant stationary noise sources. Guidelines for site selection and recommended noise level reduction for various facility types are given. Methods for reducing noise impact from all major sources are discussed and guidance for defining and analyzing a noise problem, determining and implementing an appropriate solution, and monitoring the selected solution's effectiveness are provided.

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References

REFERENCES: CHAPTER 1

1-1 U.S. Department of the Air Force, Hazardous Noise Exposure, USAF Regulation No. 161-35.'

1-2 U.S. Department of the Army, Environmental Protection and Enhancement, USA Regulation 200-l.

1-3 U.S. Department of the Army, Health and Environment, USA Regulation 40-5.

1-4 U.S. Department of the Navy, Navy Environmental Protection Manual, OPNAVINST 6240.3D.

1-5 U.S. Department of the Navy, Hearing Conservation, BUMEDINST 6260.68.

REFERENCES: CHAPTER 2

2-1 Meister, F.J., "The Influence of Effective Duration in Acoustic Excitement of the Ear", 'Larmbekampfung 10 (3/4), June/August 1966.

2-2 Parsons, K.S. and R.L. Bennett, "Effects of Temporal and Spectral Combinations in the Judged Noisiness of Aircraft Sounds", Journal of the Acoustical Society of America, Vol. 49, No. 4, April 1971.

2-3 U.S. Department of Transportation, Transportation Noise and its Control, June 1972.

2-4 von Gierke, H.E., Methodology for Assessing Large impulsive Noise, Letter with attachments to D. Kurtz, Naval facilities Engineering Command, 18 December 1975.

3-1 Schomer, Paul D., Predicting Community Response to Blast Noise, CERL Technical Report E-17, December 1973.

3-2 Stuckey, T.J. and J.O. Goddard, "Investigation and Prediction of Helicopter Rotor Noise, Part 1, Wessex Whirl Tower Results", Journal of Sound Vibration, vol. 5, No. 1, p. 50-80, 1967.

3-3 U.S. Department of the Air Force, Community Noise Exposure Resulting from Aircraft Operations: Acoustic Data on Military Aircraft, AMRL-TR-73-110 (to be published).

3-4 U.S. Department of the Air Force, Community Noise Exposure Resulting from Aircraft Operations: Computer Program Description, AMRL-TR-73-109, November 1974.

3-5 U.S. Department of the Air Force, Community Noise Exposure Resulting from Aircraft Operations: Technical Review, AMRL-TR-73-106, November 1974.

3-6 U.S. Department of the Air Force, USAF Bioenvironmental Noise Data Handbook, AMRL-TR-75-50 (multiple volume).

3-7 U.S. Department of the Army, (U.S. Army report to be published).

3-8 U.S. Department of Transportation, "Airport/Aircraft System Noise", Volume 111 of, A Study of the Magnitude of Transportation Noise Generation and Potential Abatement, USDOT Report No. OST-ONA-71-1, November 1970.

3-9 U.S. Environmental Protection Agency, Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety, USEPA Report No. 550/9-74-004, March 1974.

REFERENCES: CHAPTER 4

4-1 Beranek, L.L., Noise Reduction, McGraw-Hill Book Co., Inc. New York, 1960.

4-2 Bishop, D.E. (BBN), A Building Code for Exterior Noise Insulation with Respect to Aircraft Noise, BBN Report 2944, U.S. Air Force, June 1975.

4-3 Connor, W.K. and H.P. Paterson, Community Reaction to Aircraft Noise Around Smaller City Airports, NASA CR-2104, August 1972.

4-4 Eldred, K.M., Community Noise, U.S. Environmental Protection Agency NTID 300.3, December 1971.

4-5 Galloway, W.J. (BBN), Community Noise Exposure Resulting from Aircraft Operations: Technical Review, USAF, AMRL TR-73-106, November 1974.

4-6 H.M.S.O., Noise-Final Report, Cmnd. 2056, London, July 1963.

4-7 H.M.S.O., Second Survey of Aircraft Noise Annoyance around London (Heathrow) Airport, 1971.

4-8 Tracer Inc., Community Reaction to Airport Noise - Vol 1, NASA CR-1761, July 1971.

4-9 U.S. Department of Housing and Urban Development, HUD Circular 1390.2, Noise Abatement and Control: Department Policy, Implementation Responsibilities and Standards, 1971.

4-10 U.S. Environmental Protection Agency, Information on Levels of Environment Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety, EPA Report 550/9-74-004, March 1974.

4-11 U.S. Federal Aviation Administration, Analysis of Community and Airport Relationships/Noise Abatement: Development of Aircraft Noise Compatibility Criteria for Varied Land Uses, FAA Report SRDS RD-64-148,11, December 1964.

4-12 von Gierke, H.E., Chairman, "Draft Report on Impact Characteristics of Noise Including Implications of Identifying and Achieving Levels of Cumulative Noise Exposure", EPA Aircraft/Airport Noise Report Study, Task Group 3, July 1973.

4-13 von Gierke, H.E., Methodology for Assessing Large Impulsive Noises, Letter with attachments to D. Kurtz, Naval Facilities Engineering Command, 18 December 1975.

4-14 Webster, J.C., "Effects of Noise on Speech Intelligibility", Noise as a Public Health Hazard, American Speech and Hearing Association, No. 4, February 1969.

5-1 Beaton, J.L. and L. Zourgot (Caltrans), "Traffic Noise Near Highways: Testing and Evaluation", Highway Research Record, No. 448, 1973.

5-2 Beland, R.D., P.P. Mann, et (Wilsey & Ham), Aircraft Noise Impact, Planning Guidelines for Local Agencies, HUD, November 1972.

5-3 Bishop, D.E. (BBN), A Building Code for Exterior Noise Insulation with Respect to Aircraft Noise, BBN Report 2944, U.S. Air Force, June 1975.

5-4 Bolt Beranek and Newman, Inc., A Study -- insulating Houses from Aircraft Noise, HUD, November 1966.

5-5 Galloway, W.J. (BBN), Community Noise Exposure Resulting from Aircraft Operations: Technical Review, USAF, AMRL TR-73-106, November 1974.

5-6 Getter, Gustav, and Associates, Noise Suppressors, NAVFAC Contract N62467-73-C-0503.

5-7 Gordon, C.G., W.J. Galloway, B.A. Kugler, and D.L. Nelson (BBN), "Highway Noise: A Design Guide for Engineers", National Highway Cooperative Highway Research Program Report No. 117, 1971

5-8 Gregoire, H.C. and M.M. Strickenback (Boeing Co.), Effect of Aircraft Operation on Community Noise, June 1971.

5-9 Hurlburt, R.L., Chairman, "Report on Operations Analysis including Monitoring, Enforcement, Safety and Costs" ,EPA Airport Noise Study Report, 27 July 1973.

5-10 Kugler, B.A. and A.G. Piersol (BBN), "Field Evaluation of Traffic Noise Reduction Measures", Highway Research Record No. 448, 1973.

5-11 LeVere, Bartus, and Hart, "Electroenchaslargraphic and Behaviorial Effects of Nocturnally Occurring Jet Aircraft Sounds", Aerospace Medicine, April 1972, p. 381-389.

5-12 Ljunggren, Sten, A Design Guide for Road Traffic Noise, National Swedish Building Research, NTIS, 1973.

5-13 McHarg, Ian, Design with Nature.

5-14 Memphis State University, Effects of Noise on Wildlife and Other Animals, NTIS PB-206720, 31 December 1971.

5-15 Nelson, K.L. and T.D. Wolsko (National Argonne Laboratory), Transportation Noise, Impacts and Analysis Techniques, NTIS, October 1973.

5-16 Nethery, Sidney J., Chairman, "Military Aircraft and Airport Noise and Opportunities for Reduction without Inhibition of Military Missions", EPA Aircraft/Airport Noise Study Report, 27 July 1973.

5-17 "Noise Abatement Control", Highway Research Record No. 448, 1973, various reports.

5-18 San Diego, City of, Building Code for Exterior Noise Isolation, 28 February 1973.

5-19 Sawley, R.J. and C.G. Gordon (BBN), A Comprehensive Survey of the Noise in Communities Around Boeing Field, Seattle, BBN Report 1709, 1969.

5-20 Schomer, Paul D., Predicting Community Response to Blast Noise, Construction Engineering Research Laboratory, Technical Report E-17, December 1973.

5-21 Schultz, F.T. (BBN), Technical Background for Noise Abatement in HUD's Operating Programs, HUD, 8 September 1970.

5-22 Sims, Major William R. and Cpt. Angelo J. Cerchcone, "In Search of An Aviation Environment Master Plan", Air University Review, Vol. XX, No. 6, p. 64-72, October 1969.

5-23 "Sonic Boom Symposium", The Journal of the Acoustical Society of America, Vol. 39, No. 5, May 1966.

a. Hubarb, Harvey H., "Nature of Socic Boom Problem".

b. Kane, E.J., "Some Effects of the Nonuniform Atmosphere in the Propagation of Sonic Booms".

c. Maglieri, Dominic J., "Some Effects of Airplane Operations and the Atmosphere on Sonic Boom Signatures".

d. von Gierke, H.E., "Effects of Sonic Boom on People Review and Outlook".

5-24 Sperry, William C., Chairman, "Noise Source Abatement Technology and Cost Analysis Including Retrofitting", EPA Aircraft/Airport Noise Study Report, Task 'Group 4, June 1, 1973.

5-25 Swing, Jack W. and Donald B. Pies (Wyle Laboratories), Assessment of Noise Environments Around Railroad Operations, July 1973.

5-26 U.S. Department of the Air Force, Community Noise Exposure Resulting from Aircraft Operations: Acquisition and Analysis of Aircraft Noise and Performance Data, AMRL-TR-73-107, September 1975.

5-27 U.S. Department of the Air Force, Hazardous Noise Exposure, USAF Regulation 161-35.

5-28 U.S. Department of the Air Force, Procedures for Identifying and Justifying Base Requirements for Aircraft Turbine Engine Ground Run-up Noise Suppressors, USAF TO-00-25-237, 30 Jan 1976.

5-29 U.S. Departments of the Air Force, Army, and Navy, Land Use Planning with Respect to Aircraft Noise, AFM 86-5, TM 5-365, NAVDOCKS P-98, 1 October 1964.

5-30 U.S. Department of Commerce, The Noise Around Us: Including Technical Backup, Report of Panel on Noise Abatement, September 1970.

5-31 U.S. Department of Defense, Construction Criteria Manual, DOD 4270.1-M, 1 October 1972.

5-32 U.S. Department of the Navy, Pilot Tests for the Establishment on an Environmental Data Base for Naval Aviation Activities, Vol. 1, U.S. Navy Environmental Data Base Program, August 1972.

5-33 U.S. Department of Transportation, Transportation Noise and Its Control, June 1972.

5-34 U.S. Environmental Protection Agency, "Impact Characterization of Noise Including Implications of identifying and Achieving Accumulative Noise Exposure", EPA Aircraft/Airport Study Report, Task Group 1, July 1973.

5-35 U.S. Environmental Protection Agency, Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety, USEPA Report No. 550/9-74-004, March 1974.

5-36 U.S. Environmental Protection Agency, Legal Compilation: Guidelines and Reports, January 1973.

5-37 Wesler, J.E., Manual for Highway Noise Prediction, DOT, Federal Highway Administration, NTIS, March 1972.

5-38 Williams, T.E., "Highway Engineering and the Influence of Geometric Design Characteristics on Noise", Journal of Sound and Vibration, Vol. 15, No. 1117-22, 1971.

5-39 Wyle Laboratories, Final Report, Home Soundproofing Pi lot Project for Los Angeles Department of Airports, March 1970.

5-40 Yerges, Lyle F., "Cost/Effectiveness Approach to Machinery Noise Control", Sound and Vibration, July 1974, p.30-32.

Glossary

GLOSSARY OF TERMS

Annual Average Busy Day - The number of annual average busy day operations is the average of the twelve monthly averages of work-day operations, (See 3-1. 1.2 for further explanations.)

Audible Range (of Frequency) (Audio-Frequency Range) - The frequency range 16 Hz to 20,000 Hz (20kHz). This is conventionally taken to be the normal frequency of human hearing.

A-Weighted Sound Level, A-Level (AL) - The ear does not respond equally to sounds of all frequencies, but is less efficient at low and high frequencies than it is at medium or speech range frequencies. Thus, to obtain a single number representing the sound pressure level of a noise containing a wide range of frequencies in a manner approximating the response of the ear, it is necessary to reduce, or weight, the effects of the low and high frequencies with respect to the medium frequencies. Thus, the low and high frequencies are de-emphasized with the A-weighting.

The A-scale sound level is a quantity, in decibels, read from a standard sound-level meter with A-weighting circuitry. The A-scale weighting discriminates against the lower frequencies according to a relationship approximating the auditory sensitivity of the human ear. the A-scale sound level measures approximately the relative “noisiness” or "annoyance" of many common sounds.

Broad-Band Noise - Noise whose energy is distributed over a broad range of frequency (generally more than one octave).

Composite Noise Rating (CNR) - CNR is a measure of the noise produced by aircraft operations over a 24-hour annual average busy day. The CNR is calculated from aircraft noise expressed in PNdB, and the number of operations in daytime and nighttime periods. Both nighttime and ground runup operations are penalty weighted. The CNR has been utilize by the Department of Defense and the FAA to define the noise environmen about airports since the early 1960’s.

Continuous Noise - On-going noise whose intensity remains at a measurable level (which may vary) without interruption over an indefinite or a specified period of time.

C-Weighted Day-Night Average Sound Level (L_{Cdn}) - Refer to the day-night average sound level, L_{dn}. The C-weighted L_{dn} is determined in similar manner, with C-weighting substituted for A-weighting.

C-Weighted Sound Exposure Level (SEL_c) - The C-weighted SEL is the SEL (see definition below), based on the C-weighted level rather than the A-weighted level.

C-Weighted Sound Level, C-Level (CL) - The C-scale sound level is a quantity, in decibels, read from a standard sound level meter with C-weighting circuitry: The C-scale weighting approximates overall sound pressure level for the average range of human hearing and most common noise sources. The C-scale incorporates slight de-emphasis of the low and high portion of the audible frequency spectrum.

Day-Night - The day-night average sound level is a measure of the noise environment over a 24-hour annual average busy day. It is the 24-hour A-weighted sound level, with a 10 dB weighting applied to the nighttime levels. When hourly equivalent level (L_e) information is available, the L_{dn} is calculated as follows:

$$L_{dn} = 10 \log \frac{1}{24} \left[\sum_i 10^{Le_{di}/10} + 10 \sum_i 10^{Le_{ni}/10} \right]$$

where d and n refer to daytime and nighttime periods.

Alternatively, when a noise source produces discrete noise events, the L_{dn} may be computed by summation of individual SEL values according to:

$$L_{dn} = 10 \log \left[\sum_i 10^{SEL_{di}/10} + 10 \sum_i 10^{SEL_{ni}/10} \right] - 49.4$$

Decibel (dB) - The decibel is a logarithmic unit of measure of sound pressure, calculated according to a formula (see sound pressure level). One decibel is the level of the squared sound pressure that is $10^{1/10} = 1.259$ times the squared reference sound pressure; also, one decibel is the level of the sound pressure that is $10^{1/20} = 1.122$ times the reference pressure.

Effective Perceived Noise Level (EPNL) - EPNL is a single number rating of the noisiness of complex aircraft flyover noise signals. It is calculated by the integration with time of the tone-corrected perceived noise levels (PNLT) during a single noise event, such as an aircraft flyover. The EPNL includes adjustments for the relative duration of the noise signal and presence of audible pure tones or discrete frequencies (such as the whine of a jet engine compressor or fan). The reference signal duration is 10 seconds.

For the case where the PNLT values are measured at 0.5 second intervals during the noise event, the computational formula for EPNL is:

$$EPNL = 10 \log \left[\sum_{k=o}^{2d} 10^{\frac{PNLT(k)}{10}} \right] - 13$$

where the summation extends over the time period of the signal between the first and last times at which PNLT (k) is within 10 dB of the maximum PNLT; and d is the duration, in seconds, between the first and last values of PNLT (k) are within 10 dB of the maximum PNLT.

The EPNL is formally defined in ANSI S6.4-1973 "Definition and Procedures for Computing the Effective Perceived Noise Level for Flyover Aircraft Noise".

Equivalent Sound Level (L_{eq}) - The equivalent sound level, L_{eq}, is the level of a constant sound which, in a given situation and time period, has the same sound energy as does a time-varying sound. Technically, equivalent sound level is the level of the time-weighted, mean square, A-weighted sound pressure. The time interval over which the measurement is taken should always be specified.

The energy averaging is given explicitly by:

$$L_e = 10 \log \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} 10^{AL(t)/10} dt$$

where the averaging is performed over the period $t_2 - t_1$.

The typical averaging time for the equivalent level is a period of one hour. However , the time period can be altered to meet one's needs.

For noise sources which are not in continuous operation, the equivalent level may be obtained by summing individual SEL values and normalizing over the appropriate time period.

Frequency - Number of complete oscillation cycles per unit of time. The unit of frequency often used is the Hertz (Hz).

Frequency Band - Difference in Hertz between the upper and lower frequencies that delimit a band, or the interval in octaves between the two frequencies. The band is located frequency-wise by the geometric mean frequency between the two band-edge frequencies. Examples are: "an octave band centered at 500 Hz", or more simply, "the 500 Hz octave band".

Hertz - Unit of frequency equal to one cycle per second.

Impulse Noise (Impulsive Noise) - Noise of short duration (typically less than one second) especially of high intensity, abrupt onset and rapid decay, and often rapidly changing spectral composition. Impulse noise is characteristically associated with such sources as explosions, impacts, the discharge of firearms, the passage of super sonic aircraft (sonic boom) and many industrial processes.

Infrasonic - Having a frequency below the audible range for man (customarily deemed to cut off at 16 Hz).

Intermittent Noise - Fluctuating noise whose level falls one or more times to low or unmeasurable values during an exposure.

Noise Exposure - The cumulative acoustic stimulation reaching 'the ear of a person over a specified period of time (e.g., a work shift, a day, a working life, or a lifetime).

Noise Exposure Forecast (NEF) - NEF is a measure of the noise environment over a 24-hour annual average busy day. It is based upon summation of individual noise events over the 24-hour period, with adjustments applied for nighttime noises and aircraft ground runups. EPNL is the basic noise event measure. The nighttime adjustment differs, from that used in calculation of L_{dn}.

$$NEF = 10 \log \left[\sum_i 10^{EPNL_{di}/10} + 16.67 \sum_i 10^{EPNL_{ni}/10} \right] - 88$$

Noise Hazard (Hazardous Noise) - Acoustic stimulation of the ear which is likely to produce noise-induced permanent threshold shift in some port ion of a population.

Noise Level Reduction (NLR) - NLR is the difference in decibels, between the A-weighted sound level outside a building and the A-weighted sound level inside a designated room in the building. The NLR is dependent upon the transmission loss characteristics of the building surfaces exposed to an exterior noise source, the particular noise characteristics of the exterior noise source and the acoustic properties of the designated room in the building.

Overall Sound Pressure Level (OASPL) - OASPL level is the sound-pressure level measured in a broad frequency band. This band is often taken to extend from approximately 25 Hz to 10,000 Hz.

Perceived Noise Level (PNL) - PNL is a rating of the “noisiness” of a sound calculated from acoustic measurements. The unit is the perceived noise decibel (PNdB). The perceived noise level is calculated from sound pressure levels measured in octave (or 1/3-octave) frequency bands, This rating is most accurate in rating the noisiness of broad-band sounds of similar time duration which do not contain strong discrete frequency components.

The PNL is formally defined in the Society of Automotive Engineers (SAE) Aerospace Recommended Practice 865A “Definitions and Procedures for Computing the Perceived Noise Level of Aircraft Noise”.

Pythagorean Theorem - A theorem in geometry, the square of the lengths of the hypotenuse of a right triangle equals the sum of the squares of the lengths of the other two sides.

Sound Exposure Level (SEL) - The sound exposure level (SEL) is a measure of single noise events, such as an aircraft flyover. It is the A-weighted-sound level integrated over the duration of a noise event (referred to a reference time of one sound). Hence, it gives the equivalent level of a continuous signal of one second duration for the event.

For purposes of aircraft noise evaluation, SEL is computed from A-levels sampled at discrete intervals of 0.5 seconds or less. Thus, the working expression for SEL becomes:

$$SEL = 10 \log \sum_{k=0}^{k=\frac{d}{\Delta t}} 10^{\frac{AL(k)}{10}} + 10 \log \Delta t$$

where d is the time interval during which AL(k) is within 10 dB of the maximum A-level, and t is the time interval between noise level samples.

Sound Level Meter - A sound level meter is an instrument that provides a direct reading of the sound pressure level at a particular location. It consists of a microphone and electronic amplifier together with a meter having a scale graded in dB. Using appropriate built-in electrical filters, it is possible to directly measure the overall, the A- or D-weighted sound pressure levels. Standard sound level meters must satisfy the requirements of American National Standards Institute (ANSI) Specification for Sound Level Meters, S1.4-1971.

Sound Pressure - The sound pressure at a point in a sound field is a measure of the fluctuating variations in pressure from the static value (i.e., atmospheric pressure) caused by the presence of the sound field. For most complex sound sources, the sound pressure contains energy over a broad frequency range audible to humans.

Sound Pressure Level (SPL) - The range in sound pressures from the minimum audible sound waves to those existing in the vicinity of a modern jet airplane is greater than a factor of one million.. A measure of the sound pressures is therefore more convenient on a reduced scale. Consequently, a logarithmic scale is used in which equal increments correspond to equal multiples of sound pressure; the reference pressure corresponds approximately to the minimum audible sound pressure. This is a convenient scale to use since the ear responds to sound waves in a similar manner. On such a scale, the measurement of sound pressure is termed SPL, the units being the decibel or dB.

In more formal mathematical formulation, the sound-pressure level of a sound, in decibels, is 20 times the logarithm to the base ten of the ratio of the pressure of this sound to the reference pressure $[dB = 20\ (\log \frac{P}{P_o})]$. The common reference pressure for acoustics in air is 20 micropascals (20 micronewtons per square meter). In English units this quantity is approximately 4.2 X 10^{-7} pounds per square foot.

Sound Transmission Class (STC) - STC is a single-figure rating of the sound insulating properties of a partition as determined by methods described in “Determination of Sound Transmission Class”, American Society of Testing and Materials Designation E413-73.

Sound Transmission Loss (STL) - STL is a measure of the sound insulating properties of a wall, floor, ceiling, window, door, that are characteristics of the partition itself and not the room of which it is a part. The STL may be calculated from the noise reduction between two rooms, in a specified frequency band, plus ten times the common logarithm of the ratio of the area of the partition to the total sound absorption in the receiving room, as determined by methods described in “Measurement of Airborne Sound Insulation in Building”, American Society of Testing and Materials Designation E90-70 or latest revision thereof.

Standard Land Use Coding Manual (SLUCM) - Standard system for identifying and coding land use activities. Published by U.S. Department of Commerce in 1965.

Steady State Noise Level (L_s) - L_s is the A-weighted noise level produced in the space by the ventilation or mechanical systems (or other interior noise sources) which operate more or less continuously. The L_s value for design should be the noise level produced in the space by the equipment during the most usual mode of operation during the time of occupancy.

Tone-Corrected Perceived Noise Level (PNLT) - The tone-corrected perceived noise level is the perceived noise level adjusted for the presence of audible discrete frequency components which increase the noisiness of the sound signal. The PNLT was developed to aid in assessing the perceived noisiness of aircraft or vehicle noises which contain pure tones or have perceived irregularities in their spectrum.

The PNLT is formally defined in ANSI S6.4-1973 “Definition and Procedures for Computing the Effective Perceived Noise Level for Flyover Aircraft Noise”.

Appendices

APPENDIX A

DOD AGENCIES PROVIDING ENVIRONMENTAL NOISE CONTOURS AND ASSESSMENTS

1. PUBLICATIONS AVAILABLE:

   a. **CERL Interim Report N-10, User Manual: Interim Procedure for Planning Rotary-Wing Aircraft Traffic Patterns and Siting Noise-Sensitive Land Uses, September 1976. [NTIS].** *Presents (1) interim procedures for determining the location of rotary-wing aircraft traffic patterns and ingress and egress corridors into an airfield/heliport area to avoid conflict with noise-sensitive land uses and and (2) criteria for siting noise-sensitive land uses with respect to established airfield or heliport plans.*

   b. **CERL Technical Report E-42, User Manual for the Acquisition and Evaluation of Operational Blast Noise Data, June 1974. [NTIS].** *Presents means for acquiring operational blast noise information and evaluating the resulting contours. Forms introduced and explained to facilitate the compilation of data. Overlays to be constructed to evaluate the contour consist of generalized land-use and population density map overlays. The means is given to interpret the contours.*

   c. **CERL Technical Report E-17, Predicting Community Response to Blast Noise, December 1973 [NTIS].** *Presents a preliminary method for predicting levels of annoyance from artillery or blast noise in the environs of a military base. Means given to relate various artillery pieces to a TNT equivalent and to normalize the overpressure from detonating various quantities of TNT to the overpressure from the detonation of one pound of TNT. Buried charges and aboveground detonations considered. Ways to predict probable blast overpressure and frequency spectrum as a function of distance are discussed.*

[NTIS] - Indicates document available from National Technical Information Service, Springfield, VA 22151

2. AGENCIES TO CONTACT:

a. AIR FORCE:

Air Force Civil Engineering Center, Tyndall AFB, FL 32401. For environmental assessment assistance contact AFCEC/EV. For noise contour production contact AFCEC/DE.

b. ARMY:

(1) Construction Engineering Research Laboratory (CERL), P.O. Box 4005, Champaign, IL 61820.

(2) Commander, U.S. Army Health Services Command (HSPA-H), Fort Sam, Houston, Texas 78234.

c. NAVY/MARINE CORPS:

Aircraft Environmental Support Office, Naval Air Rework Facility (Code 64270), NAS North Island, San Diego, CA 92145. Address information copy of requests to: NAVFACENGCOM (Code 202).

APPENDIX B

NOISE DATA SOURCES FOR MANUALLY DERIVED NOISE CONTOURS

1. Aircraft Noise and Performance Data:

   a. Publications Available on Aircraft Flight and Ground Runup Noise Data :

      (1) AMRL-TR-73-110, Community Noise Exposure Resulting from Aircraft Operations - Acoustic Data on Military Aircraft. [NTIS] Six volumes:

      Vol I: Index/Explanation of Use
      Vol II: USAF Bomber/Cargo Aircraft Noise Data
      Vol III: USAF Attack/Fighter Aircraft Noise Data
      Vol IV: USAF Trainer/Fighter Aircraft Noise Data
      Vol V: USAF Propeller Aircraft Noise Data
      Vol VI: USN Aircraft Noise Data

      Provides slant range versus noise level data on military aircraft, including spectral information, ground-to-ground and air-to-ground propagation, and both tone-corrected and non-tone-connected data. Initial volume provides instructions and forms for calculating exposures.

      (2) AESO 313-76-01, Fixed Wing Aircraft Acoustical Parameters Handbook (NAVY). *Provides data and noise contours on most operational Navy fixed wing aircraft. Explains how the data and contours can be applied for the determination of noise impact in the surrounding area.*

      (3) CERL Interim Report N-10, User Manual: Interim Procedure for Planning Rotary-Wing Aircraft Traffic Patterns and Siting Noise-Sensitive Land Uses, September 1976 [NTIS]. (See Appendix A for abstract).

   b. Publications Available on Impulse (Blast) Noise Data:

      CERL Technical Report E-17, Predicting Community Response to Blast Noise, December 1973. [NTIS] (See Appendix A for abstract).

[NTIS] - Indicates document available from National Technical Information Service, Springfield, VA 22151.

C. **Publications Available on Fixed Source Noise Data:**

(1) **AMRL-TR-75-50, USAF Bioenvironmental Noise Data Handbook [NTIS].** *Complete handbook contains over 100 volumes. Volume 1 contains an introduction to handbook usage, Listing of noise data available in succeeding volumes, and a list of organizations maintaining reference file copies.*

(2) **CERL Technical Report E-53, Construction Noise: Specification, Control, Measurement and Mitigation, April 1975. [NTIS/ADA *009668*]** *Provides workable cost/benefit model for determining tradeoffs associated use of new, quieter construction equipment and/or construction process modification. Model designed for use in evaluating equipment usage, operational methods, or physical means to attenuate the noise of construction sites to acceptable levels and to describe quantitatively the cost associated with these reductions. Requires large data base for application.*

(3) **CERL Interim Report N-3, Cost Effectiveness of Alternative Noise Reduction Methods for Construction of Family Housing, July *1976* [NTIS].** *Describes application of cost/benefit model developed in CERL-TR-E-53 to multifamily housing construction. Significant findings are discussed.*

(4) **USAEHA Technical Guide (MED), Noise Hazard Evaluation-sound Level Data of Noise Sources, January 1975.** *Contains noise level data for many military noise sources.*

3. Agencies to Contact:

a. Air Force:

Aerospace Medical Research Laboratory (6570 AMRL/BBE), Wright-Patterson AFB, OH 45433. Source for noise data on military aircraft not contained in AMRL-TR-73-110 or AMRL-TR-75-50.

b. Army

(1) Construction Engineering Research Laboratory (CERL), P.O. Box 4005, Champaign, IL 61820.

(2) Commander, U.S. Army Environmental Hygiene Agency (HSE-OB) Aberdeen Proving Ground, MD 21010

C. Navy/Marine Corps:

Aircraft Environmental Support Office, Naval Air Rework Facility (Code 64270), NAS North Island, San Diego, CA 92145. Address information copy of requests to: NAVFACENGCOM (Code 202)

APPENDIX C

COMPARISON OF NOISE RATING MEASURES

There are numerous noise exposure measures in current use in this country and abroad. Most were specifically developed to rate aircraft noise exposure. While there are differences among the measures, most can be expressed in the same general format, i.e., as a summation of noise levels.

When applied to a number of identical events, this summation may be expressed as:

$$\text{Noise Measure} = \text{Noise Level} + A \log (N_d + P_e N_e + P_n N_n) + C$$

The noise level is typically based on either the A-weighted or perceived noise level, and may contain adjustments for tones and/or duration. N_d, N_e and N_n are the number of operations for daytime, evening and nighttime periods (the evening and nighttime periods are often combined). Penalties (P_e and P_n) may be applied to evening and nighttime periods. The factors A and C are constants: A determines the manner in which multiple events are added together; C is a normalizing constant.

Figure C-1 lists many common noise rating measures and their characteristics. All can be expressed in the form above. For a maximum PNL of 110 dB (assuming A-level = PNL - 13), and an assumed effective duration of 10 seconds, the equations for these measures can be plotted as a function of the number of events N (daytime only). This is shown in Figure C-2, which may also be used to translate approximately from one measure to another.

One additional measure, the Aircraft Sound Description System (ASDS), developed by the Federal Aviation Administration, does not follow the same general format as the previously described measures. The purpose of the ASDS methodology is to define the amount of time, at a location near an airport, that an A-weighted level of 85 dB is exceeded during the day. This measure cannot be easily related to any of the above measures,

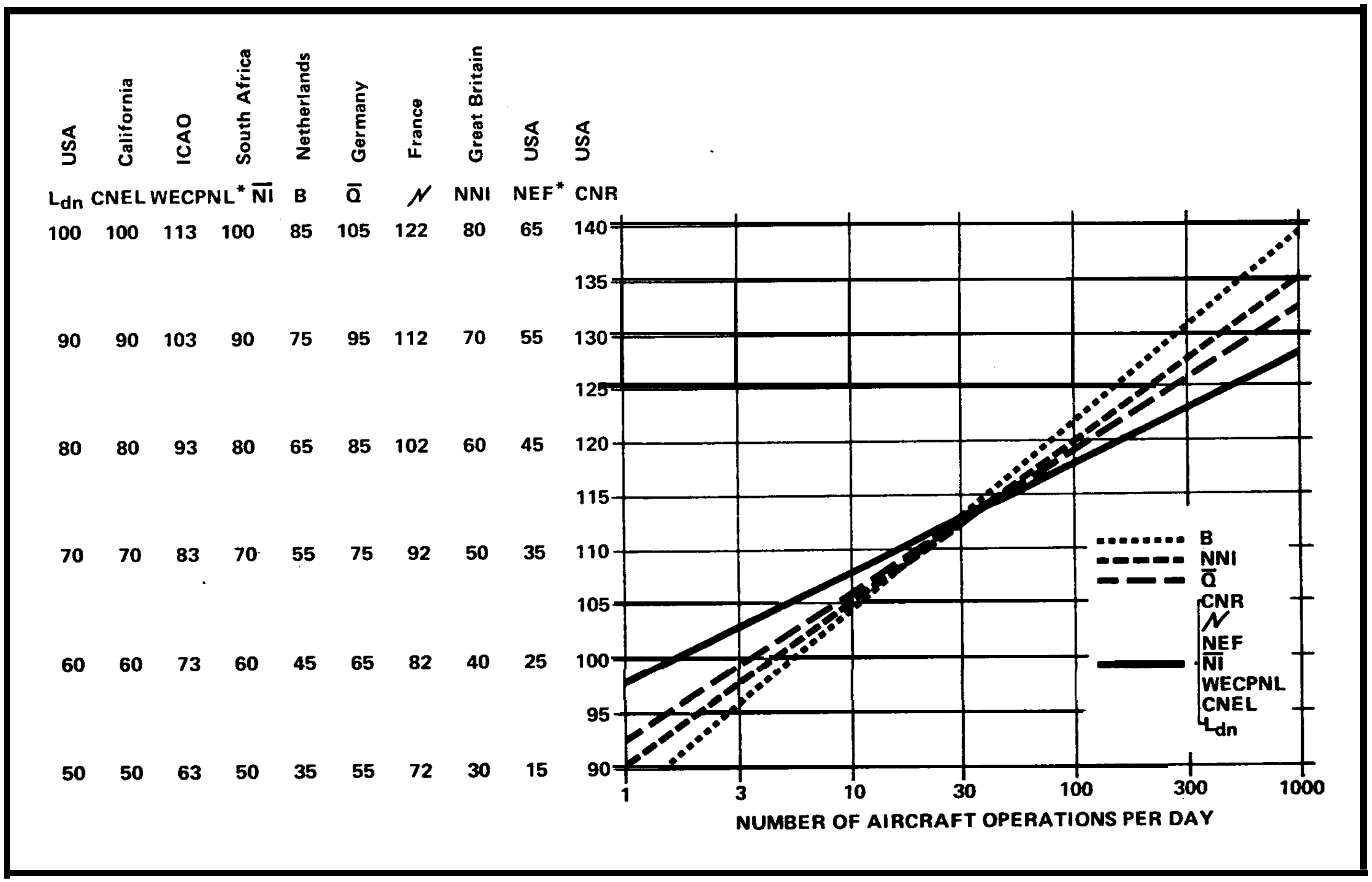
FIGURE C-1 **ATTRIBUTES OF VARIOUS NOISE RATING MEASURES**

Origin	Rating	Sound Level	Tones	Duration	Number	Day/Night*
USA	NEF	EPNL	yes	yes	10 log N	2 period/+10 dB
ICAO	WECPNL	EPNL	yes	yes	10 log N	2 or 3 period/+5
USA	CNR	Max PNL	no	no	10 log N	2 period/+10 dB
France	$\mathcal{N}$	Max PNL	no	no	10 log N	3 period/variable
UK	NNI	Max PNL	no	no	15 log N	
Germany	$\overline{Q}$	A	no	yes	13.3 log N	
USA	L_{dn}	A	no	yes	10 log N	2 period/+10 dB
California	CNEL	A	no	yes	10 log N	3 period/+5&10 dB
South Africa	$\overline{NI}$	A	yes	yes		
Netherlands	B	$\frac{4}{3}$ A max	no	no	20 log N	

*Various penalties for night or evening sound levels are used in different rating methods.

FIGURE C-2

COMPARISON OF VARIOUS NOISE EXPOSURE INDICES FOR A FLYOVER NOISE LEVEL OF 110 PNdB, EFFECTIVE DURATION OF 10 SECONDS, AND VARIABLE NUMBER OF OPERATIONS



*For 110 EPNdB Flyover.

APPENDIX D

ACOUSTICAL DES I GN

PUBLICATIONS AVAILABLE:

a. **TM-5~805-15, U.S. Army Technical Manual on Architectural Acoustics,** *Design information to provide occupant with satisfactory acoustical conditions within and protection from noise that may be injurious to health or welfare. Provides recommended techniques for reducing unwanted sounds.*

b. **AESO 330-76-02, Facility Acoustic Parameter Catalog (NAVY).** *Provides a fundamental knowledge of architectural acoustics. Provides techniques for determination of Sound Transmission Class (STC) and composite transmission loss and for relating noise reduction to STC. Provides absorption and transmission loss data.*

C. **AESO Report 330-70-01, Noise Reduction Technology Catalog (NAVY).** *Provides a fundamental acquaintance with the properties of noise and various techniques applicable to noise control, Provides absorption and transmission loss data for common building materials.*

APPENDIX E

MISCELLANEOUS NOISE DATA SOURCES

PUBLICATIONS AVAILABLE

AESO 334-77-01, Unique Mobile Vehicle Noise Catalog. (NAVY). *Provides data and noise contours on most operational stationary ground support equipment. Explains how the data and contours can be applied for determination of noise impact.*

*U.S. GOVERNMENT PRINTING OFFICE: 1981 361-647/2562 1-3