

## **Appendix G      AIRCRAFT NOISE ANALYSIS**

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## **G.1 Basics of Noise**

FAA's Order 1050.1E, "Environmental Impacts: Policies and Procedures", Appendix A, Section 14, "Noise", specifies use of a measure of cumulative noise exposure from aviation activities that operate over the course of an average day during a given year of interest. The metric is referred to as the Day-Night Average Sound Level (DNL). However, fundamental terms or metrics are helpful in explaining and understanding the elements of the noise environment that comprise the DNL around an airport. This appendix introduces the acoustic metrics, which are the relevant elements that comprise DNL and provide a basis for evaluating and understanding a broad range of noise situations.

The following sections provide a basic reference on these technical issues beginning with an introduction to fundamental acoustics and noise terminology (Section G.1.1), the effects of noise on human activity (Section G.1.2), community annoyance (Section G.1.3), and a discussion of currently accepted noise-land use compatibility guidelines (Section G.1.4).

### **G.1.1 Introduction to Acoustics and Noise Terminology**

Noise is a complex physical quantity. To better understand the noise exposure and DNL metric used in environmental studies, it is important to understand the basic elements that go into the development of quantifying sound or noise. This chapter introduces the following acoustic metrics, which are all related to DNL, but provide bases for evaluating a broad range of noise situations.

Decibel, dB;

A-Weighted Decibel;

Maximum Sound Level,  $L_{max}$ ;

Sound Exposure Level, SEL;

Equivalent Sound Level,  $L_{eq}$ ; and

Day-Night Average Sound Level, DNL.

#### **G.1.1.1 The Decibel, dB**

All sounds come from a sound source – a musical instrument, a voice speaking, or an airplane that passes overhead. It takes energy to produce sound. The sound energy produced by any sound source is transmitted through the air in sound waves – tiny, quick oscillations of pressure just above and just below atmospheric pressure. These oscillations, or sound pressures, impinge on the ear, creating the sound we hear.

Our ears are sensitive to a wide range of sound pressures. But our ears are incapable of detecting small differences in these pressures. Thus, to better match how we hear this sound energy, we compress the total range of sound pressures to a more

meaningful range by introducing the concept of sound pressure level (SPL). Sound pressure level is a measure of the sound pressure of a given noise source relative to a standard reference value (typically the quietest sound that a young person with good hearing can detect). Sound pressure levels are measured in decibels (abbreviated dB). Decibels are logarithmic quantities – logarithms of the squared ratio of two pressures, the numerator being the pressure of the sound source of interest, and the denominator being the reference pressure (the quietest sound we can hear).

The logarithmic conversion of sound pressure to sound pressure level means that the quietest sound we can hear (the reference pressure) has a sound pressure level of about zero decibels, while the loudest sounds we hear without pain have sound pressure levels of about 120 dB. Most sounds in our day-to-day environment have sound pressure levels from 30 to 100 dB.

Because decibels are logarithmic quantities, they do not behave like regular numbers with which we are more familiar. For example, if two sound sources each produce 100 dB and they are operated together, they produce only 103 dB – not 200 dB as we might expect. Four equal sources (100 dB) operating simultaneously result in a total sound pressure level of 106 dB. In fact, for every doubling of the number of equal sources, the sound pressure level goes up another three decibels.

If one source is much louder than another, the two sources together will produce the same sound pressure level (and sound to our ears) as if the louder source were operating alone. For example, a 100 dB source plus an 80 dB source produce 100 dB when operating together. The louder source “masks” the quieter one, but if the quieter source gets louder, it will have an increasing effect on the total sound pressure level. People hear changes in sound level according to the following rules of thumb: 1) a change of 1 dB or less in a given sound level is generally not readily perceptible except in a laboratory setting; 2) a 5-dB change in a sound level is considered to be generally noticeable in a community setting; and 3) it takes approximately a 10-dB increase or decrease to be heard as a doubling or halving of a sound’s loudness, respectively.

#### **G.1.1.2 A-Weighted Decibel**

Another important characteristic of sound is its frequency, or “pitch”. This is the rate of repetition of the sound pressure oscillations as they reach our ears. Frequency is expressed in units known as Hertz.

The human ear does not respond equally to identical noise levels at different frequencies. Although the normal frequency range of hearing for most people extends from a low of about 20 Hz to a high of 10,000 Hz to 20,000 Hz, people are most sensitive to sounds in the voice range, between about 500 Hz to 2,000 Hz. Therefore, to correlate the amplitude of a sound with its level as perceived by people, the sound energy spectrum is adjusted, or “weighted.”

The weighting system most commonly used to correlate with people's response to environmental noise is “A-weighting” (or the “A-filter”) and the resultant noise level is

called the “A-weighted noise level”. A-weighting significantly de-emphasizes those parts of the frequency spectrum from a noise source that occurs both at lower frequencies (those below about 500 Hz) and at very high frequencies (above 10,000 Hz) where we do not hear as well. The filter has very little effect, or is nearly “flat,” in the middle range of frequencies between 500 and 10,000 Hz. In addition to representing human hearing sensitivity, A-weighted sound levels have been found to correlate better than other weighting networks with human perception of “noisiness.”

Because of the correlation with our hearing, the A-weighted level has been adopted as the basic measure of environmental noise by the U.S. Environmental Protection Agency (EPA) and by nearly every other federal and state agency concerned with community noise.

### G.1.1.3 Maximum A-Weighted Noise Level, $L_{max}$

An additional dimension to environmental noise is that A-weighted levels vary with time. For example, the sound level increases as an aircraft approaches, then falls and blends into the background as the aircraft recedes into the distance (though even the background varies as birds chirp or the wind blows or a vehicle passes by). This variation in sound level over time often makes it convenient to describe a particular noise "event" by its maximum sound level, abbreviated as  $L_{max}$ . Figure G-1 illustrates this concept showing an  $L_{max}$  of approximately 85 dB.

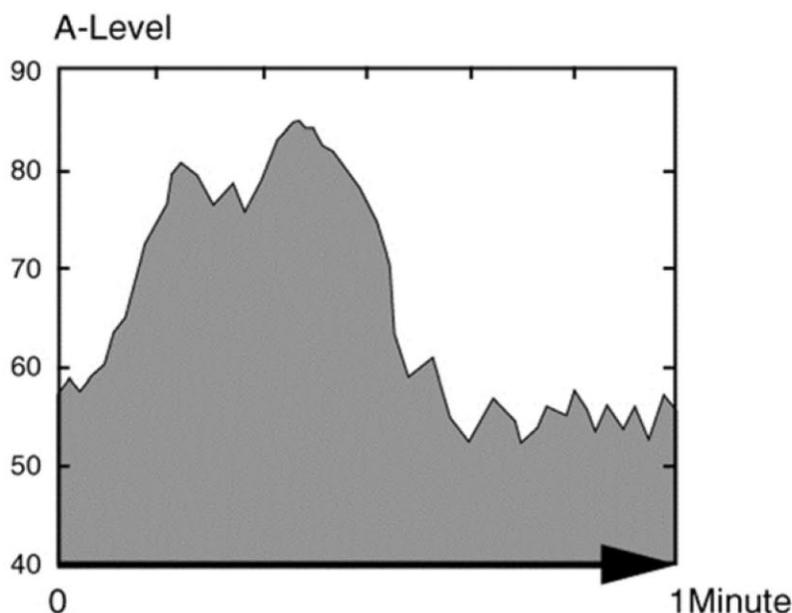


Figure G-1 Variations in the A-Weighted Sound Level Over Time

Source: HMMH

The maximum level describes only one dimension of an event; it provides no information on the cumulative noise exposure. In fact, two events with identical maxima may produce very different total exposures. One may be of very short duration, while

the other may continue for an extended period and be judged much more annoying. The Sound Exposure Level metric corrects for this deficiency.

#### G.1.1.4 Sound Exposure Level, SEL

The most frequently used measure of noise exposure for an individual aircraft noise event is the Sound Exposure Level, or SEL. SEL is a measure of the total noise energy produced during an event, from the time when the A-weighted sound level first exceeds a threshold level (normally just above the background or ambient noise) to the time that the sound level drops back down below the threshold. To allow comparison of noise events with very different durations, SEL “normalizes” the duration in every case to one second; that is, it is expressed as the steady noise level with just a one-second duration that includes the same amount of noise energy as the actual longer duration, time-varying noise. In lay terms, SEL “squeezes” the entire noise event into one second.

Figure G-2 depicts this transformation. The shaded area represents the energy included in an SEL measurement for the noise event, where the threshold is set to approximately 60 dB. The darkly shaded vertical bar, which is 90 dB high and just one second long (wide), contains exactly the same sound energy as the full event.

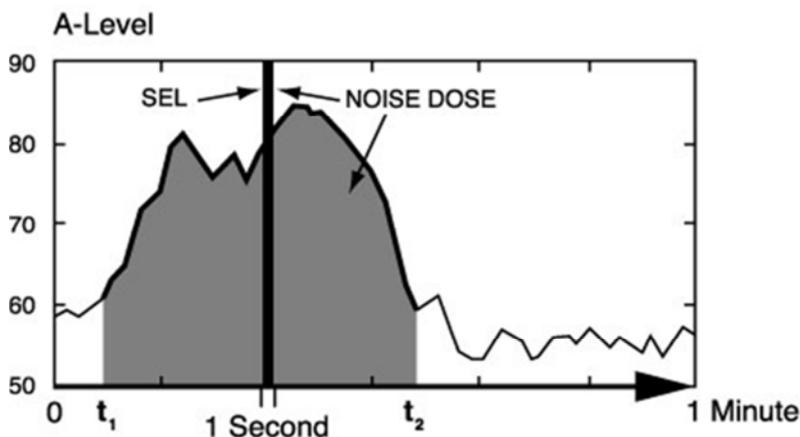


Figure G-2 Sound Exposure Level  
Source: HMMH

Because the SEL is normalized to one second, it will always be larger than the  $L_{\max}$  for an event longer than one second. In this case, the SEL is 90 dB; the  $L_{\max}$  is approximately 85 dB. For most aircraft overflights, the SEL is normally on the order of 7 to 12 dB higher than  $L_{\max}$ . Because SEL takes duration into account, longer exposure to relatively slow, quieter aircraft, such as propeller models, can have the same or higher SEL than shorter exposure to faster, louder aircraft, such as corporate jets.

Aircraft noise models use SEL as the basis for computing exposure from multiple events, as in computing Day-Night Average Sound Level or DNL.

#### **G.1.1.5 Day-Night Average Sound Level, DNL**

FAA requires that airports use a more complex measure of noise exposure to describe cumulative noise exposure during an average annual day: the Day-Night Average Sound Level, or DNL. The U.S. Environmental Protection Agency identified DNL as the most appropriate means of evaluating airport noise based on the following considerations (from “Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety,” U. S. EPA Report No. 550/9-74-004, March 1974):

1. The measure should be applicable to the evaluation of pervasive long-term noise in various defined areas and under various conditions over long periods of time.
2. The measure should correlate well with known effects of the noise environment and on individuals and the public.
3. The measure should be simple, practical and accurate. In principal, it should be useful for planning as well as for enforcement or monitoring purposes.
4. The required measurement equipment, with standard characteristics, should be commercially available.
5. The measure should be closely related to existing methods currently in use.
6. The single measure of noise at a given location should be predictable, within an acceptable tolerance, from knowledge of the physical events producing the noise.
7. The measure should lend itself to small, simple monitors, which can be left unattended in public areas for long periods of time.

Most federal agencies dealing with noise have formally adopted DNL.

The DNL represents noise as it occurs over a 24-hour period, with an important exception: DNL treats nighttime noise differently from daytime noise. In determining DNL, it is assumed that the A-weighted levels occurring at night (defined as 10 p.m. to 7 a.m.) are 10 dB louder than they really are. This 10 dB penalty is applied to account for greater sensitivity to nighttime noise, and the fact that events at night are often perceived to be more intrusive because nighttime ambient noise is less than daytime ambient noise.

Figure G-1 illustrated the A-weighted sound level due to an aircraft fly-over as it changed with time. The top frame of Figure G-3 repeats this figure. The shaded area reflects the noise dose that a listener receives during the one-minute period of the sample. The center frame of Figure G-3 includes this one-minute sample within a full hour. The shaded area represents the noise during that hour with 16 noise events, each producing an SEL. Similarly, the bottom frame includes the one-hour interval

within a full 24 hours. Here, the shaded area represents the listener's noise dose over a complete day. Note that several overflights occur when the background noise drops some 10 dB, to approximately 45 dB.

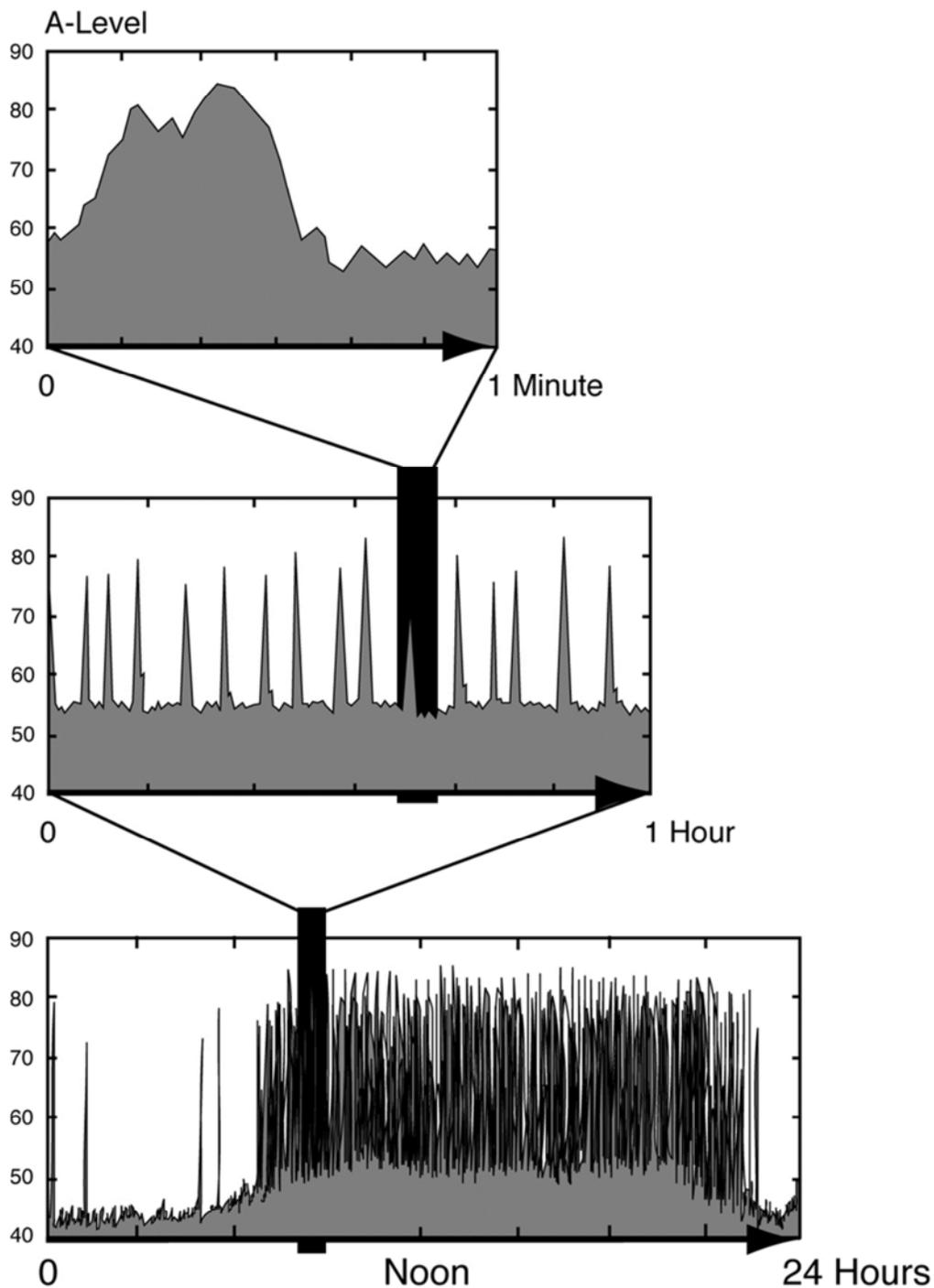


Figure G-3 Daily Noise Dose  
Source: HMMH

DNL can be measured or estimated. Measurements are practical only for obtaining DNL values for relatively limited numbers of points, and, in the absence of a permanently installed monitoring system, only for relatively short time periods. Most airport and airspace noise studies are based on computer-generated DNL estimates, determined by accounting for all of the SEL values from individual events that comprise the total noise dose at a given location. Computed DNL values are often depicted in terms of equal-exposure noise contours (much as topographic maps have contours of equal elevation), or by color-coded grid points representing population centroids, specific noise-sensitive sites (such as schools or places of worship), or non-specific but uniform coverage of an expansive study area. Figure G-4 depicts typical DNL values for a variety of noise environments.

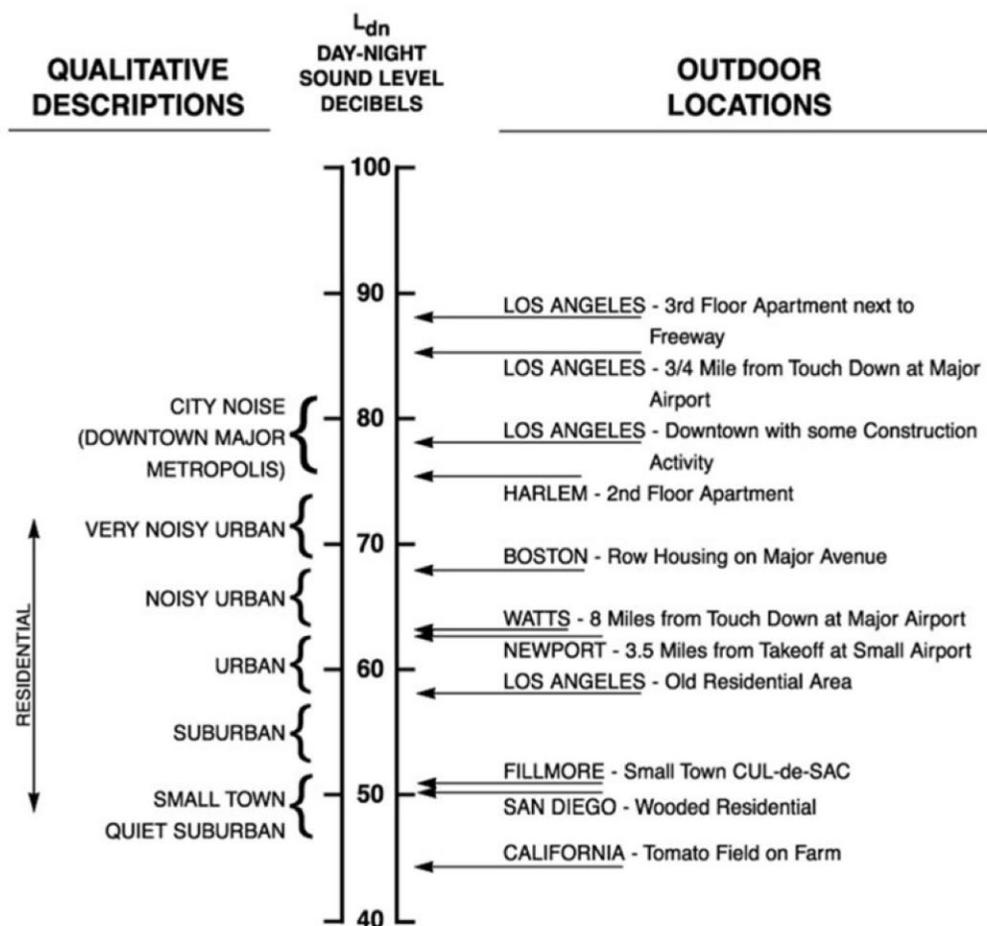


Figure G-4 Examples of Day-Night Average Sound Levels, DNL

Source: United States Environmental Protection Agency, Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety, March 1974, p. 14.

## G.1.2 The Effects of Aircraft Noise on People

To residents around airports, aircraft noise can be an annoyance and a nuisance. It can interfere with conversation and listening to television, disrupt classroom activities in schools, and disrupt sleep. Relating these effects to specific noise metrics helps in the understanding of how and why people react to their environment.

### G.1.2.1 Speech Interference

A primary effect of aircraft noise is its tendency to drown out or "mask" speech, making it difficult to carry on a normal conversation. The sound level of speech decreases as the distance between a talker and listener increases. As the background sound level increases, it becomes harder to hear speech. Figure G-5 presents typical distances between talker and listener for satisfactory outdoor conversations, in the presence of different steady A-weighted background noise levels for raised, normal, and relaxed voice effort. As the background level increases, the talker must raise his/her voice, or the individuals must get closer together to continue talking.

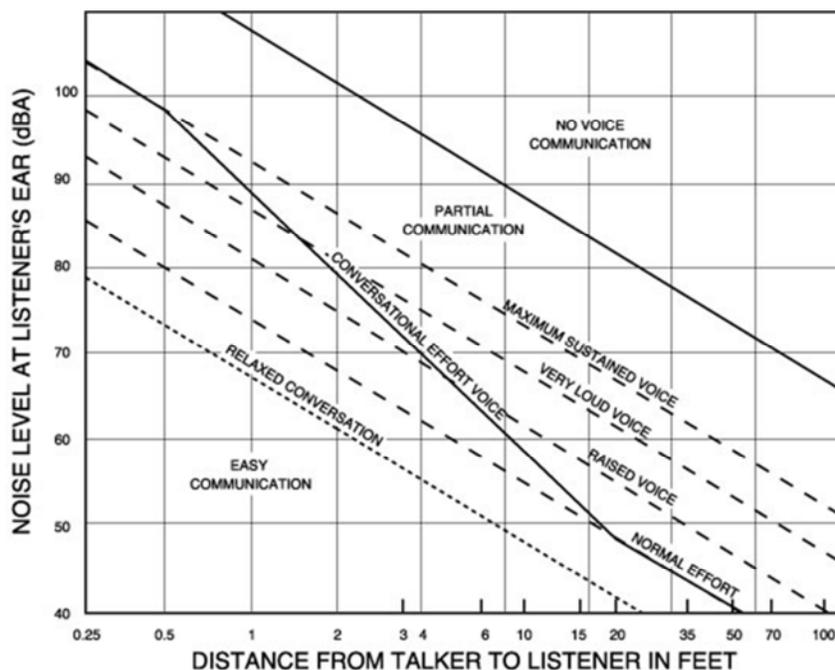


Figure G-5 Outdoor Speech Intelligibility

Source: United States Environmental Protection Agency, Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety, March 1974, p. D-5.

As indicated in the figure, "satisfactory conversation" does not always require hearing every word; 95% intelligibility is acceptable for many conversations. Listeners can infer a few unheard words when they occur in a familiar context. However, in relaxed conversation, we have higher expectations of hearing speech and generally require closer to 100% intelligibility. Any combination of talker-listener distances and background noise that falls below the bottom line in Figure G-5 (thus assuring 100%

intelligibility) represents an ideal environment for outdoor speech communication and is considered necessary for acceptable indoor conversation as well.

One implication of the relationships in Figure G-5 is that for typical communication distances of 3 or 4 feet (1 to 1.5 meters), acceptable outdoor conversations can be carried on in a normal voice as long as the background noise outdoors is less than about 65 dB. If the noise exceeds this level, as might occur when an aircraft passes overhead, intelligibility would be lost unless vocal effort were increased or communication distance were decreased.

Indoors, typical distances, voice levels, and intelligibility expectations generally require a background level less than 45 dB. With windows partly open, housing generally provides about 10 to 15 dB of interior-to-exterior noise level reduction. Thus, if the outdoor sound level is 60 dB or less, there a reasonable chance that the resulting indoor sound level will afford acceptable conversation inside. With windows closed, 24 dB of attenuation is typical.

### G.1.2.2 Sleep Interference

Research on sleep disruption from noise has led to widely varying observations. In part, this is because (1) sleep can be disturbed without awakening, (2) the deeper the sleep the more noise it takes to cause arousal, (3) the tendency to awaken increases with age, and other factors.

Figure G-6 shows a recent summary of findings on the topic.

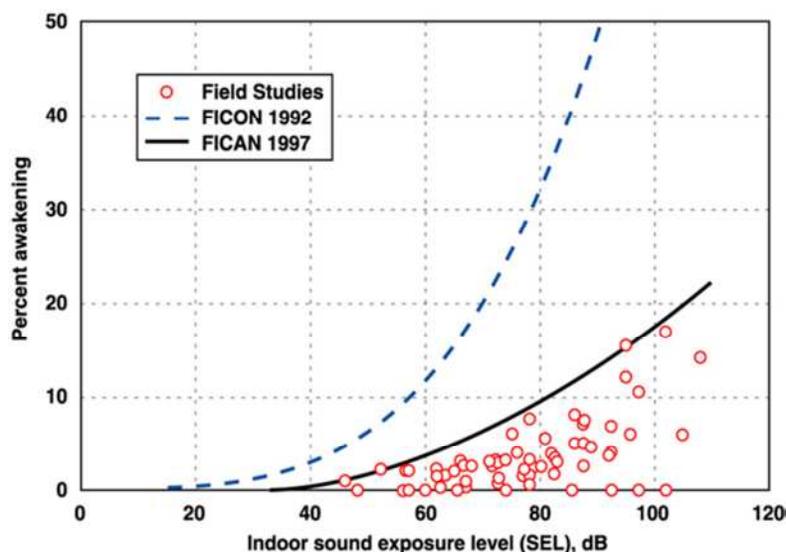


Figure G-6 Sleep Interference

Source: Federal Interagency Committee on Aviation Noise (FICAN), "Effects of Aviation Noise on Awakenings from Sleep", June 1997, page 6.

Figure G-6 uses indoor SEL as the measure of noise exposure; recent work supports the use of this metric in assessing sleep disruption. An indoor SEL of 80 dB results in a maximum of 10% awakening.

### G.1.3 Community Annoyance

Numerous psychoacoustic surveys provide substantial evidence that individuals' reactions to noise vary widely for a given noise exposure level. However, since the early 1970's, researchers have determined (and subsequently confirmed) that a community's aggregate response is generally predictable and relates reasonably well to measures of cumulative noise exposure such as DNL. Figure G-7 shows the widely recognized relationship between environmental noise and the percentage of people "highly annoyed," with annoyance being the key indicator of community response usually cited in this body of research.

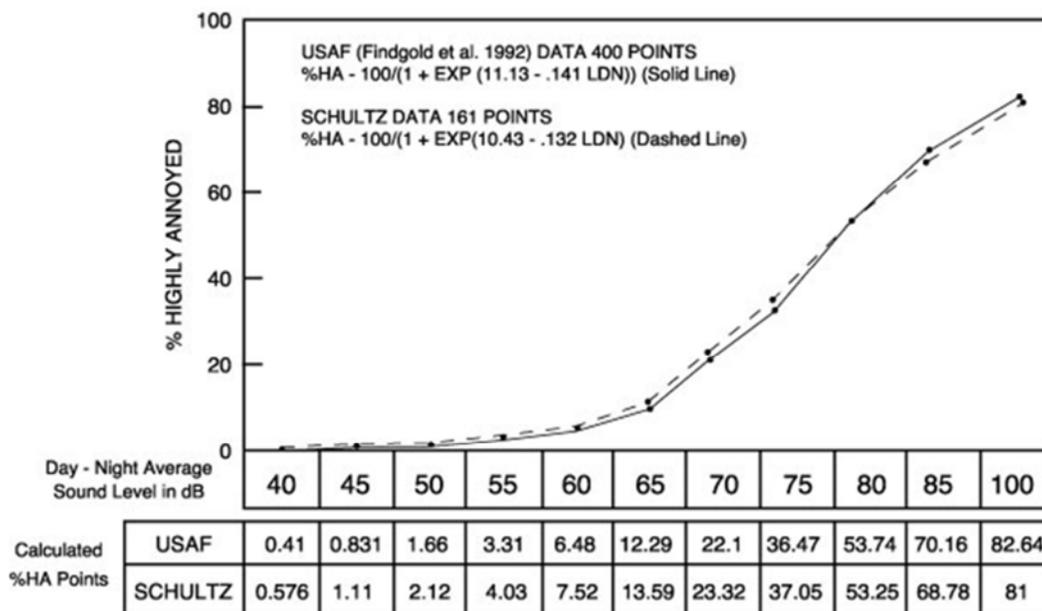


Figure G-7 Percentage of People Highly Annoyed

Source: Federal Interagency Committee on Noise. "Federal Agency Review of Selected Airport Noise Analysis Issues". August 1992. (From data provided by USAF Armstrong Laboratory). pp. 3-6.

Based on data from 18 surveys conducted worldwide, the curve indicates that at levels as low as DNL 55 dB, on the order of 3 to 4 percent of the people will still be highly annoyed, while the percentage increases more rapidly as exposure increases above DNL 65 dB.

Separate work by the EPA has shown that overall community reaction to a noise environment is also dependent on DNL. This relationship is shown in Figure G-8. Levels have been normalized to the same set of exposure conditions to permit valid comparisons between ambient noise environments. Data summarized in that figure suggest that little reaction would be expected for intrusive noise levels five decibels

below the ambient, while widespread complaints can be expected as intruding noise exceeds background levels by about five decibels. Vigorous action is likely when the background is exceeded by 20 dB.

### Community Reaction

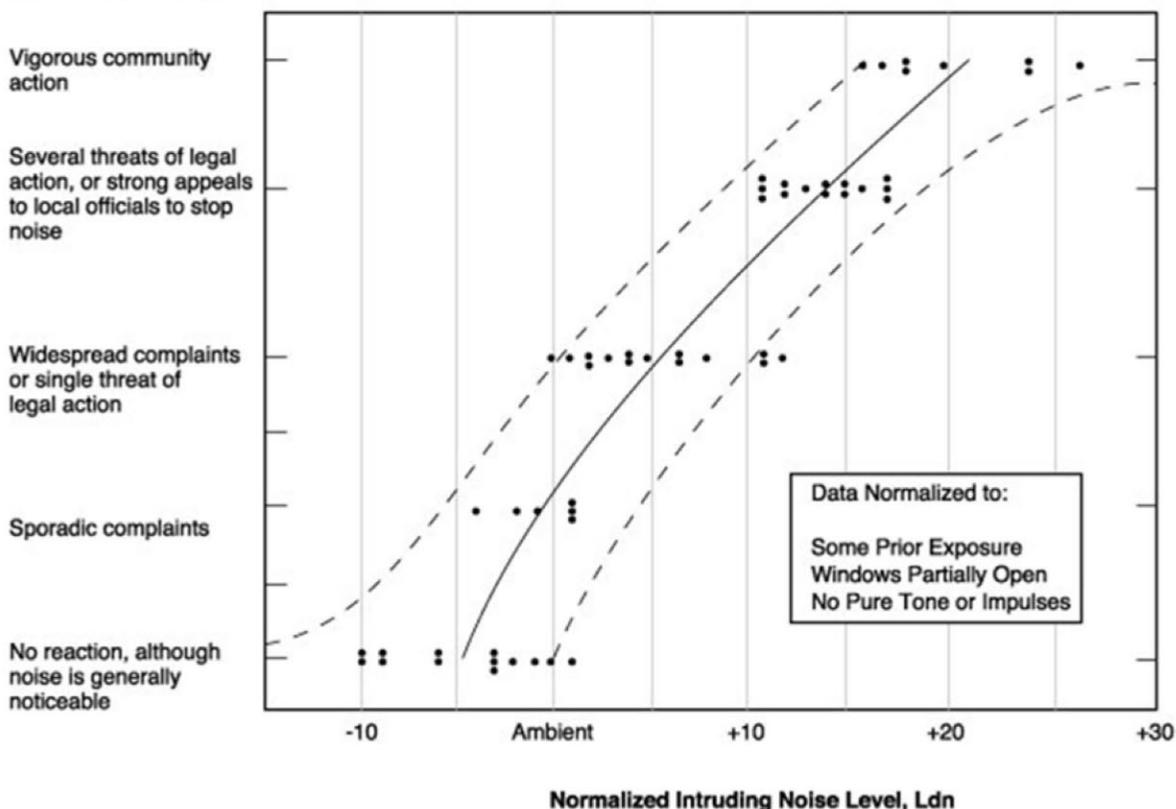


Figure G-8 Community Reaction as a Function of Outdoor DNL

Source: Wyle Laboratories, Community Noise, prepared for the U.S. Environmental Protection Agency, Office of Noise Abatement and Control, Washington, D.C. 20406, December 1971, page 63.

### G.1.4 Noise/Land Use Compatibility Guidelines

The FAA, other federal agencies, and several states have developed guidelines for identifying land use compatibility – the more noise-sensitive the land use, the lower the noise exposure should be in order to achieve compatibility. Thus, DNL estimates have two principal uses in an aviation noise analysis:

- To provide a basis for comparing existing and future noise conditions; and
- To provide a quantitative basis for identifying potential noise impacts.

Both of these functions require the application of objective criteria for evaluating noise impacts. Title 14 of the Code of Federal Regulation Part 150 (14 CFR Part 150) provides the FAA's recommended guidelines for determining noise/land use compatibility. According to these FAA guidelines, all identified land uses, even the more

noise-sensitive ones, normally are compatible with aircraft noise at DNL levels below 65 dB. The significance of this level is supported in a formal way by standards adopted by the U. S. Department of Housing and Urban Development (HUD). Part 51 of the Code of Federal Regulations indicates that areas exposed to DNL levels less than or equal to 65 dB are acceptable for HUD funding. Areas exposed to noise levels between DNL 65 dB and 75 dB are "normally unacceptable," and require special abatement measures and review. Those at DNL 75 dB and above are "unacceptable" except under very limited circumstances.