E Basics of Noise

Table of Contents

List of Figures

THIS PAGE INTENTIONALLY LEFT BLANK

E.1 Introduction

This appendix introduces the acoustic metrics that are the relevant elements comprising the Day-Night Average Sound Level (DNL) noise metric, which collectively provide a basis for evaluating and understanding a broad range of noise settings. Analysis of potential effects to the noise setting from aviation activities is conducted as directed in FAA Order 1050.1F. Specifically, the FAA uses DNL to measure cumulative noise exposure from aviation activities that occur over the course of an Average Annual Day (AAD), during a given year of interest. The DNL metric is built upon other fundamental concepts and metrics, which all help to analyze airport and airspace noise environments. The following sections provide essential reference material related to these technical concepts and metrics, including an introduction to fundamental acoustics and noise terminology (Section E.1.1), the effects of noise on human activity (Section E.1.2), community annoyance (Section E.1.3), and a discussion of currently accepted noise/land use compatibility guidelines (Section E.1.4).

E.2 Introduction to Acoustics and Noise Terminology

Noise is a complex physical quantity. Comprehension of noise exposure and the DNL metric used in environmental studies requires comprehension of the basic elements that are used to quantitatively analyze sound or noise. This chapter introduces the following acoustic metrics, all related to DNL:

- Decibel (dB)
- A-Weighted Decibel
- Maximum Sound Level (L_{max})
- Sound Exposure Level (SEL)
- Equivalent Sound Level (L_{eq})
- Day-Night Average Sound Level (DNL)

E.3 The Decibel (dB)

All sounds come from a sound source (e.g., 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 among these pressures. Therefore, the concept of sound pressure level (SPL) is employed to better match how humans hear this sound energy, compressing the total range of sound pressures to a more meaningful range. SPL is a measurement of the sound pressure from a given noise source, compared to a standard reference value (typically the quietest sound that a young person with good hearing can detect).

SPL is measured and expressed in terms of decibels (dB). SPL is a logarithm 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 (i.e., the quietest sound we can hear). After logarithmic conversion of sound pressure to SPL, the quietest sounds we can hear (i.e., reference pressure) have SPLs of approximately zero (0) decibels, while the loudest sounds we hear without pain have SPLs of about 120 dB. Most sounds in our daily environment have SPLs from 30 to 100 dB.

Decibels are logarithmic quantities and do not compound like common numerical values. For example, if two sound sources each produce 100 dB and are operating concurrently, they would produce only 103 dB, not 200 dB as we might expect. Four equal sources at 100 dB operating simultaneously would result in a total sound pressure level of 106 dB. In fact, as the number of equal sources doubles, SPL rises only three (3) decibels.

If one source is much louder than another is, the two sources together will produce the same SPL (and sound to our ears) as if the louder source were operating alone. For example, a 100 dB source plus an 80 dB source produces 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 SPL.

People hear SPL changes according to the following rules of thumb: (1) generally, a change of 1 dB or less in a given SPL is 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.

E.4 A-Weighted Decibel

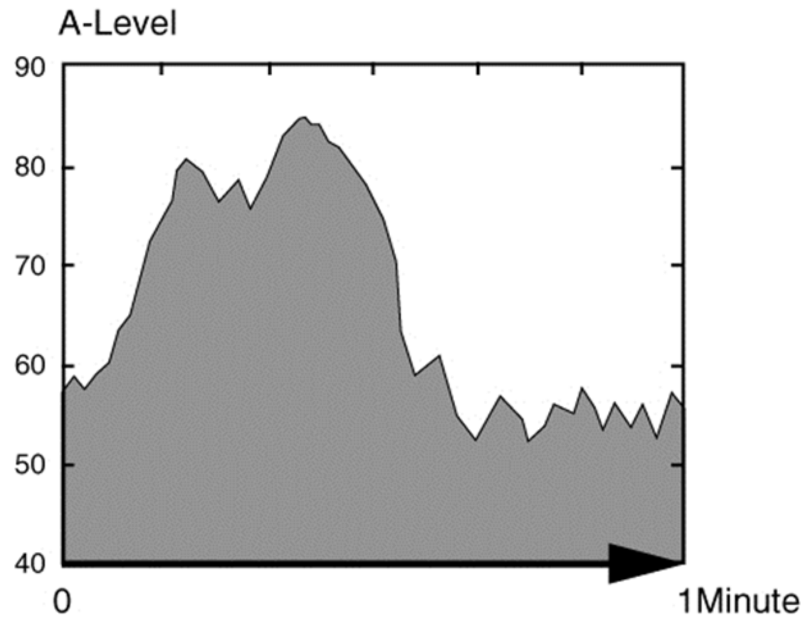
Frequency (i.e., pitch), another important characteristic of sound, is the rate of repetition of the sound pressure oscillations as they reach our ears, expressed in units known as Hertz (Hz). The human ear does not respond equally to identical noise levels at different frequencies. The normal frequency range of hearing for most people extends from a low of approximately 20 Hz to a high of 10,000 to 20,000 Hz. However, people are most sensitive to sounds in the voice range, between approximately 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 human response to environmental noise is "A-weighting" (i.e., the "A-filter") and the resultant noise level is called the A-weighted sound level. A-weighting significantly de-emphasizes those parts of the frequency spectrum from a noise source that occurs both at lower frequencies (below 500 Hz) and at very high frequencies (above 10,000 Hz) that people do not hear 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." Due to its correlation with human hearing, the A-weighted level has been adopted as the basic measure of environmental noise by the EPA, and by nearly every other Federal and state agency concerned with community noise.

E.5 Maximum A-Weighted Noise Level (L_{max})

A-weighted sound levels vary with time. For example, as an aircraft approaches, the sound level increases, 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 Lmax. Figure E.1-1 illustrates this concept showing an Lmax of approximately 85 dB.

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



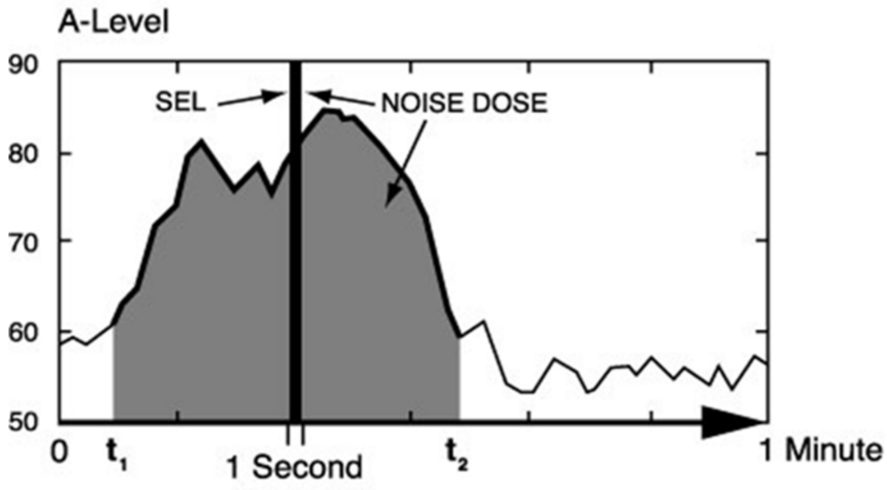
Source: HMMH, 2013.
Prepared by: ATAC Corporation, November 2017.

The maximum level describes only one dimension of an event but provides no information about 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 perceived as much more annoying. To account for this deficiency, the Sound Exposure Level metric is used.

E.6 Sound Exposure Level (SEL)

Sound Exposure Level (SEL), the most frequently used measure of noise exposure for an individual aircraft noise event, measures the total noise energy produced during an event, from the time when the A-weighted sound level first exceeds a threshold (normally just above the background or ambient noise) to the time that it again drops below the threshold. To allow comparison of noise events with very different durations, SEL "normalizes" the duration in every case to one second. SEL is expressed as the steady noise level with just a one-second duration, which includes the same amount of noise energy as the actual longer duration, time-varying noise. In other words, SEL "squeezes" the entire noise event into one second. Figure E.1-2 depicts this transformation, with the shaded area representing 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 E-2 Sound Exposure Level



Source: HMMH, 2013.
Prepared by: ATAC Corporation, November 2017.

Because the SEL is normalized to one second, its value will always be larger than the Lmax for an event longer than one second will. In this case, the SEL is 90 dB and the Lmax is approximately 85 dB. For most aircraft overflights, the SEL is normally approximately 7 to 12 dB higher than Lmax. Because SEL considers duration, longer exposure to relatively slow, quieter aircraft, such as propeller models, can yield the same or higher SEL values than a shorter duration 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 DNL.

E.7 Day-Night Average Sound Level (DNL)

FAA requires that airports use a more complex measurement of noise exposure than either a single, peak event metric like Lmax or single event total noise energy metric like SEL. Neither of these metrics would adequately characterize cumulative noise exposure during an AAD, thus requiring development of the DNL noise metric. Based on the following considerations, the EPA has identified DNL as the most appropriate means of evaluating airport noise:

1. The measure should be applicable to the evaluation of pervasive long-term noise in various defined areas, under various conditions, over long periods.
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.

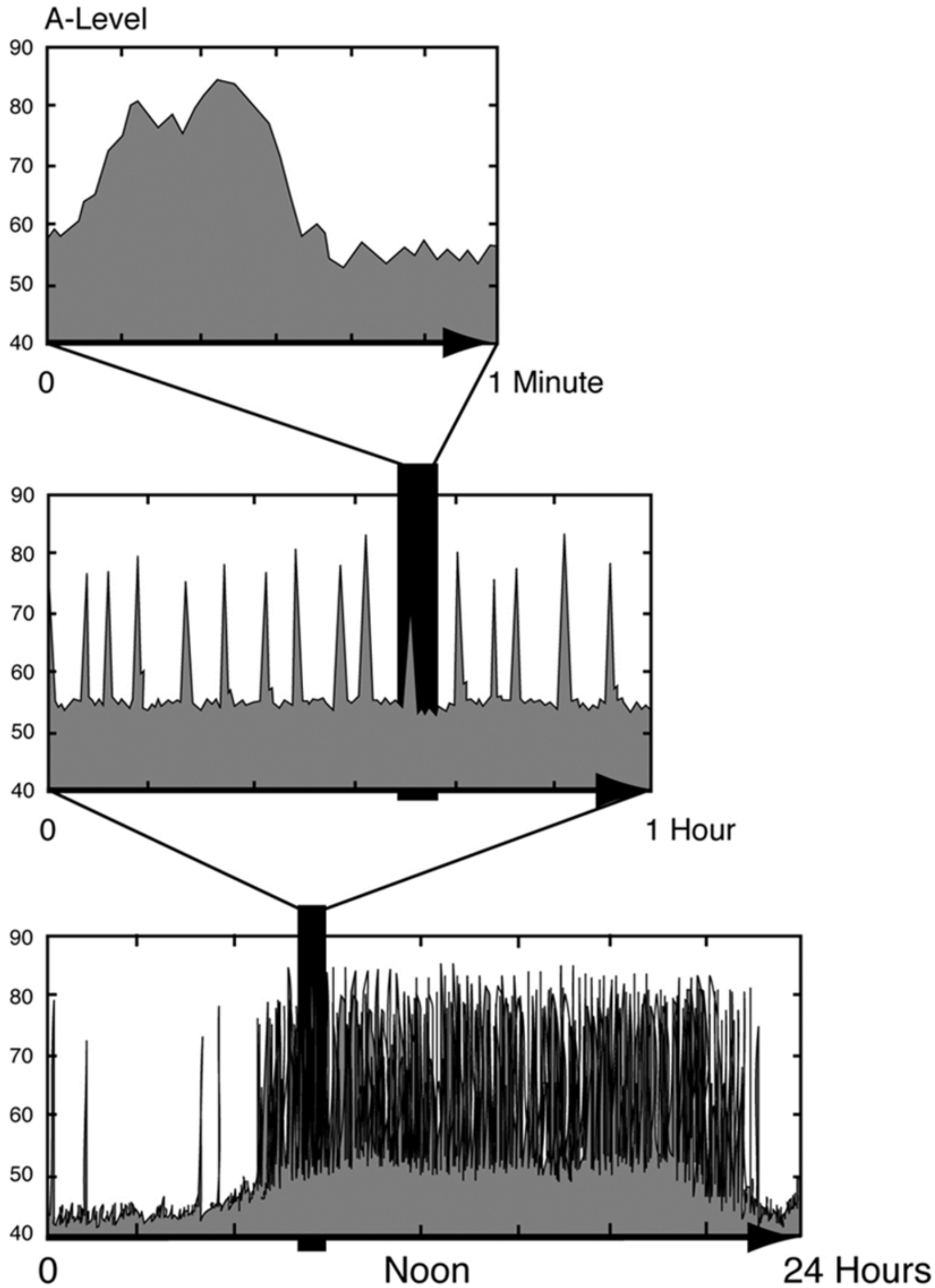
7. The measure should lend itself to small, simple monitors, which can be left unattended in public areas for long periods.

The FAA and most other Federal agencies have formally adopted DNL when evaluating effects (primarily community annoyance) from aircraft operations in or near an airport.

The DNL metric represents noise as it occurs over a 24-hour period, with one important exception: DNL treats noise occurring at night differently from daytime noise. In determining DNL, the metric assumes that the A-weighted levels occurring at night (defined as 10 p.m. to 7 a.m.) are 10 dB louder than they actually are. This 10 dB increase is applied to account for the fact that there is a 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.

The manner by which these metrics build upon each other is illustrated in Figure E.1-3. A single event, peak (Lmax or instantaneous) sound pressure level is transformed into a noise exposure metric (SEL) that accounts for and allows comparison of the magnitude and duration of the event by describing it in terms of energy over a constant duration (1 second). Figure E.1-1 illustrates changes to A-weighted sound level occurring during a single aircraft overflight event, repeated in the top frame of Figure E.1-3. The shaded area reflects the noise dose that a listener receives during the one-minute period of the sample. The center frame of Figure E.1-3 includes this one-minute sample within a full hour. The shaded area represents the noise during that hour with sixteen discrete noise events, each producing a 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.

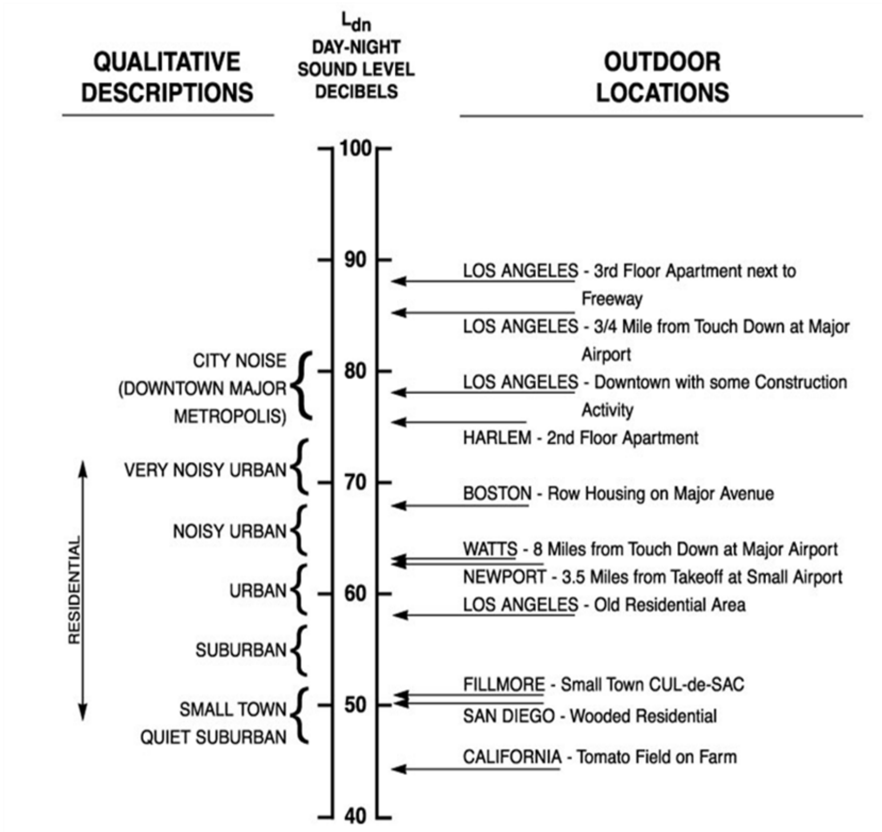
Figure E-3 Daily Noise Dose



Source: HMMH, 2013.
Prepared by: ATAC Corporation, November 2017.

While 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 delineating points of equal elevation), or by color-coded grid points representing population centroids, specific noise sensitive sites (e.g., schools or places of worship), or non-specific but uniform coverage of a large study area. Figure E.1-4 depicts typical DNL values for a variety of noise environments.

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



Source: "Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare With an Adequate Margin of Safety," P. 14, EPA, March 1974.
Prepared by: ATAC Corporation, November 2017.

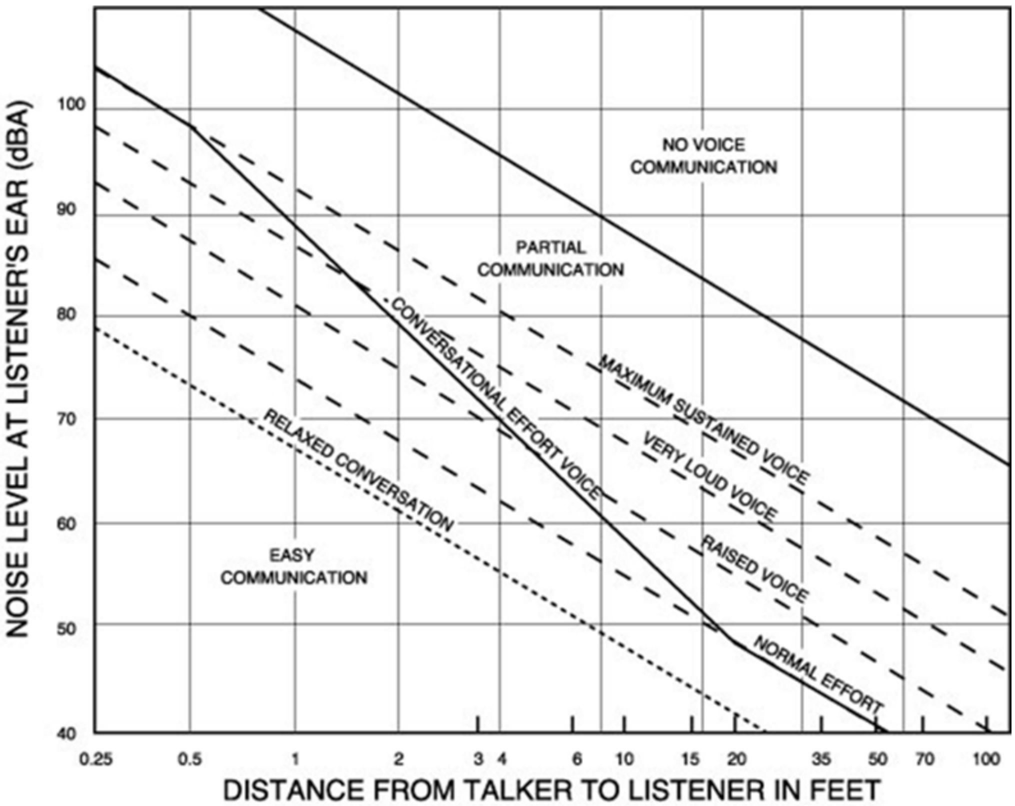
E.8 The Effects of Aircraft Noise on People

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.

E.9 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 E.1-5 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 move closer for improved intelligibility.

Figure E-5 Outdoor Speech Intelligibility



Source: "Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare With an Adequate Margin of Safety," P. D-5, EPA, March 1974.
Prepared by: ATAC Corporation, November 2017.

As indicated in the figure, "satisfactory conversation" does not always require hearing every word; 95 percent 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 percent intelligibility. Any combination of talker-listener distances and background noise that falls below the bottom line in Figure E.1-5 (thus assuring 100% intelligibility) represents an ideal environment for outdoor speech communication and is considered necessary for acceptable indoor conversation as well.

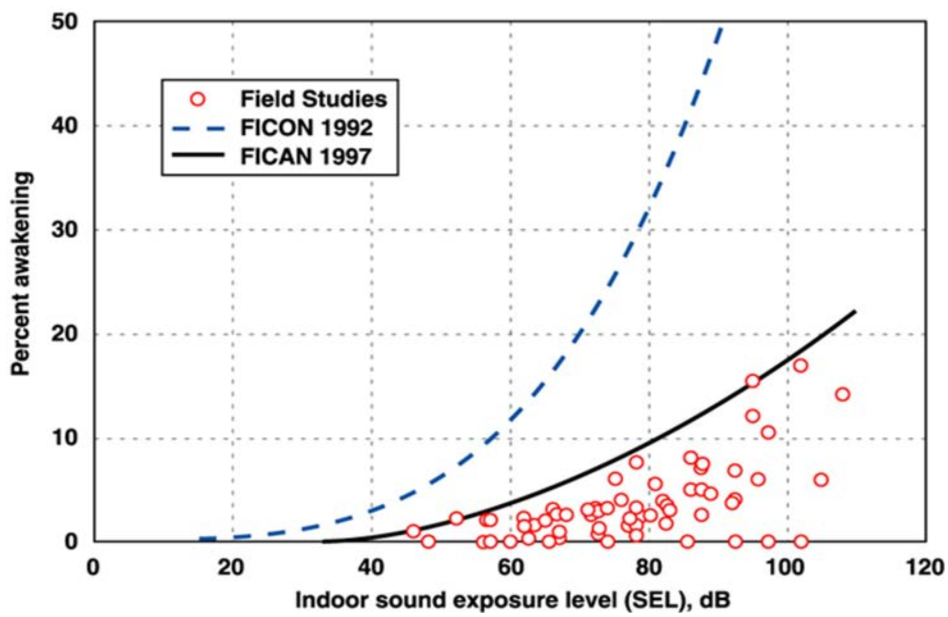
One implication of the relationships in Figure E.1-5 is that for typical communication distances of 3 to 4 ft. (1 to 1.5 m), acceptable outdoor conversations can be carried on in a normal voice as long as the background noise outdoors is less than about 65 dB. If the noise exceeds this level, as might 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 approximately 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. With windows closed, 24 dB of attenuation is typical.

E.10 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; and (3) the tendency to awaken increases with age, and other factors. Figure E.1-6 shows a recent summary of findings on the topic.

Figure E-6 Sleep Interference



Source: Effects of Aviation Noise on Awakenings From Sleep," P. 6, Federal Interagency Committee on Aviation Noise (FICAN), June 1997.
Prepared by: ATAC Corporation, November 2017.

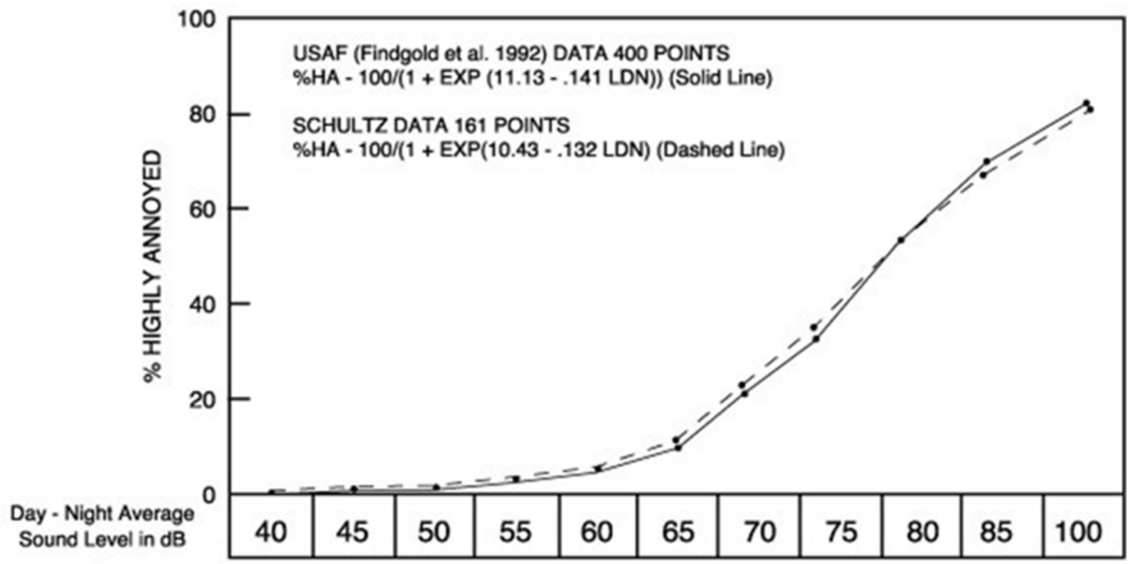
Figure E.1-6 uses indoor SEL as the measure of noise exposure as recent research supports the use of this metric in assessing sleep disruption. An indoor SEL of 80 dB results in a maximum of 10% awakening.

E.11 Community Annoyance

Numerous psychoacoustic surveys provide substantial evidence that individual reactions to noise vary widely for a given noise exposure level. However, research has confirmed that a community's aggregate response is generally predictable and relates reasonably well to measures of cumulative noise exposure such as DNL. Figure E.1-7 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.

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

Figure E-7 Percentage of People "Highly Annoyed"

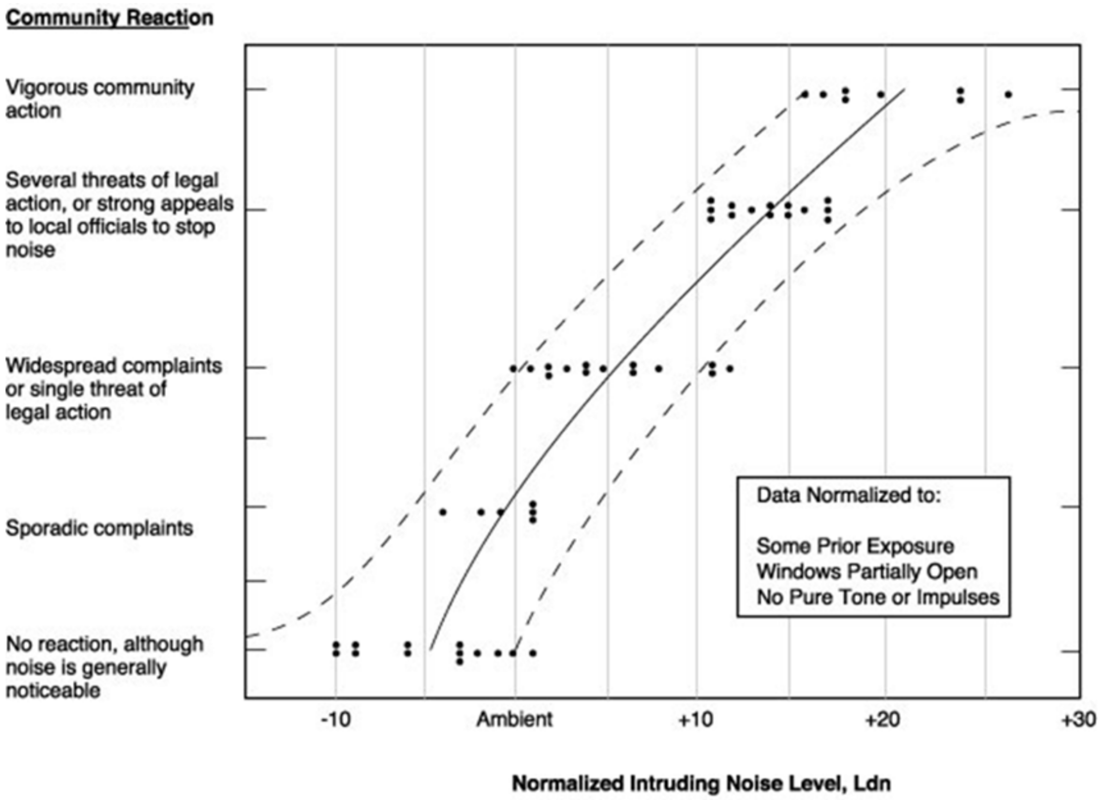


Calculated %HA Points											
USAF	0.41	0.831	1.66	3.31	6.48	12.29	22.1	36.47	53.74	70.16	82.64
SCHULTZ	0.576	1.11	2.12	4.03	7.52	13.59	23.32	37.05	53.25	68.78	81

Source: "Federal Agency Review of Selected Airport Noise Analysis Issues," Pp. 3-6, Applied Using Data Provided by USAF Armstrong Laboratory, FICAN, August 1992.
Prepared by: ATAC Corporation, November 2017.

Separate work by the EPA has shown that overall community reaction to a noise environment is also dependent on DNL, as depicted in Figure E.1-8. 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 5 dB below 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.

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



Source: EPA, Office of Noise Abatement and Control, "Community Noise," P. 63, Wyle Laboratories, December 1971
Prepared by: ATAC Corporation, November 2017.

E.12 Noise/Land Use Compatibility Guidelines

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

- Provides a basis for comparing existing and future noise conditions
- Provides a quantitative basis for identifying potential noise impacts

Both of these functions require the application of objective criteria for evaluating noise impacts. Code of Federal Regulations, Title 14, Part 150 provides the FAA's recommended guidelines for determining noise/land use compatibility. According to these FAA guidelines, all identified land uses – even those that are more noise sensitive – normally are compatible with aircraft noise at DNL levels below 65 dB. The significance of this level is formally supported in standards adopted by the U. S. Department of Housing and Urban Development (HUD). Code of Federal Regulations, Title 24, Part 51 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.

THIS PAGE INTENTIONALLY LEFT BLANK