APPENDIX A: NOISE METRICS AND ACOUSTIC TERMINOLOGY

APPENDIX A NOISE METRICS AND ACOUSTIC TERMINOLOGY

Part 150 relies largely on a measure of the cumulative noise exposure that occurs over the course of an average day during a given calendar year of interest; the metric is referred to as the Day-Night Average Sound Level (DNL). However, a variety of other measures are also helpful in explaining and understanding the complexities of an airport noise environment. This appendix 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, dBA;
- Sound Exposure Level, SEL;
- Equivalent Sound Level, L_{eq}; and
- Day-Night Average Sound Level, DNL.

A.1 The decibel, dB

All sounds come from a sound source – a musical instrument, a voice speaking, or an airplane as it flies 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. The loudest sounds that we hear without pain have about one million times more energy than the quietest sounds we hear. 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 the logarithmic quantities – logarithms of the ratio of the 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 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. A tenfold increase in the number of sources makes the sound pressure level go up 10 dB. A hundredfold increase makes the level go up 20 dB, and it takes a thousand equal sources to increase the level 30 dB!

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. When the two sources are equal, as described above, they produce a level three decibels above the sound of either one by itself.

From these basic concepts, note that one hundred 80 dB sources will produce a combined level of 100 dB; if a single 100 dB source is added, the group will produce a total sound pressure level of 103 dB. Clearly, the loudest source has the greatest effect on the total

A.2 A-weighted decibel, dBA

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 ear. Formerly expressed in cycles per second, frequency is now expressed in units known as Hertz (Hz).

Most people hear from about 20 Hz to about 10,000 to 15,000 Hz. People respond to sound most readily when the predominant frequency is in the range of normal conversation, around 1,000 to 2,000 Hz. Acousticians have developed "filters" to match our ears' sensitivity and help us to judge the relative loudness of sounds made up of different frequencies. The so-called "A" filter does the best job of matching the sensitivity of our ears to most environmental noises. Sound pressure levels measured through this filter are referred to as A-weighted levels (dBA). A-weighting significantly de-emphasizes noise at low and high frequencies (below about 500 Hz and above about 10,000 Hz) where we do not hear as well. Because this filter generally matches our ears' sensitivity, sounds having higher A-weighted sound levels are usually judged to be louder than those with lower A-weighted sound levels, a relationship which does not always hold true for unweighted levels. It is for these reasons that A-weighted sound levels are normally used to evaluate environmental noise.

Other weighting networks include the B, C, and D filters. They correspond to four different level ranges of the ear. The rarely used B-weighting attenuates low frequencies (those less than 500 Hz), but to a lesser degree than A-weighting. C-weighting is nearly flat throughout the audible frequency range, hardly de-emphasizing low frequency noise. C-weighted levels can be preferable in evaluating sounds whose low-frequency components are responsible for secondary effects such as the shaking of a building, window rattle, or perceptible vibrations. Uses include the evaluation of blasting noise, artillery fire, and in some cases, aircraft noise inside buildings.

The D-weighting network, also used only rarely, is similar to the B-weighting at low frequencies, but includes a significant amplification of the sound (up to about 10 dB) in the 2,000 to 8,000 Hz range.

Figure A-1 compares these various weighting networks.

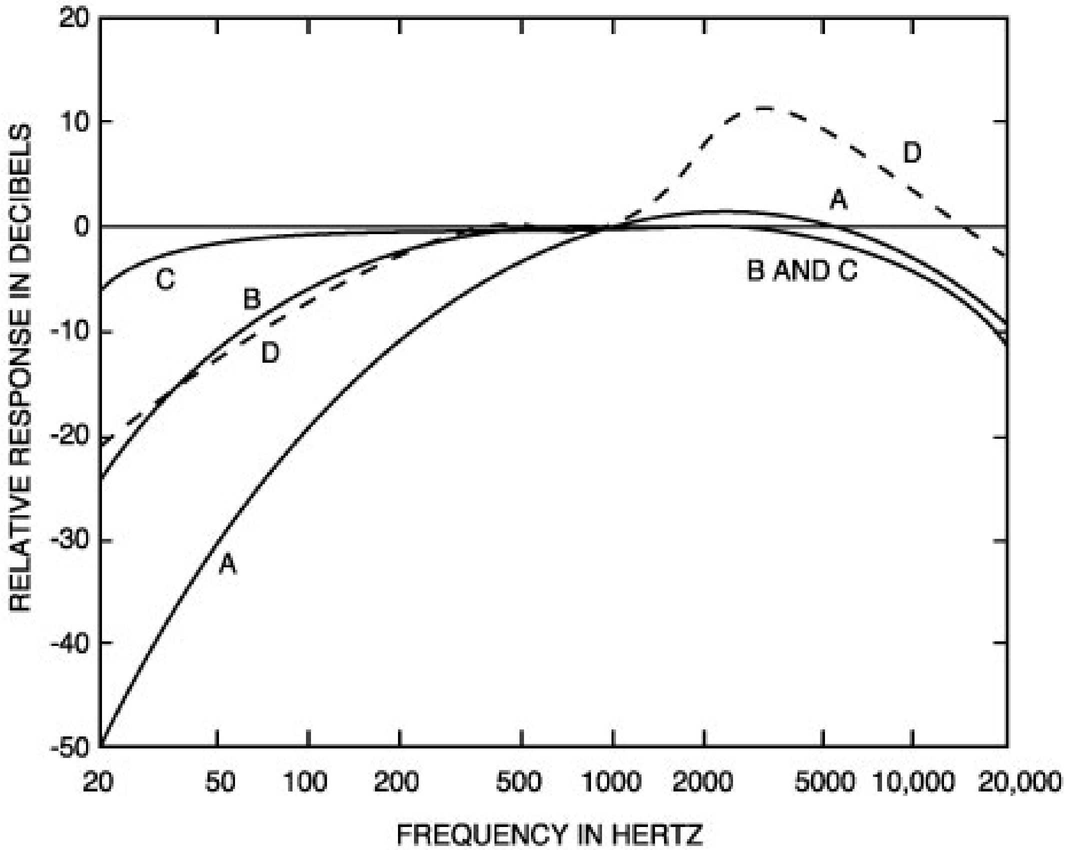


Figure A-1 Frequency-Response Characteristics of Various Weighting Networks

Source: Harris, Cyril M., editor; Handbook of Acoustical Measurements and Noise Control, (Chapter 5, "Acoustical Measurement Instruments"; Johnson, Daniel L.; Marsh, Alan H.; and Harris, Cyril M.); New York; McGraw-Hill, Inc.; 1991; p. 5.13

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. Part 150 requires airports to use A-weighted noise metrics. Figure A-2 presents typical A-weighted sound levels of several common environmental sources.

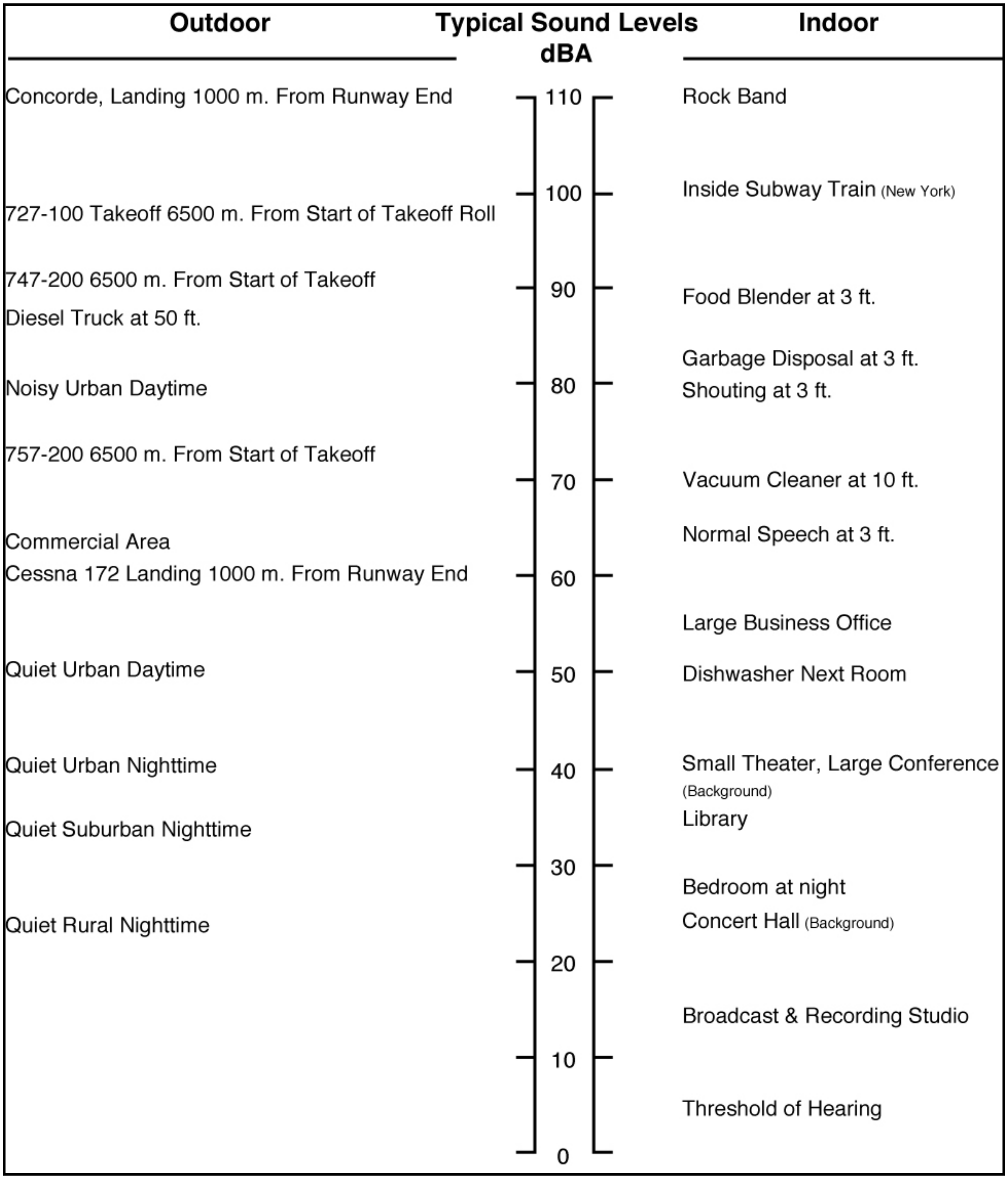


Figure A-2 Common Environmental Sound Levels, in dBA

Source: HMMH (Aircraft noise levels from FAA Advisory Circular 36-3G)

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). Figure A-3 illustrates this concept.

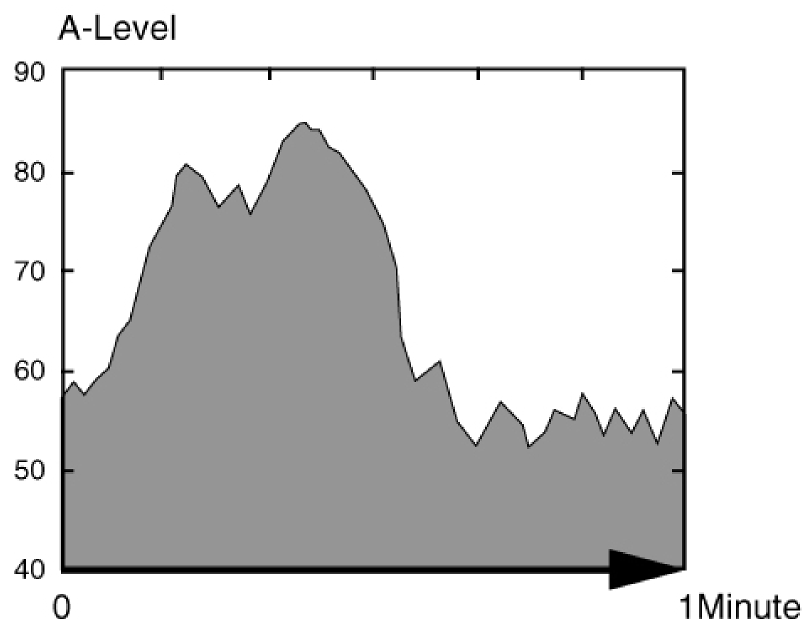


Figure A-3 Variations in the A-Weighted Sound Level Over Time

Source: HMMH

A.2.1 Maximum A-weighted noise level, L_{max}

The variation in noise level over time often makes it convenient to describe a particular noise "event" by its maximum sound level, abbreviated as $L_{max.}$ In the figure above, it is approximately 85 dBA.

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 next measure corrects for this deficiency.

A.2.2 Sound Exposure Level, SEL

The most frequently used measure of noise exposure for an individual aircraft noise event (and the measure that Part 150 specifies for this purpose) 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 A-4 depicts this transformation. The shaded area represents the energy included in an SEL measurement for the noise event, where the threshold is set to 60 dBA. 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.

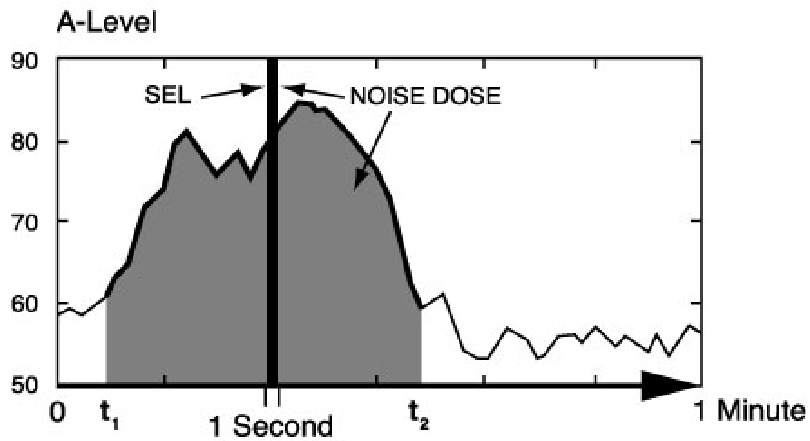


Figure A-4 Sound Exposure Level
Source: HMMH

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 dBA. 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, a long duration flyby in relatively quiet aircraft, such as propeller models, can have the same or higher SEL than louder but faster planes, such as corporate jets.

Aircraft noise models use SEL as the basis for computing exposure from multiple events. The original Part 150 study used SEL contours as a basis for analyzing the single event benefits of noise abatement measures. This study will also study SEL contours in this manner.

A.3 Equivalent Sound Level, L_{eq}

The L_{max} and SEL quantify the noise associated with individual events. The remaining metrics in this section describe longer-term cumulative noise exposure that can include many events.

The Equivalent Sound Level (L_{eq}), is a measure of exposure resulting from the accumulation of A-weighted sound levels over a particular period of interest; for example, an hour, an eight hour school day, nighttime, or a full 24-hour day. Because the length of the period can differ, the applicable period should always be identified or clearly understood when discussing the metric. Such durations are often identified through a subscript, for example $L_{eq(8)}$ or $L_{eq(24)}$.

L_{eq} is equivalent to the constant sound level over the period of interest that contains as much sound energy as the actual varying level. This is illustrated in Figure A-5. Both the solid and striped shaded areas have a one-minute L_{eq} value of 76 dB. It is important to recognize, however, that the two signals (the constant one and the time-varying one) would sound very different in real life. Also, be aware that the "average" sound level suggested by L_{eq} is not an arithmetic value, but a logarithmic, or "energy-averaged" sound level. Thus, loud events dominate L_{eq} measurements.

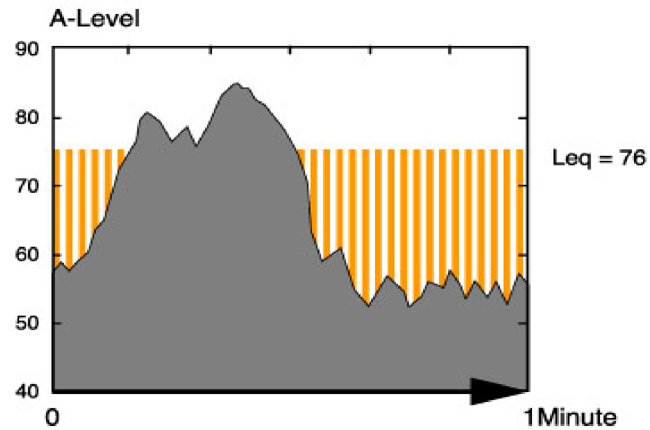


Figure A-5 Example of a One Minute Equivalent Sound Level

Source: HMMH

In airport noise studies, L_{eq} is often presented for consecutive one-hour periods to illustrate how the exposure rises and falls throughout a 24-hour period, and how individual hours are affected by unusual activity, such as rush hour traffic or a few loud aircraft.

A.4 Day-Night Average Sound Level, DNL

Part 150 requires that airports use a slightly more complicated measure of noise exposure to describe cumulative noise exposure during an average annual day: the Day-Night Average Sound Level, 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, September 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 Federal Interagency Committee on Noise (FICON) reaffirmed the appropriateness of DNL in 1992. The FICON summary report stated; "There are no new descriptors or metrics of sufficient scientific standing to substitute for the present DNL cumulative noise exposure metric."

In simple terms, DNL is the average noise level over a 24-hour period except that noises occurring at night (defined as 10:00 p.m. through 7:00 a.m.) are artificially increased by 10 dB. This weighting reflects the added intrusiveness of nighttime noise events attributable to the fact that community background noise levels decrease at night.

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 noise studies are based on computer-generated DNL estimates, depicted in terms of equal-exposure noise contours (much as topographic maps have contours of equal elevation). Part 150 requires that the 65, 70 and 75 dB DNL contours be modeled and depicted. Figure A-6 depicts typical DNL values for a variety of noise environments.

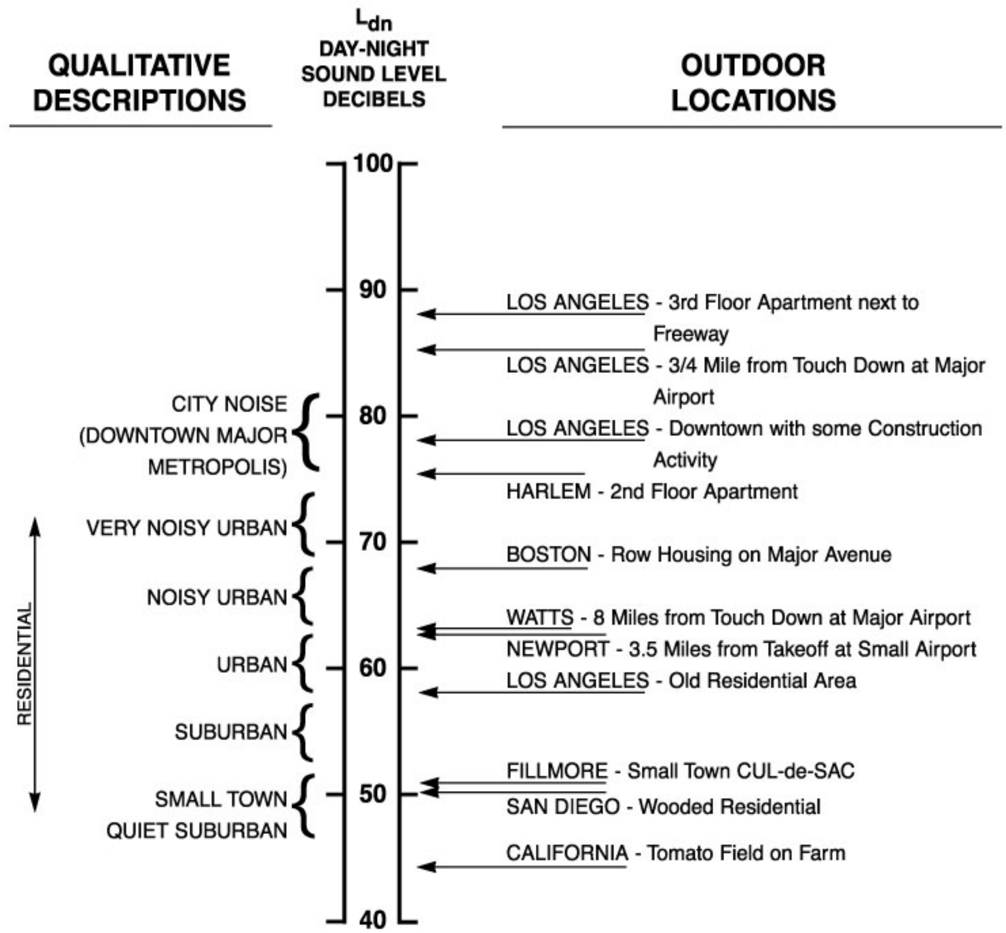


Figure A-6 Examples of Day-Night Average Sound Levels, DNL

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

A.5 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, it can disrupt classroom activities in schools, and it can disrupt sleep. Relating these effects to specific noise metrics helps in the understanding of how and why people react to their environment.

A.5.1 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 A-7 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.

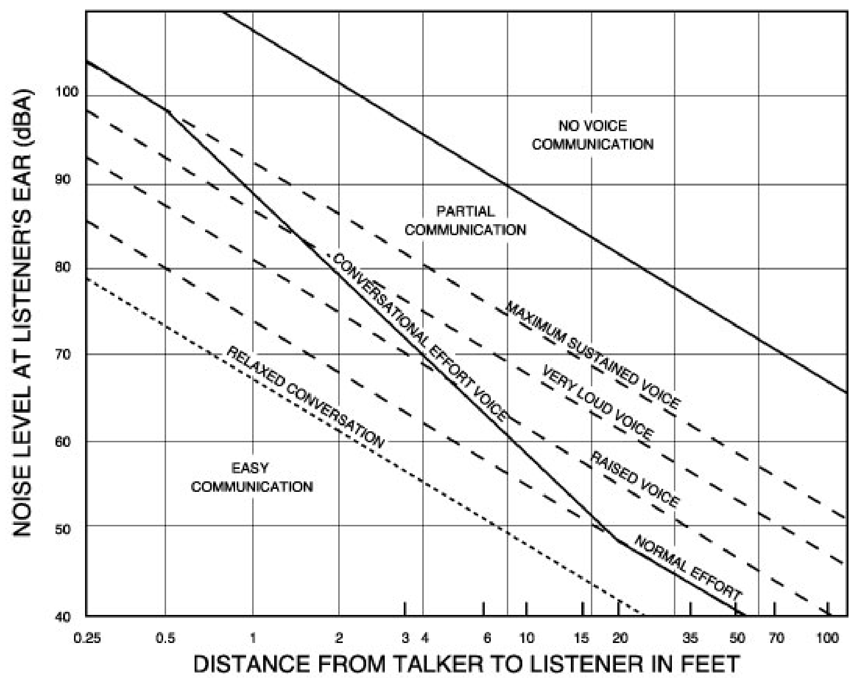


Figure A-7 Outdoors Speech Intelligibility

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 require generally require closer to 100% intelligibility. Any combination of talker-listener distances and background noise that falls below the bottom line in the figure (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 A-7 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 dBA. 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 dBA. With windows partly open, Florida housing typically provides about 12 dBA of interior-to-exterior noise level reduction. Thus, if the outdoor sound level is 60 dBA 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.

A.5.2 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 A-8 shows a recent summary of findings on the topic.

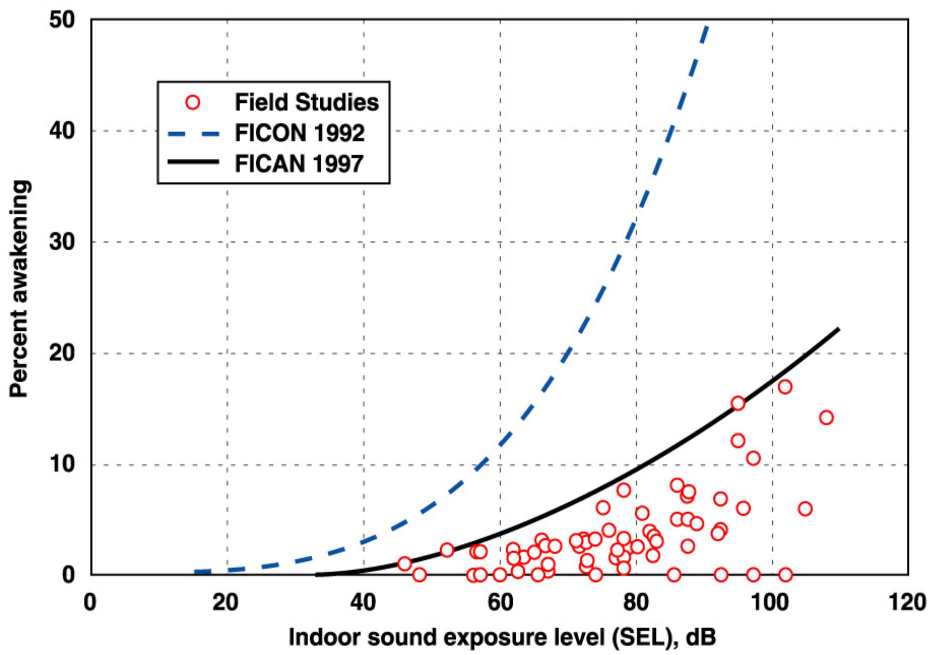


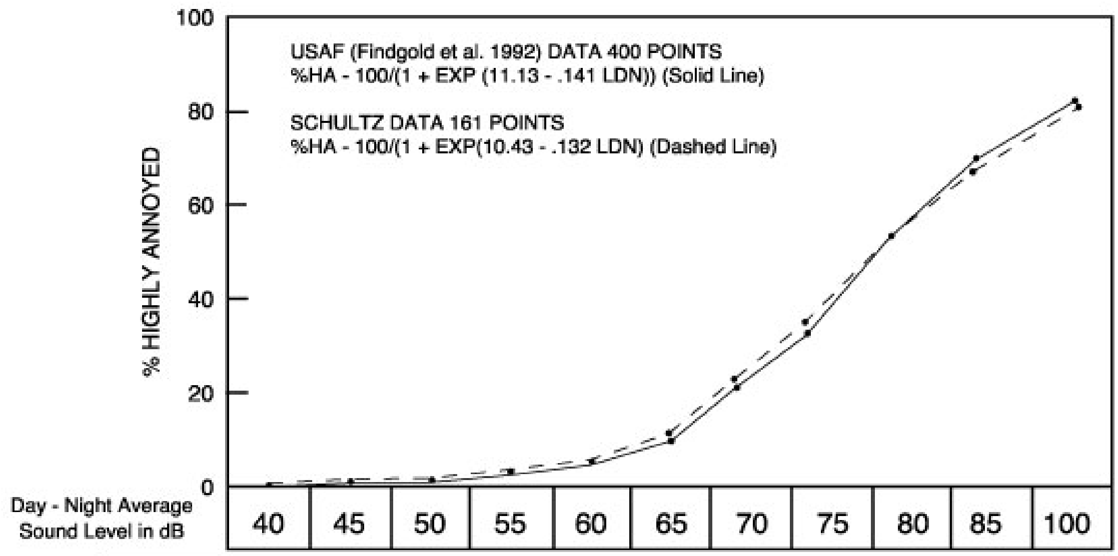
Figure A-8 Sleep Interference

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

Figure A-8 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. Assuming the typical windows-open interior-to-exterior noise level reduction of approximately 12 dB, and a typical L_{max} value for an aircraft flyover 12 dB lower than the SEL value, an interior SEL of 80 dB roughly translates into an exterior L_{max} of the same value.

A.5.3 Community Annoyance

Social survey data make it clear that individual reactions to noise vary widely for a given noise level. Nevertheless, as a group, people's aggregate response is predictable and relates well to measures of cumulative noise exposure such as DNL. Figure A-9 shows the most widely recognized relationship between environmental noise and annoyance.



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

Figure A-9 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, approximately five percent of the people will still be highly annoyed, with the percentage increasing more rapidly as exposure increases above DNL 65.

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 A-10. 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.

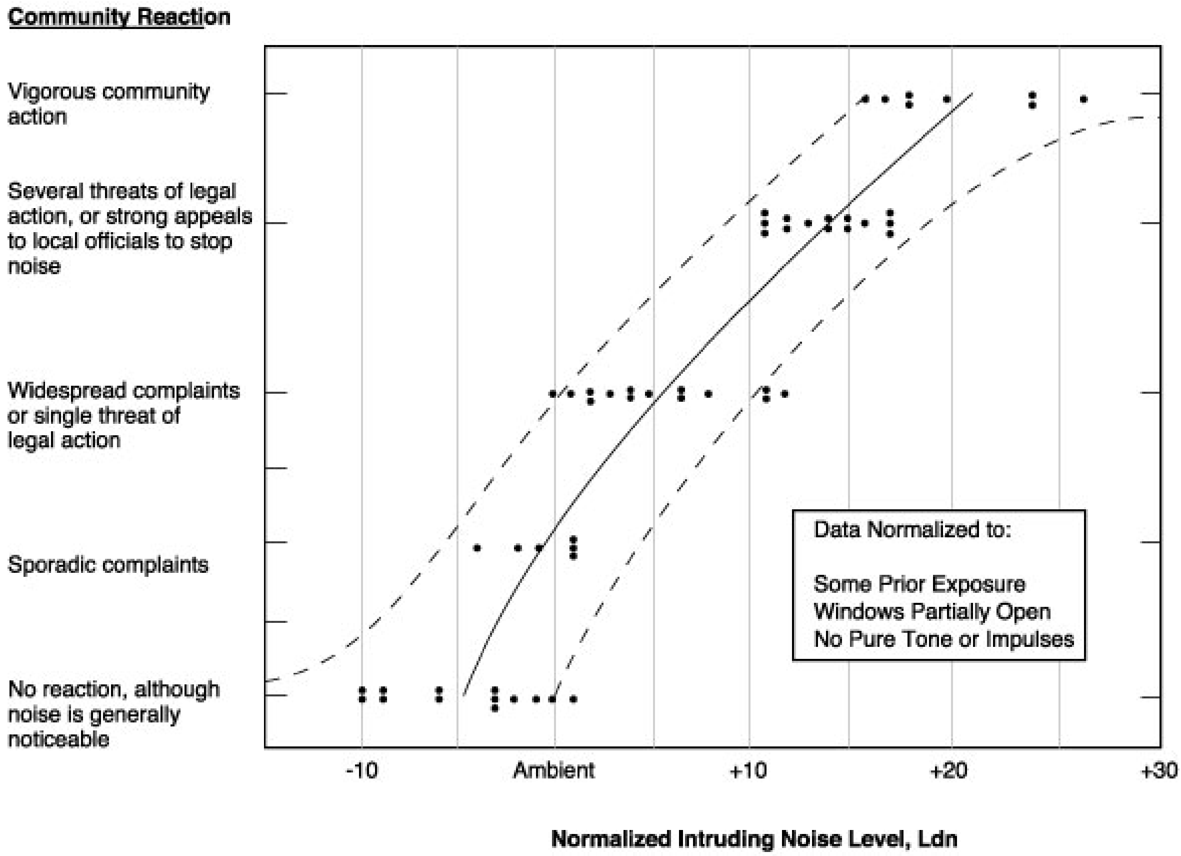


Figure A-10 Community Reaction as a Function of Outdoor DNL

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.