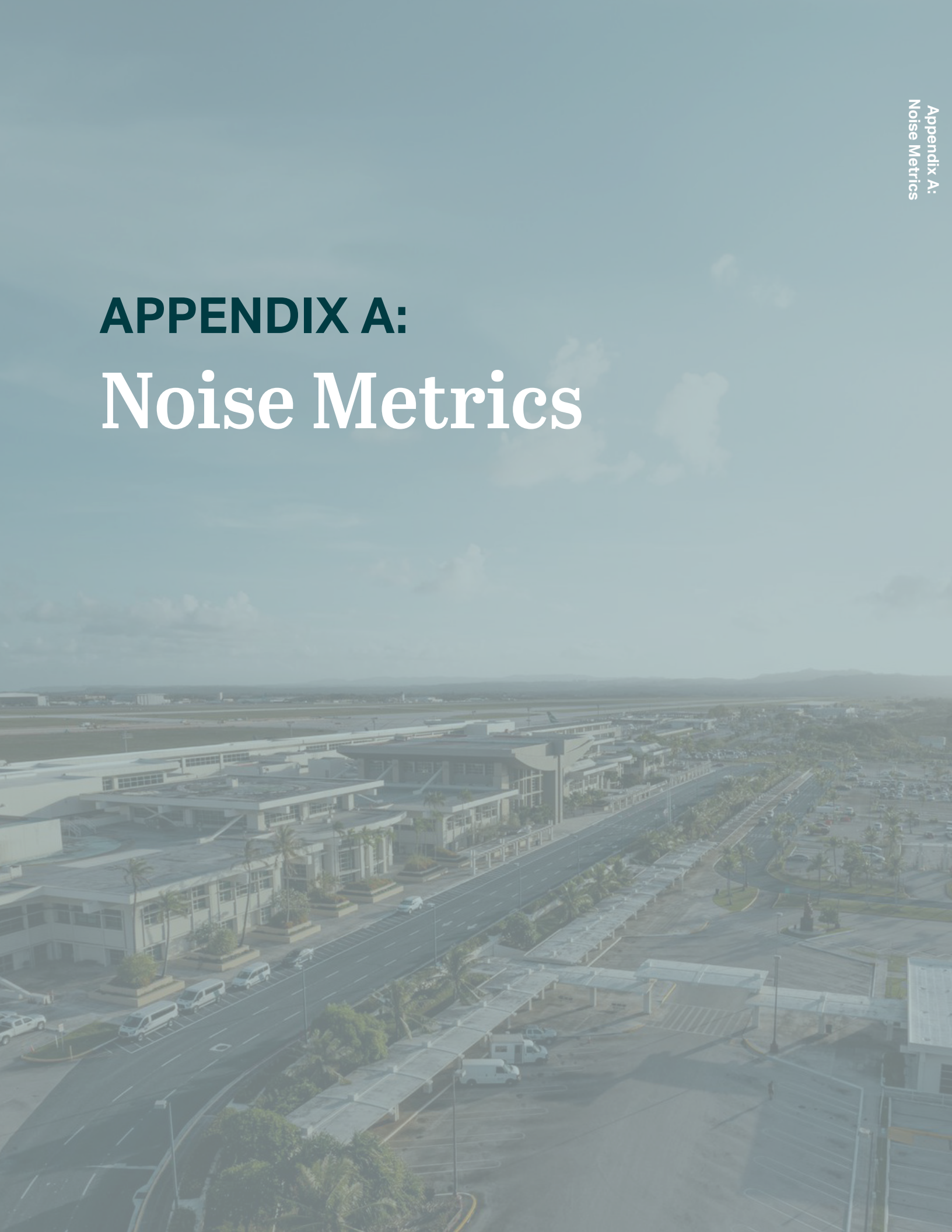
APPENDIX A:
Noise Metrics



Appendix A – Noise Metrics

1.1 Introduction

Noise is a complex physical quantity. The properties, measurement, and presentation of noise involve specialized terminology that can be difficult to understand. To assist reviewers in interpreting the complex noise metrics used in evaluating airport noise, this appendix introduces six acoustical descriptors of noise, roughly in increasing degree of complexity:

- Decibel, dB
- A-Weighted Decibel, dBA
- Maximum A-Weighted Sound Level, Lmax
- Sound Exposure Level, SEL
- Equivalent A-Weighted Sound Level, Leq
- Day-Night Average Sound Level, DNL

These noise metrics form the basis for most noise analyses conducted at U.S. airports.

1.2 Decibel, dB

All sounds come from a sound source – a musical instrument, a voice speaking, an airplane passing 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. The ear detects these oscillating pressures interpreting it as “sound.”

Our ears are sensitive to a wide range of sound pressures. Although the loudest sounds that we hear without pain have about one million times more energy than the quietest sounds we hear, 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.

Sound pressure level (SPL) is measured in decibels (dB). Decibels are logarithms of a ratio, the numerator being the pressure of the sound source of interest, and the denominator being the reference pressure (equivalent to the quietest sound that an average healthy young adult can hear):

$$Sound\ Pressure\ Level\ (SPL) = 20 * Log\left(\frac{P_{source}}{P_{reference}}\right) dB$$

The logarithmic conversion of sound pressure to sound pressure level means that the quietest sound that we can hear (the reference pressure) has a sound pressure level of about 0 dB, while the loudest sounds that we hear without pain have sound pressure levels of about 120 dB. Most sounds in our day-to-day environment have sound pressure levels on the order of 30 to 100 dB.

Because decibels are logarithmic, combining decibels is unlike common arithmetic. For example, if two sound sources each produce 100 dB and they are then operated together, they produce 103 dB – not the 200 dB we might expect. Four equal sources operating simultaneously produce another 3 dB of noise, resulting in a total sound pressure level of 106 dB. For every doubling of the number of equal sources, the sound pressure level goes up another 3 dB.

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 noise source is much louder than another, the two sources together will produce virtually the same sound pressure level (and sound to our ears) as the louder source alone. For example, a 100 dB source plus an 80 dB source produce approximately 100 dB when operating together (actually, 100.04 dB). 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 such that, when the two sources are equal, as described above, they produce a level 3 dB above the sound of either one by itself.

Conveniently, people also hear or interpret sound pressure in a logarithmic fashion. Two useful rules of thumb to remember when comparing sound pressure levels are (1) a 6 to 10 dB increase is generally perceived to be about a

doubling of loudness, and (2) changes in sound pressure level of less than about 3 dB are not readily detectable outside of a laboratory environment.

1.3 A-Weighted Decibel, dBA

An important characteristic of sound is its frequency, or "pitch." This is the per-second rate of repetition of the sound pressure oscillations as they reach our ear, expressed in units known as Hertz (Hz).

When analyzing the total noise of any source, acousticians often break the noise into frequency bands to determine how much is low-frequency noise, how much is middle-frequency noise, and how much is high-frequency noise. This breakdown is important for two reasons:

- Our ear is better equipped to hear mid and high frequencies and is less sensitive to lower frequencies. Thus, we find mid- and high-frequency noise more annoying.
- Engineering solutions to a noise problem are different for different frequency ranges. Low-frequency noise is generally harder to control.

The normal frequency range of hearing for most people extends from a low of about 20 Hz to a high of about 10,000 to 15,000 Hz. People respond to sound most readily when the predominant frequency is in the range of normal conversation, typically around 1,000 to 2,000 Hz. The acoustical community has defined several “filters,” which approximate this sensitivity of our ear and thus, help us to judge the relative loudness of various sounds made up of many different frequencies.

The "A" filter (or “A-weighting”) does this best for most environmental noise sources. A-weighted sound levels are measured in decibels, just like unweighted. To avoid ambiguity, A-weighted sound levels should be identified as such (e.g., "an A-weighted sound level of 85 dB") or in an abbreviated form (e.g., "a sound level of 85 dBA") where the "A" indicates the sound level has been A-weighted.

The Federal Aviation Administration (FAA) requires the use of A-weighted sound levels for measuring, modeling, describing, and assessing aircraft sound levels (and sound levels from most other transportation and environmental sources). **Figure A-1** depicts A-weighting adjustments to sound from approximately 20 Hz to 10,000 Hz.

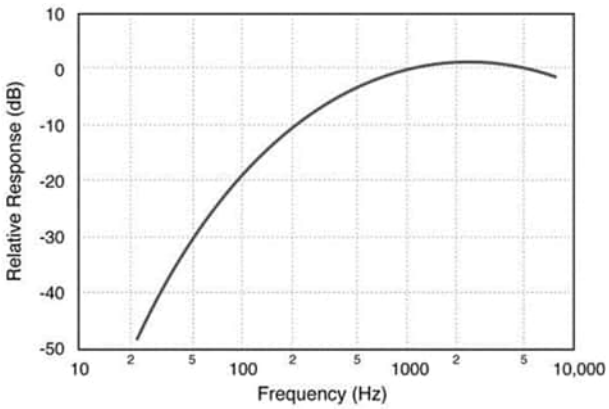


Figure A-1. Frequency-Response Characteristics of A-Weighted Sound Levels

The A-weighted filter significantly de-emphasizes those parts of the total noise at lower and higher frequencies (below about 500 Hz and above about 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 where we hear quite easily. 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 otherwise might not be true. It is for this reason that acousticians normally use A-weighted sound levels to evaluate environmental noise sources.

Figure A-2 depicts representative A-weighted sound levels for a variety of common sounds.

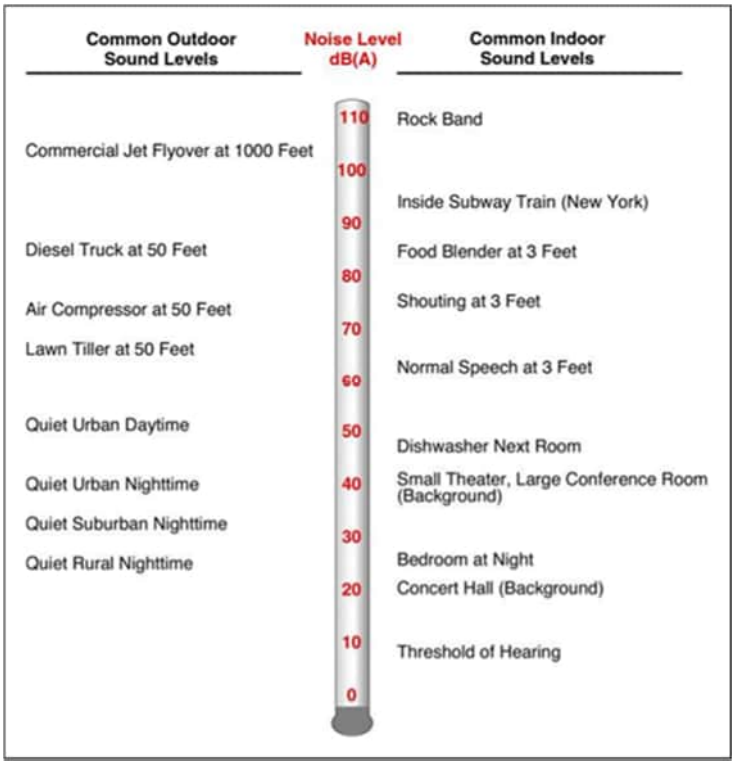


Figure A-2. Representative A-Weighted Sound Levels

A.4 Maximum A-Weighted Sound Level, Lmax

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, the wind blows, or a vehicle passes by). This is illustrated in **Figure A-3**.

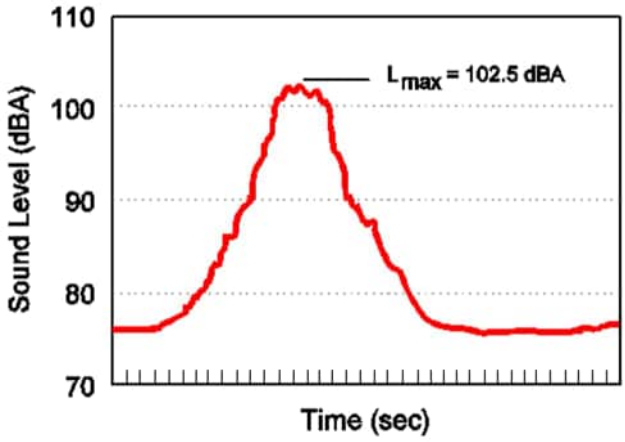


Figure A-3. Variation in the A-Weighted Sound Level over Time

Because of this variation, it is often convenient to describe a particular noise "event" by its maximum sound level, abbreviated as L_{max} (or LA_{max}, if the decibel abbreviation dB is used). In **Figure A-3**, the L_{max} is approximately 102.5 dB.

While the maximum level is easy to understand, it suffers from a serious drawback when used to describe the relative "noisiness" of an event such as an aircraft flyover; i.e., it describes only one dimension of the event and provides no information on the event's overall, or cumulative, noise exposure. In fact, two events with identical maximum levels 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 sections introduce two closely related measures that account for this concept of a noise "dose," or the cumulative exposure associated with an individual "noise event" such as an aircraft flyover.

A.5 Sound Exposure Level, SEL

The most commonly used measure of cumulative noise exposure for an individual noise event, such as an aircraft flyover, is the Sound Exposure Level, or SEL. SEL is a summation of the A-weighted sound energy over the entire duration of a noise event. SEL expresses the accumulated energy in terms of the one-second-long steady-state sound level that would contain the same amount of energy as the actual time-varying level.

In simple terms, SEL "compresses" the energy into a single second. **Figure A-4** depicts this compression.

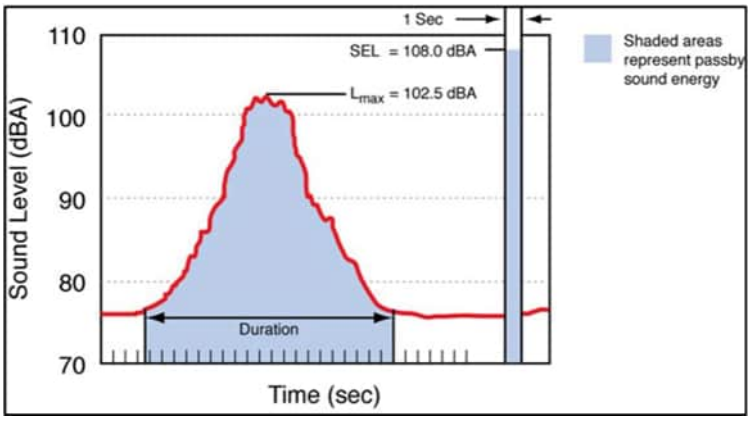


Figure A-4. Graphical Depiction of Sound Exposure Level

Note that because SEL is normalized to one second, it almost always will be higher than the event's L_{max}. In fact, for most aircraft flyovers, SEL is on the order of 5 to 12 dB higher than L_{max}. SEL provides a basis for comparing noise events that generally match our impression of their overall "noisiness," including the effects of both duration and level; the higher the SEL, the more annoying a noise event is likely to be. **Figure A-5** shows a comparison of two different noise events: the first has a shorter duration but a greater maximum level. More noise energy is contained in the second event, which has a higher SEL value.

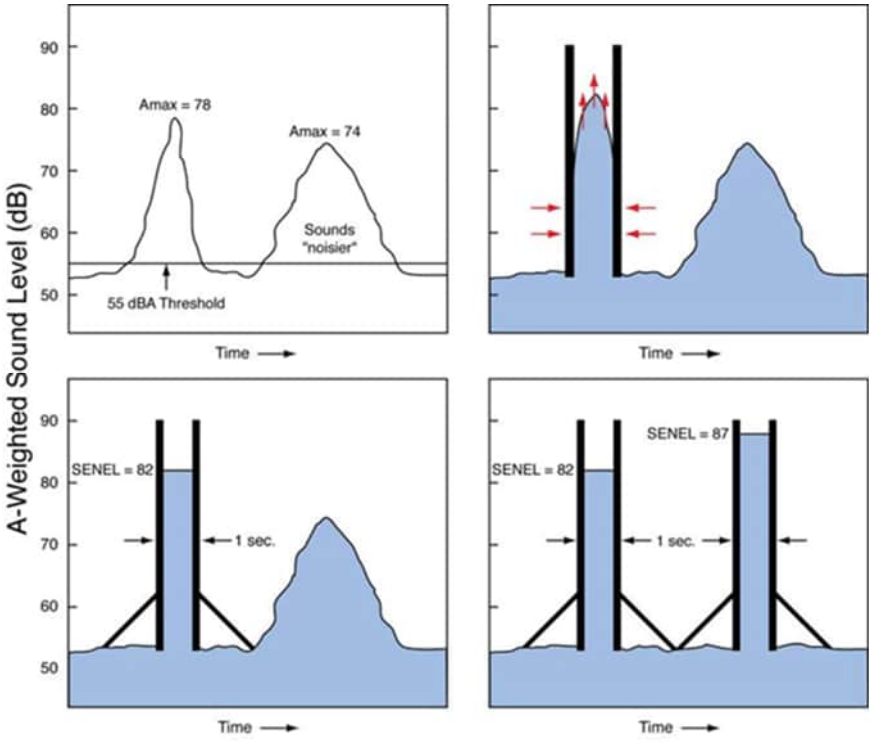


Figure A-5. Graphical Comparison of SEL for Two Noise Events with Different Maximums and Durations

A.6 Equivalent A-Weighted Sound Level, Leq

The Equivalent Sound Level, abbreviated L_{eq}, is a measure of the exposure resulting from the accumulation of sound levels over a particular period of interest, e.g., an hour, an eight-hour school day, nighttime, or a full 24-hour day. The applicable period should always be identified or clearly understood when discussing the metric.

L_{eq} may be thought of as a constant sound level over the period of interest that contains as much sound energy as the actual varying level. It is a way of assigning a single number to a time-varying sound level. This is illustrated in **Figure A-6**.

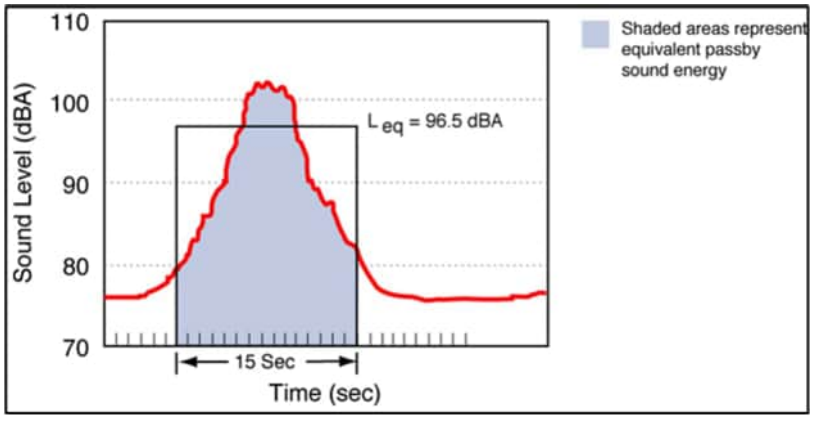


Figure A-6. Example of a One-Minute Equivalent Sound Level

In airport noise applications, L_{eq} is often presented for consecutive one-hour periods to illustrate how the hourly noise dose rises and falls throughout a 24-hour period as well as how certain hours are significantly affected by a few loud aircraft.

A.7 Day-Night Average Sound Level, DNL or Ldn

The previous sections address noise measures that account for short term fluctuations in A-weighted levels as sound sources come and go affecting the overall noise environment. The Day-Night Average Sound Level (DNL or Ldn) represents a 24-hour A-weighted noise dose. DNL is essentially equal to the 24-hour A-weighted L_{eq}, with one important adjustment: noise occurring at night—from 10 p.m. through 7 a.m.—is "factored up." The factoring up can be made in one of two ways:

- Weighting, by counting each nighttime noise contribution 10 times; e.g., if DNL is calculated by summing the SEL of aircraft operations over a 24-hour period, each nighttime operation is represented by 10 identical daytime operations.
- Penalizing, by adding 10 dB to all nighttime noise contributions; e.g., if DNL is calculated from the SEL of aircraft operations occurring over a 24-hour period, 10 dB are added to the SEL values for nighttime operations.

The 10 dB adjustment accounts for our greater sensitivity to nighttime noise and the fact lower ambient levels at night tend to make noise events, such as aircraft flyovers, more intrusive. **Figure A-7** depicts this adjustment graphically.

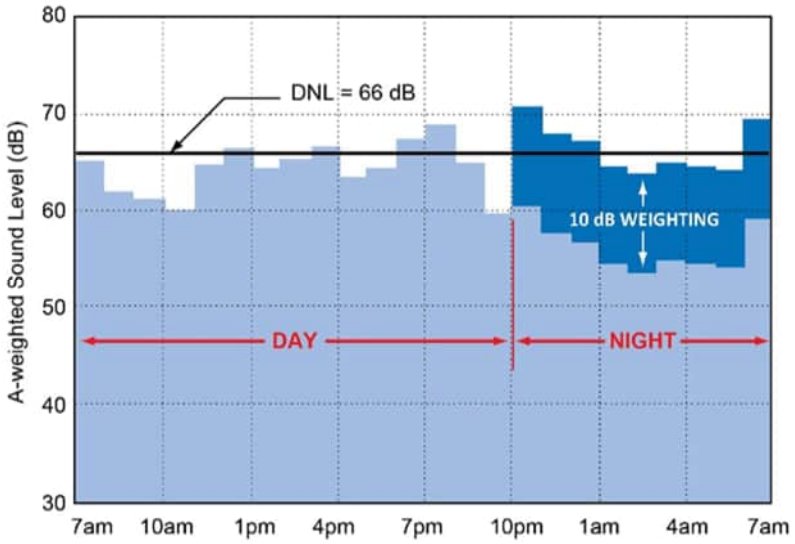


Figure A-7. Example of a Day-Night Average Sound Level Calculation

Most aircraft noise studies use computer-generated estimates of DNL, determined by adding up the energy from the SELs from each event, with the 10 dB penalty / weighting applied to night operations. Computed values of DNL are often depicted as noise contours reflecting lines of equal exposure around an airport (much as topographic maps indicate contours of equal elevation). The contours usually reflect long-term (annual average) operating conditions, considering the average flights per day, how often each runway is used throughout the year, and where over the surrounding communities the aircraft normally fly. Alternative time frames may also clarify shorter-term aspects of a noise environment.

Why is DNL used to describe noise around airports? The U.S. Environmental Protection Agency identified DNL as the most appropriate measure of evaluating airport noise based on the following considerations:

- It is applicable to the evaluation of pervasive long-term noise in various defined areas and under various conditions over long periods of time.
- It correlates well with known effects of noise on individuals and the public.
- It is simple, practical, and accurate. In principle, it is useful for planning as well as for enforcement or monitoring purposes.

- The required measurement equipment, with standard characteristics is commercially available.
- It was closely related to existing methods currently in use.

Representative values of DNL in our environment range from a low of 40 to 45 dB in extremely quiet, isolated locations, to highs of 80 or 85 dB immediately adjacent to a busy truck route. DNL would typically be in the range of 50 to 55 dB in a quiet residential community and 60 to 65 dB in an urban residential neighborhood. **Figure A-8** presents representative outdoor DNL values measured at various U.S. locations.

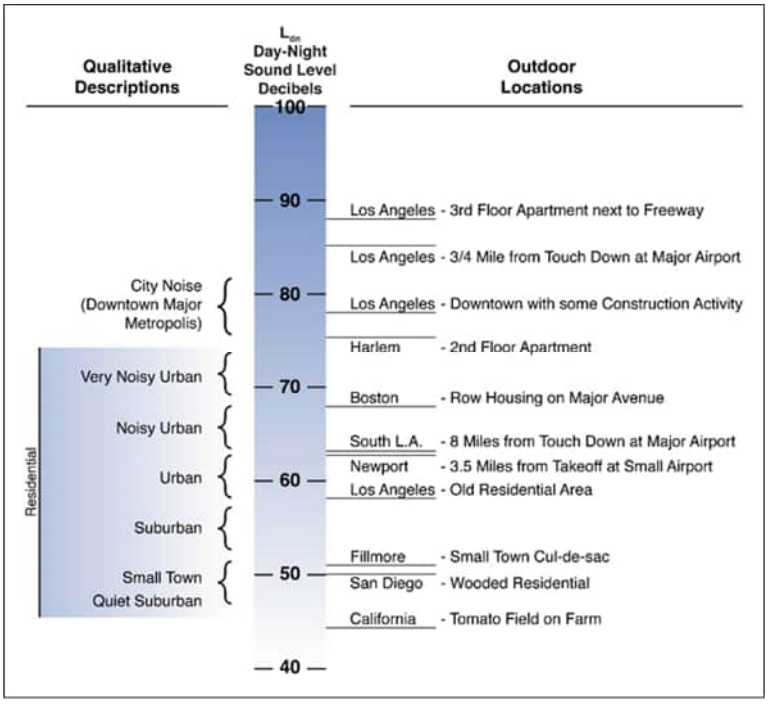


Figure A-8. Examples of Measured Day-Night Average Sound Levels

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

When preparing environmental noise analyses, the FAA considers a change of 1.5 dB within the DNL 65 dB contour to be "significant." If a change of 1.5 dB is observed, analysts should look between the DNL 60- and 65-dB contours to see if there are areas of change of 3 dB or more; this is considered a "reportable change." [1]

Table A-1 presents guidelines for interpreting changes in cumulative exposure.

Table A-1. Guidelines for Interpreting Changes in Cumulative Exposure

DNL Change	Community Response	Mitigation
0 – 2 dB	May be noticeable	Abatement may be beneficial
2 – 5 dB	Generally noticeable	Abatement should be beneficial
Over 5 dB	A change in community reaction is likely	Abatement beneficial

dB = Decibel

Most public agencies dealing with noise exposure, including the FAA, Department of Defense, and Department of Housing and Urban Development, have adopted DNL in their guidelines and regulations.

[1] FAA 1050.1f Desk Reference, July 2023

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