Appendix J

Basics of Noise

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AAD	Average annual day
ANSI	American National Standards Institute
ASA	Acoustical Society of America
CFR	Code of Federal Regulations
CI	Confidence Intervals
dB	Decibels
dBA	A-Weighted Decibel
DNL	Day-Night Average Sound Level
EA	Environmental Assessment
FAA	Federal Aviation Administration
FICAN	Federal Interagency Committee on Aviation Noise
FICON	Federal Interagency Committee on Noise
HUD	Department of Housing and Urban Development
Hz	Hertz
ISO	International Organization for Standardization
L_{eq}	Equivalent Sound Level
L_{max}	Maximum Sound Level
NES	Neighborhood Environmental Survey
NLR	Noise Level Reduction
SEL	Sound Exposure Level
SPL	Sound pressure level
TNO	The Netherlands Organisation for Applied Scientific Research
U.S.	United States

J. Basics of Noise

This appendix introduces the fundamental terms needed to understand the noise analysis presented in this Environmental Assessment (EA).

The Federal Aviation Administration (FAA) specifies how to analyze aviation noise. The Day-Night Average Sound Level (DNL) is the primary metric used to assess overall cumulative aviation noise exposure. The DNL represents the average daily sound level based on all the aviation noise occurring over the course of a year. The 24-hour period represented by DNL is referred to as the average annual day (AAD). The calculation of DNL is built on a set of more basic noise metrics, which are detailed below.

The following sections introduce basic acoustics terminology and metrics, followed by an overview of the effects of noise on human activity, community annoyance, and the current guidelines for land uses within various noise exposure levels.

J.1 Introduction to Acoustics and Noise Terminology

Noise is a complex physical quantity. The properties, measurement, and presentation of noise involve specialized terminology that is often 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, listed in order of increasing complexity:

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

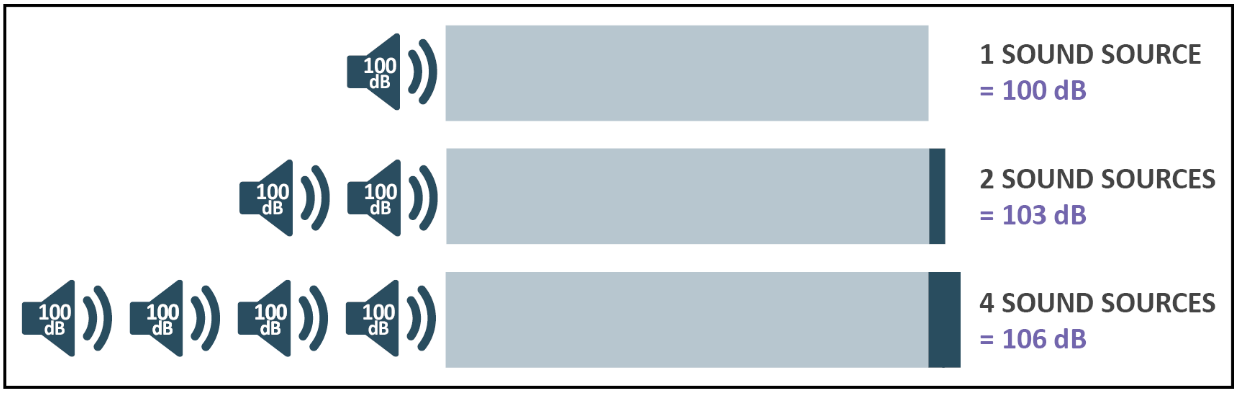
J.1.1 Sound Pressure Level and Decibels (dB)

All sounds come from a source, such as a musical instrument, a speaking voice, or an airplane passing overhead. It takes energy to produce sound. The sound energy produced by any noise source travels through the air as sound waves: tiny, quick oscillations of pressure slightly above and below atmospheric pressure. The human ear detects these pressure fluctuations and interprets them as *sound*.

Because humans cannot detect small differences in the wide range of sound pressures we can hear, a logarithmic scale is used to represent sound pressure level (SPL) in a way that corresponds more closely to the sensitivity of human hearing. SPL expresses how the sound pressure from a given source compares to the quietest sound that a person can detect. The units of SPL are decibels (abbreviated dB).

Because decibels are logarithmic quantities, they cannot be added in the same way as ordinary numbers. For example, if two sound sources each produce 100 dB at the same time, together they create a combined level of 103 dB, not 200 dB, as one might expect. Four equal and simultaneous 100 dB sources produce a combined level of 106 dB. In general, each time the number of equal sources doubles, the noise level increases by 3 dB. **Exhibit J-1** illustrates this concept.

Exhibit J-1. Combined Sound Levels for Equal Sources



If one source is much louder than another, the two sources together produce the same noise level (and sound to our ears) as if the louder source were operating alone. For example, a 100 dB source combined with an 80 dB source still produces 100 dB (rounded to the nearest whole decibel). The louder source "masks" the quieter one. However, if the quieter source increases in level, it will have an increasing effect on the total noise level.

It is important to clarify that, in general, the combining of two sound sources of equivalent level does not result in a doubling of SPL. Doubling or halving of SPL is a change of +/- 6 dB. For an increase of 6 dB to result from the combination of two equivalent SPL sources, the peaks and troughs of their pressure fluctuations must align perfectly at a listener's position. The degree to which the peaks and troughs of multiple sounds align with each other is called phase correlation. In real-world situations, the phase correlation of two (or more) sounds is random and thus results only in changes of +/- 3 dB for every doubling or halving.

People hear SPL changes according to the following principles:

1. A change of 1 dB or less is generally not noticeable except under controlled laboratory conditions.
2. A change of 5 dB is usually noticeable in a community setting.
3. An increase of 10 dB is typically heard as a doubling of a sound's loudness (i.e., perceived volume); similarly, a 10 dB decrease is perceived as halving the loudness.

J.1.2 A-Weighted Decibel (dBA)

Frequency (sometimes called *pitch*) is another important characteristic of sound. Frequency is the rate at which sound waves repeat as they reach our ears. The units of frequency are known as Hertz (Hz). The human ear does not respond equally to sounds of equal noise levels at different frequencies. The maximum frequency range of hearing for people ranges from 20 Hz to 20,000 Hz, though the high end of that range is generally only audible to very young people. People are most sensitive to sounds in the range of about 1,000 Hz to 5,000 Hz, which corresponds to the frequency range most important for speech intelligibility.

To adjust noise levels to resemble the way they are heard by humans, an "A-weighting" filter is applied. After applying the filter, the result is reported as an A-weighted sound level, with units noted as A-weighted decibels (dBA). A-weighting reduces the influence of frequencies that people do not hear well. As shown in **Exhibit J-2**, the weighting has relatively little effect in the frequency range of 800 Hz to 8,000 Hz, where the weighting adjustments are within +/- 1 dB. Studies have shown that A-weighted sound levels correlate well with how people judge the "noisiness" of transportation sources, such as aircraft. Most government agencies, including the FAA, have adopted the A-weighted level as the standard measure of environmental sound. All noise metrics presented in this document use A-weighting in the context of quantifying aviation noise levels.

Exhibit J-2. A-Weighted Sound Level

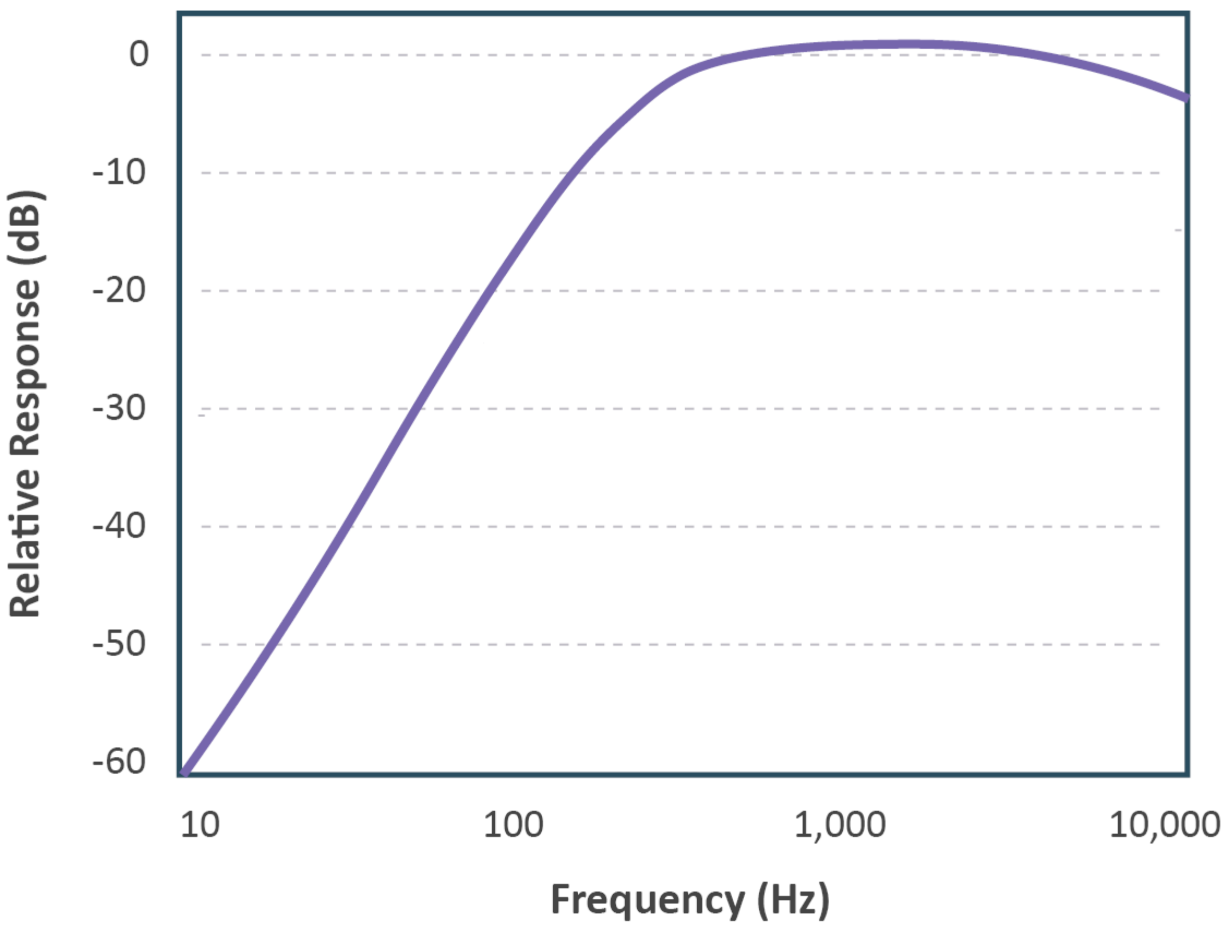
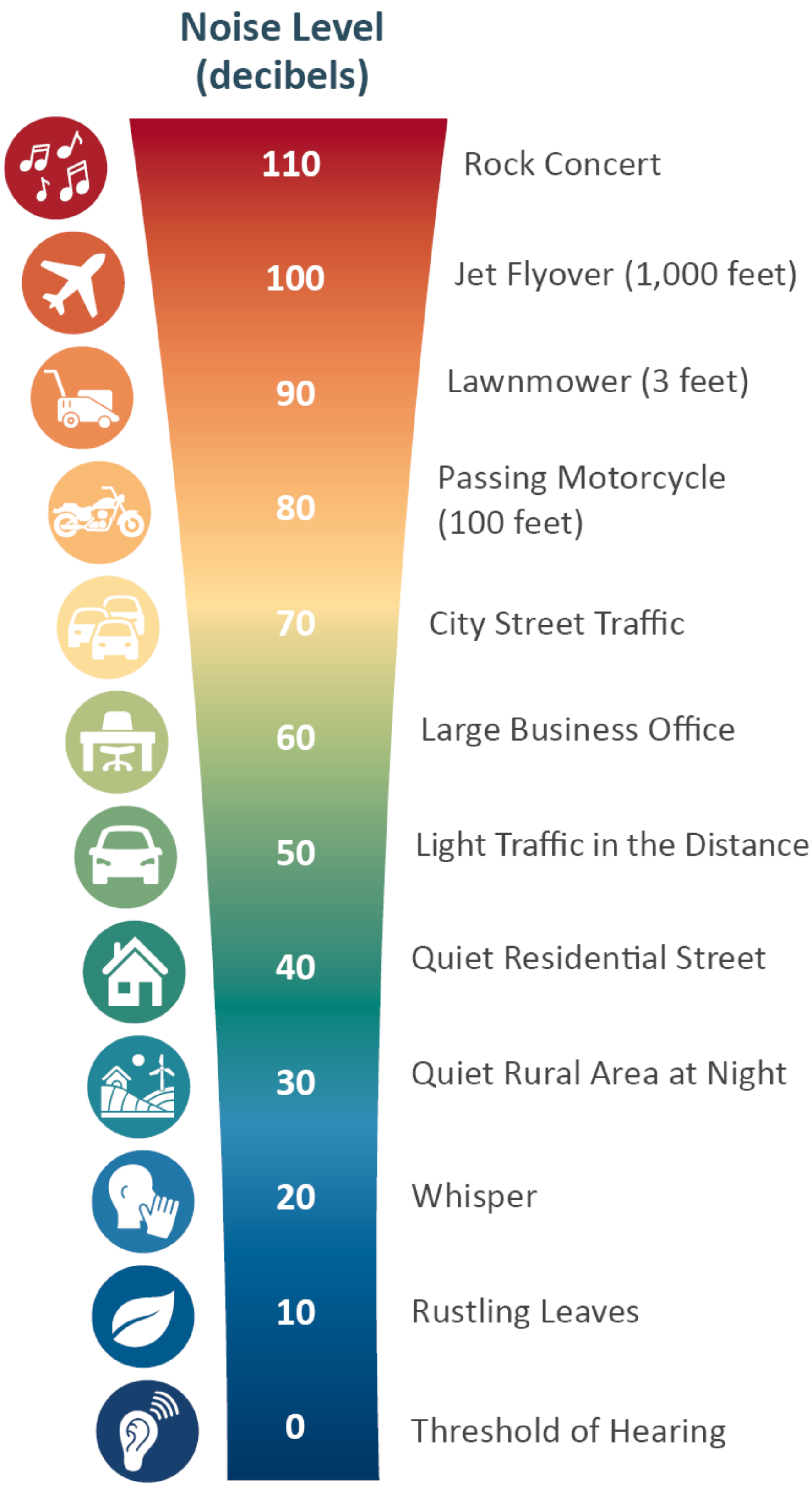


Exhibit J-3 shows A-weighted noise levels for a variety of noise environments.

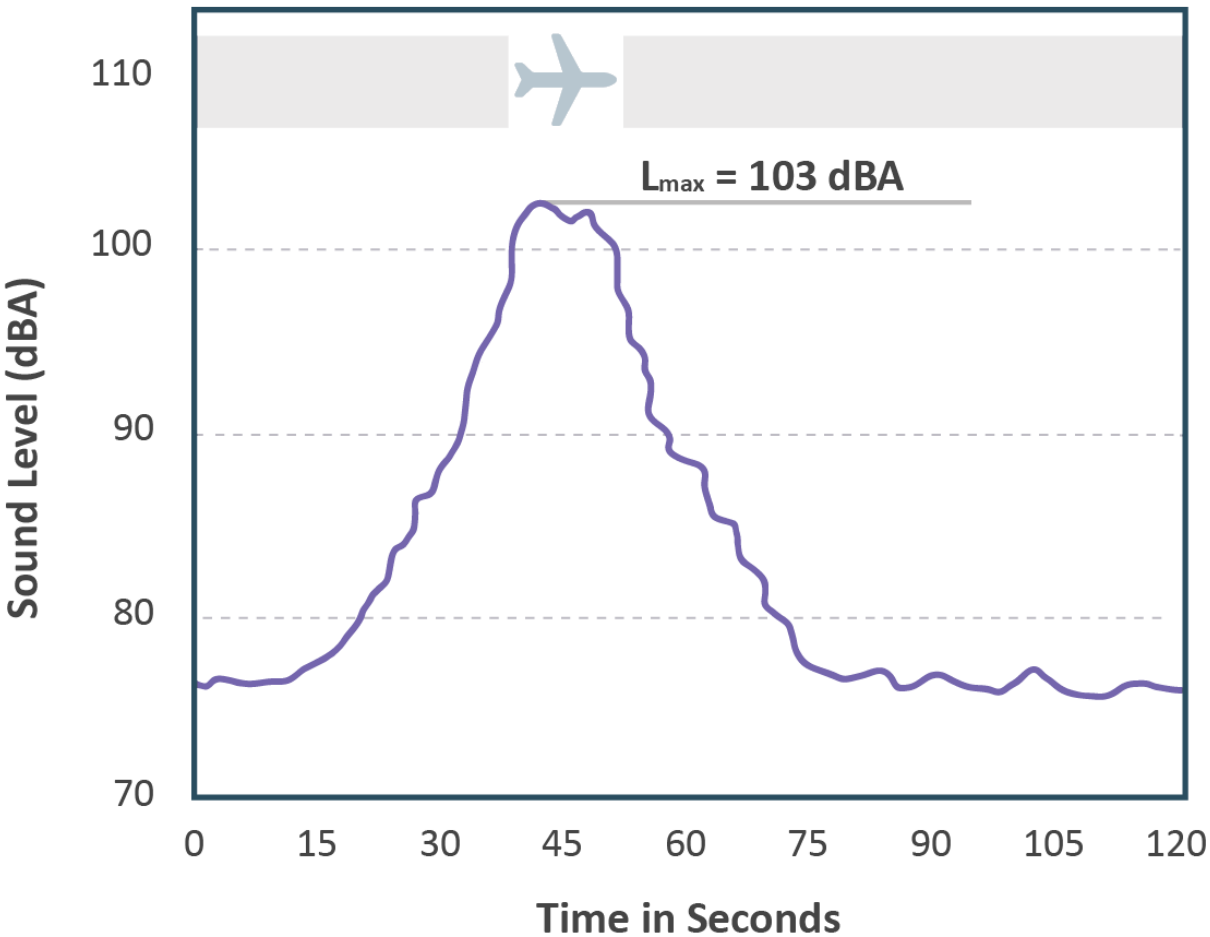
Exhibit J-3. Comparative A-Weighted Noise Levels



J.1.3 Maximum Noise Level (L_{max})

Sound levels vary over time. Even quiet background noise fluctuates—birds chirp, the wind blows, or a vehicle passes by. For an aircraft, sound typically rises as the aircraft approaches, momentarily reaches a maximum level when the aircraft is closest, and then falls and blends into the background as the aircraft recedes into the distance. Because noise changes over time, it is often useful to describe a specific "noise event" by its maximum sound level, abbreviated as L_{max}. **Exhibit J-4** illustrates this concept, showing a noise event with an L_{max} of about 103 dBA. The L_{max} represents the moment of maximum SPL occurring during the event.

Exhibit J-4. Variations in the A-Weighted Sound Level Over Time, Including L_{max}



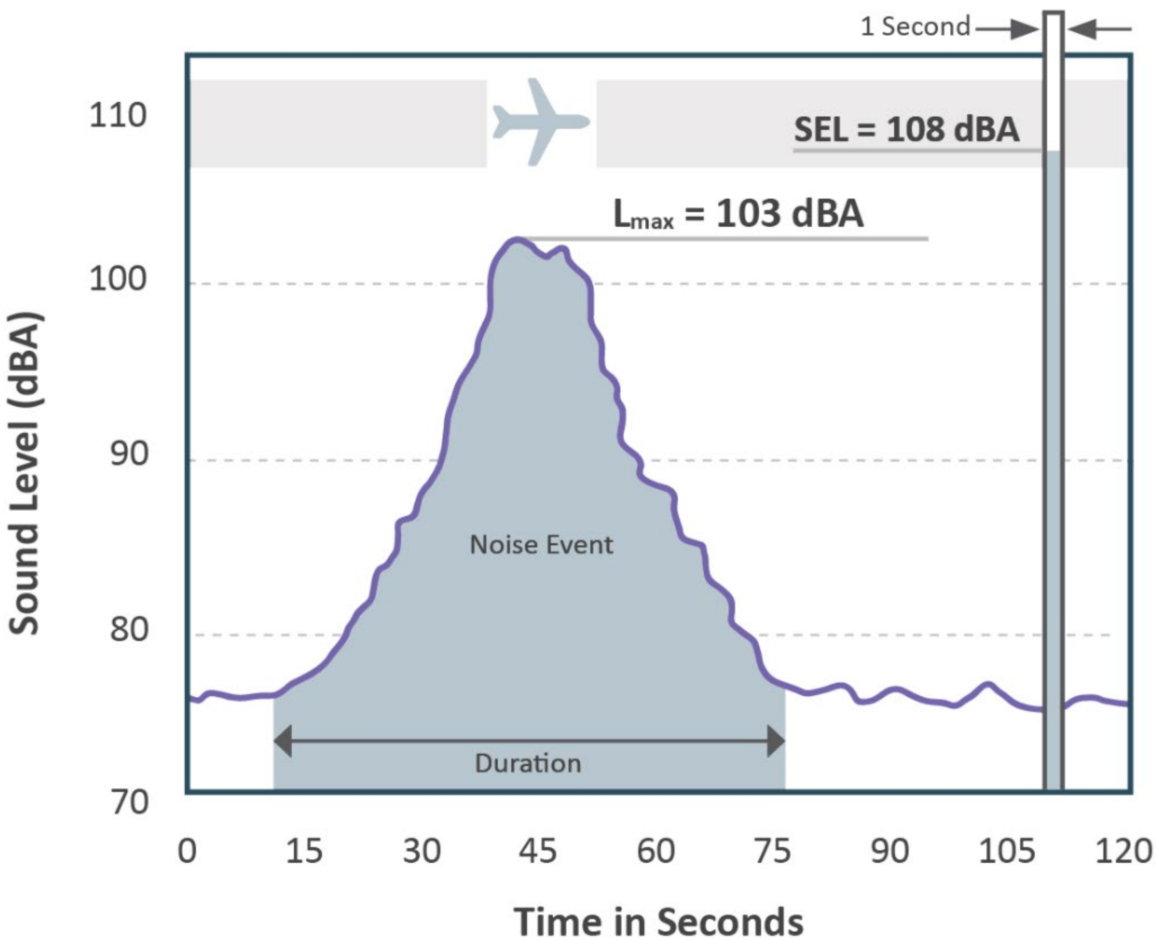
While L_{max} indicates the highest SPL of an event, it provides no information about cumulative noise exposure. Two events with identical L_{max} values may produce very different human responses. One may be of very short duration, while the other may continue for an extended period and be perceived as much more annoying. To account for the duration of noise events, the Sound Exposure Level metric is used.

J.1.4 Sound Exposure Level (SEL)

Sound Exposure Level (SEL) measures the total noise energy produced over the duration of an individual event. SEL is an integrated metric that essentially sums up the energy from a noise event over the duration its SPL is above the ambient background noise level. The SEL for an event represents the constant SPL that would produce the same total energy in one second as the event did over its entire duration. In effect, the SEL "compresses" the entire noise event's energy into one second.

Because SEL compresses all events into the same time duration, it allows direct comparison of total sound energy from events of different durations. **Exhibit J-5** depicts this process for a sample noise event. The duration shows the times at which the noise exceeded and then dropped below the ambient background noise. The shading includes the entire noise event, which lasted approximately 60 seconds and had a maximum (L_{max}) of about 103 dB. The shaded vertical bar, which is 108 dB high and just one second in duration, contains the same exact sound energy as the full event.

Exhibit J-5. Sound Exposure Level



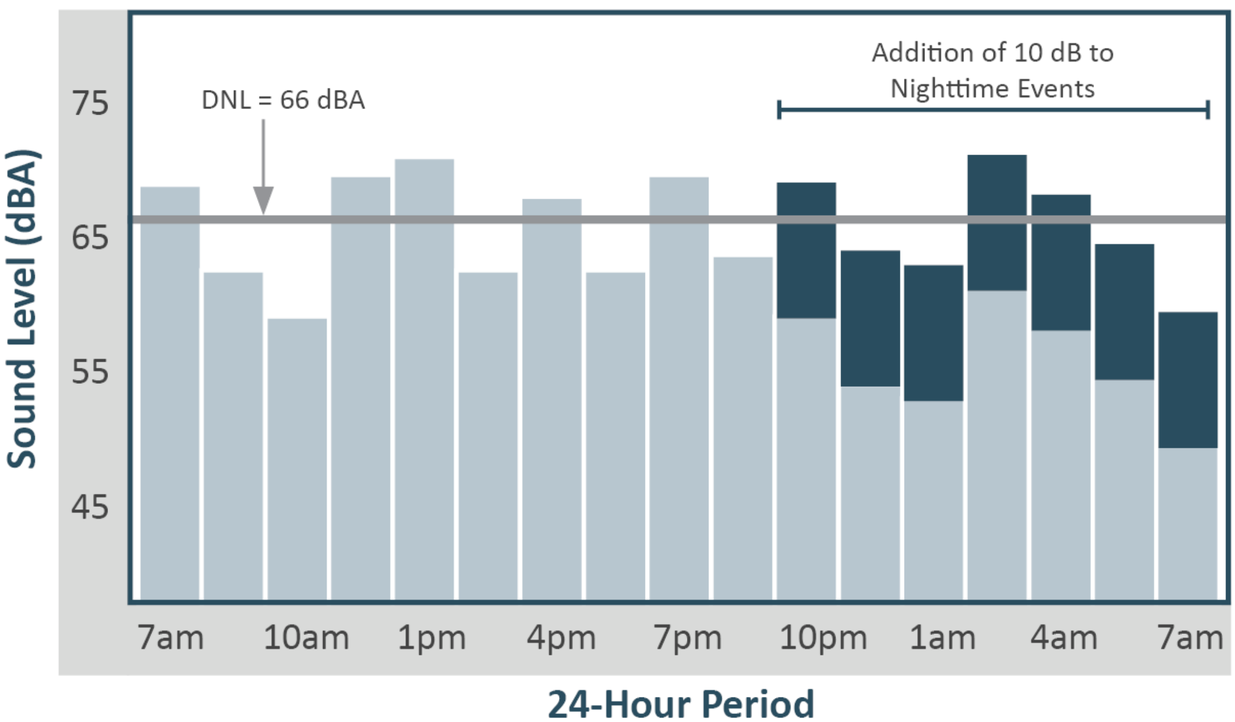
The SEL value is always larger than L_{max} for events that last longer than one second. For most aircraft overflights, SEL is normally about 7 dB to 12 dB higher than the L_{max}. Longer exposure to slower, quieter aircraft (e.g., propeller aircraft) can yield the same or higher SEL values than a shorter time exposure to faster, louder aircraft (e.g., corporate jets). SEL captures both duration and level; higher SEL values generally correspond to events that are more annoying.

Aircraft noise models use SEL as the basis for computing exposure from multiple events such as the computation of DNL.

J.1.5 Day-Night Average Sound Level (DNL)

The previous sections describe noise metrics that account for short-term fluctuations in sound levels. DNL represents noise exposure as it occurs over a 24-hour period, with one adjustment: DNL treats noise occurring at night differently from daytime noise. The calculation adds 10 dB to events occurring between 10:00:00 p.m. and 6:59:59 a.m. This increase reflects the fact that people have a greater sensitivity to nighttime sound. People often judge noises at night as more intrusive because background noise at night is generally lower. **Exhibit J-6** depicts this adjustment graphically.

Exhibit J-6. Example of a Day-Night Average Sound Level Calculation



DNL can be measured or estimated. It can be measured using community noise monitors; however, the measurement is limited to the specific locations where monitors are placed and to the period during which they operate, unless a permanent system is installed. Most noise studies use computer-generated DNL estimates. The computer model adds up all the SEL values for every event over an entire year of aircraft operations and computes the equivalent DNL for an AAD. Results are displayed as noise contours—lines connecting points with equal DNL. 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. Sometimes color-coded grid points on a map report the computed DNL at locations of interest.

Most public agencies involved in noise regulation, including the FAA, Department of Defense, and Department of Housing and Urban Development (HUD), have adopted DNL as their primary metric.

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" (FICON 1992). This determination was reaffirmed in 2018 in a report from the Federal Interagency Committee on Aviation Noise (FICAN), the successor to FICON. Additionally, in response to a requirement in the FAA Reauthorization Act of 2018 stating that the FAA "evaluate alternative noise metrics to current average day-night level standard, such as the use of actual noise sampling to address community airplane noise concerns" (United States (U.S.) 2018, §188), in 2020 the FAA published a report that recommended the continued use of DNL for its decision-making regarding noise compatibility (FAA 2020).

J.2 The Effects of Aircraft Noise on People

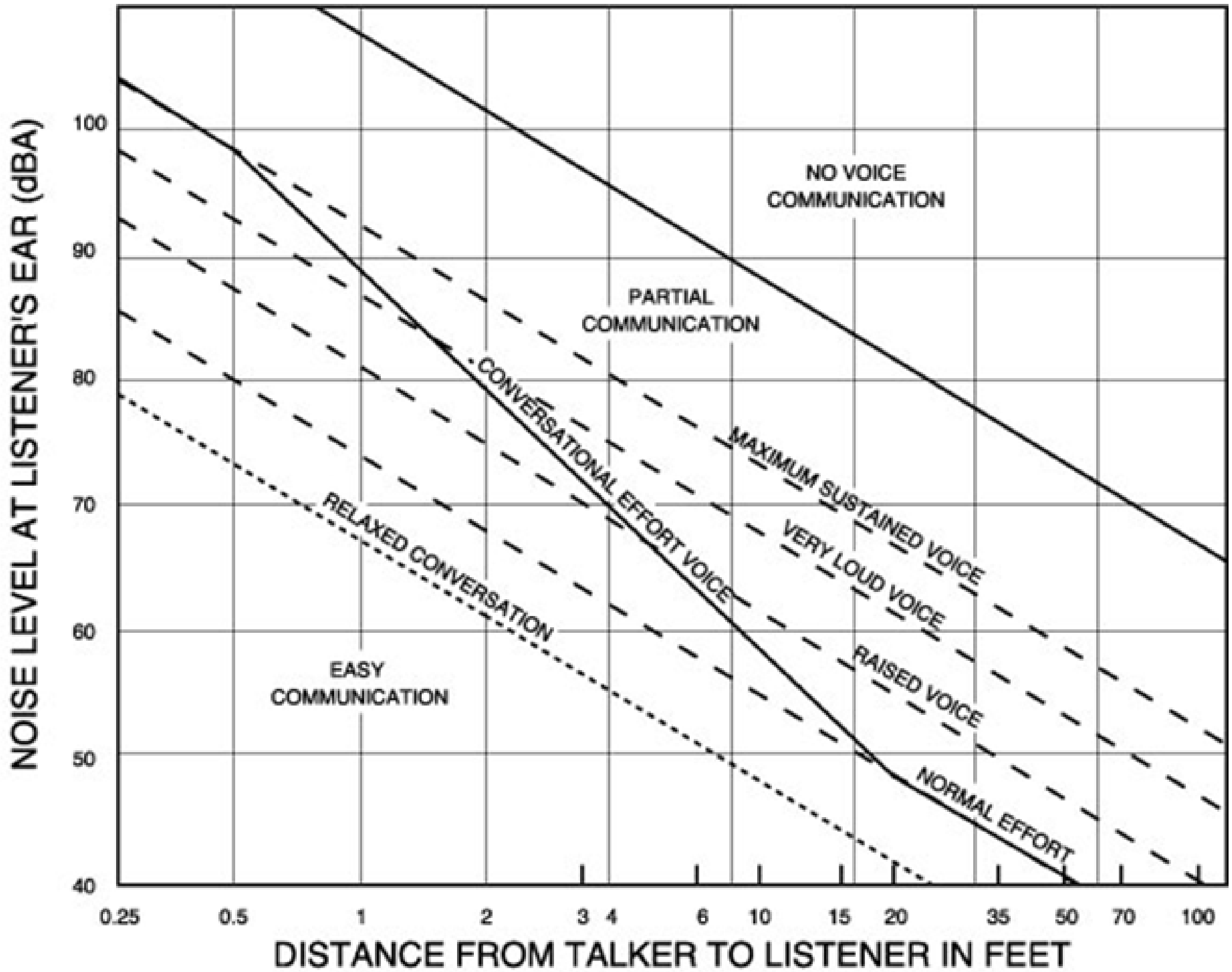
Aircraft noise can be an annoyance and a nuisance to residents living near airports. It can interfere with conversation and listening to television, disrupt classroom activities in schools, and disrupt sleep. Relating these effects to specific noise metrics helps explain how and why people react to their environment.

J.2.1 Speech Interference

Aircraft noise tends to "mask" speech, making normal conversation difficult. The sound level of speech decreases as the distance between a talker and listener increases. Additionally, as the background sound level increases, it becomes harder to hear speech. **Exhibit J-7** presents typical distances between talker and listener for satisfactory outdoor conversations, in the presence of different steady background noise levels for raised, normal, and relaxed voice effort. As the background level increases, the speaker must talk louder or the listeners must move closer to maintain intelligibility.

Normal conversational effort does not 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 **Exhibit J-7** (thus assuring 100 percent intelligibility) represents an ideal environment for outdoor speech communication and is considered necessary for acceptable indoor conversation as well.

Exhibit J-7. Outdoor Speech Intelligibility



Source: EPA, 1974, *Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare With an Adequate Margin of Safety*, p. D-5.

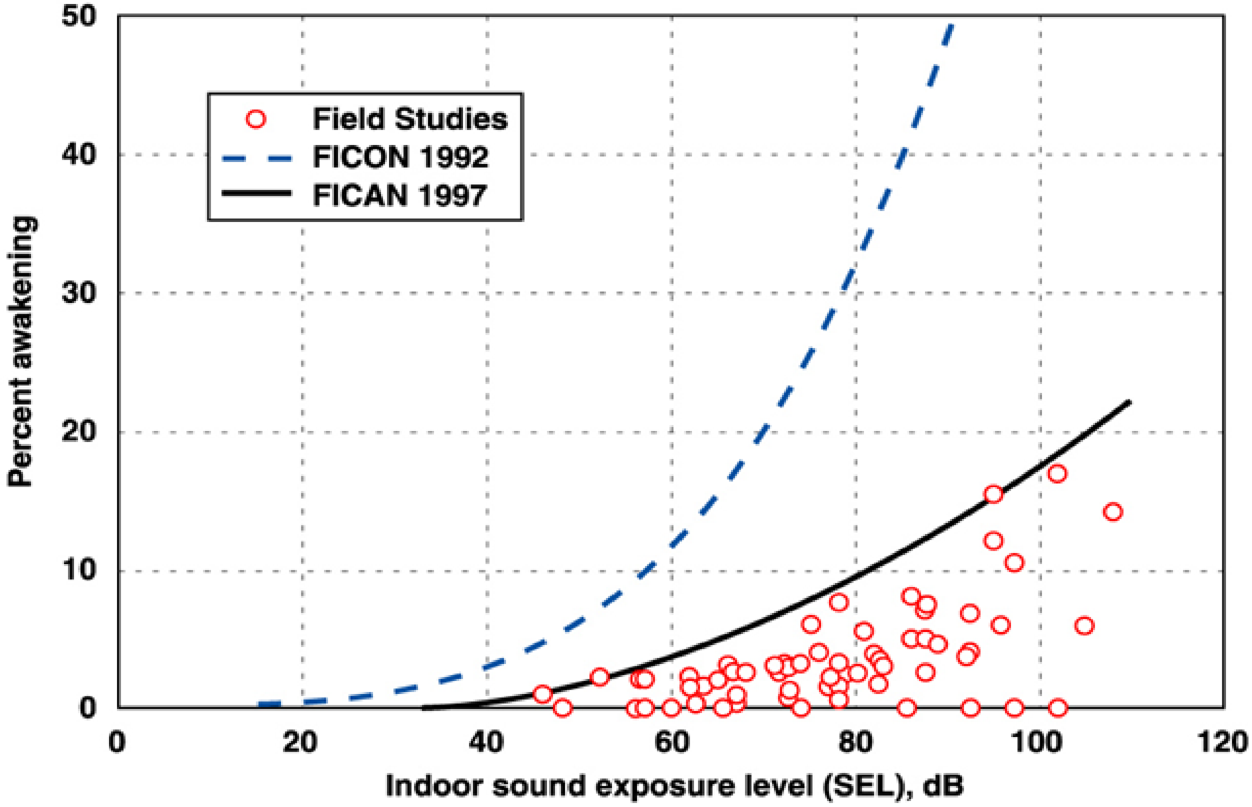
For typical communication distances of 3–4 feet (1–1.5 meters), outdoor conversations in a normal voice are intelligible if background noise is below approximately 65 dBA. If the noise exceeds this level, as might occur when an aircraft passes overhead, intelligibility would be lost unless vocal effort were increased or communication distance were decreased.

Indoors, acceptable speech generally requires a background level less than 45 dBA. With windows partly open, housing generally provides approximately 10 dBA to 15 dBA of interior-to-exterior noise level reduction. Thus, if the outdoor sound level is 60 dBA or less, there is a reasonable chance that the resulting indoor sound level will afford acceptable conversation. Closed windows typically provide about 24 dBA of noise reduction.

J.2.2 Sleep Interference

Research on sleep disruption from noise shows varying results, due to factors such as (1) sleep disturbances can occur without awakening; (2) deeper sleep requires more noise to cause arousal, and (3) the tendency to awaken increases with age and other factors. **Exhibit J-8** shows a summary of findings on the topic from the 1997 FICAN. It estimates the maximum percentage of people awakened from indoor aircraft SEL for long-term residential adults. An indoor SEL of 80 dB results in a maximum of 10 percent awakening.

Exhibit J-8. Sleep Interference



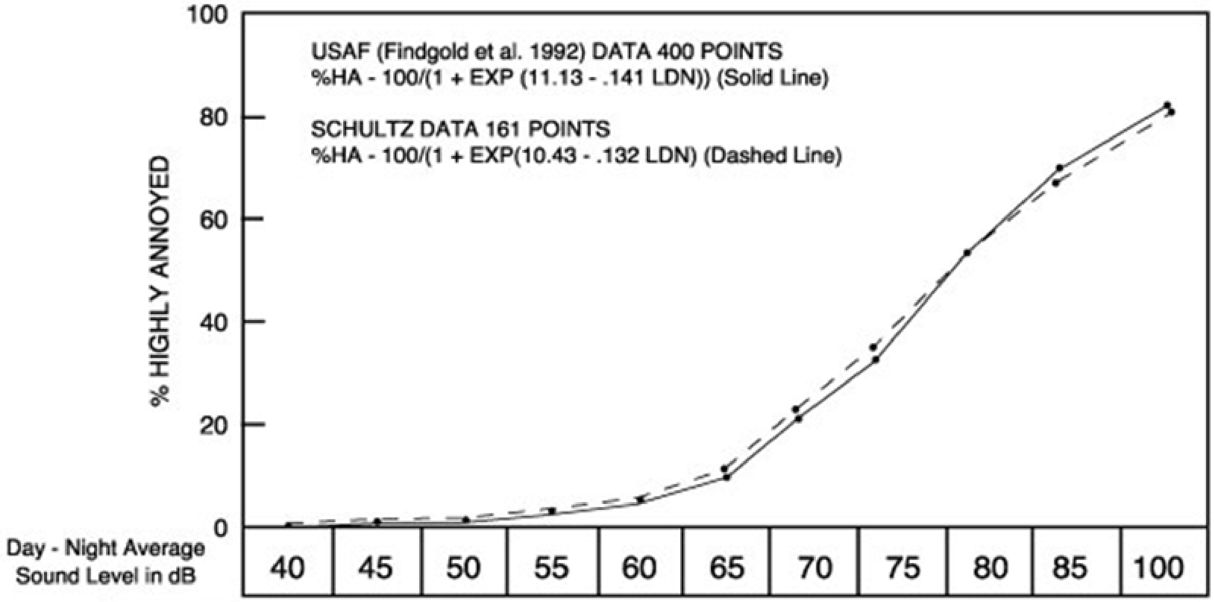
Source: FICAN, 1997, *Effects of Aviation Noise on Awakenings From Sleep*, p. 6, June.

In 2008, the American National Standards Institute (ANSI) and the Acoustical Society of America (ASA) published a method for the estimation of awakenings from outdoor noise events. This standard was withdrawn in 2017 for reasons of technical inadequacy and stated that the 2008 methodology is not obviously superior to other predictive methods, such as the FICAN 1997 method described above. The results from the FAA's National Sleep Study, expected to conclude in 2026, are anticipated to update and inform U.S. policy on sleep disturbance.

J.3 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. **Exhibit J-9** shows the Schultz curve, a 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.

Exhibit J-9. 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

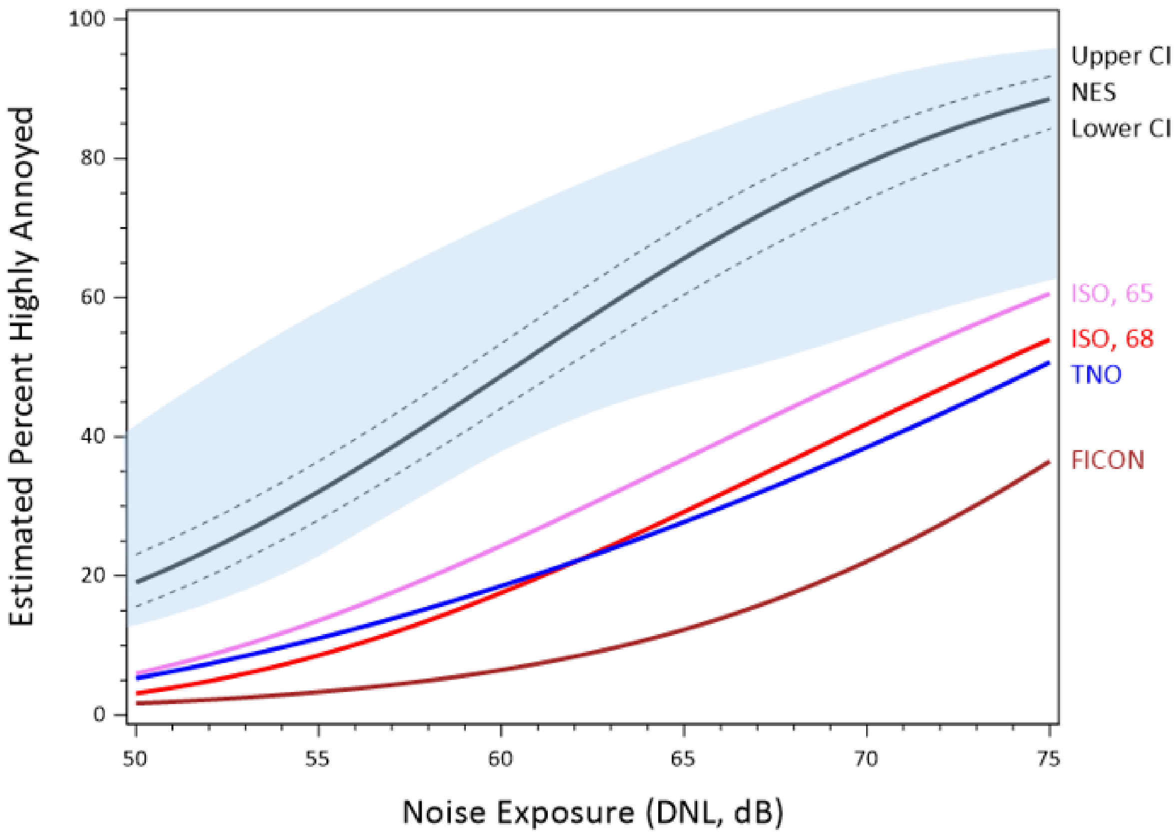
Source: FICON, 1992, *Federal Agency Review of Selected Airport Noise Analysis Issues*, pp. 3-6, applied using data provided by the USAF Armstrong Laboratory.

Based on data from 18 surveys conducted worldwide, the curve indicates that at levels as low as DNL 55 dB, approximately 3 percent to 4 percent of people would be "highly annoyed," with this percentage increasing rapidly above 65 dB DNL. The study was originally conducted in 1974 and validated in 1992 by FICON.

Published in 2021, the FAA's Neighborhood Environmental Survey (NES) was a multi-year research program to update scientific evidence on the relationship between aircraft noise exposure and its effects on communities around airports (FAA 2021). The NES resulted in an updated dose-response curve for the percentage of people highly annoyed by environmental noise at varying levels of DNL. This updated curve, provided in **Exhibit J-10**, shows a marked increase in the number of people highly annoyed by environmental noise at a given DNL compared to the FICON (1992) curve. **Exhibit J-10** also compares the national curve to three other curves from frequently cited research:

- Two community tolerance level analyses from the International Organization for Standardization (ISO) (2016), and
- The Netherlands Organisation for Applied Scientific Research (TNO) curve (2011).

Exhibit J-10. National Dose-Response Curve (NES), with 95 Percent Confidence Intervals (CI), and TNO, FICON and ISO Curves on Annoyance for a given DNL



Source: FAA. 2021. Analysis of the Neighborhood Environmental Survey.

In 2023, the FAA initiated a review of its policies regarding civil aviation noise in response to public and stakeholder input on the FAA's ongoing research. This National Policy Review includes a review of research on the effects of exposure to aviation noise and review and possible revision of the noise metrics used to describe exposure to aircraft and vehicle noise, the defined thresholds for significant noise exposure, and thresholds for land uses compatible with airport operations (FAA 2023). Specifically, the FAA is reviewing the use of DNL as the primary noise metric for cumulative aircraft noise exposure, as well as the significance threshold for noise impact and land use compatibility.

J.4 Noise/Land Use Compatibility Guidelines

The FAA, other federal agencies, and several states have developed guidelines for identifying compatible land uses. Increasingly noise-sensitive land uses require lower noise exposure 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 functions require the application of objective criteria for evaluating noise impacts. Title 14 of the Code of Federal Regulations (CFR), Part 150, provides the FAA's recommended guidelines for determining noise/land use compatibility, as shown in **Table J-1**. 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 HUD. Title 24 CFR 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.

Table J-1. Land Use Compatibility with Yearly Day-Night Average Sound Levels

Land Use	<65	65-70	70-75	75-80	80-85	>85
Residential						
Residential, other than mobile homes and transient lodgings	Y	N(1)	N(1)	N	N	N
Mobile home park	Y	N	N	N	N	N
Transient lodgings	Y	N(1)	N(1)	N(1)	N	N
Public Use						
Schools	Y	N(1)	N(1)	N	N	N
Hospitals and nursing homes	Y	25	30	N	N	N
Churches, auditoriums, and concert halls	Y	25	30	N	N	N
Governmental services	Y	Y	25	30	N	N
Transportation	Y	Y	Y(2)	Y(3)	Y(4)	Y(4)
Parking	Y	Y	Y(2)	Y(3)	Y(4)	N
Commercial						
Offices, business and professional	Y	Y	25	30	N	N
Wholesale and retail—building materials, hardware, and farm equipment	Y	Y	Y(2)	Y(3)	Y(4)	N
Retail trade—general	Y	Y	Y(2)	Y(3)	Y(4)	N
Utilities	Y	Y	Y(2)	Y(3)	Y(4)	N
Communication	Y	Y	25	30	N	N
Manufacturing and Production Use						
Manufacturing, general	Y	Y	Y(2)	Y(3)	Y(4)	N
Photographic and optical	Y	Y	25	30	N	N
Agriculture (except livestock) and forestry	Y	Y(6)	Y(7)	Y(8)	Y(8)	Y(8)
Livestock farming and breeding	Y	Y(6)	Y(7)	N	N	N
Mining and fishing, resource production and extraction	Y	Y	Y	Y	Y	Y

Land Use	<65	65-70	70-75	75-80	80-85	>85
Recreational Use						
Outdoor sports arenas and spectator sports	Y	Y(5)	Y(5)	N	N	N
Outdoor music shells, amphitheaters	Y	N	N	N	N	N
Nature exhibits and zoos	Y	Y	N	N	N	N
Amusements, parks, resorts, and camps	Y	Y	Y	N	N	N
Golf courses, riding stables, and water recreation	Y	Y	25	30	N	N

Source: 14 CFR Part 150, Appendix A, Table 1.
Numbers in parentheses refer to the notes below.

Key to Table 1:

SLUCM: Standard Land Use Coding Manual
Y (Yes): Land use and related structures compatible without restrictions
N (No): Land use and related structures are not compatible and should be prohibited
NLR: Noise Level Reduction (outdoor to indoor) to be achieved through incorporation of noise attenuation into the design and construction of the structure
25, 30, or 35: Land use and related structures generally compatible; measures to achieve NLR of 25, 30, or 35 dBA must be incorporated into design and construction of structure

Notes for Table 1:

(1) Where the community determines that residential or school uses must be allowed, measures to achieve outdoor to indoor Noise Level Reduction (NLR) of at least 25 dBA and 30 dBA should be incorporated into building codes and be considered in individual approvals. Normal residential construction can be expected to provide a NLR of 20 dBA, thus, the reduction requirements are often started as 5, 10, or 15 dBA over standard construction and normally assume mechanical ventilation and closed windows year-round. However, the use of NLR criteria will not eliminate outdoor noise problems.
(2) Measures to achieve NLR of 25 dBA must be incorporated into the design and construction of portions of these buildings where the public is received, office areas, noise-sensitive areas, or where the normal noise level is low.
(3) Measures to achieve NLR of 30 dBA must be incorporated into the design and construction of portions of these buildings where the public is received, office areas, noise-sensitive areas, or where the normal noise level is low.
(4) Measures to achieve NLR of 35 dBA must be incorporated into the design and construction of portions of these buildings where the public is received, office areas, noise-sensitive areas, or where the normal noise level is low.
(5) Land-use compatible, provided special sound reinforcement systems are installed.
(6) Residential buildings require an NLR of 25 dBA.

J.5 References

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