Appendix F NOISE AND ITS EFFECTS ON PEOPLE

F.1 Background Information on Noise Metrics

FAA's Order 1050.1E addressing "Environmental Impacts: Policies and Procedures" specifies use of a measure of cumulative noise exposure caused by aircraft 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, other measures are also helpful in explaining and understanding the elements of the noise environment that comprise the DNL around an airport. This appendix introduces the following acoustic metrics, which are the relevant elements that comprise DNL and provide a basis for evaluating and understanding a broad range of noise situations.

- Decibel, dB;
- A-Weighted Decibel, dBA;
- Sound Exposure Level, SEL;
- Equivalent Sound Level, Leq; and
- Day-Night Average Sound Level, DNL.

F.2 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, the total range of sound pressures is compressed 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 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!

It is also true that 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.

F.3 A-weighted decibels, 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 decibels (abbreviated as 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 noise-induced vibrations affecting 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 F.3-1 compares these various weighting networks. 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 F.3-2 presents typical A-weighted sound levels of several common environmental sources.

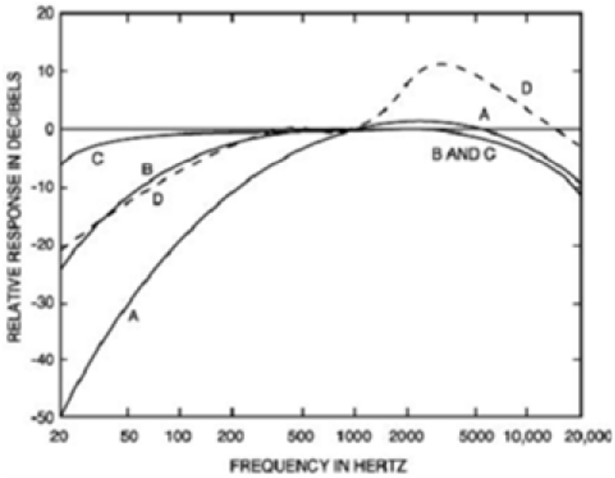


Figure F.3-1. Frequency-Response Characteristics of Various Weighting Networks
Source: Harris, Cyril M., editor; Handbook of Acoustical Measurements and Noise Control, (Chapter 5, "Acoustical Measurement Instruments"; Johnson, Daniel L.; Marsh, Alan H.; and Harris, Cyril M.); New York; McGraw-Hill, Inc.; 1991; p. 5.13

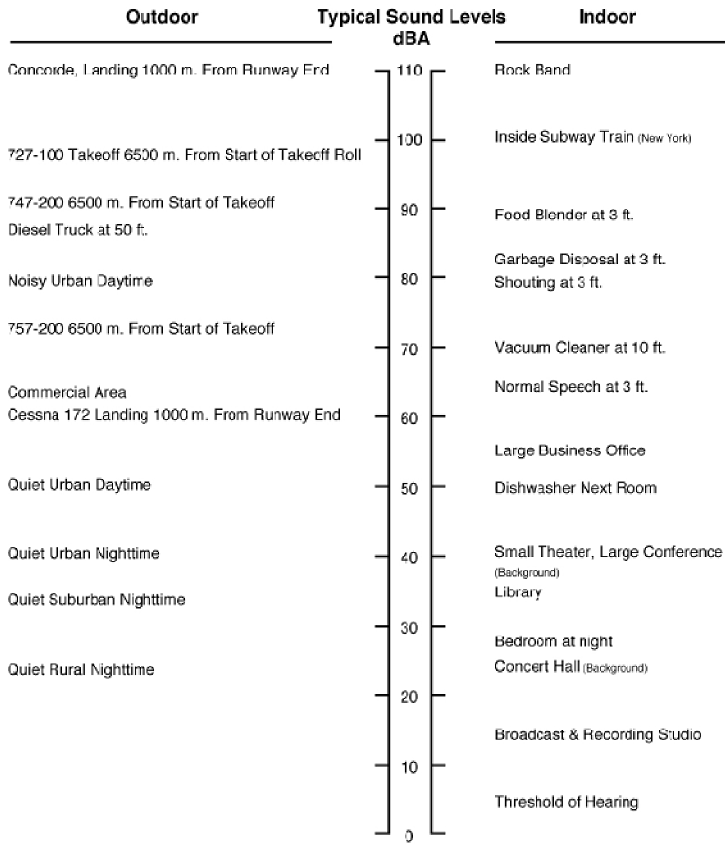


Figure F.3-2. Common Environmental Sound Levels, in dBA
Source: HMMH (Aircraft noise levels from FAA Advisory Circular 36-3G)

Though the chart and discussion above may not imply it, A-weighted sound levels in our environment vary over time as different sound sources occur throughout the day and night; sometimes the levels are caused by aircraft, sometimes by passing trucks or automobiles, or sometimes by children playing outdoors. Figure F.3-3 presents a noise event that is representative of an aircraft flyover and shows how noise levels may change over the course of the event.

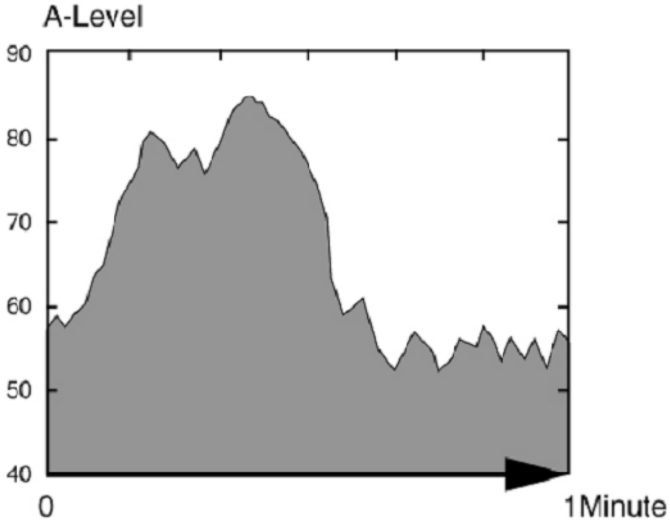


Figure F.3-3. Variations in the A-Weighted Sound Level Over Time
Source: HMMH

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 Figure F.3-3, the L_{max} is approximately 85 dBA.

However, the maximum level describes only one dimension of an event; it provides no information on the cumulative noise exposure caused by the source. 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 accounts for this deficiency by accommodating duration.

F.4 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 F.4-1 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.

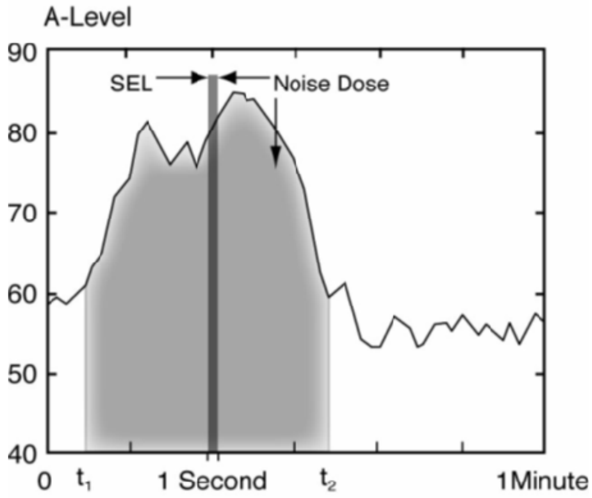


Figure F.4-1. Sound Exposure Level
Source: HMMH

F.5 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 additional notation, for example $L_{eq}(8)$ or $L_{eq}(24)$. L_{eq} is equivalent to the constant sound level over a period of interest that contains as much sound energy as the actual time-varying level. This is illustrated in Figure F.5-1. Both the solid and striped shaded areas have a one-minute L_{eq} value of 76 dB. Note, however, that the two signals (the constant one and the time-varying one) will sound very different.

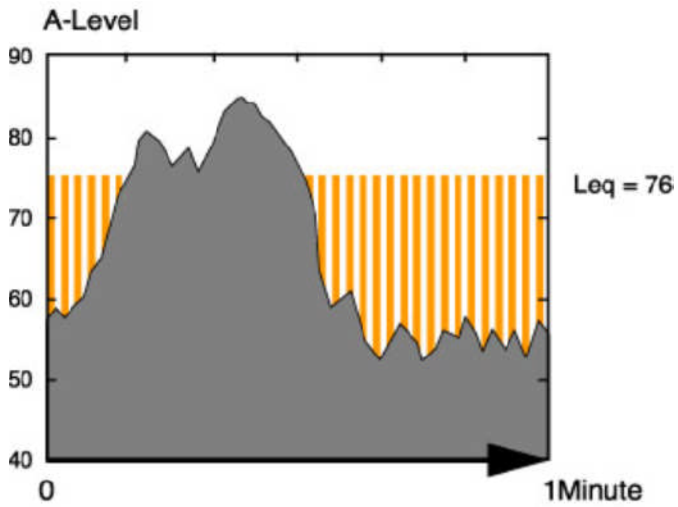


Figure F.5-1. Example of a One Minute Equivalent Sound Level
Source: HMMH

Also, be aware that the "average" sound level suggested by Leq is not an arithmetic value, but a logarithmic, or "energy-averaged" sound level. Thus, loud events dominate L_{eq} measurements.

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.

F.6 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 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."

The DNL represents A-weighted noise as it occurs over a 24-hour period, with on 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 F.3-3 illustrated the A-weighted sound level due to an aircraft fly-over as it changed with time. The top frame of Figure F.6-1 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 F.6-1 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 at when the background noise drops some 10 dB, to approximately 45 dBA.

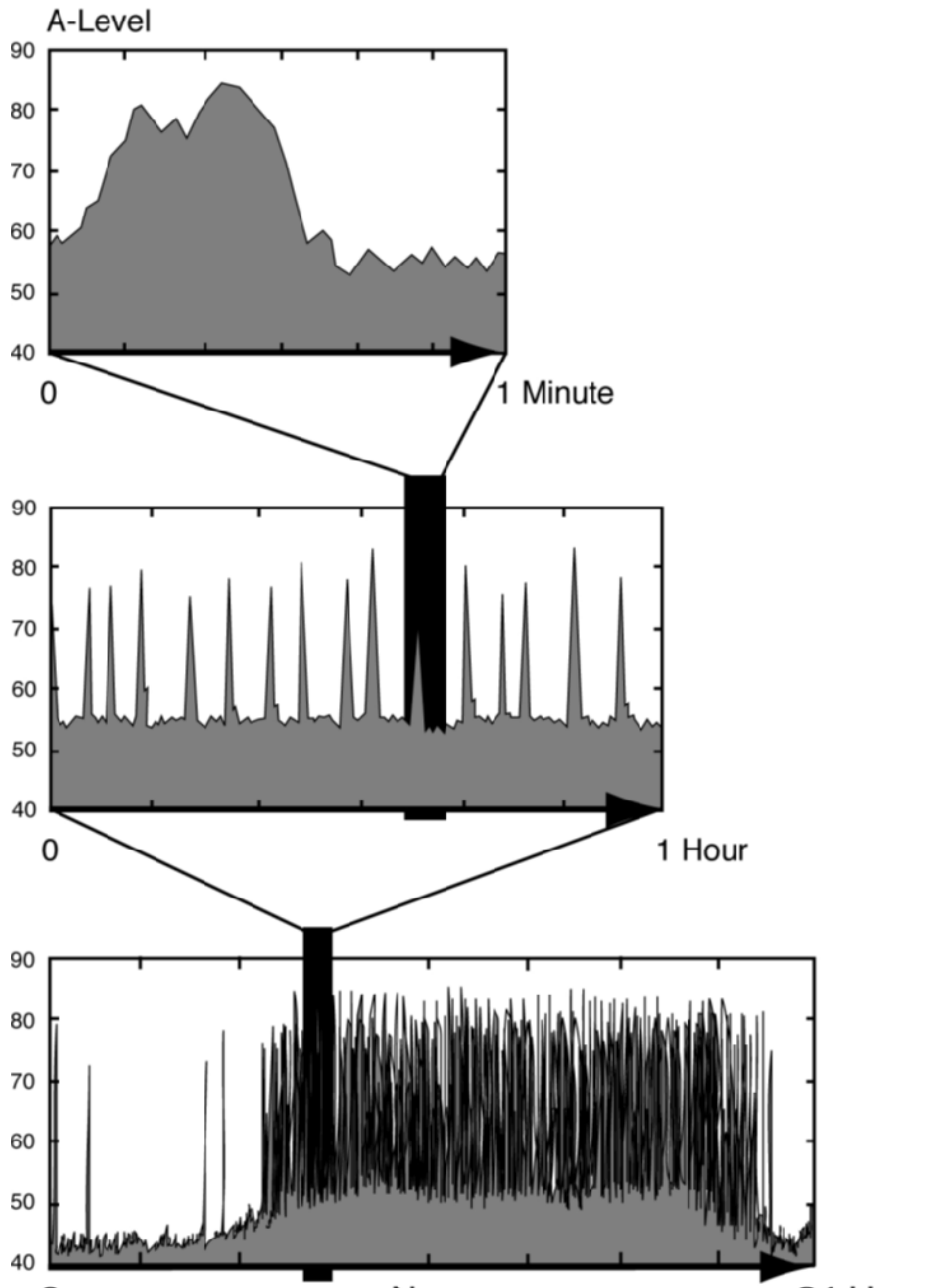


Figure F.6-1. Daily Noise Dose
Source: HMMH

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 SELs from individual events which 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 a hugely-expansive study area. Figure F.6-2 depicts typical DNL values for a variety of noise environments.

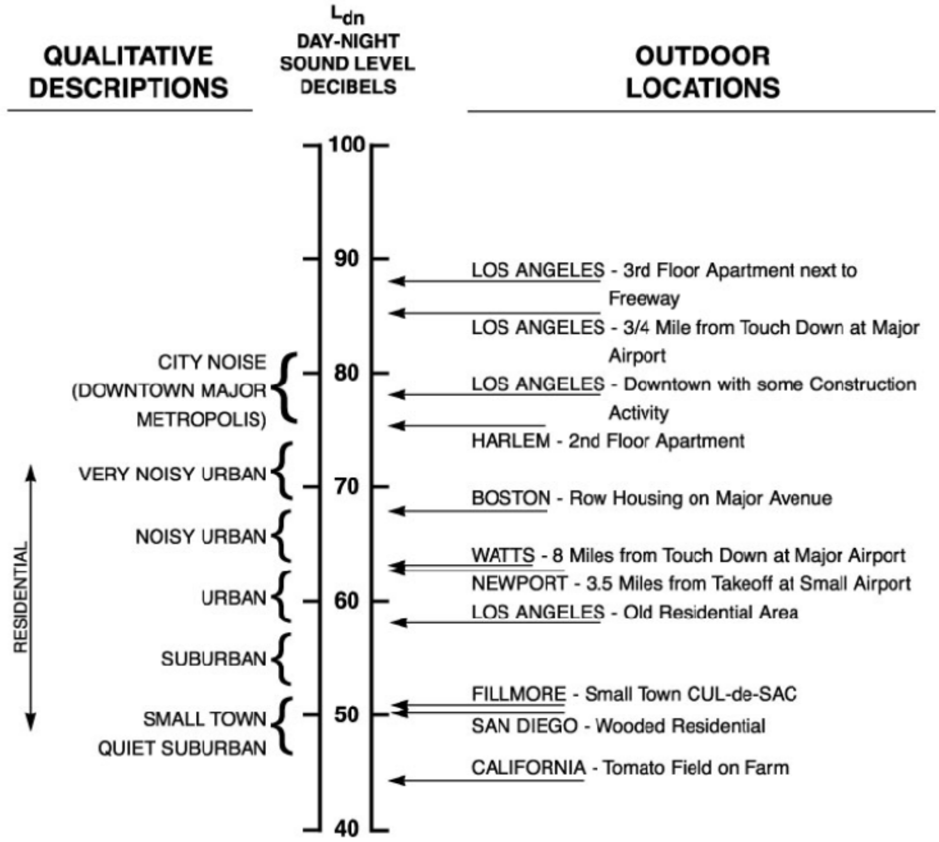
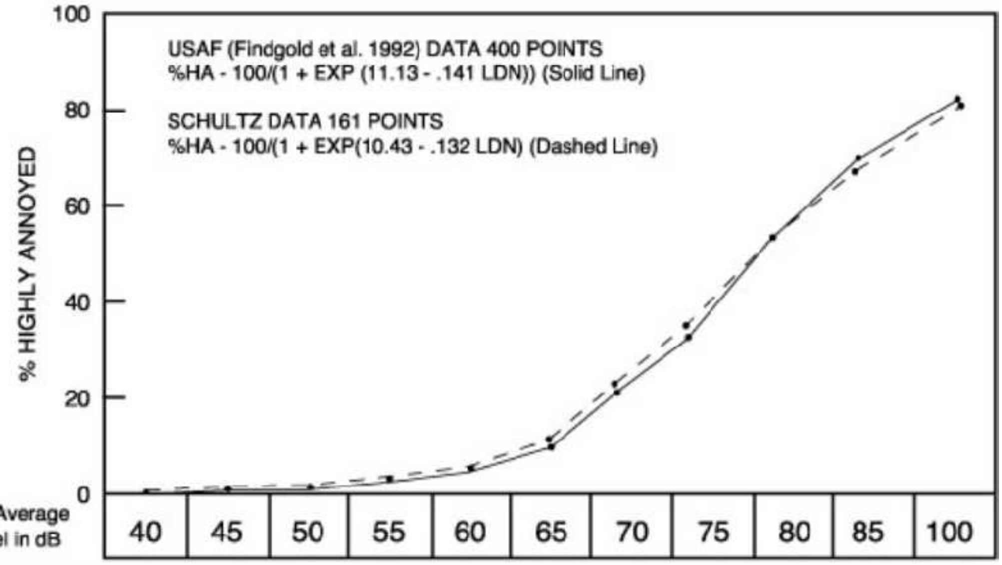


Figure F.6-2. Examples of Day-Night Average Sound Levels, DNL
Source: United States Environmental Protection Agency, Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety, March 1974, p. 14.

F.7 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 F.7-1 shows the widely recognized relationship between environmental noise and the percentage of people "highly annoyed," annoyance being the key indicator of community response usually cited in this body of research.



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 F.7-1. 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.

This relationship indicates that at levels as low as the EPA's identified DNL of 55 dB, on the order of 3 to 4 percent of the exposed population will still be highly annoyed, while the percentage increases to 12 to 13 percent at DNL levels of 65 dB, and 22 to 23 percent at DNL levels of 70 dB.

F.8 Noise/Land Use Compatibility Guidelines

The FAA, other federal agencies, and several states have developed guidelines for identifying which land uses are compatible with which noise exposure levels – 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 noise conditions with the future effects of noise abatement procedures and/or forecast changes in airport activity; 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. 14 CFR Part 150 provides the FAA's recommended guidelines for determining noise/land use compatibility. They are shown in Table F.8-1 below.

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 75 dB and above are "unacceptable" except under very limited circumstances. Part 150 permits airports and local land use control jurisdictions to adopt land use compatibility criteria that differ from the guidelines reproduced in Table F.8-1. Seattle has not done so.

Table F.8-1. FAR PART 150 Noise/Land Use Compatibility Guidelines

	Yearly Day-Night Average Sound Level, DNL, in Decibels (Key and notes on following page)					
Land Use	<65	65-70	70-75	75-80	80-85	>85
Residential Use						
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 Use						
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						
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
Recreational						
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

Key to Table F.8-1. FAR Part 150 Noise/Land Use Compatibility Guidelines

SLCUM:	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 dB must be incorporated into design and construction of structure.

Notes for Table F.8-1. FAR Part 150 Noise/Land Use Compatibility Guidelines

The designations contained in this table do not constitute a Federal determination that any use of land covered by the program is acceptable or unacceptable under Federal, State, or local law. The responsibility for determining the acceptable and permissible land uses and the relationship between specific properties and specific noise contours rests with the local authorities. FAA determinations under Part 150 are not intended to substitute federally determined land uses for those determined to be appropriate by local authorities in response to locally determined needs and values in achieving noise compatible land uses.

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 dB and 30 dB should be incorporated into building codes and be considered in individual approvals. Normal residential construction can be expected to provide a NLR of 20 dB, thus, the reduction requirements are often started as 5, 10, or 15 dB 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 dB 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 dB 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 dB 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.

7. Residential buildings require an NLR of 30

8. Residential buildings not permitted.