APPENDIX B

Noise and Its Effect on People

APPENDIX B: NOISE AND ITS EFFECT ON PEOPLE

This appendix presents the details of noise metrics and the effect of noise on people. In the State of California, the evaluation of aircraft noise exposure in environmental documents is based primarily on analysis using the Community Noise Equivalent Level (CNEL) metric. While the FAA uses the methodologically similar Day-Night Average Sound Level (DNL) metric for noise analyses throughout the United States, the FAA accepts use of the CNEL metric for federal aviation noise assessments in California. Therefore, the Sponsor's Proposed Action in this Environmental Assessment (EA) is reported in CNEL.

To assist reviewers in interpreting these noise metrics, this appendix presents an introduction to the relevant fundamentals of acoustics and noise terminology (see Section B.1) and the effects of noise on human activity (see Section B.2). The technical details of the noise model used to calculate aircraft noise exposure are discussed in Section B.3. Sections 4.4, *Affected Environment, Noise* and 5.1, *Environmental Consequences, Noise* builds on this background information to provide impact analysis of aircraft noise.

B.1 NOISE METRICS

Noise, which is often defined as unwanted sound, is one of the most common environmental issues associated with aircraft operations. Of course, aircraft are not the only sources of noise in an urban or suburban surrounding, where interstate and local roadway traffic, rail, industrial, and neighborhood sources may also intrude on the everyday quality of life. Nevertheless, aircraft are readily identifiable to those affected by aviation noise and are typically singled out for criticism. Consequently, aircraft noise problems often dominate analyses of environmental impacts.

A "metric" is defined as something "of, involving, or used in measurement." As used in environmental noise analyses, a metric refers to the unit or quantity that quantitatively measures the effect of noise on the environment. The Community Noise Equivalent Level (CNEL) is the noise metric used by the State of California to assess cumulative (i.e., multiple aircraft events) community noise in the vicinity of airports. As mentioned previously, the FAA uses the methodologically similar Day-Night Average Sound Level (DNL) metric for noise analyses through the United States. However, the FAA accepts use of the CNEL metric for federal aviation noise assessments in California.

Accordingly, this appendix discusses the following acoustic terms and metrics:

- Decibel (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)
- Community Noise Equivalent Level (CNEL)

B.1.1 Decibel (dB)

All sounds come from a sound source—a musical instrument, a speaking voice, and an airplane passing overhead. Energy is needed 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.

Human ears are sensitive to a wide range of sound pressures. The loudest sound that people hear without pain has about one trillion times more energy than the quietest sounds heard. As this range, on a linear scale, is unwieldy, the total range of sound pressures is compressed into to a more meaningful range by introducing the concept of sound pressure level (SPL) and its logarithmic unit of decibel (dB).

SPL 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). Decibels are logarithmic quantities, i.e., the ratio of the two pressures: the numerator being the pressure of the sound source of interest (e.g., an aircraft), and the denominator being the reference pressure (the quietest sound we can hear).

The logarithmic conversion of sound pressure to SPL means that the quietest sound people can hear (the reference pressure) has a SPL of about zero decibels, while the loudest sounds heard without pain have SPLs of about 120 dB. Most sounds in our day-to-day environment have SPLs from 30 to 100 dB.

Because decibels are logarithmic quantities, they require logarithmic math and not simple (linear) addition and subtraction. For example, if two sound sources each produce 100 dB and are operated together, they produce only 103 dB—not 200 dB as might be expected. Four equal sources operating simultaneously result in a total SPL of 106 dB. In fact, for every doubling of the number of equal sources, the SPL (of all of the sources combined) increases another three decibels. A ten-fold increase in the number of sources makes the SPL increase by 10 dB. A hundredfold increase makes the level increase by 20 dB and it takes a thousand equal sources to increase the level by 30 dB.

If one source is much louder than another, 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 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 SPL. When the two sources are equal, as described above, they produce a level 3 decibels above the sound level 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 SPL of 103 dB. Clearly, the loudest source has the greatest effect on the total.

There are two useful rules of thumb to remember when comparing SPLs: (1) most of us perceive a 6 to 10 dB increase in the SPL to be an approximate doubling of loudness, and (2) changes in SPL of less than about 3 dB are not readily detectable outside of a laboratory environment.

B.1.2 A-Weighted Decibel (dBA)

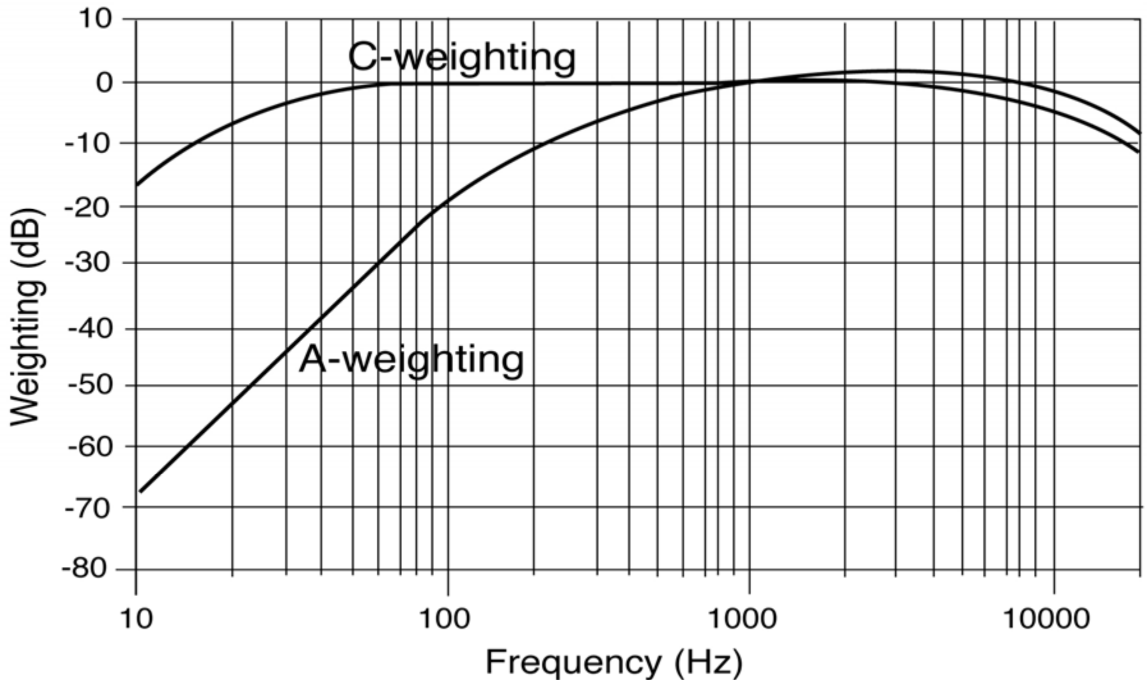
Another important characteristic of sound is its frequency, or "pitch." This is the rate of repetition of the sound pressure oscillations as they reach our ear. Frequency can be expressed in units of cycles per second (cps) or Hertz (Hz). Although cps and Hz are equivalent, Hz is the preferred scientific unit and terminology.

A very good ear can hear sounds with frequencies from 16 Hz to 20,000 Hz. However, most people hear from approximately 20 Hz to approximately 10,000-15,000 Hz. People respond to sound most readily when the predominant frequency is in the range of normal conversation, around 1,000 to 4,000 Hz. Acousticians have developed and applied "filters" or "weightings" to SPLs to match our ears' sensitivity to the pitch of sounds and to help us judge the relative loudness of sounds made up of different frequencies. Two such filters, "A" and "C," are most applicable to environmental noises.

A-weighting significantly deemphasizes noise at low and high frequencies (below approximately 500 Hz and above approximately 10,000 Hz) where people do not hear as well. The filter has little or no effect at intervening frequencies where human hearing is most efficient. **Figure B-1** shows a graph of the A-weighting as a function of frequency and its aforementioned characteristics. 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. Therefore, A-weighted sound levels are normally used to evaluate environmental noise. SPLs measured through this filter are referred to as A-weighted decibels (dBA).

As shown in Figure B-1, C-weighting is nearly flat throughout the audible frequency range, hardly deemphasizing the low frequency noise. C-weighted levels are not used as frequently as A-weighted levels, but they may be preferable in evaluating sounds whose low-frequency components are responsible for secondary effects such as the shaking of a building, window rattle, perceptible vibrations, or other factors that can cause annoyance and complaints. Uses include the evaluation of blasting noise, artillery fire, sonic boom, and, in some cases, aircraft noise inside buildings. SPLs measured through this filter are referred to as C-weighted decibels (dBC).

Figure B-1
Frequency Response Characteristics of A and C Weighting



Source: ANSI S1.4-1983 “Specification of Sound Level Meters”

Other weighting networks have been developed to correspond to the sensitivity and perception of other types of sounds, such as the “B” and “D” filters. However, A-weighting has been adopted as the basic measure of community environmental noise by the U.S. Environmental Protection Agency (EPA) and nearly every other agency concerned with aircraft noise throughout the United States.

Figure B-2 presents typical A-weighted sound levels of several common environmental sources. Sound levels measured (or calculated) using A-weighting are most properly called “A-weighted sound levels” while sound levels measured without any frequency weighting are most properly called “sound levels.” However, since this study deals only with A-weighted sound levels, the A-weighted sound levels are referred to simply as sound levels in the interests of conciseness.

An additional dimension to environmental noise is that sound levels vary with time and typically have a limited duration, as shown in **Figure B-3.** For example, the sound level increases as an aircraft approaches, then falls and blends into the background as the aircraft recedes into the distance. Sounds can be classified by their duration as continuous like a waterfall, impulsive like a firecracker or sonic boom, or intermittent like an aircraft overflight or vehicle passby.

Figure B-2
Sound Levels of Typical Noise Sources (dBA)

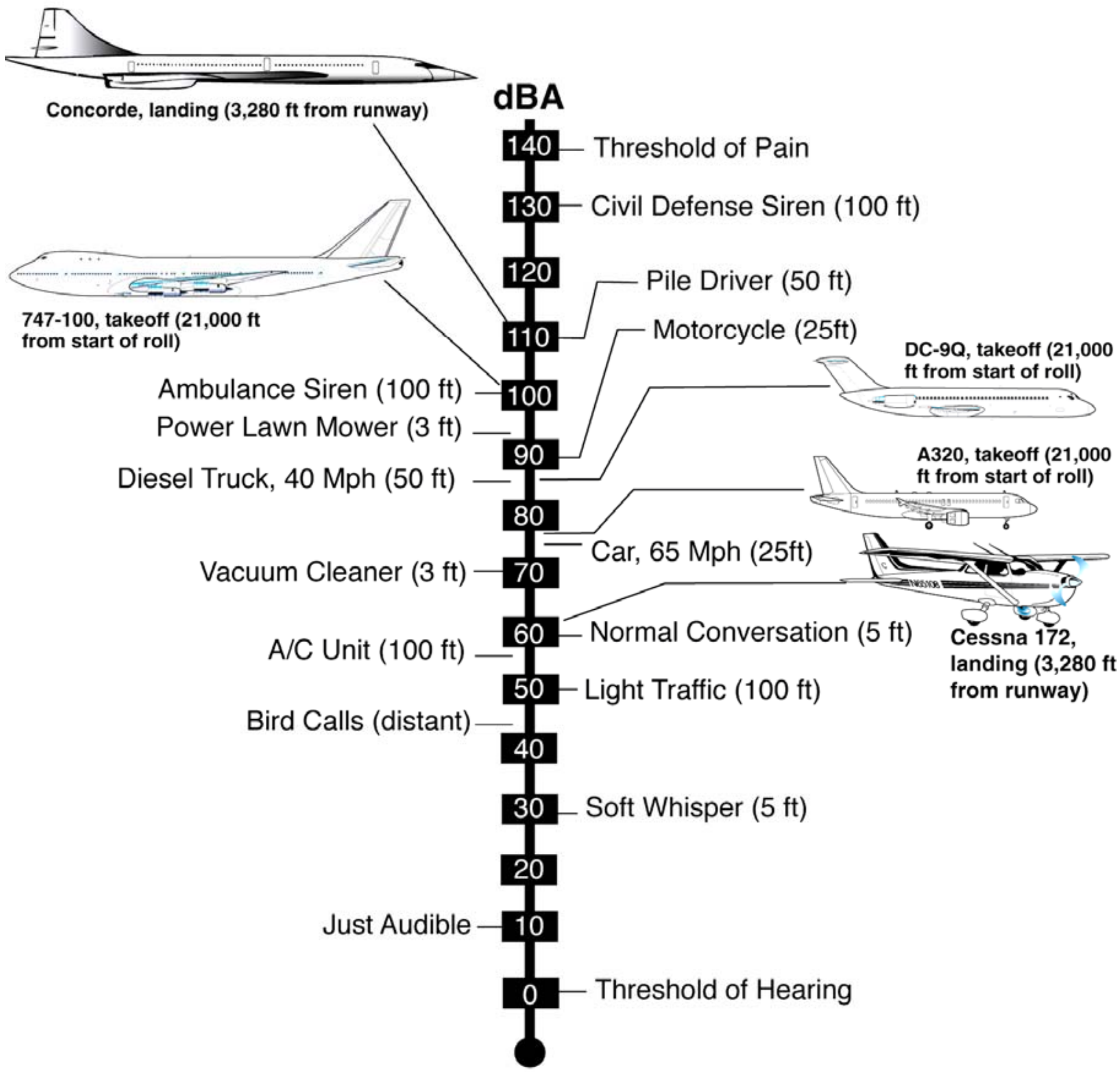
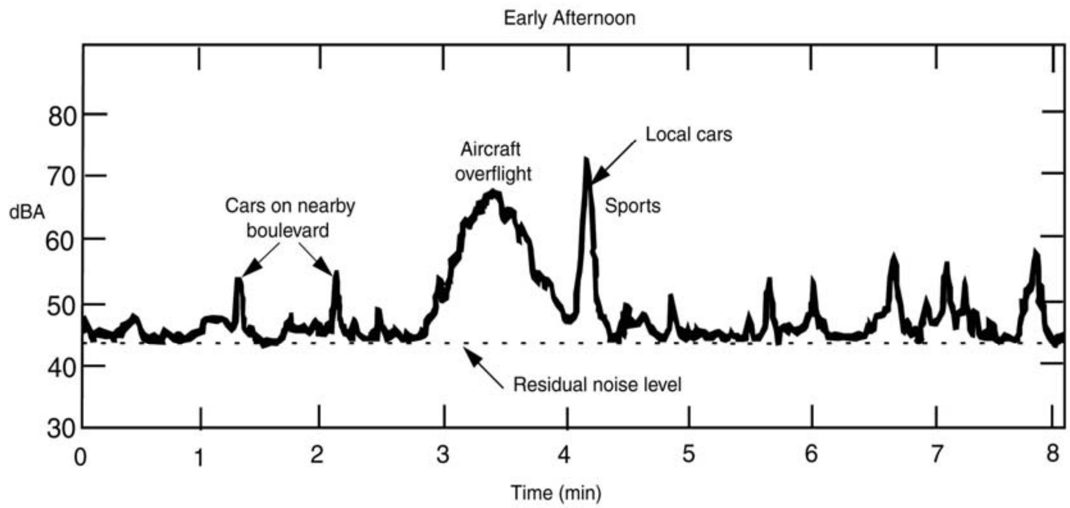


Figure B-3
Variation of Community Noise in a Suburban Neighborhood



Source: "Community Noise," NTID 300.3 EPA, December 1971.

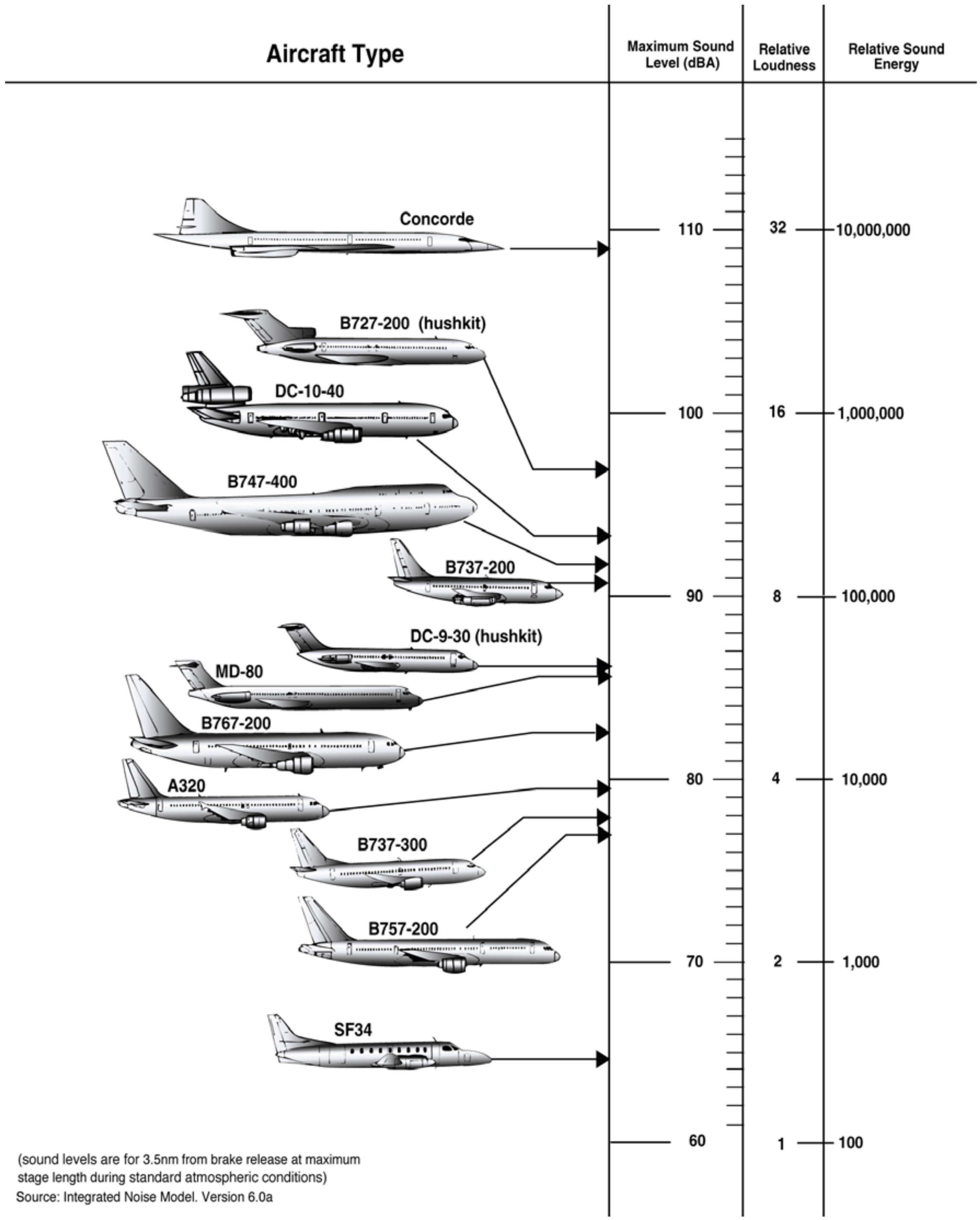
B.1.3 Maximum Sound Level (L_{max})

The variation in sound level over time often makes it convenient to describe a particular noise "event" by its maximum sound level, abbreviated as L_{max}. For example, the L_{max} due to the aircraft overflight event in Figure B-3 is approximately 67 dBA.

Figure B-4 shows L_{max} values for a variety of common aircraft from the FAA's Integrated Noise Model database. These L_{max} values for each aircraft type are for aircraft performing a maximum stage (trip) length departure on a day with standard atmospheric conditions at a reference distance of 3.5 nautical miles from their brake release point. Of the dozen aircraft types listed on the figure, the Concorde has the highest L_{max} and the Saab 340 turboprop has the lowest L_{max}.

The L_{max} describes only one dimension of an event; it provides no information on the cumulative noise exposure generated by a sound source. In fact, two events with identical maxima may produce very different total exposures (i.e., total influence of an event). One may be of short duration, while the other may continue for an extended period. This Sound Exposure Level metric, as discussed in the next section, corrects for this deficiency.

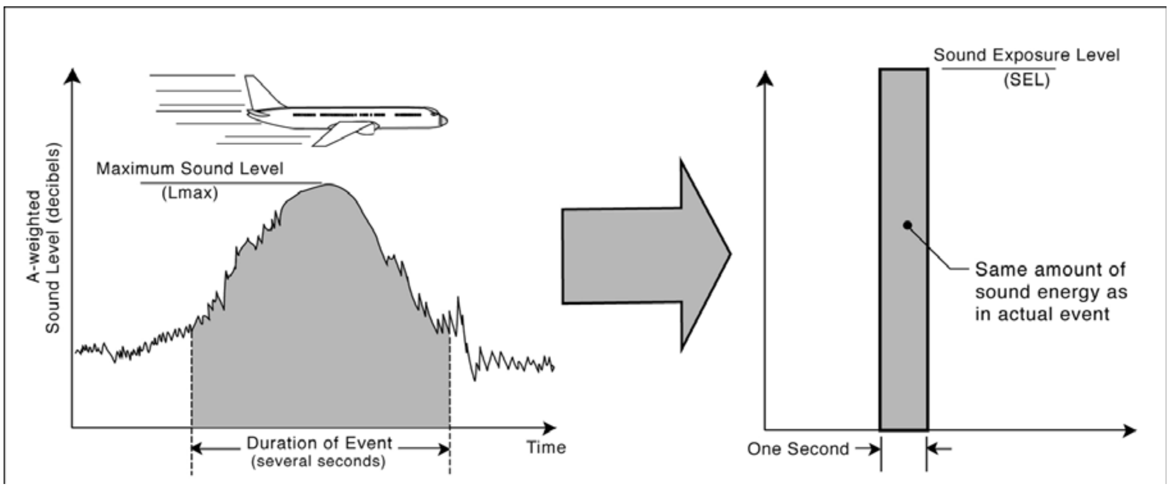
Figure B-4
Common Aircraft Departure Noise Levels



B.1.4 Sound Exposure Level (SEL)

The Sound Exposure Level (SEL) is frequently used to describe noise exposure for a single aircraft flyover. This metric is also sometimes referenced as the Single Event Sound Exposure Level, or SENEL. SEL may be considered an accumulation of the sound energy over the duration of an event. The shaded area in **Figure B-5** illustrates that portion of the sound energy (or "dose") included in an SEL computation. The dose is then normalized (standardized) to a duration of one second.

Figure B-5
Relationship between Single Event Noise Metrics



This "revised" dose is the SEL, shown as the shaded rectangular area in Figure B-5. Mathematically, the SEL represents the sound level of the constant sound that would, in one second, generate the same acoustic energy as the actual time-varying noise event. For events that last more than one second, SEL does not directly represent the sound level heard at any given time, but rather provides a measure of the net impact of the entire acoustic event.

Note that, because the SEL is normalized to one second, it will always be larger in magnitude than the L_{max} (for an event that lasts longer than one second). In fact, for most aircraft overflights, the SEL is on the order of 7 to 12 dBA higher than the L_{max}. With the SEL metric, not only do louder flyovers have higher SELs than quieter ones (of the same duration), but longer flyovers also have greater SELs than shorter ones (of the same L_{max}).

SEL's inclusion of both the intensity and duration of a sound source makes it the metric of choice for comparing the single-event levels of varying duration and maximum sound level. This metric provides a comprehensive basis for modeling a noise event in determining overall noise exposure; aggregate SEL values from multiple events are used to calculate cumulative noise exposure levels with the L_{eq}, DNL, and CNEL noise metrics.

B.1.5 Equivalent Sound Level (L_{eq})

The Equivalent Sound Level (abbreviated L_{eq}), is a measure of the noise exposure resulting from the accumulation of A-weighted sound levels over a particular period of interest (e.g., an hour, an 8-hour school day, nighttime, or a full 24-hour day). However, because the length of the period can be different depending on the time frame of interest, 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 $L_{eq(24)}$.

Conceptually, 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 time-varying sound level with its normal “peaks” and “valleys,” as illustrated in Figure B-3. In the context of noise from typical aircraft flight events and as noted for SEL, L_{eq} does not represent the sound level heard at any particular time, but rather represents the total sound exposure for the period of interest. Also, it should be noted 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 tend to dominate the noise environment described by the L_{eq} metric.

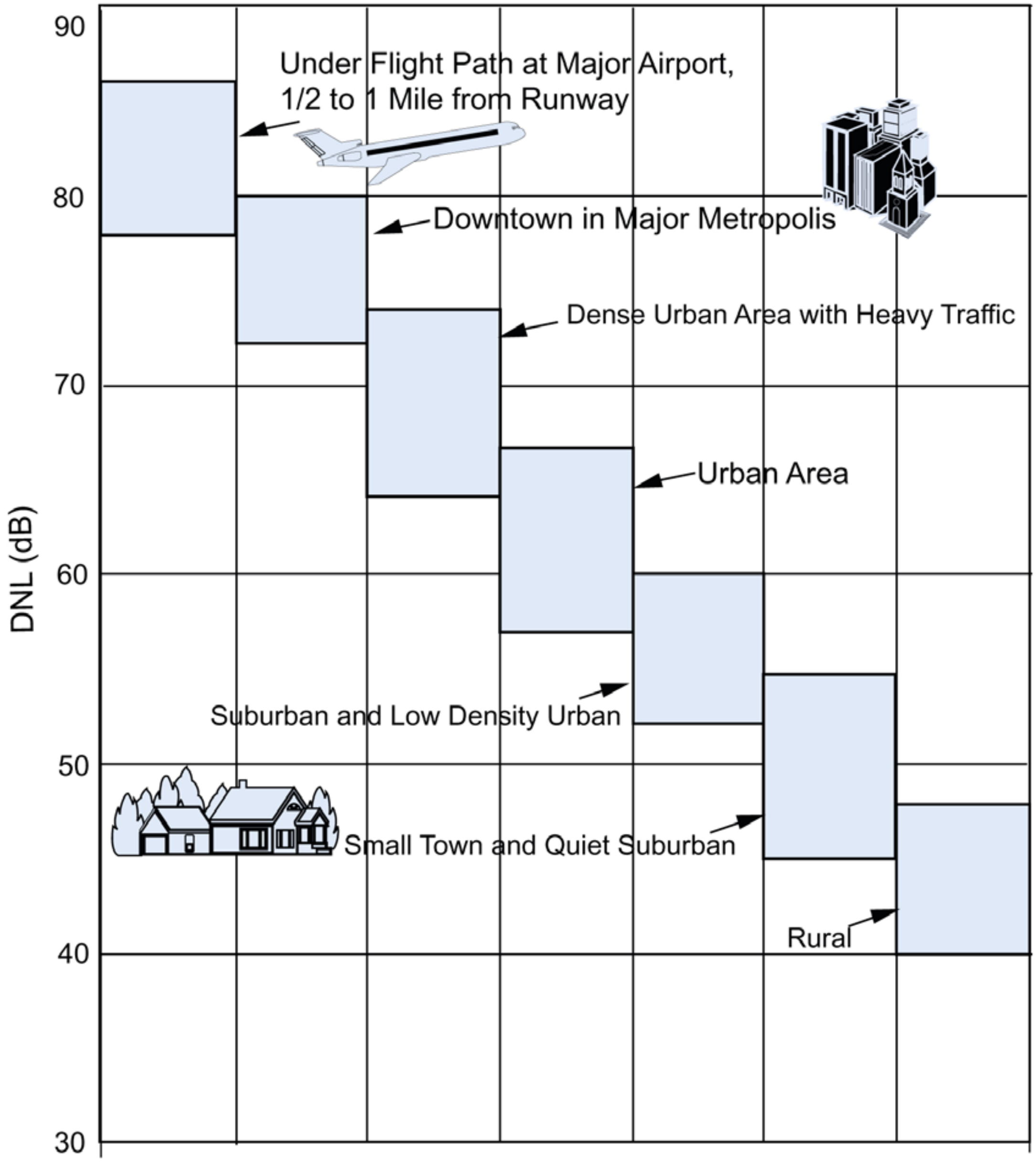
As for its application to airport noise issues, L_{eq} is often presented for consecutive 1-hour periods to illustrate how the hourly noise dose rises and falls throughout a 24-hour period, as well as how certain hours of the day are significantly affected by a few loud aircraft.

B.1.6 Day-Night Average Sound Level (DNL)

DNL is the same as L_{eq} (an energy-average noise level over a 24-hour period) except that 10 dB is added to those noise events occurring during the nighttime (between 10 p.m. and 7 a.m.). This weighting reflects the added intrusiveness of nighttime noise events due to community background noise levels that typically decrease by about 10 dB during those nighttime hours.

Typical DNL values for a variety of noise environments are shown in **Figure B-6** to indicate the range of noise exposure levels usually encountered.

Figure B-6
Typical Range of Outdoor Community Day-Night Average Sound Levels



Source: U.S. Department of Defense. Departments of the Air Force, the Army, and the Navy, 1978. *Planning in the Noise Environment.* AFM 19-10. TM 5-803-2, and NAVFAC P-970. Washington, D.C.: U.S. DoD.

As an example of the cumulative time-average nature of the DNL metric, **Table B-1** shows the correlation between the number of flights at a given SEL that are needed to generate a specific DNL. The table shows how the DNL metric correlates the number and sound energy of events into a time-average cumulative metric. As such, DNL represents the total sound exposure on the average day and not a specific single-event heard at a particular time.

Table B-1:
Correlation between Operations Frequency, SEL, and DNL

Number of Flights	SEL of Flights	Resulting DNL
500	87.4 dB	65 dB
100	94.4 dB	65 dB
50	97.4 dB	65 dB

Source: FAA Office of Environment and Energy

Due to the DNL metric's excellent correlation with the degree of community annoyance from aircraft noise (the subject of Section B.2), DNL has been formally adopted by most federal agencies for measuring and evaluating aircraft noise for land use planning and noise impact assessment. Federal interagency committees such as the Federal Interagency on Urban Noise (FICUN) and the Federal Interagency on Noise (FICON), which include the EPA, FAA, Department of Defense, Department of Housing and Urban Development (HUD), and Veterans Administration, found DNL to be the best metric for land use planning.

Also, the federal interagency committees have not identified a new cumulative sound descriptors or metrics of sufficient scientific standing to substitute for DNL. Other cumulative metrics can be used to supplement, but not replace, DNL. FAA Orders 1050.1E and 5050.4B require that environmental studies use the DNL metric to describe cumulative noise exposure and identify aircraft noise/land use compatibility issues. [1] [2] [3] [4] [5] [6]

B.1.7 Community Noise Equivalent Level (CNEL)

CNEL is the average noise level over a 24-hour period with a 10 dB increase to nighttime operations (between 10 p.m. and 7 a.m.) and a 3 dB increase to evening operations (operations between 7 PM to 10 PM). CNEL is similar to DNL, except that CNEL adds a 3-dB penalty to evening operations. The State of California has adopted the CNEL as the standard for assessing community noise impact.

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1 U.S. Environmental Protection Agency, "Information on Levels of Environmental Noise Requisite to Protect the Public Health and Welfare with an Adequate Margin of Safety," Report 550/9-74-004, March 1974.

2 "Guidelines for Considering Noise in Land Use Planning and Control," Federal Interagency Committee on Urban Noise, June 1980.

3 Federal Interagency Committee on Noise, "Federal Agency Review of Selected Airport Noise Analysis Issues," August 1992.

4 14 CFR Part 150, Amendment 150-3, December 8, 1995.

5 FAA Order 1050.1E, Environmental Impacts: Policies and Procedures, Department of Transportation, Federal Aviation Administration, June 8, 2004.

6 FAA Order 5050.4B, National Environmental Policy Act Implementing Instructions for Airport Actions, Department of Transportation, Federal Aviation Administration, April 28, 2006.

B.2 THE EFFECTS OF AIRCRAFT NOISE ON PEOPLE

To many people, 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 aids in the understanding of how and why people react to their environment. This section addresses three ways we are potentially affected by aircraft noise: annoyance, interference of speech, and disturbance of sleep.

B.2.1 Community Annoyance

The primary potential effect of aircraft noise on exposed communities is one of annoyance. The U.S. EPA defines noise annoyance as any negative, subjective reaction on the part of an individual or group.[7]

Scientific studies [8] [9] [10] [11] [12] and a large number of social/attitudinal surveys[13] [14] have been conducted to appraise U.S. and international community annoyance due to all types of environmental noise, especially aircraft events. These studies and surveys have found the DNL to be the best measure of that annoyance.

This relation between community annoyance and DNL has been confirmed, even for infrequent aircraft noise events.[15] For helicopter overflights occurring at a rate of 1 to 52 per day, the stated reactions of community individuals correlated with the daily time-average sound levels of the helicopter overflights.

The relationship between annoyance and DNL (that has been determined by the scientific community and endorsed by many federal agencies, including the FAA) is shown in **Figure B-7**. Two lines in Figure B-7 represent two large sets of social/attitudinal surveys: one for a curve fit of 161 data points compiled by an individual researcher, Ted Schultz, in 1978[16] and one for a curve fit of 400 data points (which include Schultz's 161 points) compiled in 1992 by the U.S. Air Force.[17] The agreement of these two curves simply means corroborates the survey results.

[7] U.S. Environmental Protection Agency, "Information on Levels of Environmental Noise Requisite to Protect the Public Health and Welfare with an Adequate Margin of Safety," Report 550/9-74-004, March 1974.
[8] Ibid.
[9] "Guidelines for Considering Noise in Land Use Planning and Control," Federal Interagency Committee on Urban Noise, June 1980.
[10] Federal Interagency Committee on Noise, "Federal Agency Review of Selected Airport Noise Analysis Issues," August 1992.
[11] "Sound Level Descriptors for Determination of Compatible Land Use," American National Standards Institute Standard ANSI S3.23-1980."

[12] "Quantities and Procedures for Description and Measurement of Environmental Sound, Part I," American National Standards Institute Standard ANSI S21.9-1988.

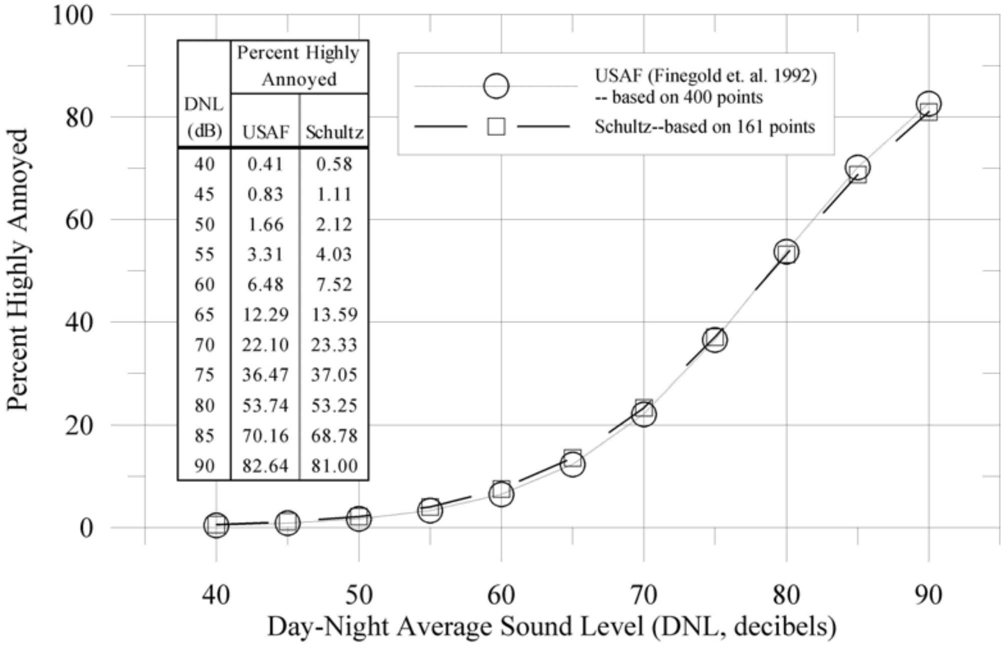
[13] Schultz, T.J., "Synthesis of Social Surveys on Noise Annoyance," J. Acoust. Soc. Am., 64, 377-405, August 1978.

[14] Fidell, S., Barger, D.S., Schultz, T.J., "Updating a Dosage-Effect Relationship for the Prevalence of Annoyance Due to General Transportation Noise." J. Acoust. Soc. Am., 89, 221-233, January 1991.

[15] "Community Reactions to Helicopter Noise: Results from an Experimental Study," J. Acoust. Soc. Am., 479-492, August 1987.

[16] Schultz, T.J., "Synthesis of Social Surveys on Noise Annoyance," J. Acoust. Soc. Am., 64, 377-405, August 1978.
[17] Fidell, S., Barger, D.S., Schultz, T.J., "Updating a Dosage-Effect Relationship for the Prevalence of Annoyance Due to General Transportation Noise." J. Acoust. Soc. Am., 89, 221-233, January 1991.

Figure B-7
Relationship between Annoyance and Day-Night Average Sound Level



DNL (dB)	Percent Highly Annoyed USAF	Percent Highly Annoyed Schultz
40	0.41	0.58
45	0.83	1.11
50	1.66	2.12
55	3.31	4.03
60	6.48	7.52
65	12.29	13.59
70	22.10	23.33
75	36.47	37.05
80	53.74	53.25
85	70.16	68.78
90	82.64	81.00

Source: Federal Interagency Committee on Noise (FICON),
"*Federal Agency Review of Selected Airport Noise Analysis Issues*",
August 1992, p. 3-6, Figure 3.1

Figure B-7 shows the percentage of people "highly annoyed" by a given DNL. For example, the two curves in the figure yield a value of about 13% for the percentage of the people that would be highly annoyed by a DNL exposure of 65 dB. The figure also shows that at very low values of DNL, such as 45 dB or less, 1% or less of the exposed population would be highly annoyed. Furthermore, at very high values of DNL, such as 90 dB, more than 80% of the exposed population would be highly annoyed.

Recently, the use of DNL has been criticized as not accurately representing community annoyance and land-use compatibility with aircraft noise. One frequent criticism is based on the inherent feeling that people react more to single noise events, rather than difficult-to-comprehend time-average sound levels. In fact, a time-average noise metric, such as DNL, takes into account both the noise levels of all individual events which occur during a 24-hour period and the number of times those events occur. As described briefly above, the logarithmic nature of the decibel unit causes the noise levels of the loudest events to control the 24-hour average.

As a simple example of this characteristic, consider a case in which only one aircraft overflight occurs in daytime hours during a 24-hour period, creating a sound level of 100 dB for 30 seconds. During the remaining 23 hours 59 minutes and 30 seconds of the day, the ambient sound level is 50 dB. The DNL for this 24-hour period is 65.5 dB.

As a second example, assume that ten such 30-second overflights occur in daytime hours during the next 24-hour period, with the same ambient sound level of 50 dB during the remaining 23 hours and 55 minutes of the day. The DNL for this 24-hour period is 75.4 dB.

Clearly, the averaging of noise over a 24-hour period does not ignore the louder single events and tends to emphasize both the sound levels and number of those events. This is the basic concept of a time-average sound metric, and, specifically, the DNL. It is often suggested that a lower DNL, such as 60 or 55 dB, be adopted as the threshold of community noise annoyance for airport environmental analysis documents. While there is no technical reason why a lower level cannot be measured or calculated for comparison purposes, a DNL of 65 dB:

(1) Provides a valid basis for comparing and assessing community noise effects.

(2) Represents a noise exposure level that is normally dominated by aircraft noise and not other community or nearby highway noise sources.

(3) Reflects the FAA's threshold for grant-in-aid funding of airport noise mitigation projects.

(4) Is used by HUD in determining eligibility for federally guaranteed home loans.

B.2.2 Speech Interference

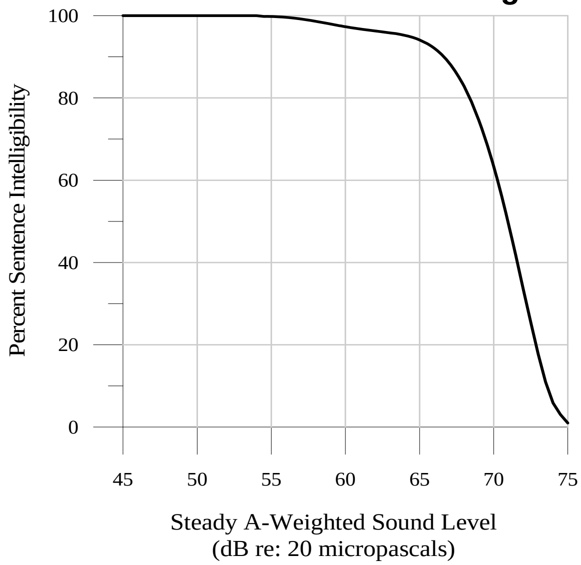
A primary effect of aircraft noise is its tendency to drown out or "mask" speech, making it difficult to carry on a normal conversation. Speech interference associated with aircraft noise is a primary cause of annoyance to individuals on the ground. The disruption of routine activities, such as radio or television listening, telephone use, or family conversation, causes frustration and aggravation. Research has shown that "whenever intrusive noise exceeds approximately 60 dB indoors, there will be interference with speech communication."[18]

Indoor speech interference can be expressed as a percentage of sentence intelligibility among two people speaking in relaxed conversation approximately one meter apart in a typical living room or bedroom.[19] The percentage of sentence intelligibility is a non-linear function of the (steady) indoor background sound level, as shown in **Figure B-8**. This curve was digitized and curve-fitted for the purposes of this document. Such a curve-fit yields 100 percent sentence intelligibility for background levels below 57 dB and yields less than 10 percent intelligibility for background levels above 73 dB. Note that the function is especially sensitive to changes in sound level between 65 dB and 75 dB. As an example of the sensitivity, a 1 dB increase in background sound level from 70 dB to 71 dB yields a 14 percent decrease in sentence intelligibility. In the same document from which Figure B-8 was taken, the EPA established an indoor criterion of 45 dB DNL as requisite to protect against speech interference indoors.

[18] U.S. Environmental Protection Agency, "Information on Levels of Environmental Noise Requisite to Protect the Public Health and Welfare with an Adequate Margin of Safety," Report 550/9-74-004, March 1974.

[19] Ibid.

Figure B-8
Sentence Intelligibility



Source: EPA, 1974

B.2.3 Sleep Disturbance

Sleep disturbance is another source of annoyance associated with aircraft noise. This is especially true because of the intermittent nature and content of aircraft noise, which is more disturbing than continuous noise of equal energy and neutral meaning.

Sleep disturbance can be measured in one of two ways. “Arousal” represents awakening from sleep, while a change in “sleep stage” represents a shift from one of four sleep stages to another stage of lighter sleep without awakening. In general, arousal requires a higher noise level than does a change in sleep stage.

In terms of average daily noise levels, some guidance is available to judge sleep disturbance. The EPA identified an indoor DNL of 45 dB as necessary to protect against sleep interference.[20] In June 1997, the Federal Interagency Committee on Aviation Noise (FICAN) reviewed the sleep disturbance issue and presented a sleep disturbance dose-response prediction curve.[21] FICAN based their curve on data from field studies[22] [23] [24] [25] and recommends the curve as the tool for analysis of potential sleep

[20] U.S. Environmental Protection Agency, “Information on Levels of Environmental Noise Requisite to Protect the Public Health and Welfare with an Adequate Margin of Safety,” Report 550/9-74-004, March 1974.

[21] Federal Interagency Committee on Aviation Noise (FICAN), “Effects of Aviation Noise on Awakenings from Sleep,” June 1997.

[22] Pearson, K.S., Barber, D.S., Tabachnick, B.G., “Analyses of the Predictability of Noise-Induced Sleep Disturbance,” USAF Report HSD-TR-89-029, October 1989.

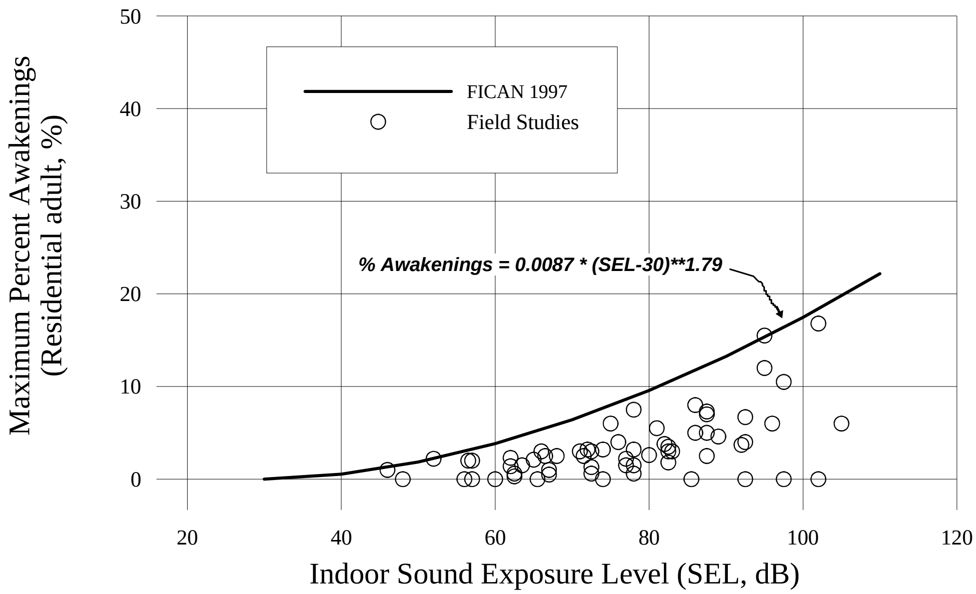
[23] Ollerhead, J.B., Jones, C.J., Cadous, R.E., Woodley, A., Atkinson, B.J., Horne, J.A., Pankhurst, F., Reyner, L, Hume, K.I., Van, F., Watson, A., Diamond, I.D., Egger, P., Holmes, D., McKean, J., “Report of a Field Study of Aircraft Noise and Sleep Disturbance.” London Department of Safety, Environment, and Engineering, 1992.

[24] Fidell, S., Pearsons, K., Howe, R., Tabachnick, B., Silvati, L., Barber, D.S. “Noise-Induced Sleep Disturbance in Residential Settings,” AL/OE-TR-1994-0131, Wright Patterson AFB, OH, Armstrong Laboratory, Occupational and Environmental Health Division, 1994.

[25] Fidell, S., Howe, R., Tabachnick, B., Pearsons, K., Sneddon, M., “Noise-Induced Sleep Disturbance in Residences Near Two Civil Airports,” Langley Research Center, 1995.

disturbance for residential areas. **Figure B-9** shows this curve which, for an indoor SEL of 60 dB, predicts that a maximum of approximately 5 percent of the residential population exposed are expected to be behaviorally awakened. FICAN cautions that this curve should only be applied to long-term adult residents.

Figure B-9
Sleep Disturbance Dose-Response Relationship



Source: FICAN, 1997

B.3 AIRCRAFT NOISE MODELING TECHNICAL REPORT

This section summarizes development of the noise model used to evaluate aircraft-induced noise impacts for this study.

B.3.1 Noise Model

The development of CNEL contours were generated using version 7.0 of the FAA's Integrated Noise Model (INM). INM uses annual average daily operations to compute existing and forecast noise. Annual average daily operations are representative of all aircraft operations that occur over the course of a year. The total annual operations are divided by 365 days to determine the annual average daily operations. Runway and flight track use is also averaged over one year.

The use of INM and computer-based noise modeling allow for the projection of future, forecast noise exposure. When the calculations are made in a consistent manner, INM is most accurate for comparing "before-and-after" noise effects resulting from forecast changes or potential alternatives. INM allows noise predictions for such forecast change actions without the actual implementation and noise monitoring of those actions.

Average temperature (60.4F), humidity (72.7%), pressure values (28.44 in-Hg) were calculated using a 10-year sample of NCDC hourly weather data at SDIA. High temperatures decrease air density, which decreases aircraft performance (e.g., takeoff distance increases and climb rate decreases) and generally results in increased noise. In conjunction with temperature, humidity affects the propagation of noise through the air. In general, sound travels farther in more humid conditions. Relative humidity is highest at night and gradually drops during the day, with the lowest point generally occurring in the afternoon.

Terrain data at 10-foot intervals were used in the noise model. Also, the displaced landing thresholds on Runways 09 and 27 are included in the noise model.

B.3.2 Fleet Mix

Table B-2 summarizes the fleet mix by aircraft type used for the years 2005 and 2015. For a given year of analysis, the fleet mix and operational level is the same for each alternative. **Table B-3** summarizes the fleet mix by aircraft type used for the year 2020 for the No Action Alternative, the East Terminal Alternative, and the Sponsor's Proposed Action (Preferred Alternative). The fleet mix was developed from the gated flight schedule that was produced from the aviation activity forecasts, as described in Appendix D. For the noise analysis, the simulation results (see Appendix C) were used to define the time of day for aircraft operations (i.e., daytime, evening, and nighttime periods of CNEL) based upon the effect of delay as estimated by the SIMMOD analysis. The gated flight schedule provided information on stage lengths.

Table B-2
Average Daily Fleet Mix (2005 and 2015)
(Includes Proposed Action, No Action, and East Terminal Alternatives)

Aircraft Group	ICAO Aircraft Type	2005	2015
Passenger	A319	20	22
	A320	42	88
	A321	6	-
	A342	-	-
	A343	-	2
	B733	104	82
	B734	14	8
	B735	4	26
	B737	86	136
	B738	20	36
	B739	4	4
	B752	40	28
	B762	-	-
	B763	12	10
	B772	-	10
	CRJ1	18	40
	CRJ7	-	24
	CRJ9	14	-
	E120	36	-
	E140	18	44
	E190	-	30
	MD11	-	2
	MD83	42	46
	MD90	-	8
	SF34	38	-
	Total	518	646
Cargo	A306	8	2
	B72Q	8	4
	B752	2	2
	B762	2	4
	B763	-	2
	DC10	-	4
	MD11	-	-
	Total	20	18

Table B-2

Average Daily Fleet Mix (2005 and 2015)

(Includes Proposed Action, No Action, and East Terminal Alternatives)

General Aviation	BE20	4	12
	BE55	2	-
	C340	2	-
	C525	2	-
	C560	2	-
	C650	2	-
	C680	2	-
	CL60	-	8
	GLF4	4	18
	GLF5	2	-
	H25B	2	12
	L29B	2	-
	LJ35	2	-
	LJ60	2	-
	PRM1	2	-
	SR22	2	-
	WW24	2	-
	Total	36	50
Military	HU25	-	2
	Total	-	2
Grand Total		574	716

Sources: Gated fight schedule as discussed Appendix D.

Table B-3

Average Daily Fleet Mix (2020)

Air Craft Group	ICAO Aircraft Type	No Project	East Terminal Alternative	Proposed Action (Preferred Alternative)
Cargo	A306	4	4	4
	B72Q	4	4	4
	B752			
	B762	4	4	4
	B763	4	4	4
	DC10	4	4	4
	MD11	2	2	2
	Total	22	22	22

Table B-3				
Average Daily Fleet Mix (2020)				
Air Craft Group	**ICAO Aircraft Type**	**No Project**	**East Terminal Alternative**	**Proposed Action (Preferred Alternative)**
General Aviation	BE20	12	12	12
	CL60	8	8	8
	GLF4	18	18	18
	H25B	12	12	12
	Total	50	50	50
Military	FA20	2	2	2
	Total	2	2	2
Passenger	A319-131	28	28	28
	A320-211	98	98	98
	A321-232	4	4	4
	A343	4	4	4
	B733	38	38	38
	B734	8	8	8
	B735	26	26	26
	B737	188	188	188
	B738	46	46	46
	B739	2	2	2
	B752	32	32	32
	B763	12	12	12
	B764	2	2	2
	B772	12	12	12
	CRJ1	42	42	42
	CRJ7	22	22	22
	E140	44	44	44
	E190	32	32	32
	MD11	2	2	2
	MD83	44	44	44
	MD90	8	8	8
	Total	694	694	694
Grand Total		768	768	768

Sources: Gated fight schedule as discussed Appendix D.

Standard aircraft types and profiles for INM version 7.0 were used in the CNEL contours. For aircraft not included in INM, the FAA's pre-approved substitution list was used to identify appropriate substitution aircraft.

B.3.3 Runway Use

Table B-4 shows overall average runway use. Runway use information for the noise modeling was developed from the simulation results, in order to be consistent with the overall operational assumptions and the air quality analysis. Runway use in the SIMMOD is derived from the annual usage of the runway use configurations (i.e., West Flow VFR, West Flow IFR, and East Flow IFR). Runway use is similar for all alternatives and years of analysis.

For the purpose of calculating the average headwind for each runway end, hourly weather data was matched to the 3-month sample of ANOMS data from the fourth quarter of 2003. Typical headwinds for Runway 27 operations are 3.5 mph, while Runway 09 has typical headwinds of 0.9 mph.

Previous noise analysis for the Airport Comprehensive Land Use Plan (ACLUP) has shown slightly higher arrival usage to Runway 9 during nighttime hours than is reflected in the SIMMOD analysis. During the morning hours (during the nighttime period extending up to 7 a.m.), aircraft will often land on Runway 09 in order to utilize the ILS approach when there is ground fog. This is not directly modeled in SIMMOD, due to the practical limitations of the model. A sensitivity analysis was performed to compare a higher percentage of nighttime arrivals to Runway 09, similar to what was modeled for the ACLUP. The difference in the arrival lobes at the 60 CNEL, versus the SIMMOD-derived runway use, was about 0.1 dB. Accordingly, this difference is not considered substantial.

Table B-4
Average Annual Runway Use

Operation Type	Time of Day	Runway		
		09	27	Total
Arrival	Daytime	3.2%	96.8%	100.0%
	Evening	3.7%	96.3%	100.0%
	Nighttime	3.7%	96.3%	100.0%
	Total (EDO)	3.6%	96.4%	100.0%
Departure	Daytime	1.6%	98.4%	100.0%
	Evening	1.7%	98.3%	100.0%
	Nighttime	2.0%	98.0%	100.0%
	Total (EDO)	1.8%	98.2%	100.0%
Overall	Daytime	2.3%	97.7%	100.0%
	Evening	2.9%	97.1%	100.0%
	Nighttime	2.8%	97.2%	100.0%
	Total (EDO)	2.7%	97.3%	100.0%

Notes:
EDO: Equivalent Daily Operations
Small differences exist between alternatives

Source: SIMMOD analysis.

B.3.4 Flight Tracks

Flight track layout was developed from a 15-day sample of radar data from October 11 to 25, 2003, as part of the ACLUP. This sample was identified for flight track analysis due to the near-average temperature spreads that prevailed during the period and the availability of operations data for both Runways 09 and 27. **Figures B-10 and B-11** show arrival and departure flight tracks in west and east flows, respectively. **Table B-5** shows average daily flight track use, with the same track identifiers shown on Figures B-10 and B-11.

Modeled departure flight tracks were developed for the 250, 275, 290, and 305/310 headings off Runway 27, as well as the 090-heading and left turn tracks off Runway 09. Multiple sub tracks were developed to the left and right of the primary flight tracks in order to model the dispersion that occurs due to weather, wind, and varying aircraft performance. Modeled arrival flight tracks were developed for the approaches to Runways 09 and 27 (e.g., the ILS RWY 9 and LOC RWY 27 IAPs), with dispersion and turns onto the final approach path as indicated by the radar data. The modeled flight tracks were developed to depict typical flight paths in the vicinity of SDIA, i.e., within a few miles of the airport to include the extents of the CNEL contours.

Table B-5
Average Daily Flight Track Use

Operation Type	Runway	Track Identifier	Time of Day			Equivalent Daily Ops
			Daytime	Evening	Nighttime	
Arrivals	09	A09A0	78.7%	87.7%	86.4%	84.7%
		A09A1	2.9%	1.5%	0.4%	1.3%
		A09A2	17.8%	10.8%	9.8%	12.2%
		A09A3	0.0%	0.0%	0.0%	0.0%
		A09A4	0.6%	0.0%	3.4%	1.8%
		Total	100.0%	100.0%	100.0%	100.0%
	27	A27A0	90.7%	90.9%	91.9%	91.3%
		A27A1	2.8%	2.7%	3.0%	2.8%
		A27A2	3.1%	1.2%	1.8%	2.0%
		A27A3	0.7%	0.8%	0.4%	0.6%
		A27A4	0.6%	0.9%	0.6%	0.6%
		A27B0	0.1%	0.1%	0.0%	0.1%
		A27B1	0.1%	0.0%	0.0%	0.0%
		A27B2	0.1%	0.3%	0.8%	0.5%
		A27B3	0.1%	0.1%	0.0%	0.0%
		A27B4	0.3%	0.0%	0.2%	0.2%
		A27C0	0.3%	2.0%	0.5%	0.8%
		A27C1	0.1%	0.2%	0.4%	0.3%
		A27C2	0.4%	0.4%	0.2%	0.3%
		A27C3	0.2%	0.3%	0.0%	0.1%
		A27C4	0.2%	0.1%	0.0%	0.1%
		A27C5	0.0%	0.0%	0.2%	0.1%
		A27C6	0.2%	0.0%	0.0%	0.1%
		Total	100.0%	100.0%	100.0%	100.0%

Table B-5 Average Daily Flight Track Use						
Operation Type	**Runway**	**Track Identifier**	**Time of Day**			**Equivalent Daily Ops**
			Daytime	**Evening**	**Nighttime**	
Departures	09	D09A0	10.9%	0.0%	0.3%	3.3%
		D09A1	0.0%	32.1%	0.0%	5.3%
		D09A2	43.5%	25.5%	53.9%	46.2%
		D09A3	0.0%	0.0%	19.6%	10.7%
		D09A4	27.9%	17.3%	3.7%	13.0%
		D09B0	4.4%	0.0%	0.0%	1.3%
		D09B1	4.4%	0.0%	1.4%	2.1%
		D09B2	0.0%	0.0%	19.6%	10.7%
		D09B3	0.0%	0.0%	1.4%	0.8%
		D09B4	8.9%	0.0%	0.0%	2.6%
		D09B5	0.0%	0.0%	0.0%	0.0%
		D09B6	0.0%	25.1%	0.0%	4.1%
		Total	100.0%	100.0%	100.0%	100.0%
	27	D27A0	0.0%	0.0%	0.0%	0.0%
		D27A1	0.0%	0.1%	0.0%	0.0%
		D27A2	0.0%	0.0%	0.0%	0.0%
		D27A3	0.0%	0.1%	0.0%	0.0%
		D27A4	0.0%	0.0%	0.0%	0.0%
		D27A5	0.0%	0.0%	0.0%	0.0%
		D27A6	0.0%	0.0%	0.0%	0.0%
		D27B0	16.6%	20.7%	12.2%	15.1%
		D27B1	15.8%	23.3%	24.4%	21.4%
		D27B2	5.2%	2.4%	0.3%	2.3%
		D27B3	4.5%	15.9%	18.0%	13.2%
		D27B4	0.6%	0.4%	0.0%	0.3%
		D27B5	0.4%	1.4%	1.0%	0.9%
		D27B6	0.3%	0.0%	0.0%	0.1%
		D27C0	18.7%	7.8%	17.7%	16.3%
		D27C1	5.8%	8.0%	5.3%	6.0%
		D27C2	24.8%	15.0%	16.4%	18.9%
		D27C3	1.0%	2.7%	1.3%	1.4%
		D27C4	5.9%	1.5%	3.2%	3.8%
		D27C5	0.1%	0.6%	0.0%	0.2%
		D27C6	0.1%	0.0%	0.2%	0.1%
		D27C7	0.0%	0.0%	0.0%	0.0%
		D27C8	0.0%	0.0%	0.0%	0.0%
		D27D0	0.0%	0.0%	0.0%	0.0%
		D27D1	0.0%	0.0%	0.0%	0.0%
		D27D2	0.0%	0.0%	0.0%	0.0%
		D27D3	0.0%	0.0%	0.0%	0.0%
		D27D4	0.0%	0.0%	0.0%	0.0%
		D27D5	0.0%	0.0%	0.0%	0.0%
		D27D6	0.1%	0.0%	0.0%	0.0%
		Total	100.0%	100.0%	100.0%	100.0%

Notes: EDO: Equivalent Daily Operations
Small differences exist between alternatives

Source: HNTB analysis of 15-day sample of radar data from October 2003.

Flight track use (including dispersion about the primary and sub tracks) was developed in reference to the modeled flight tracks and the aircraft operations within the 15-day sample of radar data from October 11 to 25, 2003. Similar to runway use data, the flight track use data was categorized by reference to arrival/departure, time of day, and aircraft group.

B.3.5 Ground Noise

In order to assess the effects of noise produced during ground movements (e.g., aircraft taxiing, engine start, pulling up to a gate/RON, etc.), a sensitivity analysis was conducted to assess single event noise levels and the potential effect on cumulative noise exposure levels in the vicinity of SDIA.

The noise from aircraft that are taking off and landing is substantially louder than that produced during ground movements and so the noise from aircraft ground movements is not typically included in noise modeling as it would not appreciably change the CNEL contours. In addition, INM does not account for the substantial shielding effects due to buildings and other objects on the ground. This is an important limitation.

The ground noise from two aircraft types, the B737-300 (i.e., INM type 7373B2) and MD83, which represent the most numerous and largest contributor to cumulative noise exposure, respectively, in 2010 were analyzed to estimate SEL and the potential for ground noise to change the CNEL contours. The aircraft were modeled with daytime operations at a sample of RON and gate positions that are part of the Sponsor's Proposed Action (Preferred Alternative). As these locations are farther to the west than current ground movements at SDIA, the analysis of noise from these positions provides for a conservative evaluation. In addition, the aircraft were modeled at a high idle/breakaway thrust setting for a period of 20 minutes per sampled operation. This provides for a conservative estimate of engine start and movement in/out of a gate, as aircraft in the gate area would often be operating at lower thrust settings.

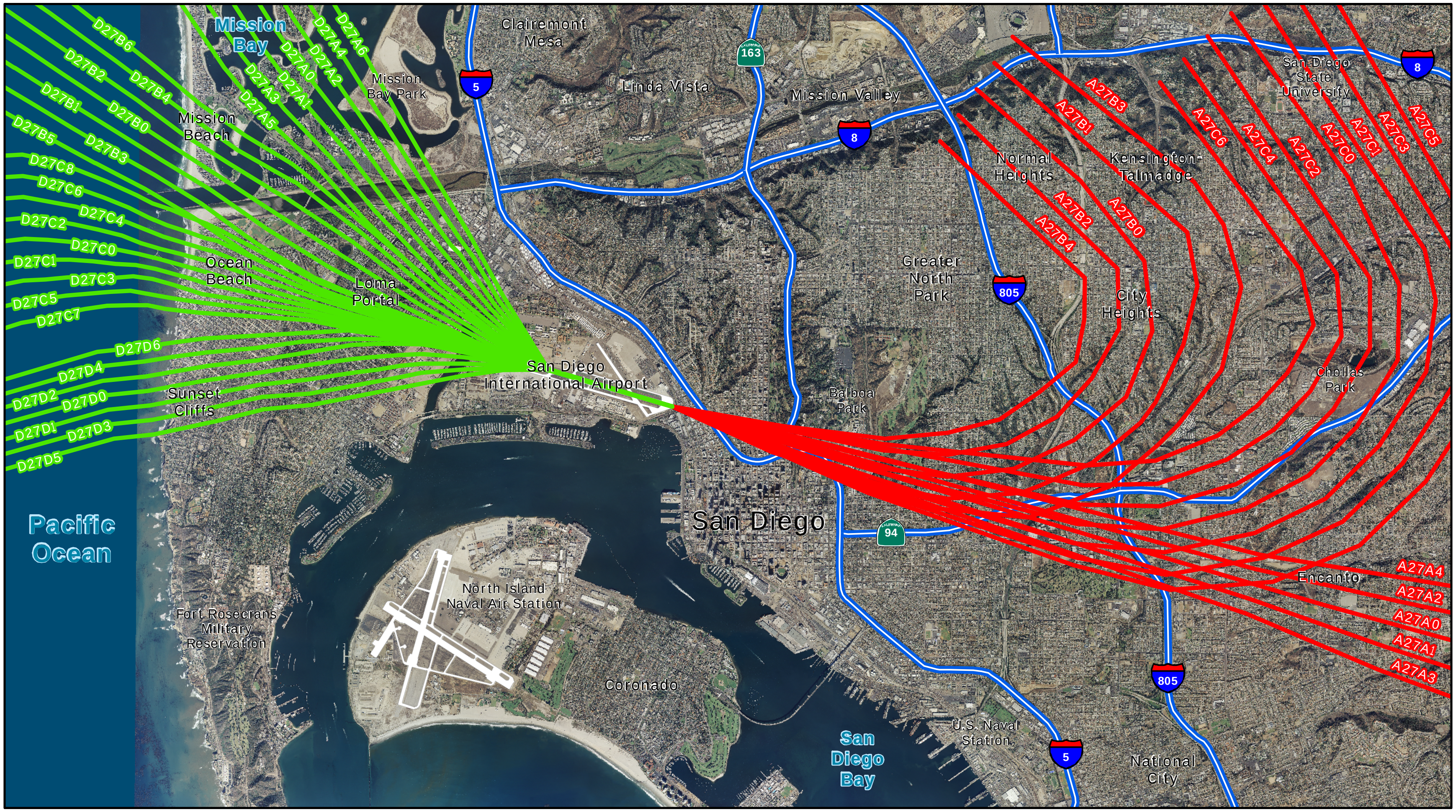
The resulting noise at locations along Harbor Island and the Navy Channel were calculated. SELs varied from a low of about 70 dB to a high of 114 dB, with a median value of 90 dB. Note that the value of 114 SEL is not realistic, given the typical attenuation and blocking provided by buildings and vegetation. Also, INM does not account of the effect of water on sound propagation, which is a noteworthy limitation for consideration of ground noise at SDIA. SEL diminishes substantially with distance from the fixed noise source, and the analysis indicates that a substantial number of operations would be needed to appreciably increase CNEL levels.

B.3.6 Results and Limitations

The noise model provides a reasonable estimate of existing and future noise exposure due to aircraft operations at SDIA. Due to the predominant west flow runway use with arrivals to and departures from Runway 27, the CNEL contours to the east of SDIA are relatively narrow and thus reflect the concentration of arrival aircraft on the approach path. Conversely, the wider CNEL contours to the west of SDIA reflect the dispersion of departure tracks that occurs as aircraft are routed in different directions.

Note that variances in factors such as the fleet mix and time of day of operations will likely affect actual future noise exposure levels. Additionally, there are limitations and constraints with INM that are important to consider. Due to terrain, the approaches into SDIA are flown at steeper angles than the standard 3.0-degree approach that is used at most airports. The standard profiles used in INM are modeled at a 3.0-degree approach angle. As a result, aircraft in the SDIA noise model are at a slightly lower altitude and higher thrust setting than actual operations; calculated noise exposure is increased slightly as a result. Additionally, noise monitoring efforts by SDIA staff have previously indicated measured data differs from INM’s calculations of lateral attenuation due to takeoff noise in the vicinity of the Runway 27 approach end. Depending on the location, INM can overstate or understate noise exposure levels. This is due to the terrain (including buildings) in the vicinity of SDIA, and the prevalence of both hard and soft ground coverage. INM assumes that surfaces are soft and absorb some sound energy; however, in reality the hard surfaces (such as water, streets, etc.) in the vicinity of SDIA tend to reflect and increase noise exposure.

HNTB



Arrival Flight Tracks

Departure Flight Tracks

0 0.25 0.5 1 1.5 2 Miles

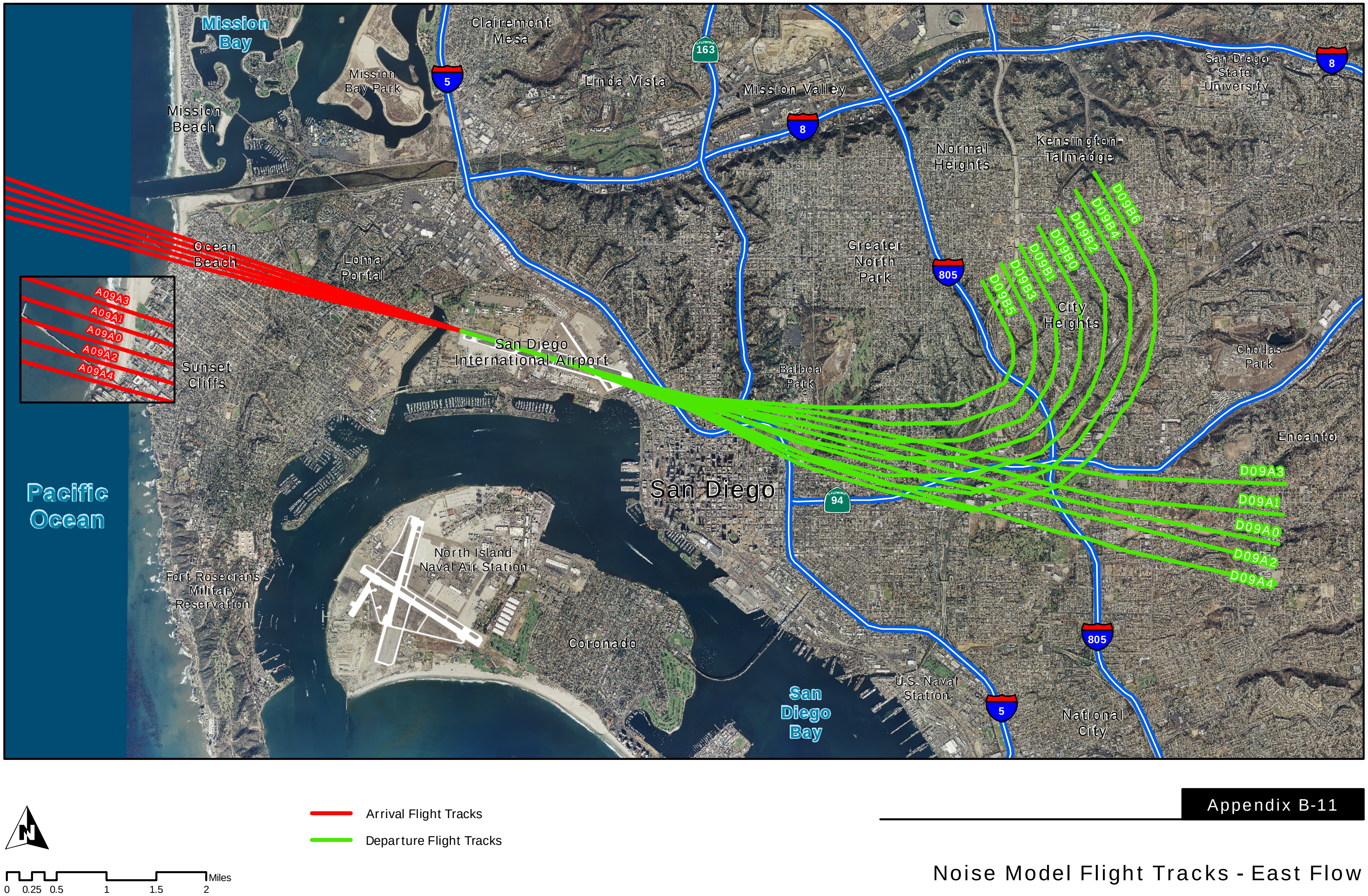
Appendix B-10

Noise Model Flight Tracks - West Flow

Source: As noted in text

Prepared by: HNTB Corporation, 2006

HNTB



Appendix B-11

Noise Model Flight Tracks - East Flow

Source: As noted in text

Prepared by: HNTB Corporation, 2006