

Appendix D-1

**INTRODUCTION TO
NOISE AND ITS EFFECTS**

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Introduction to Aircraft Noise and Its Effects

Section 1 addresses aircraft noise descriptors. Section 2 discusses the effects of noise on people.

Section 1 ***Aircraft Noise Descriptors***

A variety of noise metrics are used to assess airport noise impacts in different ways. Noise metrics are used to describe individual noise events (such as a single operation of an aircraft taking off overhead) or groups of events (such as the cumulative effect of numerous aircraft operations, the collection of which creates a general noise environment, or overall exposure level). Both types of descriptors are helpful in explaining how people tend to respond to a given noise condition. Descriptions of these metrics are provided below.

Decibel, dB – Sound is a complex physical phenomenon consisting of complex minute vibrations traveling through a medium, such as air. These vibrations are sensed by the human ear as sound pressure. Because of the vast range of sound pressure or intensity detectable by the human ear, sound pressure level (SPL) is represented on a logarithmic scale known as decibels (dB). A sound level of 0 dB is approximately the threshold of human hearing and is barely audible under extremely quiet (laboratory-type) listening conditions. A SPL of 120 dB begins to be felt inside the ear as discomfort and pain at approximately 140 dB. Most environmental sounds have SPLs ranging from 30 to 100 dB.

Because decibels are logarithmic, they cannot be added or subtracted directly like other (linear) numbers. For example, if two sound sources each produce 100 dB, when they are operated together they will produce 103 dB, not 200 dB. Four 100 dB sources operating together again double the sound energy, resulting in a total SPL of 106 dB, and so on. In addition, if one source is much louder than another, the two sources operating together will produce the same SPL 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.

Two useful rules to remember when comparing SPLs are: (1) most people perceive a 6 to 10 dB increase in SPL between two noise events to be about a doubling of loudness, and (2) changes in SPL of less than about 3 dB between two events are not easily detected outside of a laboratory.

A-Weighted Decibel, dBA – Frequency, or pitch, is a basic physical characteristic of sound and is expressed in units of cycles per second or hertz (Hz). The normal frequency range of hearing for most people extends from about 20 to 15,000 Hertz (Hz). Because the human ear is more sensitive to middle and high frequencies (i.e., 1000 to 4000 Hz), a frequency weighting called “A” weighting is applied to the measurement of sound. The internationally standardized “A” filter approximates the sensitivity of the human ear and helps in assessing the perceived loudness of various sounds. In this document all sound levels are A-weighted sound levels and the adjective “A-weighted” has been omitted.

Figure D-1.1 charts common indoor and outdoor sound levels. A quiet rural area at nighttime may be 30 dBA or lower while the operator of a typical gas lawn mower may experience a level of 90 dBA. Similarly, the level in a library may be 30 dBA or lower while the listener at a rock band concert may experience levels near 110 dBA.

Maximum A-Weighted Noise Level, L_{max} – Sound levels vary with time. For example, the sound increases as an aircraft approaches, then falls and blends into the ambient or background as the aircraft recedes into the distance. Because of this variation, it is often convenient to describe a particular noise "event" by its highest or maximum sound level (L_{max}). Note 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 L_{max} may produce very different total exposures. One may be of very short duration, while the other may be much longer.

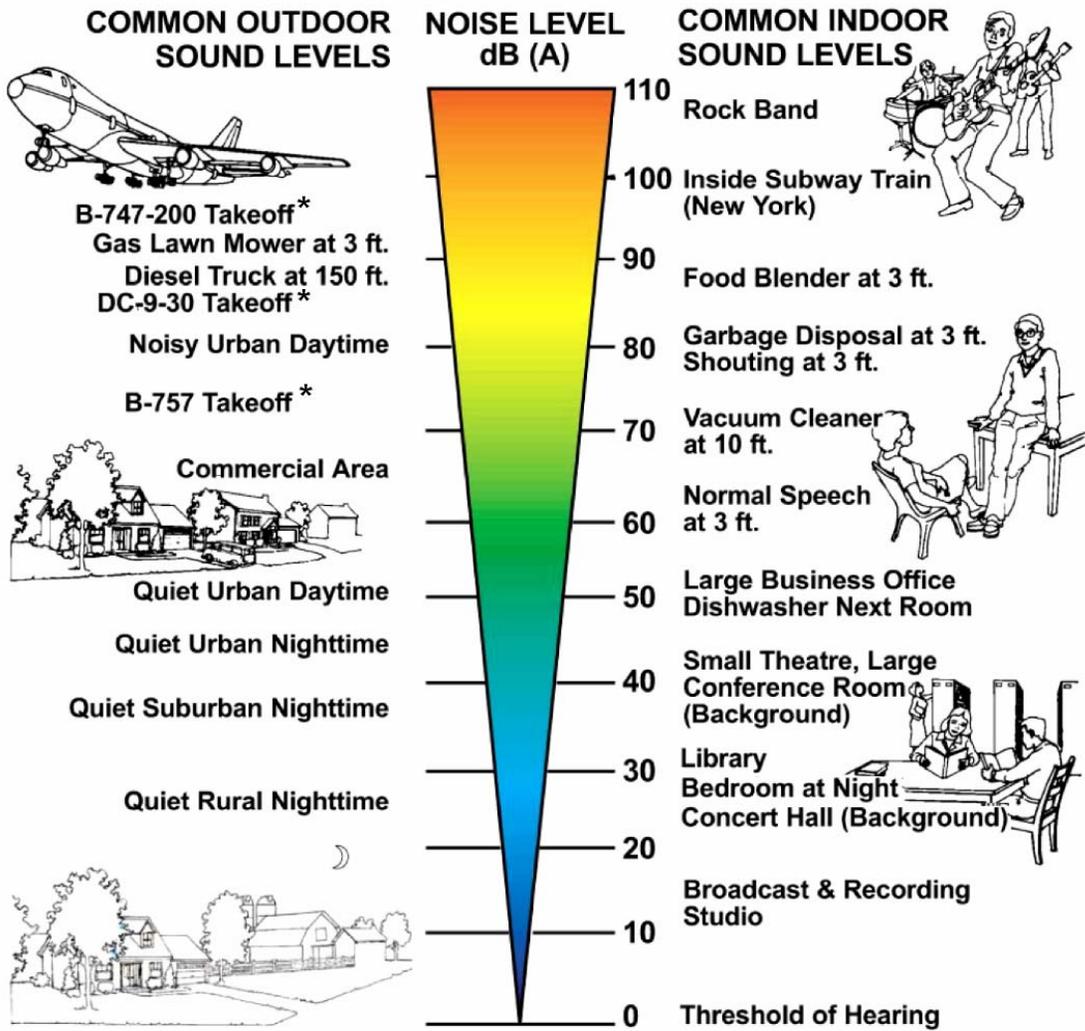
Sound Exposure Level, SEL – The most common measure of noise exposure for a single aircraft flyover is the SEL. SEL is a summation of the A-weighted sound energy at a particular location over the true duration of a noise event normalized to a fictional duration of one second. The true duration is defined as the amount of time the noise event exceeds background levels. For events lasting 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.

The normalization to the fictional duration of one second enables the comparison of noise events with differing true duration and/or maximum level. Because the SEL is normalized to one second, it will almost always be larger in magnitude than the L_{max} for the event. In fact, for most aircraft events, the SEL is about 7 to 12 dB higher than the L_{max} . Additionally, since it is a cumulative measure, a higher SEL can result from either a louder or longer event, or some combination.

As SEL combines an event's overall sound level along with its duration, SEL provides a comprehensive way to describe noise events for use in modeling and comparing noise environments. Computer noise models, such as the one employed for this document, base their computations on these SELs.

Figure D-1.2 shows an event's "time history", the variation of sound level with time. For typical sound events experienced by a fixed listener, like a person experiencing an aircraft pass-by, the sound level rises as the source (or aircraft) approaches the listener, peaks and then diminishes as the aircraft flies away from the listener. The area under the time history curve represents the overall sound energy of the noise event. The L_{max} for the event shown in the figure was 93.5 dBA. Compressing the event's total sound energy into one second to compute its SEL yields 102.7 dBA.

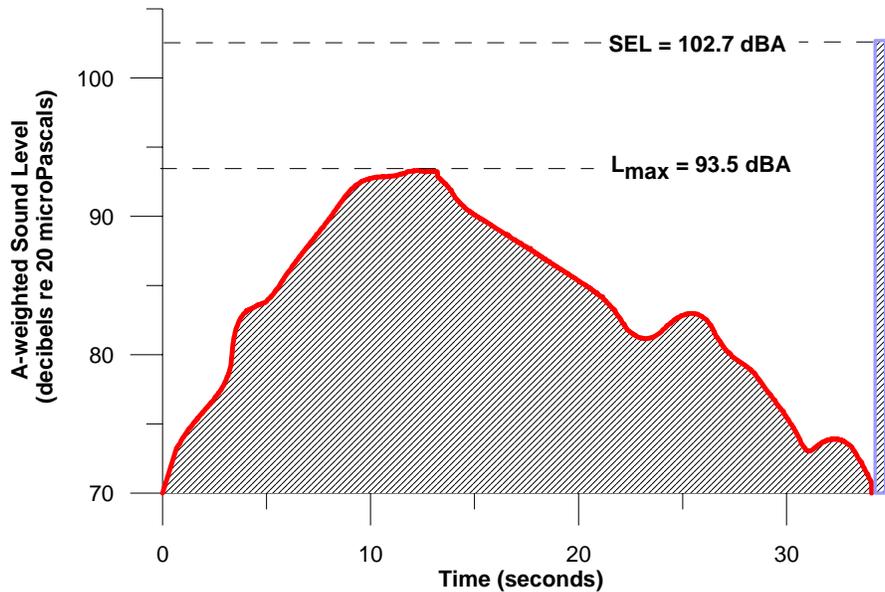
**FIGURE D-1.1
COMMON OUTDOOR AND INDOOR SOUND LEVELS**



* 2 Miles from Brake Release

Source: Draft EIS/EIR LAX Proposed Master Plan Improvements, Los Angeles, CA
U.S. Department of Transportation, FAA, January 2001.

**FIGURE D-1.2
COMPARISON OF MAXIMUM SOUND LEVEL (L_{MAX}) AND SOUND EXPOSURE LEVEL (SEL)**



Source: URS Corporation

Equivalent Sound Level, L_{eq} -- Equivalent sound level (abbreviated L_{eq}) is a measure of the 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 “dips”. In the context of noise from typical aircraft flight events and as noted earlier 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.

Since the period of interest for this study is in the nighttime period, $L_{eq(n)}$ is the proper nomenclature. The definition of nighttime follows in the next paragraph.

Day-Night Average Sound Level, DNL – Time-average sound levels are measurements of sound levels averaged over a specified length of time. These levels provide a measure of the average sound energy during the measurement period. For the evaluation of community noise effects, and particularly aircraft noise effects, the Day-Night Average Sound Level (abbreviated DNL) is used. DNL (logarithmically) averages aircraft sound levels at a location over a complete 24-hour period, with a 10-decibel adjustment added to those noise events occurring between 10:00 p.m. and 7:00 a.m. (local time) the following morning. The 10:00 p.m. to 7:00 a.m. period is defined as nighttime (or night) and the 7:00 a.m. to 10:00 p.m. period is defined as daytime (or day). Because of the increased sensitivity to noise during normal sleeping hours and because ambient (without aircraft) sound levels during nighttime are typically about 10 dB lower than during daytime hours, the 10-decibel "penalty" represents the added intrusiveness of sounds occurring during nighttime hours.

DNL accounts for the noise levels (in terms of SEL) of all individual aircraft events, the number of times those events occur and the period of day/night in which they occur. Values of DNL can be measured with standard monitoring equipment or predicted with computer models. This document utilizes estimates of DNL with an FAA-approved computer-based noise model.

Typical DNL values for a variety of noise environments are shown in [Figure D-1.3](#). DNL values can be approximately 85 dBA outdoors under a flight path within a mile of a major airport and 40 dBA or less outdoors in a rural residential area.

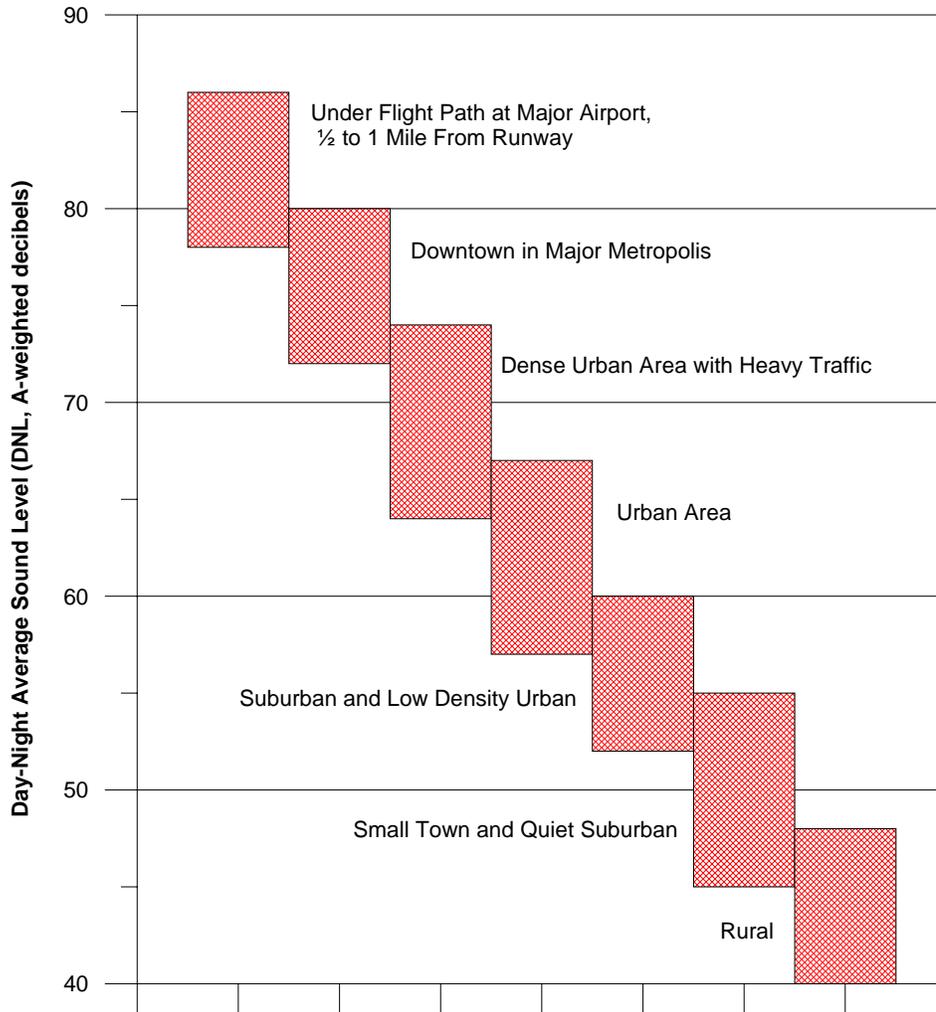
Due to the DNL descriptor's close correlation with the degree of community annoyance from aircraft noise, DNL has been formally adopted by most federal agencies for measuring and evaluating aircraft noise for land use planning and noise impact assessment. Federal committees such as the Federal Interagency Committee on Urban Noise (FICUN) and the Federal Interagency Committee 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. They also found no new cumulative sound descriptors or metrics of sufficient scientific standing to substitute for DNL. Other cumulative metrics could be used only to supplement, not replace DNL. Furthermore, FAA Order 1050.1E for environmental impact studies, requires DNL be used in describing cumulative noise exposure and in identifying aircraft noise/land use compatibility issues (EPA, 1974; FICUN, 1980; FICON, 1992; 14 CFR Part 150, 1995; FAA, 2004).

Time-Above a Specified Level – The Time-Above a Specified Level (TA) metric describes the total number of minutes that instantaneous sound level (usually from aircraft) are above a given threshold. For example, if 75 dB is the specified threshold, the metric would be referred to as "TA75." The TA metric is typically associated with 24-hour annual average daily conditions but can be used to represent any time period. Any threshold may be chosen for the TA calculation. For this study, the threshold is 75 dB for the full 24-hour day.

Number of Events Above a Specified Level -- Number-of-events Above (NA) is a noise metric that reflects the average number of times noise equals or exceeds a chosen threshold level during a specified time period. NA contours can be depicted at any noise threshold level (x) and any user defined number of events (z), using the notation 'NAX(z),' meaning 'z' events at or above noise level 'x'. These analysis

parameters (x and z) may differ in each affected community, based on specific circumstances. No guidelines have yet been established for NA analyses, but individual jurisdictions may apply Federal guidelines in such a way as to reflect unique conditions at each airport. So, each jurisdiction has some latitude in establishing local noise standards. The NA metric provides for much flexibility and can be tailored to any noise environment, such as daytime, nighttime, or any user-defined number of hours.

FIGURE D-1.3
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.

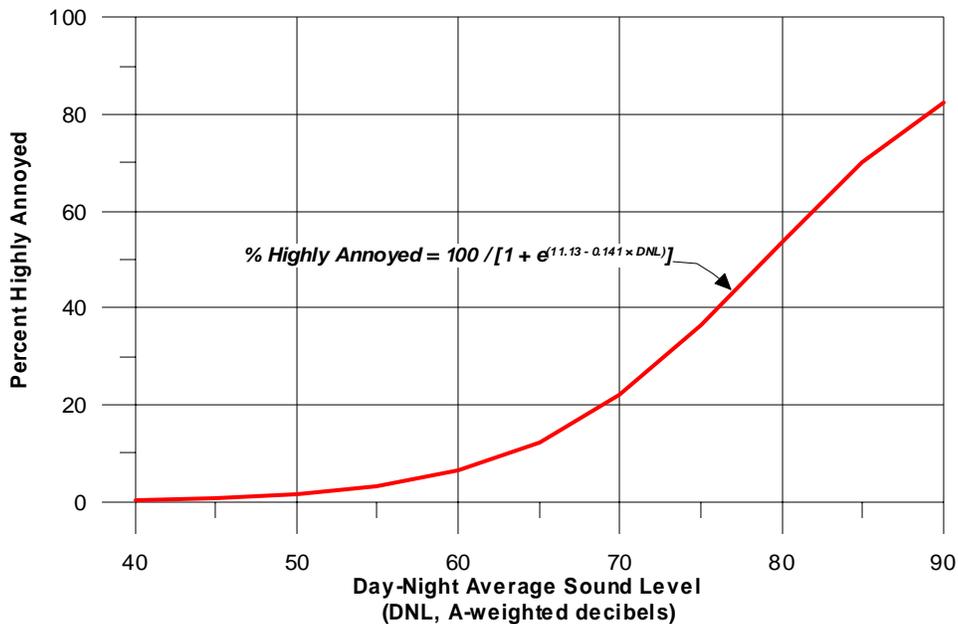
Section 2 Effects of Aircraft Noise on People

This section addresses three ways humans can be affected by aircraft noise: annoyance, speech interference and sleep disturbance.

Annoyance – The primary potential effect of aircraft noise on exposed communities is one of annoyance. Noise annoyance is defined by the U.S. Environmental Protection Agency as any negative subjective reaction on the part of an individual or group (US EPA, 1974). Scientific studies and a large number of social/attitudinal surveys have been conducted to appraise people's annoyance to all types of environmental noise, especially aircraft events. These studies and surveys have found the DNL to be the best measure of this annoyance (EPA, 1974; FICUN, 1980; FICON, 1992; ANSI, 1980; ANSI, 1988; Schultz, 1978; Fidell, et. al., 1991).

The relationship between annoyance and DNL determined by the scientific community and endorsed by many federal agencies, including the FAA, is shown in [Figure D-1.4](#). For a DNL of 65 dBA, approximately 13% of the exposed population would be highly-annoyed. The figure also shows at very low values of DNL, such as 45 dB or less, 1% or less of the exposed population would be highly annoyed. At very high values of DNL, such as 90 dBA, more than 80% of the exposed population would be highly annoyed.

FIGURE D-1.4
RELATIONSHIP BETWEEN ANNOYANCE AND DAY-NIGHT AVERAGE SOUND LEVEL



Source: Federal Interagency Committee on Noise (FICON),
"Federal Agency Review of Selected Airport Noise Analysis Issues",
August 1992, p. 3-6, Figure 3.1, USAF (Finogold et. al. 1992) curve
based on 400 points.

It is often suggested a lower DNL, such as 60 or 55 dB, be adopted as the threshold of community noise annoyance for FAA 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:

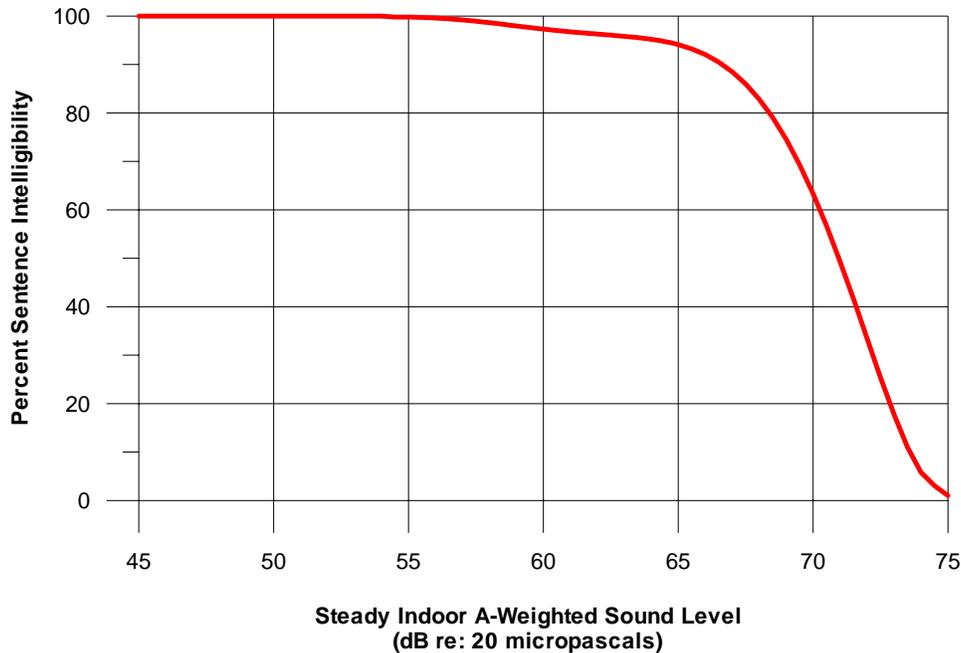
- 1) Provides a valid basis for comparing and assessing community noise effects.
- 2) Represents a noise exposure level normally dominated by aircraft noise and not other community or nearby highway noise sources
- 3) Reflects the FAA's threshold for grant-in-aid funding of airport noise mitigation projects.
- 4) HUD also established a DNL standard of 65 dBA for eligibility for federally guaranteed home loans.

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. As an aircraft approaches and its sound level increases, speech becomes harder to hear. As the ambient level increases, the talker must raise his/her voice, or the individuals must get closer together to continue talking.

For typical communication distances of 3 or 4 feet (1 to 1.5 meters), acceptable outdoor conversations can be carried on in a normal voice as long as the ambient noise outdoors is less than about 65 dBA (FICON, 1992). If the noise exceeds this level, intelligibility would be lost unless vocal effort was increased or communication distance was decreased.

Indoor speech interference can be expressed as a percentage of sentence intelligibility between two average adults with normal hearing speaking fluently in relaxed conversation approximately one meter apart in a typical living room or bedroom (EPA, 1974). As shown in [Figure D-1.5](#), the percentage of sentence intelligibility is a non-linear function of the (steady) indoor ambient or background sound level (24-hour energy-average equivalent sound level ($L_{eq(24)}$)). Steady ambient indoor sound levels of up to 45 dBA $L_{eq(24)}$ are expected to allow 100% intelligibility of sentences. The curve shows 99 percent sentence intelligibility for $L_{eq(24)}$ at or below 54 dBA and less than 10 percent intelligibility for $L_{eq(24)}$ greater than 73 dBA. In the same document from which [Figure D-1.5](#) was taken, the EPA established an indoor criterion of 45 dBA DNL as requisite to protect against speech interference indoors (EPA, 1974).

FIGURE D-1.5
PERCENT SENTENCE INTELLIGIBILITY FOR INDOOR SPEECH



Source: U.S. Environmental Protection Agency, 1974.

Classroom Word Intelligibility -- An important application of speech interference criteria is in the classroom where the percent of words (rather than whole sentences) transmitted and received, 'commonly referred to as 'word intelligibility', is critical. For teachers to be clearly understood by their students, it is important that regular voice communication is clear and uninterrupted. Not only does the steady background sound level have to be low enough for the teacher to be clearly heard, but intermittent outdoor noise events also need to be unobtrusive. It is therefore important to evaluate the steady ambient level, the level of voice communication, and the single event level (e.g., aircraft over-flights) that might interfere with speech.

The noise from aircraft events is not continuous, but consists of individual events where the noise level can greatly exceed the background level for a limited time period as the aircraft flies over. Since speech interference in the presence of aircraft noise is essentially determined by the magnitude and frequency of individual aircraft flyover events, a time-averaged metric alone such as L_{eq} , is not necessarily appropriate when setting standards regarding acceptable levels. In addition to the background levels described above, single event criteria, which account for those sporadic intermittent noisy events, are also essential to specifying speech interference criteria.

Accounting for the typically intermittent nature of aircraft noise where speech is impaired only for the short time when the aircraft noise is close to its maximum value, different researchers and regulatory organizations have recommended maximum allowable indoor noise levels ranging between 40 and 60 dBA L_{max} . For the purposes of this document, the criteria is an indoor noise level of 50 dBA L_{max} for single

event noise with an indoor ambient (background) noise level of 35 dBA L_{eq} ¹. These criteria are assumed to apply for the duration of school hours and assume the teacher's voice located at the front of the room measures at least 50 dBA L_{max} in the rear of the classroom. These criteria are consistent with research (Lind, et. al., 1998; Sharp and Plotkin, 1984; Wesler, 1986), World Health Organization (WHO) and American Speech-Language-Hearing Association (ASLHA) recommendations (WHO, 1999; ASLHA, 1995) and ANSI standards (ANSI, 2002). The single event noise level of 50 dBA L_{max} correlates to 90 percent of the words being understood by students with normal hearing and no special needs seated throughout a classroom (Lind, et. al., 1998). At-risk students may be adversely affected at lower sound levels. The 15 dB difference between the aircraft noise and ambient noise (aka "signal-to-noise" ratio) is the minimum difference to ensure that children with hearing impairments and language disabilities are able to enjoy high speech intelligibility (ANSI, 2002; ASLHA, 1995; Lazarus, 1990; Bradley, 1985).

Speech Interference Criteria -- For this study's assessment of potential speech interference, contours of outdoor daytime NA70 dBA L_{max} were developed. Daytime (7am – 10pm) was chosen because it is when most people are awake and when schools would be active. The level of 70 dBA L_{max} was chosen because it pertains to an indoor noise level of 50 dBA L_{max} assuming a conservative structural noise insulation of 20 dB for typical dwellings with windows closed. As explained above, 50 dBA L_{max} is an adequate criterion for indoor classroom word intelligibility and, if it were a steady level, 50 dBA correlates to nearly 100% sentence intelligibility based on EPA research.

Sleep Disturbance –The U.S. Environmental Protection Agency identified an indoor DNL of 45 dB as necessary to protect against sleep interference (EPA, 1974). Assuming a conservative structural noise insulation of 20 dB for typical dwellings with windows closed, an indoor DNL of 45 dB corresponds to an outdoor DNL of 65 dB as minimizing sleep interference.

Prior to and after the EPA's 1974 guidelines, research on sleep disruption from noise has led to widely varying observations. In part, this is because: (1) sleep can be disturbed without causing awakening, (2) the deeper the sleep the more noise it takes to cause arousal, (3) the tendency to awaken increases with age, (4) the person's previous exposure to the intruding noise and other physiological, psychological and situational factors. The most readily measurable effect of noise on a sleeping person is the number of arousals or awakenings.

In June 1997, the U.S. Federal Interagency Committee on Aviation Noise (FICAN) reviewed the sleep disturbance issue along with data from the 1992 Federal Interagency Committee on Noise recommendations (which was primarily the result of many laboratory studies) and presented a new sleep disturbance dose-response prediction curve (FICAN, 1997) as the recommended tool for analysis of potential sleep disturbance for residential areas. The FICAN curve, shown in [Figure D-1.6](#), was based on data from field studies of major civilian and military airports. For an indoor SEL of 60 dBA, [Figure D-1.6](#) predicts a maximum of approximately 5 percent of the exposed residential population would be

¹ ANSI recommends when the background noise level of the noisiest hour is dominated by aircraft noise, the indoor ambient noise level criteria of 35 dBA L_{eq} can be increased to 40 dBA L_{eq} as long as the noise level does not exceed 40 dBA for more than 10 percent of the noisiest hour (i.e., L10 less than 40 dBA), for a room with a volume less than 20,000 cubic feet (e.g., a room measuring 50 feet long, 50 feet wide and 8 feet high) (ANSI, 2002).

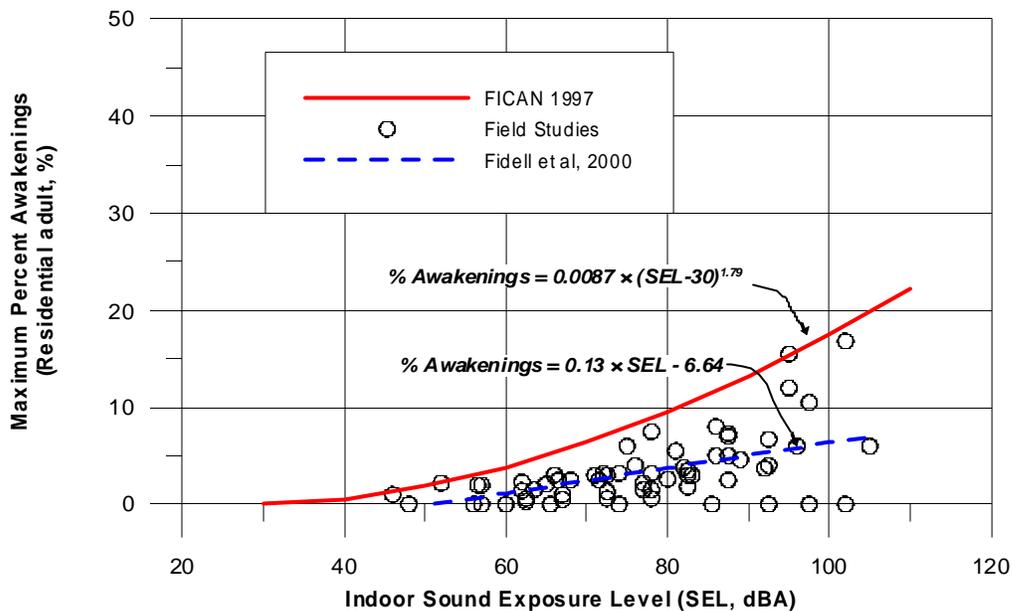
behaviorally awakened. FICAN cautions that his curve should only be applied to long-term adult residents.

Note that the focus of this research was the human response to individual SELs rather than the response to multiple events in the same night. The relationship of SEL and percent awakenings presented in the figure is for each event, not a cumulative percent awakening for all events during a sleep period.

It should be noted that the FICAN curve shown in the figure is conservative as it is aligned with the upper bounds of the field studies. If the field data was curve-fitted (Fidell, et. al., 2000), the maximum percent awakenings would be less than the upper bound depicted by the FICAN curve. In a range of indoor SEL from 50 dBA to 90 dBA, the curve-fit methodology would yield from 1% to approximately 7% less awakenings than the FICAN curve.

Sleep Disturbance Criteria -- For this study's assessment of potential sleep disturbance, contours of outdoor nighttime NA90 dBA SEL were developed. Nighttime (10pm – 7am) was chosen because it is when most people sleep. The level of 90 dBA SEL was chosen because it pertains to less than 10 percent indoor awakenings assuming a conservative structural noise insulation of 20 dB for typical dwellings with windows closed or 15 dB with windows open.

**FIGURE D-1.6
SLEEP DISTURBANCE DOSE-RESPONSE RELATIONSHIP**



Source: FICAN, 1997; Fidell, et. al., 2000;

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