APPENDIX B

AIRCRAFT NOISE

B.1 AIRCRAFT NOISE

Aircraft noise originates from the engines as well as the airframe or structure of aircraft. The engines are generally the most significant source of noise. While noise generated by propeller-driven aircraft can be annoying, jet aircraft are commonly the source of disturbing noise at airports. Two basic types of jet aircraft are operated today equipped with turbofan or turbojet engines. Aircraft flying faster than the speed of sound generate an intense pressure wave called a sonic boom, in addition to the propulsion and airframe noise.

Turbofan engines produce thrust as reaction to the rate at which high-velocity gas is exhausted from nozzles. The engine core consists of a compressor, combustion chambers, a turbine and a front fan. The major sources of noise include the core engine fan streams, the compressor, turbine blades and exhaust nozzles. In comparison, turbojet aircraft do not have the front fan component. It has been found in several cases that the sound energy produced by a turbojet engine is greater than that of a turbofan engine with an equivalent thrust rating.

The noise produced by jet aircraft flyovers is characterized by an increase in sound energy as the aircraft approaches, up to a maximum level. This sound level begins to lessen as the aircraft passes overhead and then decreases in a series of lesser peaks as the aircraft departs the area.

Noise produced by propeller driven aircraft and helicopters emanates from the blades and rotors. There are two components of this noise, namely vortex and periodic. Vortex noise is generated by the formation and shedding of vortices in the airflow past the blade. Periodic noise is produced by the oscillating pressure field in the air that results from the passage of air past the blade. Blade slap is an additional source of noise in helicopters. This is high-amplitude periodic noise and highly modulated vortex noise caused by fluctuating forces as one blade cuts through the tip vortices of another.

B.2 AIRCRAFT NOISE TERMINOLOGY

The Federal Aviation Administration (FAA) uses a variety of noise metrics to assess potential airport noise impacts. Different noise metrics can be used to describe individual noise events (e.g., a single operation of an aircraft taking off overhead) or groups of events (e.g., 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 the metrics used in this NEM Update are provided in the following text.

Decibel, dB – Sound is a complex physical phenomenon consisting of many minute vibrations traveling through a medium, such as air. The human ear senses these vibrations 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 SPL of 0 dB is approximately the threshold of human hearing and is barely audible under extremely quiet (laboratory-type) listening conditions. A person begins to feel a SPL of 120 dB inside the ear as discomfort, and pain begins 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 produces 100 dB when operating together. The louder source masks the quieter one.

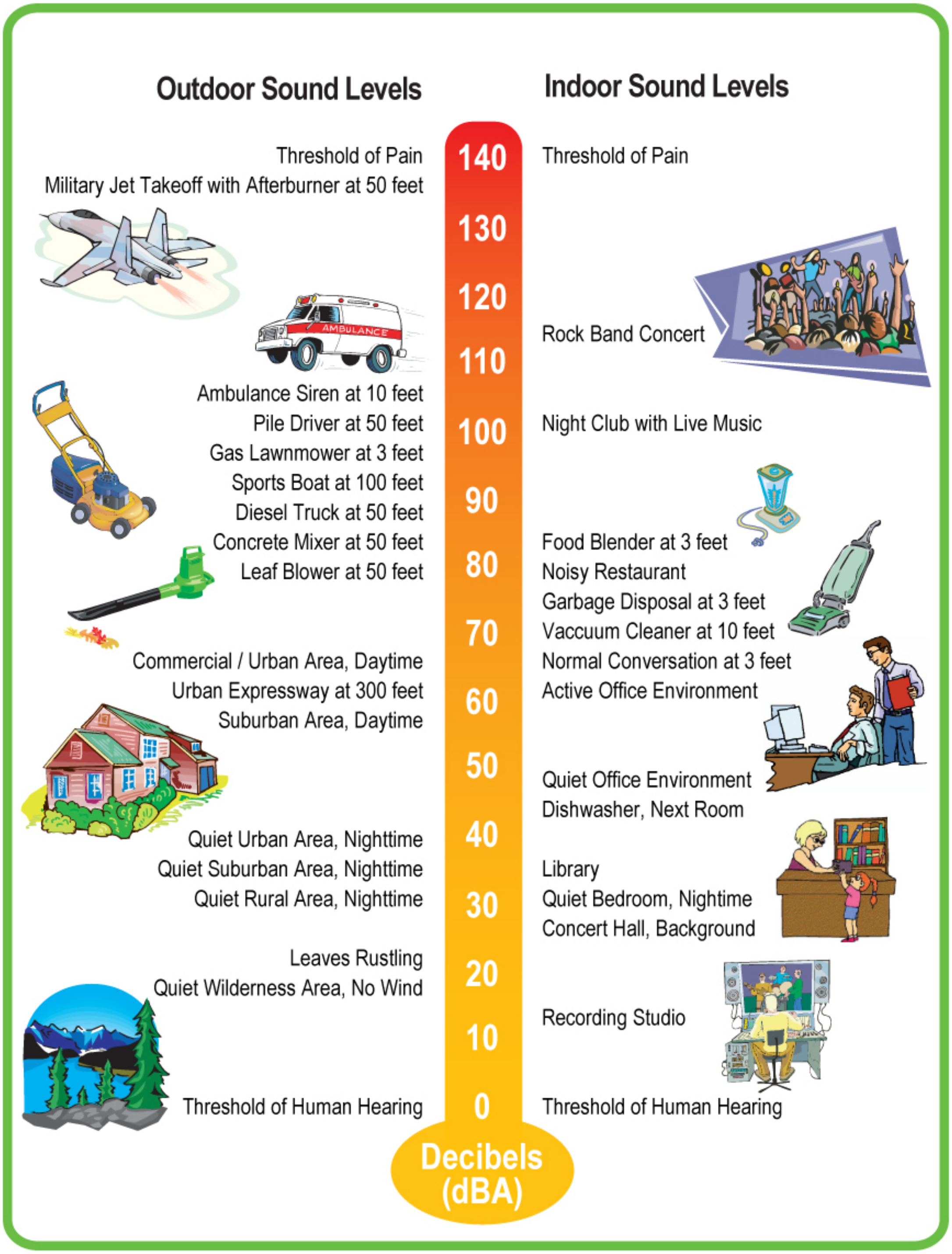
Two useful rules to remember when comparing SPLs are: (1) most people perceive a 6 to 10 dB increase in SPL between two noise events to be about a doubling of loudness, and (2) changes in SPL of less than about 3 dB between two events are not easily detected outside of a laboratory.

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 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. For this Part 150 Study, all sound levels are A-weighted sound levels and the text typically omits the adjective "A-weighted".

Figure B.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_{Amax} – 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_{Amax}). It should be noted that L_{Amax} 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_{Amax} levels may produce very different total noise exposures. One may be of very short duration, while the other may last much longer.

FIGURE B.1
COMMON OUTDOOR AND INDOOR SOUND LEVELS



Source: URS Corp, 2008.

Sound Exposure Level, SEL – The most common measure of noise exposure for a single aircraft flyover event 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 noise event duration is defined as the amount of time the noise event exceeds a specified level (that is at least 10 dB below the maximum value measured during the noise event). For noise 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_{Amax} for the event. In fact, for most aircraft events, the SEL is about 7 to 12 dB higher than the L_{Amax}. Additionally, since it is a cumulative measure, a higher SEL can result from either a louder or longer event, or a combination thereof.

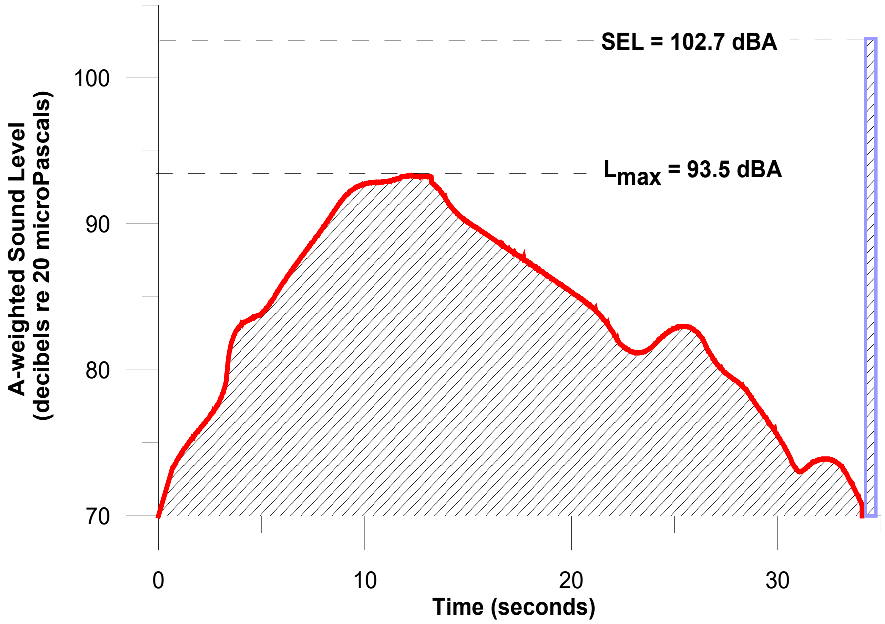
Since SEL combines an event's overall sound level along with its duration, SEL provides a comprehensive way to describe noise events for use in modeling and comparing noise environments. Computer noise models, such as the Aviation Environmental Design Tool (AEDT) that was used for this study, base their computations on these SELs.

Figure B.2 shows an event's "time history," or the variation of sound level with time. For typical sound events experienced by a stationary listener, like a person experiencing an aircraft flyover, 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_{Amax} for the event shown in **Figure B.2** was 93.5 dBA. Compressing the event's total sound energy into one second yields an SEL of 102.7 dBA.

Equivalent Sound Level, L_{eq} – Equivalent sound level (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 period of interest, the applicable period should always be identified or clearly understood when discussing this metric. Such durations are often identified through a subscript. For example, for an 8 hour or 24 hour day, $L_{eq(8)}$ or $L_{eq(24)}$ is used, respectively.

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.

FIGURE B.2
COMPARISON OF MAXIMUM SOUND LEVEL (L_{MAX}) AND SOUND EXPOSURE LEVEL (SEL)



Source: URS Corporation, 2008.

<u>Day-Night Average Sound Level, DNL</u> – Time-average sound levels are measurements of sound 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 6:59 a.m. (local time) the following morning. The FAA defines the 10:00 p.m. to 6:59 a.m. period as nighttime (or night) and the 7:00 a.m. to 9:59 p.m. period 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 adjustment, or "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 such as the AEDT.

Typical DNL values for a variety of noise environments are shown in **Figure B.3**. DNL values can be approximately 85 dBA outdoors under an aircraft 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, most federal agencies have formally adopted DNL 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 Environmental Protection Agency (EPA), the FAA, Department of Defense, Department of Housing and Urban Development, and the 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 are used only to supplement, not replace, DNL. Furthermore, FAA Order 1050.1E, *Policies and Procedures for Considering Environmental Impacts*, requires DNL be used in describing cumulative noise exposure and in identifying aircraft noise/land use compatibility issues (EPA, 1974; FICUN, 1980; FICON, 1992; title 14 CFR part 150, 2004; FAA, 2006).

The accuracy and validity of DNL calculations depend on the basic information used in the calculations. At airports, the reliability of DNL calculations is affected by a number of uncertainties:

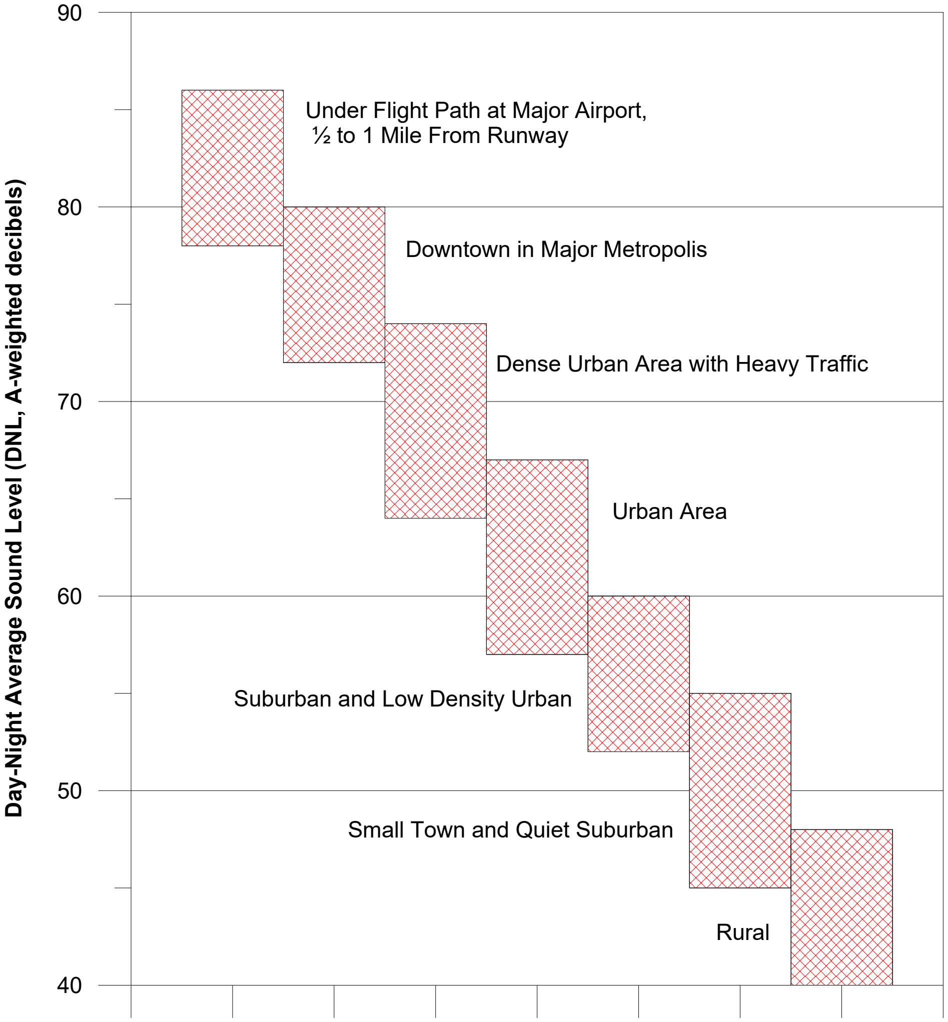
- The noise descriptions used in the DNL procedure represent the typical human response to aircraft noise. Since people vary in their response to noise and because the physical measure of noise accounts for only a portion of an individual's reaction to that noise, the DNL scale can show only an average response to aircraft noise that may be expected from a community.
- Future aviation activity levels such as the forecast number of operations, the operational fleet mix, the times of operation (day versus night) and flight tracks are estimates. Achievement of forecasted levels of activity cannot be assured.
- Aircraft acoustical and performance characteristics for new aircraft designs are estimates.

Figures B.4 through **B.11** illustrate how we measure aircraft noise and assess its impact.

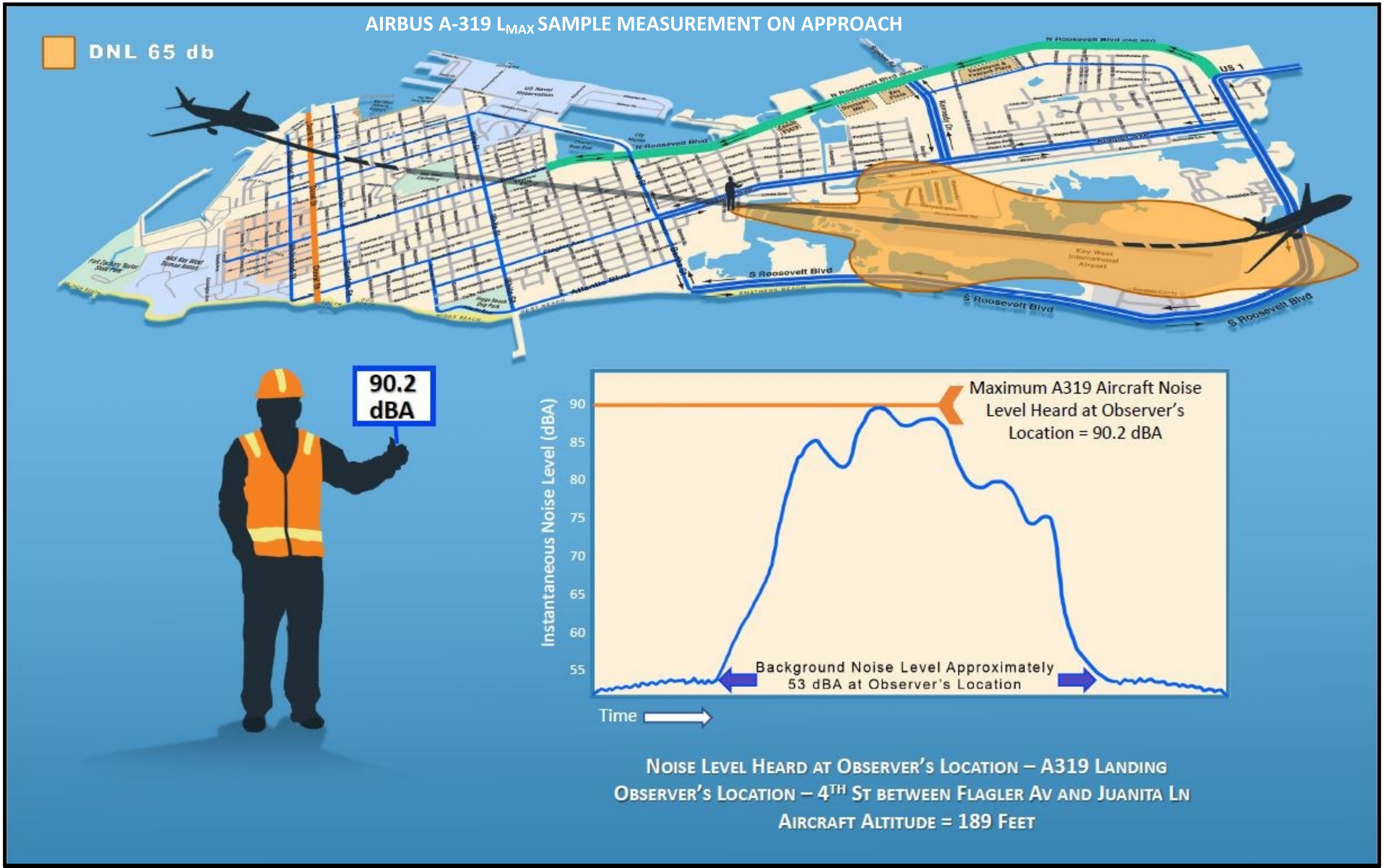
Outdoor vs. Indoor Noise Levels – AEDT calculates outdoor noise levels, while some of the supplemental noise analysis effects are based on noise levels experienced indoors. In order to convert outdoor noise levels to indoor noise levels, an Outdoor-to-Indoor Noise Level Reduction (OILR) is identified. The indoor noise level is equal to the outdoor noise level minus the OILR. Based on accepted research, typical OILR values range between 15 dBA to 25 dBA, depending on the structure and whether windows are open or closed (Wyle, 1989).

FIGURE B.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.



Noise Level Heard at Observer's Location – A319 Landing
Observer's Location – 4th St between Flagler Av and Juanita Ln
Aircraft Altitude = 189 Feet

FIGURE B.4

AIRCRAFT NOISE: HOW WE MEASURE IT AND ASSESS ITS IMPACT

STEP 1: WHAT DID YOU HEAR?

KEY WEST INTERNATIONAL AIRPORT
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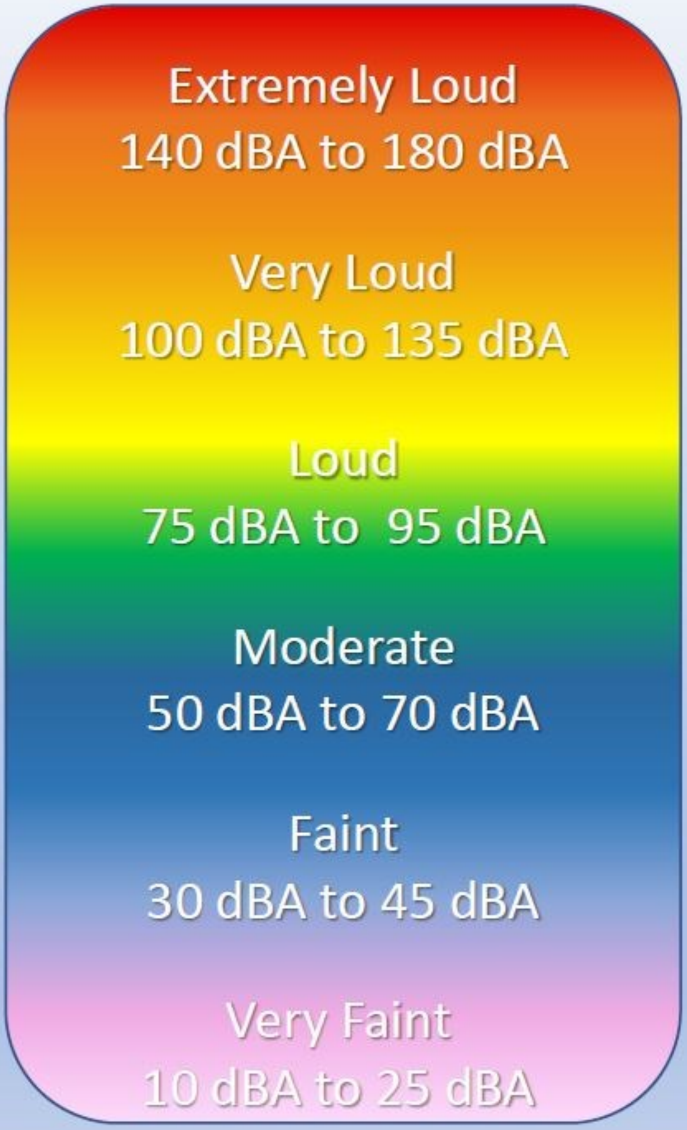
L_{MAX} SOUND COMPARISON



Rocket Launch	Extremely Loud 140 dBA to 180 dBA	Shotgun Blast
Firecrackers		Popping Balloon
Sloppy Joe's with Live Band		Stadium Crowd with Maximum Cheering
Large Thunderclap	Very Loud 100 dBA to 135 dBA	Emergency Siren
Leaf Blower		Chainsaw
Airboat		Handheld Drill
Weed eater	Loud 75 dBA to 95 dBA	Scooter
Riding Lawnmower		Duval Street During Fantasy Fest
Hair Blow Dryer	Moderate 50 dBA to 70 dBA	Blender
Coffee Grinder		Garbage Disposal
Vacuum Cleaner		Toilet Flush
Normal Conversation	Faint 30 dBA to 45 dBA	Electric Toothbrush
Refrigerator		Dishwasher
Whisper	Very Faint 10 dBA to 25 dBA	Light Rain
Normal Breathing		Pin Dropping

Threshold of Hearing for a Healthy Young Person

FIGURE B.5

AIRCRAFT NOISE: HOW WE MEASURE IT AND ASSESS ITS IMPACT

STEP 2: HOW LOUD IS THAT?

KEY WEST INTERNATIONAL AIRPORT

NEM Update

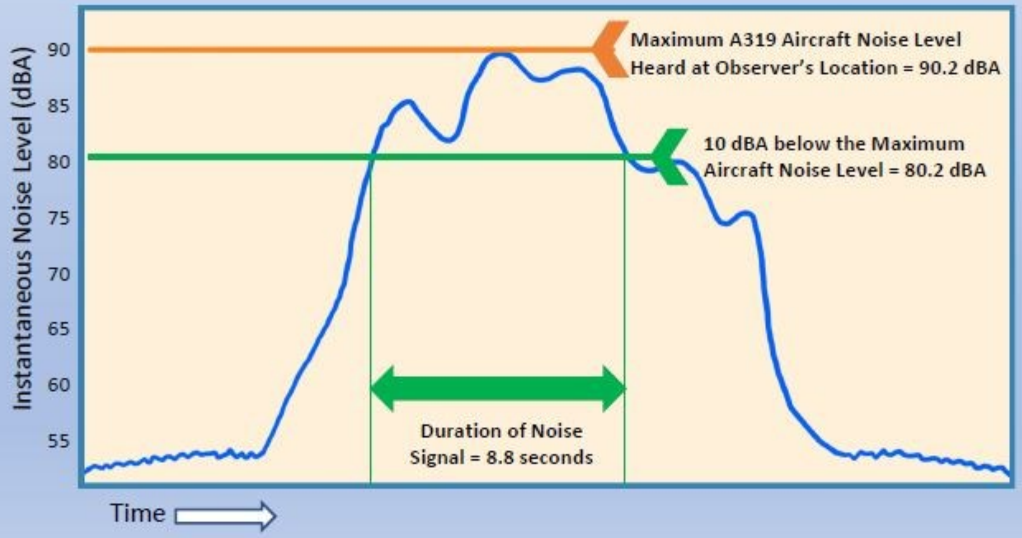
The duration of an aircraft noise event is defined as the number of seconds between the first and last values of the instantaneous noise level which are a minimum of 10 dBA below the maximum aircraft noise level (L_{max}). The Sound Exposure Level (SEL) describes with a single number the sound energy during an aircraft noise event.

SEL takes into account both the duration and the magnitude of the aircraft noise event. The duration correction increases the magnitude in an attempt to account for the increased noisiness of sounds of long duration versus sounds of short duration. Because the duration of aircraft noise events are greater than one second, the numerical value of the SEL for an aircraft noise event is always greater than the numerical value of the maximum level, L_{max}.

<u>For Example</u>:

L_{max} = 90.2 dBA Duration = 8.8 seconds SEL = 95.7 dBA

SOUND EXPOSURE COMPARISON



NOISE LEVEL HEARD AT OBSERVER'S LOCATION – A319 LANDING ON RUNWAY 09
OBSERVER'S LOCATION – 4TH ST BETWEEN FLAGLER AV AND JUANITA LN

FIGURE B.6

AIRCRAFT NOISE: HOW WE MEASURE IT AND ASSESS ITS IMPACT

STEP 3: HOW LONG DID IT LAST?

DNL NOISE EXPOSURE = LEVEL OF NOISE + NUMBER OF OPERATIONS AND TIME OF DAY

$$\text{DNL} = \text{SEL} + 10\ x\ log\frac{[D + (10\ x\ N)]}{86{,}400}$$

DNL = Day-Night Average Sound Level (in decibels)
Represents an average 24-hour noise level, with a nighttime penalty to represent the added intrusiveness of noises at night. The DNL represents the long-term impact by averaging the periods of aircraft noise and no aircraft noise.

SEL = Sound Exposure Level (in decibels) for one aircraft flight

D = Number of daytime flights (between 7:00 a.m. and 10:00 p.m.)

N = Number of nighttime flights (between 10:00 p.m. and 7:00 a.m.)
Each nighttime flight is counted ten times $(10\ x\ N)$ to account for the added intrusiveness of noise occurring during nighttime hours (between 10:00 p.m. and 7:00 a.m.).

86,400 = Number of seconds in one day $(24\ hours\ x\ 60\ minutes/hour\ x\ 60\ seconds/minute\ =\ 86{,}400\ seconds)$
Dividing the number of flights by 86,400 seconds per day, averages the periods of aircraft noise and no aircraft noise.

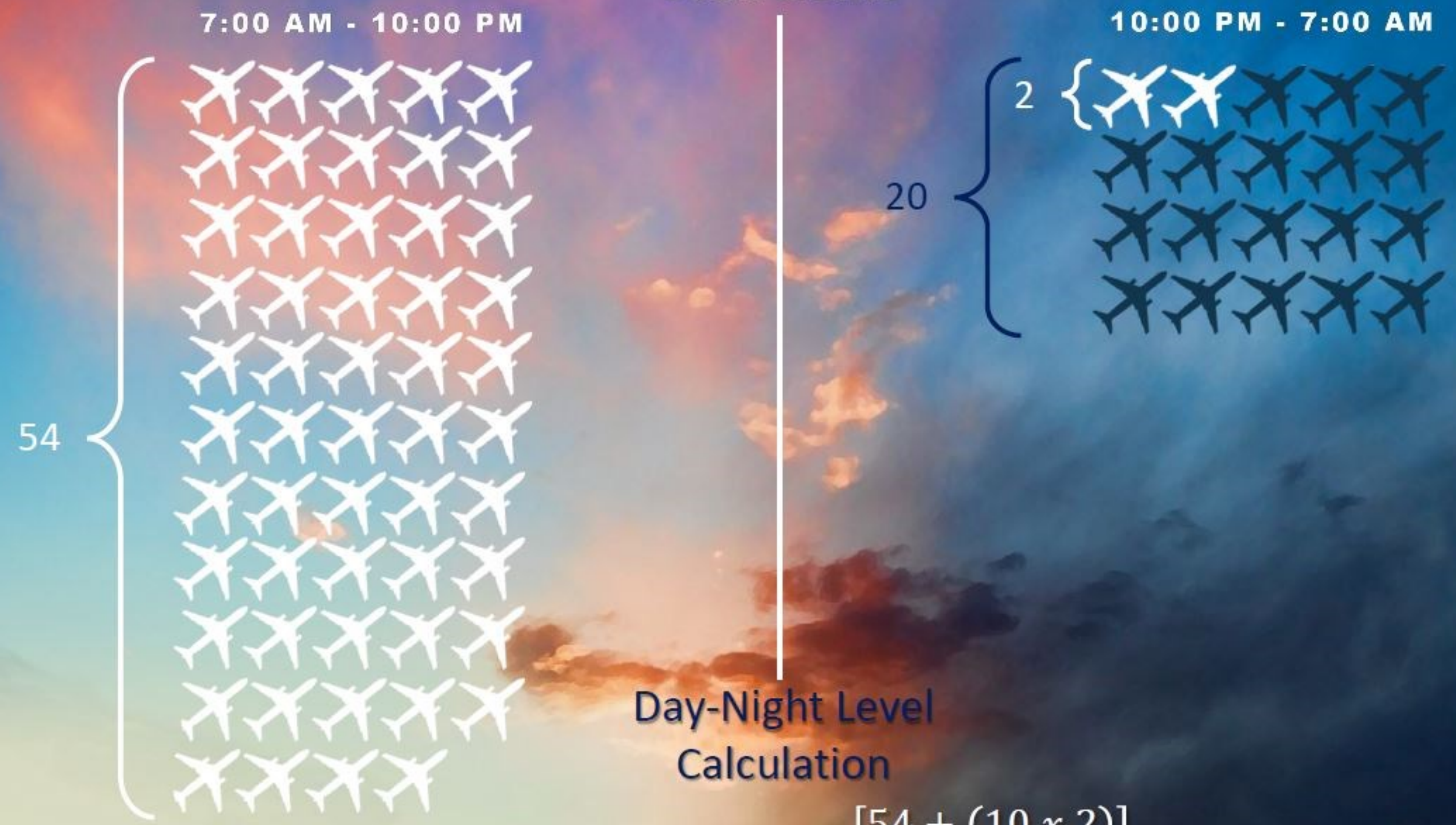
FIGURE B.7

AIRCRAFT NOISE: HOW WE MEASURE IT AND ASSESS ITS IMPACT

DAY-NIGHT AVERAGE SOUND LEVEL EQUATION

DAY-NIGHT AVERAGE SOUND LEVEL SAMPLE CALCULATION

OVERFLIGHTS



Day-Night Level Calculation

$$DNL = 95.7 + 10\,x\,log\frac{[54 + (10\,x\,2)]}{86{,}400}$$

$$DNL = 65\text{ dB}$$

FIGURE B.8

AIRCRAFT NOISE: HOW WE MEASURE IT AND ASSESS ITS IMPACT

STEP 4: HOW OFTEN DID YOU HEAR IT?

KEY WEST INTERNATIONAL AIRPORT

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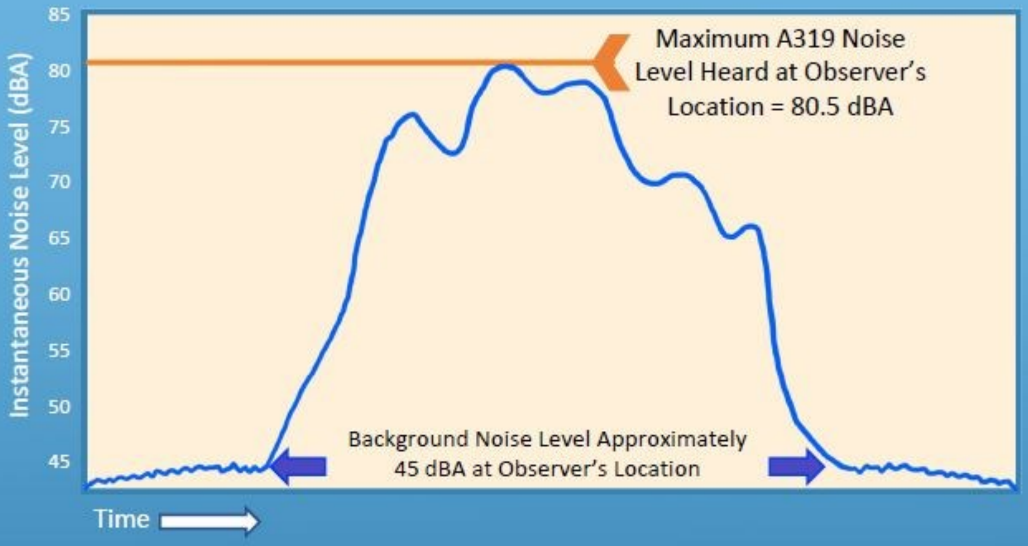
ANOTHER AIRBUS A-319 L_{MAX} SAMPLE MEASUREMENT ON APPROACH



NOISE LEVEL HEARD AT OBSERVER'S LOCATION – A319 LANDING
OBSERVER'S LOCATION – KEY WEST CEMETERY
AIRCRAFT ALTITUDE = 561 FEET

FIGURE B.9

AIRCRAFT NOISE: HOW WE MEASURE IT AND ASSESS ITS IMPACT

STEP 1: WHAT DID YOU HEAR?

KEY WEST INTERNATIONAL AIRPORT
NEM Update

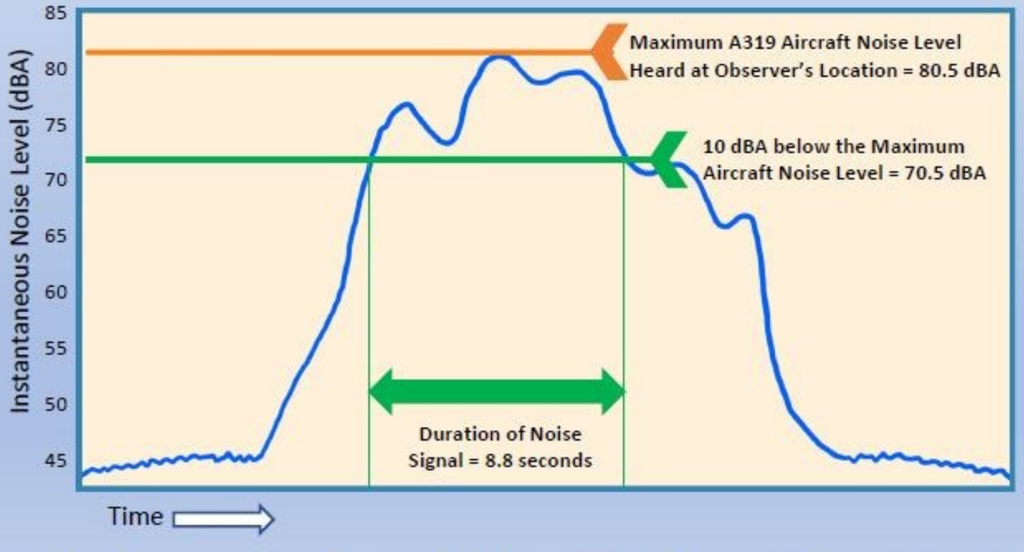
The duration of an aircraft noise event is defined as the number of seconds between the first and last values of the instantaneous noise level which are a minimum of 10 dBA below the maximum aircraft noise level (L_{max}). The Sound Exposure Level (SEL) describes with a single number the sound energy during an aircraft noise event.

SEL takes into account both the duration and the magnitude of the aircraft noise event. The duration correction increases the magnitude in an attempt to account for the increased noisiness of sounds of long duration versus sounds of short duration. Because the duration of aircraft noise events are greater than one second, the numerical value of the SEL for an aircraft noise event is always greater than the numerical value of the maximum level, L_{max}.

For Example:

L_{max} = 80.5 dBA Duration = 8.8 seconds SEL = 89.4 dBA

ANOTHER SOUND EXPOSURE COMPARISON

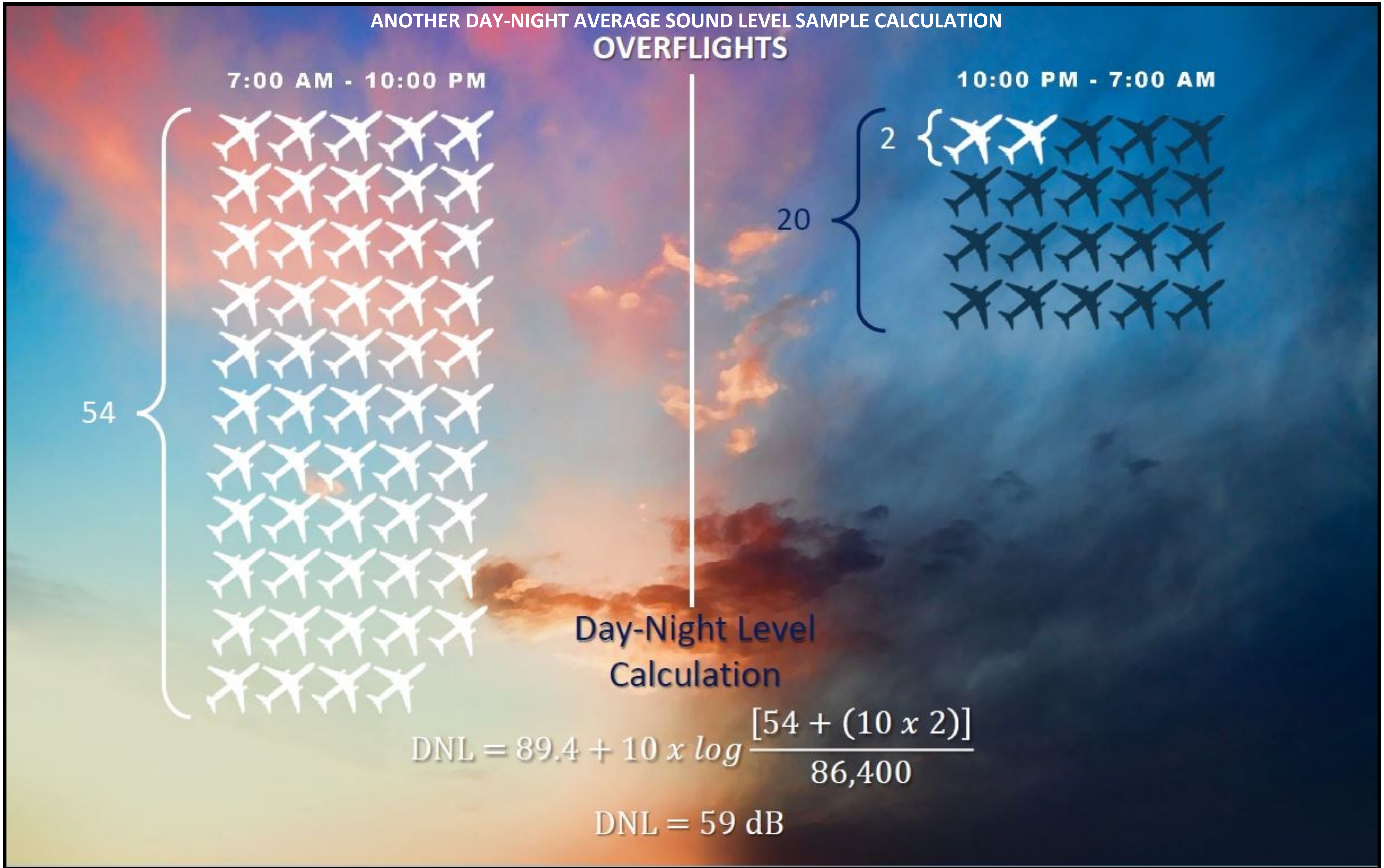


Noise Level Heard at Observer's Location – A319 Landing on Runway 09
Observer's Location – Key West Cemetery

FIGURE B.10

AIRCRAFT NOISE: HOW WE MEASURE IT AND ASSESS ITS IMPACT

STEP 3: HOW LONG DID IT LAST?



ANOTHER DAY-NIGHT AVERAGE SOUND LEVEL SAMPLE CALCULATION

OVERFLIGHTS

Day-Night Level Calculation

$$DNL = 89.4 + 10 \, x \, log \frac{[54 + (10 \, x \, 2)]}{86{,}400}$$

$$DNL = 59 \, dB$$

FIGURE B.11

AIRCRAFT NOISE: HOW WE MEASURE IT AND ASSESS ITS IMPACT

STEP 4: HOW OFTEN DID YOU HEAR IT?

KEY WEST INTERNATIONAL AIRPORT

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B.3 EFFECTS OF AIRCRAFT NOISE ON PEOPLE

The most common effects regarding aircraft noise are related to annoyance and activity interference (e.g., speech disruption and sleep interference). These effects have been studied extensively and relationships between various noise metrics and effects have been established. The following sections summarize these effects, and the noise metrics that are used to describe them.

B.3.1 Speech Interference

Speech interference is the most readily quantified adverse effect of noise, and speech is the activity most often affected by environmental noise. The levels of noise that interfere with listening to a desired sound, such as speech, music, or television, can be defined in terms of the level of noise required to mask the desired sound. Such levels have been quantified for speech communications by directly measuring the interference with speech. Several studies have been conducted over the last 30 years resulting in various noise level criteria for speech interference.

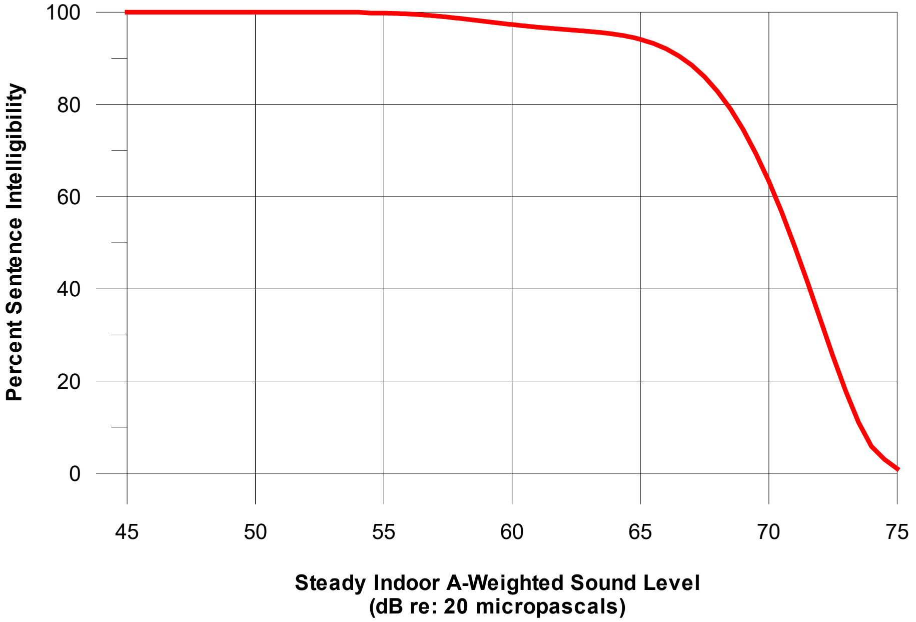
As an aircraft approaches and its sound level increases, speech becomes harder to hear. As the ambient level increases, the speaker must raise his/her voice, or the individuals must get closer together to continue talking. For typical communication distances of 3 or 4 feet (1 to 1.5 meters), acceptable 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). Intelligibility pertains to the percentage of speech units correctly understood out of those transmitted, and specifies the type of speech material used, i.e. sentence or word intelligibility (ANSI, 1994). As shown in **Figure B.12**, the percentage of sentence intelligibility is a non-linear function of the (steady) indoor ambient or background sound level (energy-average equivalent sound level (L_{eq})). For an average adult with normal hearing and fluency in the language, steady ambient indoor sound levels of up to 45 dBA L_{eq} are expected to allow 100 percent intelligibility of sentences. The curve shows 99 percent sentence intelligibility for L_{eq} at or below 54 dBA and less than 10 percent intelligibility for L_{eq} greater than 73 dBA. It should be noted that the function is especially sensitive to changes in sound level between 65 dBA and 75 dBA. As an example of the sensitivity, a 1 dBA increase in background sound level from 70 dBA to 71 dBA results in a 14 percent decrease in sentence intelligibility. In contrast, a 1 dBA increase in background sound level from 60 dBA to 61 dBA results in less than 1 percent decrease in sentence intelligibility.

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 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 (such as L_{eq}) alone, 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. In order for two people to communicate reasonably using normal voice levels indoors, the background noise level should not exceed 60 dBA (EPA, 1974). In other words, an indoor noise event that exceeds 60 dBA has the potential to cause speech and communication disruption (Eagan, 2007).

Figure B.12

PERCENT SENTENCE INTELLIGIBILITY FOR INDOOR SPEECH



B.3.2 Effect on Children's Learning

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. The steady ambient level, the level of voice communication, and the single event level (e.g., aircraft over-flights) that might interfere with speech in the classroom are measures that can be evaluated to quantify the potential for speech interference in the classroom.

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_{Amax}. (Lind, et. al., 1998; Sharp and Plotkin, 1984; Wesler, 1986; WHO, 1999; ASLHA, 1995; ANSI, 2002). A single event noise level of 50 dBA L_{Amax} 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.

ANSI has developed a standard for classrooms that states that the sound level during the noisiest hour should not exceed a one-hour average L_{eq} of 40 dBA for schools exposed to intermittent noise sources such as aircraft noise (ANSI, 2002). The standard further states that the hourly L_{eq} should not be exceeded for more than 10 percent of the noisiest hour (i.e., L_{eq} should not exceed L_{10}). FAA Order 5100.38C, Airport Improvement Program Handbook, Chapter 7, Section 2, Paragraph 812c(1) indicates that schools should have an A-weighted L_{eq} of 45 dB, or less, during school hours, in the classroom environment. Facilities not typically disrupted by aircraft, such as gymnasiums, cafeterias, or hallways, are not usually eligible for noise insulation. However, ANSI recommends that schools have a maximum one-hour average A-weighted unsteady background noise level of L_{eq} of 40 dB, or less, during school hours. Ancillary spaces, such as gymnasiums and cafeterias are recommended to have a maximum L_{eq} of 45 dB.

B.3.3 Sleep Disturbance

The EPA identified an indoor DNL of 45 dB as necessary to protect against sleep interference (EPA, 1974). 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, and (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.

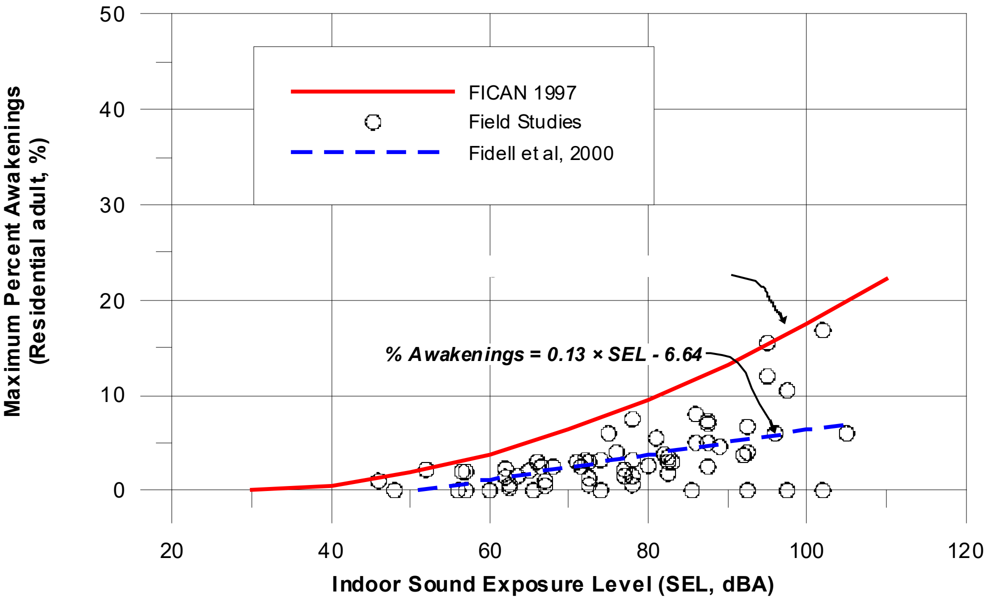
A study performed in 1992 by the Civil Aviation Policy Directorate of the Department of Transportation in the United Kingdom concluded that average sleep disturbance rates (those that are unrelated to outdoor noise) are unlikely to be affected by aircraft noise at outdoor levels below an L_{Amax} of 80 dBA (Ollerhead, 1992). At higher levels of 80-95 dBA L_{Amax} the chance of the average person being awakened is about 1 in 75. The study concludes that there is no evidence to suggest that aircraft noise at these levels is likely to increase the overall rates of sleep disturbance experienced during normal sleep. However, the authors emphasize that these conclusions are based on ‘average’ effects, and that there are more susceptible individuals and there are periods during the night when people are more sensitive to noise, especially during the lighter stages of sleep.

In June 1997, the U.S. Federal Interagency Committee on Aviation Noise (FICAN) reviewed the sleep disturbance issue along with data from the 1992 FICON 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 B.13**, was based on data from field studies of major civilian and military airports. For an indoor SEL of 60 dBA, **Figure B.13** predicts a maximum of approximately 5 percent of the exposed residential population would be behaviorally awakened. FICAN cautions that this curve should only be applied to long-term adult residents.

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.

Other studies indicate that for a good night's sleep, the number of noise occurrences plays a role as important as the level of the noise. Vallet & Vernet (1991) recommend that, to avoid any adverse effects on sleep, indoor noise levels should not exceed approximately 45 dBA L_{Amax} more than 10-15 times per night and that lower levels might be appropriate to provide protection for sensitive people. This L_{Amax} level is equivalent to an SEL of approximately 55 dBA indoors.

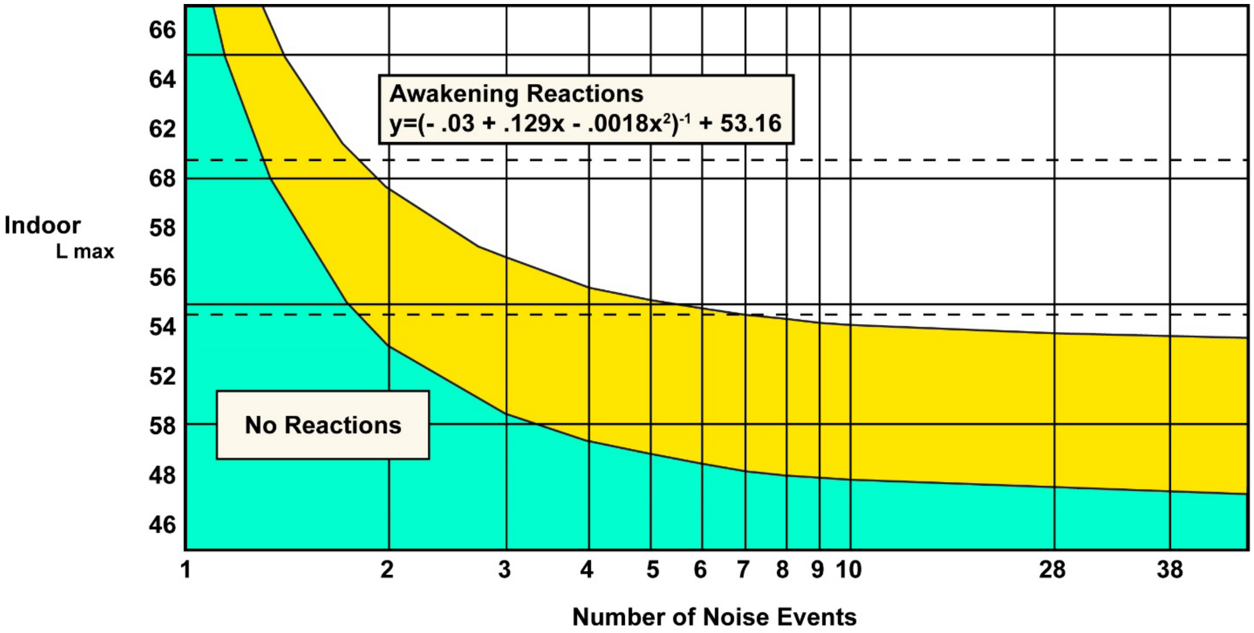
FIGURE B.13
SLEEP DISTURBANCE DOSE-RESPONSE RELATIONSHIP



Griefahn (1978) suggests that awakenings from aircraft overflights are dependent upon the number of events and their sound levels. **Figure B.14** illustrates Griefahn's compilation of data indicating the number of events and noise level that constitute a threshold for sleep. The data in her research were based on levels at which the most sensitive 10 percent of the population would be disturbed, and includes a correction to these levels to represent the most sensitive sleep state and age group. The lower curve represents the indoor noise level (expressed in terms of L_{Amax}) and number of noise event combinations at which fewer than 10 percent of the population will show signs of sleep interference. The upper curve indicates the level at which more than 90 percent of the population will be awakened for the given combination of noise levels and noise events. Griefahn suggests that, to avoid any long-term health effects, the upper curve should not be exceeded. The bottom curve represents a preferred, preventative goal. The curves indicate that nearly 90 percent of people will show signs of sleep interference in the presence of 10 to 30 flights per night at an approximate indoor L_{Amax} of 54 dB. They also show that for the same number of flights but at an indoor L_{Amax} of 48 dB, the percentage of the most sensitive population affected is much lower, at less than 10 percent, (with 'no reaction' for the less sensitive population).

FIGURE B.14

NUMBER OF AWAKENINGS AS A FUNCTION OF MAXIMUM INDOOR NOISE LEVEL



Source: Griefahn, B. (1990). "Critical Loads for Noise Exposure During the Night," InterNoise 90, pg. 1165.

B.3.4 Vibration from Aircraft Operations

The effects of vibration in a residence are observed in two ways; it is felt by the occupant, or it causes physical damage to the structure. Subjective detection can be one of direct perception from rattling of windows and ornaments, or dislodgement of hanging pictures and other loose objects. Structural damage may be either architectural (cosmetic or minor effects) such as plaster cracking, movement or dislodgements of wall tiles, cracked glass, etc., or major, such as cracking walls, complete collapsing of ceilings, etc., which is generally considered to impair the function or use of the dwelling.

Research has shown that vibration can be felt at levels well below those considered to cause structural damage. Complaints from occupants are usually due to the belief that if vibration can be felt, then it is likely to cause damage. Residents living in proximity to airports often complain that aircraft operations cause vibration induced damage to their homes. Research has also shown however, that the slamming of doors or footfalls within a building can produce vibration levels above those produced by aircraft activities (Reverb Acoustics Noise and Vibration Consultants, 2005).

Since people spend the majority of time indoors, the perceptions of aircraft noise leading to annoyance or complaint response and potentially to structural/architectural effects are directly and indirectly affected by the building structure. The acoustic loads resulting from aircraft noise can induce vibration in the structure, which can in turn, result in radiation of noise into its interior, rattling of items in contact with the structure, the perception of the occupants that the structure is vibrating, and the assumption that the vibration is causing structural/architectural effects. Consequently, the response of buildings, particularly older residential structures, to aircraft noise and the resulting effects on human and structural response has been the subject of considerable research.

C-weighted metrics appear to correlate well with subjective evaluations of low frequency noise from aircraft operations (Fidell, et al, 2002; Eagan, 2006). Perceptible wall vibrations in homes are likely to occur for C-weighted levels between 75 and 80 dB (Eagan, 2006). The likelihood of rattle due to low frequency noise increases notably for C-weighted levels within the range of 75 to 80 dB (Hubbard, 1982, Fidell, et. al, 2002). Rattle always occurs above a threshold of roughly 97 dB L_{max} (Hodgdon, 2007). In addition, C-weighting is the only weighting scale currently in the AEDT that addresses low-frequency noise. However, it should be noted that AEDT predictions are based on extrapolation of A-weighted aircraft sound levels. The same data are used in C-weighted predictions by simply reverse filtering the A-weighted levels. The predictions do not extend to frequencies less than 50 Hz where much of rattle and structural response can be attributed. This is a major limitation of AEDT C-weighted predictions for vibration assessment.

Generally, fixed-wing subsonic aircraft do not generate vibration levels of a frequency or intensity high enough to result in damage to structures. It has been found that exposure to normal weather conditions, such as thunder and wind, usually have more potential to result in significant structural vibration than aircraft (FAA, 1985). Two studies involving the measurement of vibration levels resulting from aircraft operations upon sensitive historic structures concluded that aircraft operations did not result in significant structural vibration.

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