APPENDIX C

NOISE

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ACRONYMS, ABBREVIATIONS, AND SYMBOLS

ADNL	A-weighted Day-Night Average Sound Level, as measured in decibels
AFB	Air Force Base
ANSI	American National Standards Institute
ASA	Acoustical Society of America
CDNL or L_{Cdn}	C-weighted Day-Night Average Sound Level
CHABA	Committee on Hearing, Bioacoustics and Biomechanics
CSEL	C-weighted Sound Exposure Level, as measured in decibels
dB	Decibels
dBA or dB(A)	A-Weighted Decibels
dBC	C-Weighted Decibels
DLR	German Aerospace Center
DNL	Day-Night Average Sound Level
DoD	Department of Defense
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FICAN	Federal Interagency Committee on Aviation Noise
FICON	Federal Interagency Committee on Noise
FICUN	Federal Interagency Committee on Urban Noise
Hz	Hertz
kHz	Kilohertz
LBS	Pounds of Thrust
L_{Cdn}	C-weighted Day-Night Average Sound Level, as measured in decibels
L_{dn}	Day-Night Average Sound Level, as measured in decibels
L_{dnmr} or DNL_{mr}	Onset-Rate Adjusted Monthly Day-Night Average Sound Level
LEIS	Legislative Environmental Impact Statement
L_{eq}	Equivalent Sound Level
L_{max}	Maximum Sound Level
L_{pk}	Peak Sound Level
MOA	Military Operating Area
NLR	Noise Level Reduction
NZ I, II, or III	Noise Zone I, II, or III
OSHA	Occupational Safety and Health Administration
PK_{15}(met)	Peak Noise Exceeded by 15 Percent of Firing Events
psf	Pounds Per Square Foot
RCNM	Roadway Construction Noise Model
RPM	Revolutions per Minute
SEL	Sound Exposure Level
SUA	Special Use Airspace
USACHPPM	U.S. Army Center for Health Promotion and Preventive Medicine
USEPA	U.S. Environmental Protection Agency

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C.1 NOISE IMPACT ASSESSMENT METHODS

Noise impacts can be quantified based on objective effects (such as hearing loss or damage to structures) or subjective judgments (such as community annoyance). Thus, assessment of impacts requires a combination of physical measurement of noise as well as assessment of psycho-acoustic and socio-acoustic effects. Noise is defined subjectively as being any unwanted sound. The following sections discuss how noise is described, the potential effects that noise may have on its receivers, and the methods by which noise levels are predicted.

C.1.1 Characteristics of Sound

Sounds can be generally characterized based on three physical characteristics: amplitude, frequency, and duration. Amplitude is a measure of the strength of the sound and is directly measured in terms of the pressure of a sound wave. Frequency, which is perceived as “pitch,” is the number of times per second sound causes air molecules to vibrate. Duration is simply how long the sound lasts. All three characteristics are critical to determining impacts of a particular sound source and are discussed in more detail below.

Amplitude. The loudest sounds that can be comfortably heard by humans have acoustic energy one trillion times the acoustic energy of the quietest sounds that humans detect. Because of this vast range in magnitude, attempts to represent sound amplitude by direct expression of sound pressure are unwieldy. In addition, human hearing is proportional rather than absolute (i.e., detecting whether one sound is twice as big as another rather than detecting whether one sound is a given number of pressure units bigger than another). Sound is, therefore, usually represented on a logarithmic scale, reflecting the way in which it is perceived, using a unit named the decibel (dB).

The threshold (level at which an effect starts) of human hearing is approximately 0 dB, and the threshold of discomfort is approximately 120 dB. Under laboratory conditions, differences in sound level of 1 dB can be detected by the human ear. In the community, the smallest change in average noise level that can be detected is about 3 dB. A change in sound level of about 10 dB is usually perceived by the average person as a doubling (or halving) of the sound’s loudness, and this relation holds true for loud sounds and quieter sounds. A decrease in sound level of 10 dB actually represents a 90-percent decrease in sound <u>intensity</u> but only a 50-percent decrease in perceived <u>loudness</u> because of the nonlinear response of the human ear.

Figure C-1 is a chart of A-weighted sound levels from typical sounds. Some sounds (air conditioner, vacuum cleaner) are continuous, and their levels are constant for some time. Other sounds (automobile, heavy truck) are the maximum sound during a vehicle pass-by. Some sounds (urban daytime, urban nighttime) are averages over some extended period.

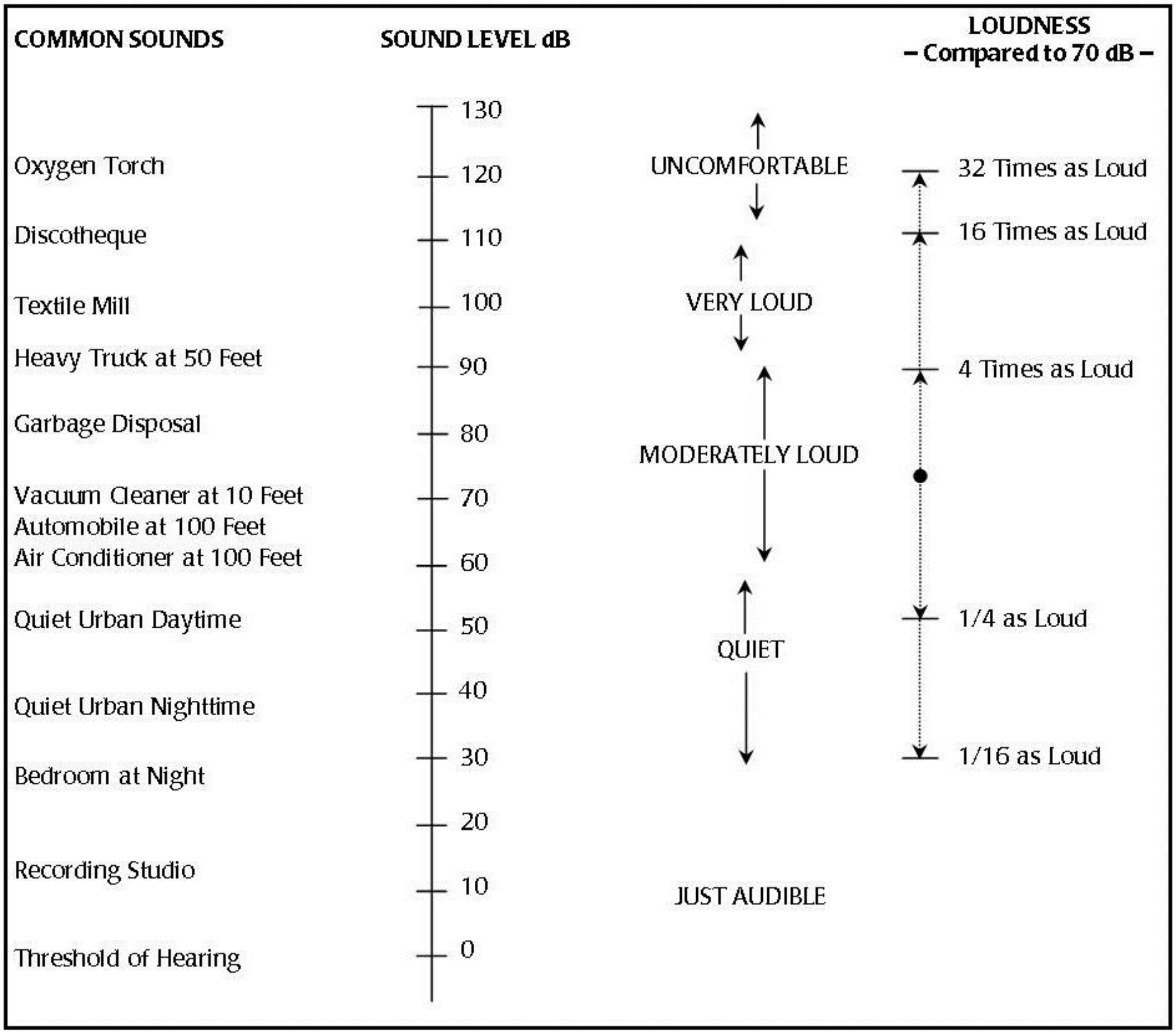


Figure C-1. Typical A-Weighted Sound Levels of Common Sounds

Because of the logarithmic nature of the decibel scale, sound levels do not add and subtract directly and are somewhat cumbersome to handle mathematically. However, some simple rules of thumb are useful in dealing with sound levels. First, if a sound's intensity is doubled, the sound level only increases by 3 dB, regardless of the initial sound level. For example:

60 dB + 60 dB = 63 dB, and

80 dB + 80 dB = 83 dB.

The total sound level produced by two sounds of different levels is usually only slightly more than the higher of the two. For example:

60.0 dB + 70.0 dB = 70.4 dB.

Sound pressure of what is perceived as being continuous sound actually varies greatly over minute increments of time, so it is customary to deal with sound levels that represent averages over time. Levels presented as instantaneous (i.e., as might be read from the dial of a sound level meter) are based on averages of sound energy over either 1/8 second (fast) or 1 second (slow). This distinction becomes important when discussing sounds whose peak noise level lasts for only a short time, such as sonic booms.

Frequency. The normal human ear can hear frequencies from about 20 hertz (Hz) to about 20,000 Hz. It is most sensitive to sounds in the 1,000- to 4,000-Hz range. When measuring community response to noise, it is common to adjust the frequency content of the measured sound to correspond to the frequency sensitivity of the human ear. This adjustment is called A-weighting (American National Standards Institute [ANSI], 1988). Sound levels that have been so adjusted are referred to as A-weighted and may be denoted dBA or dB(A). However, because use of A-weighting to express sound level is so prevalent, it can normally be assumed that dB is equivalent to dBA or dB(A). In this LEIS, sound levels are reported in dB and are A-weighted unless otherwise specified.

A-weighting is appropriate for sounds that are perceived by the ear. Impulsive sounds, such as sonic booms, thunder, and other sudden "booming" sounds, are perceived by more than just the ear; listeners may *feel* this type of sound as well as hearing it. When experienced indoors, this type of sound may cause rattling of the structure and its contents. Because A-weighting would de-emphasize the intrusive low-frequency component of this type of sound, C-weighting (ANSI, 1988) is applied, which only de-emphasizes frequencies that are outside the range of human hearing (about 20 Hz to 20,000 Hz). In this LEIS, and in accordance with standard methodologies, C-weighted sound levels are used for the assessment of sonic booms, blasts from high explosives, and other impulsive sounds. C-weighting is specifically denoted as dBC whenever it is used in this LEIS.

Duration. Sound varies over time at almost all locations. Sound can be classified into four basic categories that define its basic time pattern:

<u>Ambient.</u> Ambient sound is the ever-present collection of background sounds at any given place. Ambient sound can be strictly natural, such as frogs and cicadas in the deep woods; strictly mechanical, such as street noise in a busy city; or a combination of both, like sounds occurring in the suburbs. It is important to consider the existing ambient soundscape because what exists already has much to do with how annoying people will find a new sound. For example, the hum of a generator may be tolerated much better by those already living in an area with high mechanized ambient noise than those living in the far woods.

- <u>Steady-state.</u> Steady-state sound is of a consistent level and spectral content; examples are sounds originating from ventilation or mechanical systems that operate more or less continuously. From a military perspective, generators and aircraft run-up sounds are the most prominent steady-state sounds, and as a rule, the longer a steady-state sound persists, the more annoyed people will be.
- <u>Transient Sound.</u> Transient sound has a clearly defined beginning and end, rising above the background and then fading back into it. Transient sounds are typically associated with "moving" sound sources such an aircraft overflight or a

single vehicle driving by, and they usually last for only a few minutes at the most. The annoyance caused by transient sounds is dependent upon both the maximum sound level and the duration.

- Impulsive Sound. Impulsive sound is of short duration (typically less than one second), high intensity, abrupt onset, rapid decay, and often a fast-changing spectral composition. It is characteristically associated with such sources as explosions, impacts, the discharge of firearms, the passage of supersonic aircraft (sonic booms), and many industrial processes. Impulsive sound can be particularly annoying because of the "startle factor" where the receiver has no warning that exposure to a loud sound is imminent.

C.2 NOISE METRICS

To communicate sound levels, the Department of Defense (DoD) uses three general types of noise-measuring descriptors, or metrics: (1) measuring the highest sound level occurring during a noise event, (2) combining the maximum level of that single event with its duration, and (3) describing the noise environment based on the total noise energy received over a specified length of time. The metrics used in this environmental impact statement (LEIS) are described below.

Maximum Sound Level. This metric, denoted as L_{max}, is the highest sound level measured (using time integration of either 1/8 second or 1 second) during a noise event. For a listener observing an aircraft overflight, the noise level starts at the ambient or background noise level, rises to the maximum level as the aircraft flies closest to the observer, and returns to the background level as the aircraft recedes into the distance. L_{max} decreases as altitude or distance from the observer increases and varies according to the type of aircraft, airspeed, and power setting.

Peak Sound Level. For impulsive sounds, the true instantaneous peak sound pressure level, which lasts for only a fraction of a second, is important in determining impacts. For sonic booms, this is the peak pressure of the shock wave. This pressure usually is presented in physical units of pounds per square foot (psf). Peak sound levels are not frequency weighted. Sometimes it is represented on the decibel scale, with the symbol L_{pk}. Because the amount of sound energy that reaches a receiver from a given noise event varies so much with specific atmospheric conditions, a special metric sometimes is used to account for this variability. The PK_{15}(met) metric represents the peak sound level that will not be exceeded 85 percent of the time with a given noise event. This metric is useful for expressing, in general terms, how loud an area will get while a particular weapon is firing.

Sound Exposure Level. The Sound Exposure Level (SEL) metric is a single-number representation of a noise energy dose for an entire aircraft overflight. This measure takes into account the effect of both the duration and intensity of a noise event by summing the noise energy from each second in an event, which typically lasts several seconds into a single second.

SEL is useful for comparing aircraft that move at different speeds. As an example, fighter aircraft tend to create a high L_{max}, but their noise level tends to drop off quickly as the plane moves away from the listener at high speed. On the other hand, cargo-type aircraft tend to be quieter but generally take more time to move past the listener and out of earshot. It is important to remember that SEL does not directly represent the sound level heard at any given time, but rather, it provides a measure of the exposure of the entire acoustic event. SEL is useful for predicting several noise impacts, including sleep disturbance and animal escape response. SEL can be computed for C-weighted levels (appropriate for impulsive sounds), and the results denoted as CSEL. SEL for A-weighted sound is sometimes denoted as ASEL. Within this LEIS, SEL is used for A-weighted sounds and CSEL for C-weighted.

Onset-Rate Adjusted Sound Exposure Level. When an aircraft is flying fast and low to the ground, listeners may experience a very quick rise in noise as it flies overhead. To account for the resulting "surprise effect," a penalty of up to 11 dB is applied to the SEL value for the overflight. SEL values with this "onset-rate adjustment" are denoted as SEL_r.

Equivalent Sound Level. To summarize noise levels over longer periods of time, total sound is represented by the equivalent sound level (L_{eq}). L_{eq} is the average sound level over some time period (often an hour or a day, but any explicit time span can be specified), with the averaging being done on the same energy basis as used for SEL. SEL and L_{eq} are closely related, differing by (1) whether they are applied over a specific time period or over an event, and (2) whether the duration of the event is included or divided out. Just as SEL has proven to be a good measure of the noise impact of a single event, L_{eq} has been established to be a good measure of the impact of a series of events during a given time period. Cumulative noise metrics, such as L_{eq}, are useful because they represent a complicated set of noise events with a single number.

Day–Night Average Sound Level (DNL or L_{dn}). Noise tends to be more intrusive at night than during the day. This effect is accounted for by applying a 10-dB penalty to events that occur after 10:00 PM and before 7:00 AM. DNL is similar to L_{eq} except DNL has a nighttime penalty added. DNL is the community noise metric recommended by the U.S. Environmental Protection Agency (USEPA) (USEPA, 1974) and has been adopted by most federal agencies (Federal Interagency Committee on Noise [FICON], 1992). It has been widely accepted that DNL correlates well with community response to noise (Schultz, 1978; Finegold et al., 1994). This correlation is presented in the section titled "Noise Impacts on Humans." Furthermore, DNL has also been proven applicable to infrequent events (Fields and Powell, 1985) and to rural populations exposed to sporadic military aircraft noise (Stusnick et al., 1992, 1993).

It was noted earlier that, for impulsive sounds, C-weighting is more appropriate than A-weighting. The DNL can be computed for C-weighted noise and is denoted CDNL or L_{Cdn}. This procedure has been standardized, and impact interpretive criteria similar to those for DNL have been developed (Committee on Hearing, Bioacoustics and Biomechanics [CHABA], 1981).

Onset-Rate Adjusted Monthly Day–Night Average Sound Level. The Onset-Adjusted Monthly Day–Night Average Sound Level is denoted as L_{dnmr}. Aircraft operations in military airspace (such as ranges, military operating areas [MOAs], military training routes, and Warning Areas) generate a noise environment somewhat different from other community noise environments. Overflights are sporadic, occurring at random times and varying from day to day and week to week. This situation differs from most community noise environments, where noise tends to be continuous or patterned. Individual military overflight events also differ from typical community noise events in that noise from a low-altitude, high-airspeed flyover can have a sudden onset. To represent these differences, the conventional DNL metric is adjusted to account for the "surprise" effect of the sudden onset of aircraft noise events on humans (Plotkin et al*.*, 1987; Stusnick et al., 1992, 1993). For aircraft exhibiting a rate of increase in sound level (called onset rate) of from 15 to 150 dB per second, an adjustment or penalty ranging from 0 to 11 dB is added to the normal SEL. Onset rates above 150 dB per second require an 11 dB penalty, while onset rates below 15 dB per second require no adjustment. In addition, because of the irregular occurrences of aircraft operations, the number of average daily operations is determined by using the calendar month with the highest number of operations.

C.3 NOISE IMPACTS ON HUMANS

Annoyance. The primary effect of aircraft noise on exposed communities is one of annoyance. Noise annoyance is defined by the USEPA as any negative subjective reaction on the part of an individual or group (USEPA, 1974). Studies of community annoyance resulting from numerous types of environmental noise show that DNL correlates well with impact. Schultz (1978) showed a consistent relationship between DNL and percentage of the impacted population that was "highly annoyed" (9 or 10 on a scale of 1 to 10, with 10 being the most annoyed). A more recent study reaffirmed and updated this relationship (Finegold et al., 1994) (Table C-1). In general, correlation coefficients of 0.85 to 0.95 are found between the percentages of groups of people highly annoyed and the level of average noise exposure. The correlation coefficients for the annoyance of individuals are relatively low, however, on the order of 0.5 or less. This is not surprising, considering the varying personal factors that influence the manner in which individuals react to noise. Nevertheless, findings substantiate that, as a whole, communities' level of annoyance to aircraft noise is represented fairly reliably using DNL.

Table C-1. Relationship Between Annoyance and DNL

Noise Exposure (DNL)	Percent of Population Highly Annoyed
<65	<12
65–70	12–21
70–75	22–36
75–80	37–53
80–85	54–70
>85	>71

Source: Finegold et al., 1994

It is important to note that DNL does not represent the sound level heard at any particular time, but rather, it represents a cumulative sound exposure. DNL accounts for the sound level of individual noise events, the duration of those events, and the number of events. Its use is endorsed by the scientific community and is recognized as the standard methodology by most federal agencies (ANSI, 1980, 1988; USEPA, 1974; Federal Interagency Committee on Urban Noise [FICUN], 1980; FICON, 1992).

There are several commonly recognized average noise level thresholds that are based on expected community reaction. The first is DNL of 65 dB. This is a level most commonly used for noise planning purposes and represents a compromise between community impact and the need for activities like aviation, which unavoidably result in noise. Areas exposed to DNL above 65 dB generally are not considered suitable for residential use. The second is DNL of 55 dB, which was identified by the USEPA as a level ". . . requisite to protect public health and welfare with an adequate margin of safety," (USEPA, 1974). From a noise exposure perspective, that would be an ideal selection. However, financial and technical resources are generally not available to achieve that goal. Most agencies have identified DNL of 65 dB as a criterion that protects those most impacted by noise, and that often can be achieved on a practical basis (FICON, 1992). This corresponds to about 12 percent of the exposed population being highly annoyed. The third is DNL of 75 dB. This is the lowest level at which adverse health effects could be credible (USEPA, 1974).

Community annoyance from sonic booms, firing of heavy weaponry, and other impulsive noises is predicted using CDNL. The correlation between CDNL and annoyance has been estimated based on community reaction to impulsive sounds over several years (CHABA, 1981). Values of the C-weighted equivalent to the Schultz curve are different than that of the Schultz curve itself. Table C-2 shows the relationship between percentage of the population highly annoyed, DNL, and CDNL. If both continuous and impulsive noise occurs in the same area, impacts are assessed separately for each.

Table C-2. Relation Between Annoyance, DNL, and CDNL

CDNL	% Highly Annoyed	DNL
48	2	50
52	4	55
57	8	60
61	14	65
65	23	70
69	35	75

Source: CHABA, 1981

Speech Interference. Speech interference associated with aircraft noise is a primary cause of annoyance for communities. The disruption of routine activities such as radio or television listening, telephone use, or family conversation gives rise to frustration and irritation. The quality of speech communication is particularly important in classrooms and offices. In industrial settings it can cause fatigue and vocal strain in those who attempt to communicate over the noise.

The disruption of speech in the classroom is a primary concern, due to the potential for adverse effects on children's learning ability. There are two aspects to speech comprehension:

- *Word Intelligibility* - the percent of words transmitted and received. This might be important for students in the lower grades who are learning the English language, and particularly for students who have English as a Second Language.
- *Sentence Intelligibility* – the percent of sentences transmitted and understood. This might be important for high-school students and adults who are familiar with the language, and who do not necessarily have to understand each word in order to understand sentences.

U.S. Federal Criteria for Interior Noise. In 1974, the USEPA identified a goal of an indoor 24-hour average sound level $L_{eq(24)}$ of 45 dB to minimize speech interference based on the intelligibility of sentences in the presence of a steady background noise (USEPA, 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. sentences or words. The curve displayed in Figure C-2 shows the effect of steady indoor background sound levels on sentence intelligibility. For an average adult with normal hearing and fluency in the language, steady background sound levels indoors of less than 45 dB L_{eq} are expected to allow 100-percent intelligibility of sentences.

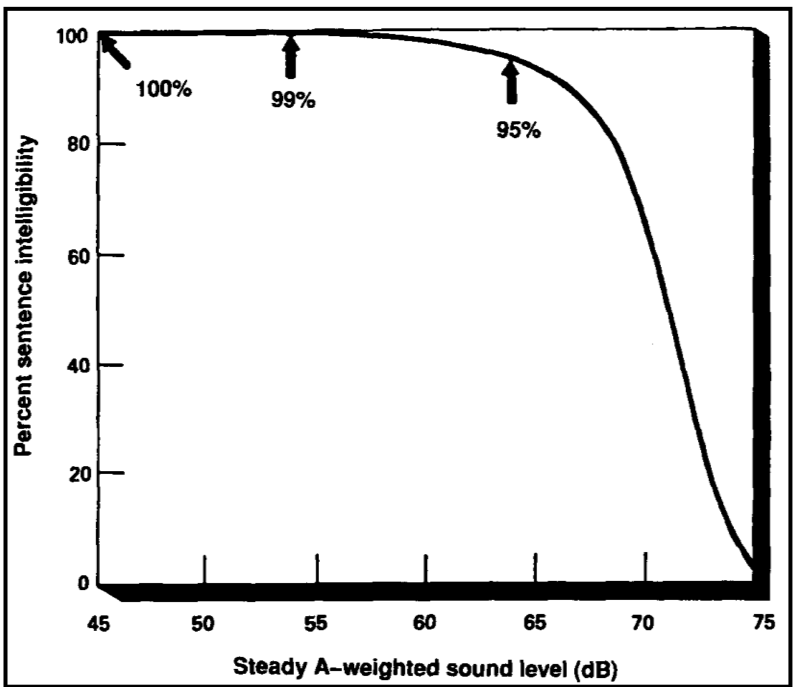


Figure C-2. Speech Intelligibility Curve
Source: USEPA, 1974

The curve shows 99-percent sentence intelligibility for background levels at a L_{eq} of 54 dB, and less than 10-percent intelligibility for background levels above a L_{eq} of 73 dB. Note that the curve is especially sensitive to changes in sound level between 65 dB and 75 dB—an increase of 1 dB in background sound level from 70 dB to 71 dB results in a

14-percent decrease in sentence intelligibility, whereas a 1-dB increase in background sound level from 60 dB to 61 dB results in less than 1-percent decrease in sentence intelligibility.

Sleep Interference. The disturbance of sleep is a major concern for communities exposed to nighttime aircraft noise. There have been numerous research studies that have attempted to quantify the complex effects of noise on sleep. This section provides an overview of the major noise-induced sleep disturbance studies that have been conducted, with particular emphasis placed on those studies that have influenced U.S. federal noise policy. The studies have been separated into two groups:

- Initial studies performed in the 1960s and 1970s, where the research was focused on laboratory sleep observations.
- Later studies performed in the 1990s up to the present, where the research was focused on field observations, and correlations to laboratory research were sought.

Initial Studies. The relationship between noise levels and sleep disturbance is complex and not fully understood. The disturbance depends not only on the depth of sleep, but also on the previous exposure to aircraft noise, familiarity with the surroundings, the physiological and psychological condition of the recipient, and a host of other situational factors. The most readily measurable effect of noise on sleep is the number of arousals or awakenings, and so the body of scientific literature has focused on predicting the percentage of the population that will be awakened at various noise levels. Fundamentally, regardless of the tools used to measure the degree of sleep disturbance (awakenings, arousals, etc.), these studies have grouped the data points into bins to predict the percentage of the population likely to be disturbed at various sound level thresholds.

FICON produced a guidance document that provided an overview of the most pertinent sleep disturbance research that had been conducted throughout the 1970s (FICON, 1992). Literature reviews and meta-analysis conducted between 1978 and 1989 made use of the existing datasets that indicated the effects of nighttime noise on various sleep-state changes and awakenings (Lukas, 1978; Griefahn, 1978; Pearsons et al., 1989). FICON noted that various indoor A-weighted sound levels—ranging from 25 to 50 dB—were observed to be thresholds below which significant sleep effects were not expected. Due to the large variability in the data, FICON did not endorse the reliability of the results.

However, FICON did recommend the use of an interim dose-response curve—awaiting future research—that predicted the percent of the exposed population expected to be awakened as a function of the exposure to single event noise levels expressed in terms of SEL. This curve was based on the research conducted for the U.S. Air Force (Finegold, 1994). The dataset included most of the research performed up to that point, and predicted that 10 percent of the population would be awakened when exposed to an interior SEL of approximately 58 dB. The data utilized to derive this relationship were primarily the results of controlled laboratory studies.

Recent Sleep Disturbance Research—Field and Laboratory Studies. It was noted in the early sleep disturbance research that the controlled laboratory studies did not account for many factors that are important to sleep behavior, such as habituation to the environment and previous exposure to noise and awakenings from sources other than aircraft noise. In the early 1990s, field studies were conducted to validate the earlier laboratory work. The most significant finding from these studies was that an estimated 80 to 90 percent of sleep disturbances were not related to individual outdoor noise events, but were instead the result of indoor noise sources and other non–noise-related factors. The results showed that there was less of an effect of noise on sleep in real-life conditions than had been previously reported from laboratory studies.

Federal Interagency Committee on Aviation Noise (FICAN). The interim FICON dose-response curve that was recommended for use in 1992 was based on the most pertinent sleep disturbance research that was conducted through the 1970s, primarily in laboratory settings. After that time, considerable field research was conducted to evaluate the sleep effects in peoples' normal home environment. Laboratory sleep studies tend to show higher values of sleep disturbance than field studies because people who sleep in their own homes are habituated to their environment and, therefore, do not wake up as easily (FICAN, 1997).

Based on the new information, FICAN updated its recommended dose-response curve in 1997, depicted as the lower curve in Figure C-3. This figure is based on the results of three field studies (Ollerhead, 1992; Fidell et al., 1994; Fidell et al., 1995a; Fidell et al., 1995b), along with the datasets from six previous field studies.

The new relationship represents the higher end, or upper envelope, of the latest field data. It should be interpreted as predicting the "maximum percent of the exposed population expected to be behaviorally awakened" or the "maximum percent awakened" for a given residential population. According to this relationship, a maximum of 3 percent of people would be awakened at an indoor SEL of 58 dB, compared to 10 percent using the 1992 curve. An indoor SEL of 58 dB is equivalent to outdoor SELs of 73 and 83 dB respectively assuming 15 and 25 dB noise level reduction from outdoor to indoor with windows open and closed, respectively.

Note the relatively low percentage of awakenings to fairly high noise levels. People think they are awakened by a noise event, but usually the reason for awakening is otherwise. For example, the 1992 U.K. Civil Aviation Authority study found the average person was awakened about 18 times per night for reasons other than exposure to an aircraft noise—some of these awakenings are due to the biological rhythms of sleep and some to other reasons that were not correlated with specific aircraft events.

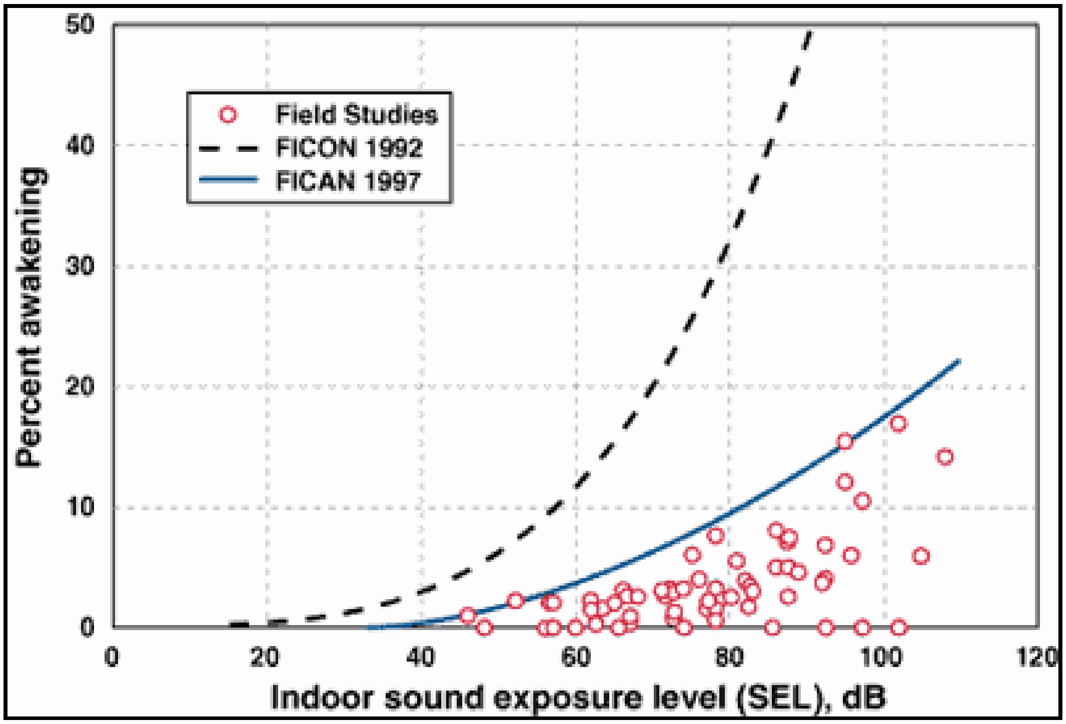


Figure C-3. FICAN's 1997 Recommended Sleep Disturbance Dose-Response Relationship

The FICAN 1997 curve is represented by the following equation:

$$\textit{Percent Awakenings} = 0.0087 \times [SEL - 30]^{1.79}$$

Number of Events and Awakenings. In recent years, there have been studies and one proposal that attempted to determine the effect of multiple aircraft events on the number of awakenings. The German Aerospace Center (DLR) conducted an extensive study focused on the effects of nighttime aircraft noise on sleep and other related human performance factors (Basner, 2004). The DLR study was one of the largest studies to examine the link between aircraft noise and sleep disturbance and involved both laboratory and in-home field research phases. The DLR investigators developed a dose-effect curve that predicts the number of aircraft events at various values of L_{max} expected to produce one additional awakening over the course of a night. The dose-effect curve was based on the relationships found in the field studies.

In July 2008 ANSI and the Acoustical Society of America (ASA) published a method to estimate the percent of the exposed population that might be awakened by multiple aircraft noise events based on statistical assumptions about the probability of awakening (or not awakening) (ANSI, 2008). This method relies on probability theory rather than direct field research/experimental data to account for multiple events.

Figure C-4 depicts the awakenings data that form the basis and equations of ANSI S12.9-2008. The curve labeled ‘Eq. (B1)’ is the relationship between noise and awakening endorsed by FICAN in 1997. The ANSI recommended curve labeled ‘Eq. (1)’ quantifies the probability of awakening for a population of sleepers who are exposed to an outdoor noise event as a function of the associated indoor SEL in the bedroom. This curve was derived from studies of behavioral awakenings associated with noise events in “steady state” situations where the population has been exposed to the noise long enough to be habituated. The data points in Figure C-4 come from these studies. Unlike the FICAN curve, the ANSI 2008 curve represents the average of the field research data points.

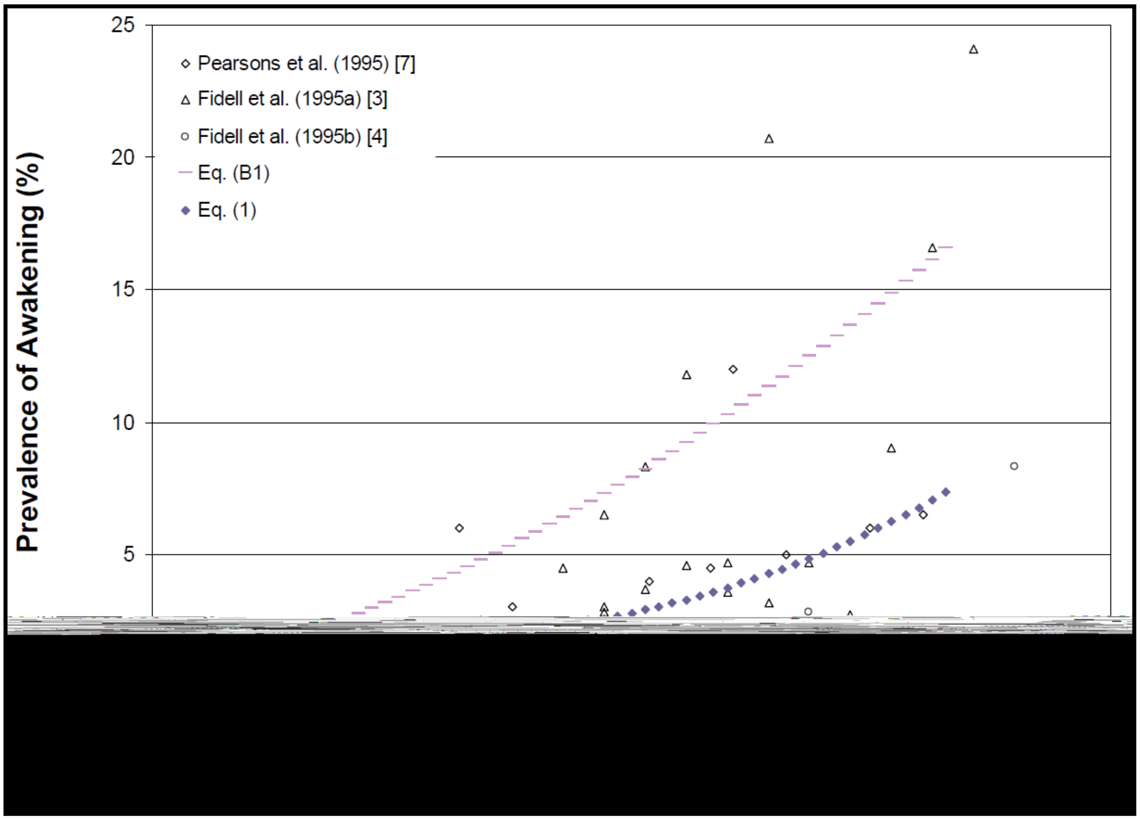
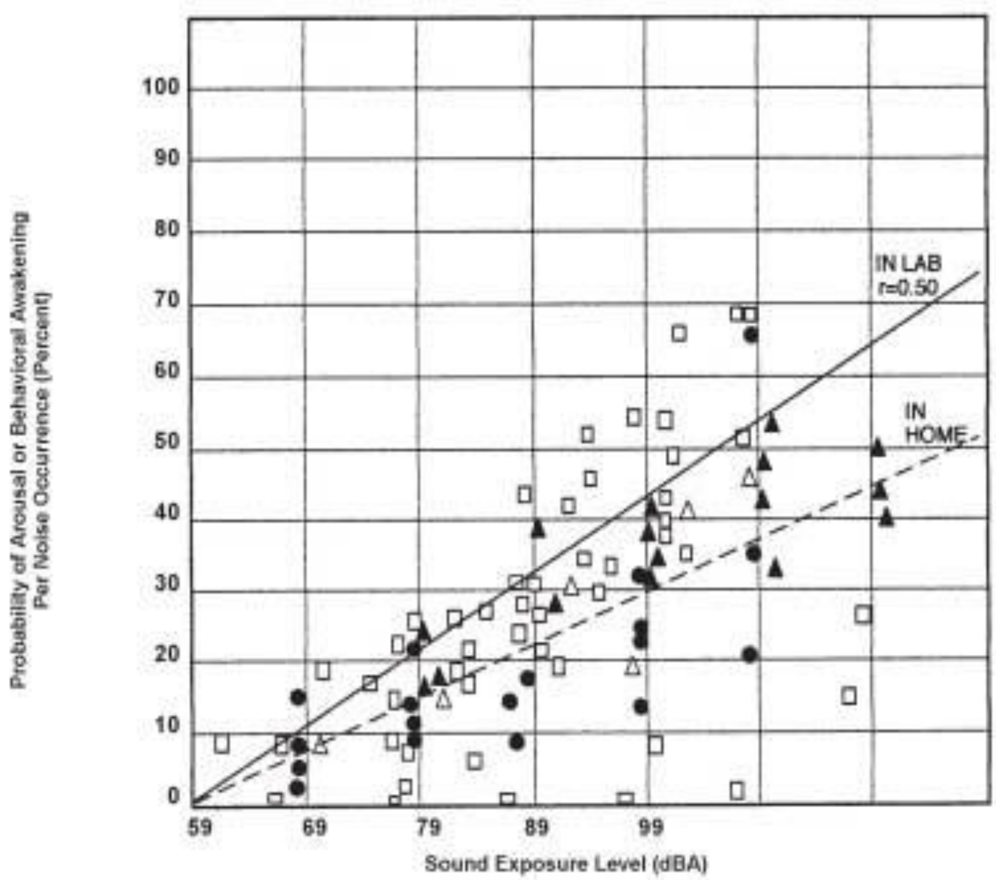


Figure C-4. Plot of Sleep Awakening Data versus Indoor SEL
Source: ANSI 2008

In December 2008, FICAN recommended the use of this new estimation procedure for future analyses of behavioral awakenings from aircraft noise (Figure C-5 and Figure C-6). In that statement, FICAN also recognized that additional sleep disturbance research is underway by various research organizations, and results of that work may result in additional changes to FICAN’s position. Until that time, FICAN recommends the use of ANSI S12.9-2008.



LEGEND

- □ Laboratory Studies, Variety of Noises, Lukas
- ● Steady State (In Home)
- ▲ Transient (In Home)
- △ Truck Noise, Laboratory Study, Thiesen

Transformer, Transmission Line, Window Air Conditioner, and Distant Traffic Noise, Horonjeff

Figure C-5. Probability of Arousal or Behavioral Awakening in Terms of Sound Exposure Level

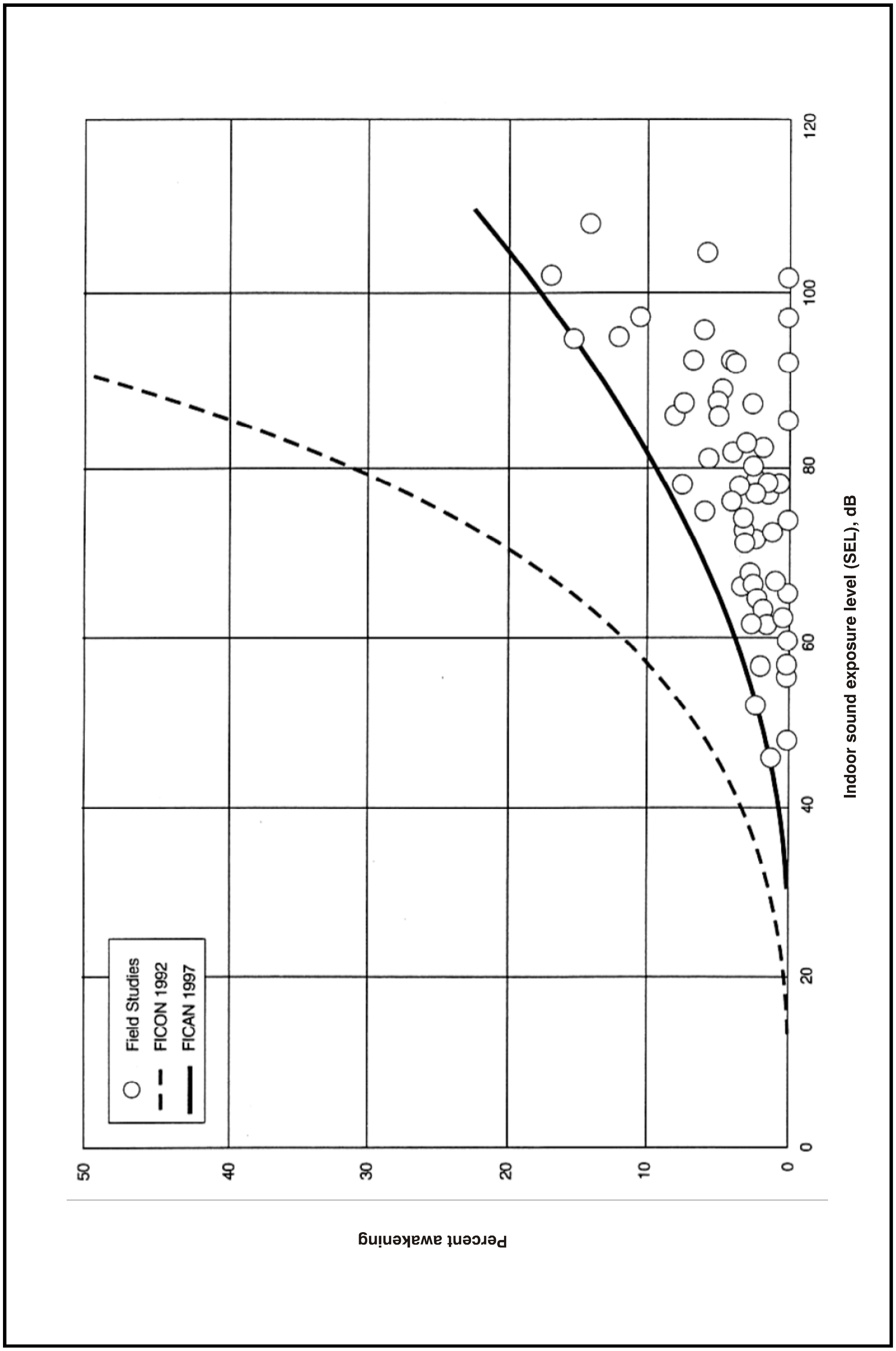


Figure C-6. Recommended Sleep Disturbance Dose-Response Relationship

Land Use Compatibility. As noted above, the inherent variability between individuals makes it impossible to predict accurately how any individual will react to a given noise event. Nevertheless, when a community is considered as a whole, its overall reaction to noise can be represented with a high degree of confidence. As described above, the best noise exposure metric for this correlation is the DNL or L_{dnmr} for military overflights. Impulsive noise can be assessed by relating CDNL to an "equivalent annoyance" DNL.

In June 1980, the ad hoc FICUN published guidelines (FICUN, 1980) relating DNL to compatible land uses. This committee was composed of representatives from the DoD; Transportation, Housing and Urban Development; USEPA; and the Veterans Administration. Since issuance of the FICUN guidelines, federal agencies have generally adopted the guidelines for their noise analyses. These guidelines are reprinted in Table C-3. The designations contained in the table do not constitute a federal determination that any use of land covered by the program is acceptable or unacceptable under federal, state, or local law. The responsibility for determining the acceptable and permissible land uses, and the relationship between specific properties and specific noise contours rests with the local authorities. The Federal Aviation Administration (FAA) determinations under Part 150 are not intended to substitute federally determined land uses for those determined to be appropriate by local authorities in response to locally determined needs and values in achieving noise-compatible land uses.

It is important to note that the guidelines presented in Table C-3 are recommendations, and compliance with them is not mandatory.

Table C-3. Land Use Compatibility with Yearly Day–Night Average Sound Levels

Land Use	Yearly Day–Night Average Sound Level in Decibels					
	Below 65	65–70	70–75	75–80	80–85	Over 85
Residential Use						
Residential, other than mobile and transient lodgings	Y	N[1]	N[1]	N	N	N
Mobile home parks	Y	N	N	N	N	N
Transient lodgings	Y	N[1]	N[1]	N[1]	N	N
Public Use						
Schools	Y	N[1]	N[1]	N	N	N
Hospitals and nursing homes	Y	25	30	N	N	N
Churches, auditoriums, and concert halls	Y	25	30	N	N	N
Government services	Y	Y	25	30	N	N
Transportation	Y	Y	Y[2]	N[3]	Y[4]	Y[4]
Parking	Y	Y	Y[2]	Y[3]	Y[4]	N
Commercial Use						
Offices—business and professional	Y	Y	25	30	N	N
Wholesale and retail—building materials, hardware, and farm equipment	Y	Y	Y[2]	Y[3]	Y[4]	N
Retail trade—general	Y	Y	25	30	N	N
Utilities	Y	Y	Y[2]	Y[3]	Y[4]	N
Communication	Y	Y	25	30	N	N

Table C-3. Land Use Compatibility with Yearly Day–Night Average Sound Levels

Land Use	Yearly Day–Night Average Sound Level in Decibels					
	Below 65	65–70	70–75	75–80	80–85	Over 85
Manufacturing and Production						
Manufacturing—general	Y	Y	Y[2]	Y[3]	Y[4]	N
Photographic and optical	Y	Y	25	30	N	N
Agriculture (except livestock) and forestry	Y	Y[6]	Y[7]	Y[8]	Y[8]	Y[8]
Livestock farming and breeding	Y	Y[6]	Y[7]	N	N	N
Mining and fishing, resource production and extraction	Y	Y	Y	Y	Y	Y
Recreational						
Outdoor sports arenas and spectator sports	Y	Y[5]	Y5[6]	N	N	N
Outdoor music shells, amphitheaters	Y	N	N	N	N	N
Nature exhibits and zoos	Y	Y	N	N	N	N
Amusements, parks, resorts, and camps	Y	Y	Y	N	N	N
Golf courses, riding stables, and water recreation	Y	Y	25	30	N	N

Data for this table were taken from the Standard Land Use Coding Manual.

Y (YES) = land use and related structures compatible without restrictions.

N (No) = land use and related structures are not compatible and should be prohibited.

NLR = Noise Level Reduction (outdoor to indoor) to be achieved through incorporation of noise attenuation into the design and construction of the structure.

25, 30, or 35 dB = land use and related structures generally compatible; measures to achieve NLR of 25, 30, or 35 dB must be incorporated into design and construction of structures.

(1) Where the community determines that residential or school uses must be allowed, measures to achieve outdoor-to-indoor NLR of at least 25 dB and 30 dB should be incorporated into building codes and be considered in individual approvals. Normal residential construction can be expected to provide an NLR of 20 dB; thus, the reduction requirements are often stated as 5, 10, or 15 dB over standard construction and normally assume mechanical ventilation and closed windows year round. However, the use of NLR criteria will not eliminate outdoor noise problems.

(2) Measures to achieve NLR 25 dB must be incorporated into the design and construction of portions of these buildings where the public is received, office areas, noise-sensitive areas, or where the normal noise level is low.

(3) Measures to achieve NLR 30 dB must be incorporated into the design and construction of portions of these buildings where the public is received, office areas, noise-sensitive areas, or where the normal noise level is low.

(4) Measures to achieve NLR 35 dB must be incorporated into the design and construction of portions of these buildings where the public is received, office areas, noise-sensitive areas, or where the normal noise level is low.

(5) Land use compatible provided special sound reinforcement systems are installed.

(6) Residential buildings require an NLR of 25.

(7) Residential buildings require an NLR of 30.

(8) Residential buildings not permitted.

Effects on Children. The effect of aircraft noise on children is a controversial area. Certain studies indicate that, in certain situations, children are potentially more sensitive to noise compared to adults. For example, adults average roughly 10 percent better than young children on speech intelligibility tests in high noise environments (ASA, 2000). Some studies indicate that noise negatively impacts classroom learning (Shield and Dockrell, 2008).

In response to noise-specific and other environmental studies, Executive Order 13045, *Protection of Children from Environmental Health Risks and Safety Risks* (1997), requires federal agencies to ensure that their policies, programs, and activities address environmental health and safety risks and to identify any disproportionate risks to children. While the issue of noise impacts on children's learning is not fully settled, in June 2002 ANSI released a new classroom acoustics standard entitled "Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools" (ANSI S12.60-2002). At present, complying with the standard is voluntary in most locations. Essentially, the criteria states that when the noisiest hour is dominated by noise from such sources as aircraft, the limits for most classrooms are an hourly average A-weighted sound level of 40 dB, and the A-weighted sound level must not exceed 40 dB for more than 10 percent of the hour. For schools located near airfields, indoor noise levels would have to be lowered by 35 to 45 dBA relative to outdoor levels (ANSI, 2002).

Non-auditory Health Effects. Non-auditory health effects of long-term noise exposure, where noise may act as a risk factor, have not been found to occur at levels below those protective against noise-induced hearing loss (as described above). Most studies attempting to clarify such health effects have found that noise exposure levels established for hearing protection will also protect against any potential non-auditory health effects, at least in workplace conditions. The lead paper at the National Institutes of Health Conference on Noise and Hearing Loss, held on 22–24 January 1990 in Washington, D.C., stated the following: "The non-auditory effects of chronic noise exposure, when noise is suspected to act as one of the risk factors in the development of hypertension, cardiovascular disease, and other nervous disorders, have never been proven to occur as chronic manifestations at levels below these criteria (an average of 75 dBA for complete protection against hearing loss for an eight-hour day)." At the 1988 International Congress on Noise as a Public Health Problem, most studies attempting to clarify such health effects did not find them at levels below the criteria protective of noise-induced hearing loss, and even above these criteria, results regarding such health effects were ambiguous. Consequently, it can be concluded that establishing and enforcing exposure levels to protect against noise-induced hearing loss would not only solve the noise-induced hearing loss problem but also any potential non-auditory health effects in the work place (von Gierke, 1990).

Although these findings were directed specifically at noise effects in the work place, they are equally applicable to aircraft noise effects in the community environment. Research studies regarding the non-auditory health effects of aircraft noise are ambiguous, at best, and often contradictory. Yet, even those studies that purport to find such health effects use time–average noise levels of 75 dB and higher for their research.

The potential for noise to affect physiological health, such as the cardiovascular system, has been speculated; however, no unequivocal evidence exists to support such claims (Harris, 1997). Conclusions drawn from a review of health effect studies involving military low-altitude flight noise, with its unusually high maximum levels and rapid rise in sound level, have shown no correlation to cardiovascular disease (Schwartze and Thompson, 1993). Since the aircraft fly predominantly at high altitudes, even less concern exists for such health effects. Additional unsupported claims include flyover noise that produces increased mortality rates, adverse effects on the learning ability of middle- and low-aptitude students, aggravation of post-traumatic stress syndrome, increased stress, increase in admissions to mental hospitals, and adverse effects on pregnant women and the unborn fetus (Harris, 1997). Harris' comments are based on a report by The Health Council of The Netherlands (1996). That study discusses two epidemiological studies that looked at the hearing abilities of children whose mothers had been exposed to occupational noise during pregnancy. The results were conditionally qualified by the committee concluding "…that equivalent sounds levels of 85 dB(A) or higher during an 8-hour working day appear to be detrimental to the hearing of the unborn child," but then they also recommended that further research be undertaken to verify that conclusion.

In summary, there is no scientific basis for a claim that potential health effects exist for aircraft time–average sound levels below 75 dB.

Aircraft Noise Effects on Structures. Normally, the most sensitive components of a structure to airborne noise are the windows and, infrequently, the plastered walls and ceilings. An evaluation of the peak sound pressures impinging on the structure is normally sufficient to determine the possibility of damage. In general, at sound levels above 130 dB, there is the possibility of the excitation of structural component resonance. While certain frequencies (such as 30 Hz for window breakage) may be of more concern than other frequencies, conservatively, only sounds lasting more than 1 second above a sound level of 130 dB are potentially damaging to structural components (CHABA, 1977).

One study, directed specifically at low-altitude, high-speed aircraft, showed that there is little probability of structural damage from such operations (Sutherland, 1989). Sound levels at damaging frequencies (e.g., 30 Hz for window breakage or 15 to 25 Hz for whole-house response) produced by most military aircraft are rarely above 130 dB.

Noise-induced structural vibration may also cause annoyance to dwelling occupants because of induced secondary vibrations or "rattle" of objects (such as hanging pictures, dishes, plaques, and bric-a-brac) within the dwelling. Windowpanes may also vibrate noticeably when exposed to high levels of airborne noise, causing homeowners to fear breakage. In general, such noise-induced vibrations occur at sound levels above those considered normally compatible with residential land use. Thus, assessments of noise exposure levels for compatible land use should also be protective of noise-induced secondary vibrations.

Sonic Boom Effects on Structures. Sonic booms are commonly associated with structural damage. Most damage claims are for window panes, glass and plaster. Table C-4 summarizes the threshold of damage that might be expected at various overpressures. There is a large degree of variability in damage experience, and much of the damage depends on the pre-existing condition of a structure. Breakage data for glass, for example, spans a range of two to three orders of magnitude at a given overpressure. While glass can suffer damage at low overpressures, as shown in Table C-4, laboratory tests of glass (White, 1972) have shown that properly installed window glass will not break at overpressures below 10 psf, even when subjected to repeated booms. In general, structural damage from sonic booms should be expected only for overpressures above 10 psf.

Table C-4. Possible Damage to Structures from Sonic Booms

Sonic Boom Overpressure Nominal (psf)	Type of Damage	Item Affected
0.5–2	Plaster	Fine cracks; extension of existing cracks, with more in ceilings, over doorframes, between some plaster boards.
	Glass	Rarely shattered, either partial or extension of existing.
	Roof	Slippage of existing loose tiles/slates; sometimes new cracking of old slates at nail hole.
	Damage to outside walls	Existing cracks in stucco extended.
	Bric-a-brac	Items carefully balanced or on edges can fall; fine glass, such as large goblets, can fall and break.
	Other	Dust falls in chimneys.
2–4	Glass, plaster, roofs, ceilings	Failures would have been difficult to forecast in terms of their existing, localized condition. Nominally in good condition.
4–10	Glass	Regular failures within a population of well-installed glass; industrial as well as domestic greenhouses.
	Plaster	Partial ceiling collapse of good plaster; complete collapse of very new, incompletely cured, or very old plaster.
	Roofs	High probability rate of failure in nominally good state, slurry-wash; some chance of failures in tiles on modern roofs; light roofs (bungalow) or large area can move bodily.
	Walls (out)	Old, free standing, but in fairly good condition, can collapse.
	Walls (in)	Inside ("party") walls known to move at 10 psf.
Greater than 10	Glass	Some good glass will fail regularly to sonic booms from the same direction. Glass with existing faults could shatter and fly. Large window frames move.
	Plaster	Most plaster affected.
	Ceilings	Plaster boards displaced by nail popping.
	Roofs	Most slate/slurry roofs affected, some badly; large roofs having good tile can be affected; some roofs bodily displaced causing gale-end and will-plate cracks; domestic chimneys dislodged if not in good condition.
	Walls	Internal party walls can move even if carrying fittings such as hand basins or taps; secondary damage due to water leakage.

Table C-4. Possible Damage to Structures from Sonic Booms

Sonic Boom Overpressure Nominal (psf)	Type of Damage	Item Affected
	Bric-a-brac	Some nominally secure items can fall; e.g., large pictures, especially if fixed to party walls.

Source: Haber and Nakaki, 1989

Noise Effects on Historical and Archaeological Sites. Aircraft noise may affect historical sites more severely than newer modern structures because of the potential for increased fragility of structural components of historical buildings and other historical sites. There are limited scientific studies of such effects to provide guidance for their assessment.

One study involved the measurement of sound levels and structural vibration levels in a superbly restored plantation house, originally built in 1795, and now situated approximately 1,500 feet from the centerline at the departure end of Runway 19L at Washington Dulles International Airport. These measurements were made in connection with the proposed scheduled operation of the supersonic Concorde airplane at Dulles (Wesler, 1977). There was special concern for the building's windows, since roughly half of the 324 panes were original. No instances of structural damage were found. Interestingly, despite the high levels of noise during Concorde takeoffs, the induced structural vibration levels were actually less than those induced by touring groups and vacuum cleaning within the building itself.

As noted above for the effects of noise-induced vibrations of normal structures, assessments of noise exposure levels for normally compatible land uses should also be protective of historic and archaeological sites.

C.4 NOISE IMPACTS MODELING

C.4.1 Aircraft Noise

Subsonic Aircraft Noise Modeling. An aircraft in subsonic flight emits noise from two sources: the engines and flow noise around the airframe. To estimate noise impacts on the ground, the DoD first measures noise from each aircraft in several flight configurations in straight and level flight at a reference altitude above an array of microphones. These measurements are stored in the NOISEFILE database. Next, this information on aircraft source noise is applied to a computer model to show how aircraft noise can be expected to propagate in real-world conditions. The algorithms at the core of these models account for spherical spreading, atmospheric absorption, and lateral attenuation. Spherical spreading is, in essence, the reduction in noise due to the spreading of sound energy away from its source. Sound energy decreases by approximately 6 dB every time the distance between the source and receiver is doubled. Daily and hourly variations in atmospheric conditions (such as humidity and clouds) can alter the amount of sound energy at a given location. The noise models use monthly average temperature and humidity conditions to derive acoustically average atmospheric absorption coefficients for each given location. Lateral attenuation, or the loss of sound energy due to reflection of sound by the ground, depends upon the altitude of the aircraft and the distance to the receiver.

The *MOA and Range NOISEMAP (MR_NMAP)* suite of computer programs is used for computing subsonic aircraft noise underneath SUAs. The suite of computer programs includes MR_OPS (Version 1), OMEGA10R, MRNMAP (Version 2.2), NMPlot, and NOISEFILE Version 6.4 as follows:

- MR_OPS – This program allows for entry of airspace information, distribution of sorties, flight profiles (average power settings, altitude distributions, and speeds), and numbers of sorties. “Distribution of sorties” refers to the modeling of airspace utilization via three broad representations: uniformly distributed sorties for modeling of MOAs and Restricted Areas, normally distributed operations for modeling of MTRs, and defined tracks for modeling race tracks, air refueling tracks, and other routes within MOAs or Restricted Areas.
- OMEGA10R – This program extrapolates/interpolates the reference single event Sound Exposure Level (SEL) for each model of aircraft from the NOISEFILE Version 6.4 database, taking into consideration the specified speeds, engine power settings, and environmental conditions appropriate to each flight operation, and generates tables of SEL versus altitude.
- MR_NMAP – The core MR_NMAP program incorporates the number of sorties between 0700–2200 and between 2200–0700, specified horizontal distributions, volume of the airspace, and profiles of the aircraft to calculate the Onset Rate Adjusted Day Night Average Sound Level (Ldnmr) as follows: (a) Ldnmr at points of a regularly spaced grid, (b) Ldnmr for an entire piece of airspace, or (c) maximum Ldnmr under the centerline of MTRs or similar routes.
- NMPLOT – From calculations of Ldnmr at many points on the ground, the NMPLOT program draws contours of equal Ldnmr values for overlay onto land-use maps. Ldnmr values are measured in A-weighted decibels denoted dBA or simply dB.

The *NOISEMAP* suite of computer programs was used for computing subsonic aircraft noise in the vicinity of Creech AFB. The NOISEMAP suite of computer programs includes BaseOps, OMEGA10, OMEGA11, NOISEMAP and NMPlot. The suite also includes the NOISEFILE databases. The different modules are described in the following sections.

- BASEOPS – The BaseOps program allows entry of runway coordinates, airfield information, flight tracks, flight profiles (engine thrust settings, altitudes, speeds, and pitch, yaw, roll and nacelle angles for tilt rotors and helicopters), numbers of daily flight operations, and pre-flight and engine ground run-up spots and operations.
- OMEGA10 – For fixed-wing and helicopters modeled using NOISEMAP, the OMEGA10 program calculates SEL versus distance for each model of aircraft

from the NOISEFILE database, taking into consideration the specified speeds, engine thrust settings, and environmental conditions appropriate to each type of flight operation. The NOISEFILE database contains one-third octave band sound data for pre-flight run-up and flight operations by most military aircraft and some civil aircraft. The OMEGA10 output is used by NOISEMAP in subsequent calculations.

- OMEGA11 - The OMEGA11 program calculates maximum A-weighted sound levels from the NOISEFILE database for each model of aircraft taking into consideration the engine thrust settings and environmental conditions appropriate to ground engine maintenance run-up operations. Similar to the OMEGA10 output, the OMEGA11 output is also used by NOISEMAP in subsequent calculations.

NOISEMAP uses the OMEGA10 and OMEGA11 outputs, incorporates the number of operations between 0700-2200 and 2200-0700 hours, flight paths, and profiles of the aircraft to calculate the Day-Night Average Sound Level (DNL) at a series of points on the ground around the facility. This process results in a “grid” file containing noise levels at different points of a user specified rectangular area. NOISEMAP Version 7 has been expanded to include atmospheric sound propagation effects over varying terrain, including hills and mountainous regions, as well as regions of varying acoustical impedance—for example, water around coastal regions

Supersonic Aircraft Noise Modeling The BOOMAP model was used to model supersonic noise. The tool is based on long-term sonic boom measurements of Air Combat Maneuvers (ACM) in White Sands Proving Grounds, New Mexico (Plotkin et al. 1989); the eastern portion of the Goldwater Range, Arizona (Plotkin et al. 1992); the Elgin MOA at Nellis AFB, Nevada (Frampton et al. 1993); and the western portion of the Goldwater Range (Page et al. 1994). Analyses of these observations were developed into the empirical BOOMAP model (Plotkin et al. 1992). BOOMAP, therefore, accounts for the statistical variations in ACM maneuvers when computing C-weighted DNL (CDNL) levels and the number of sonic booms per month on the ground underneath an SUA. CDNL values are measured in C-weighted decibels and are denoted dBC.

C.4.2 Munitions Noise

Noise from detonation of large caliber weapons (20mm or greater) is computed using DoD’s Blast Noise (BNOISE) program. BNOISE is a collection of computer programs which together can produce CDNL contours for impulsive sources such as guns, artillery, mortars, demolitions, bombs, etc. BNOISE Version 2 is used in this analysis and the required data include:

- Firing and target areas (location, point or area distribution, and elevation)
- Activity data (activity name, site weather, and detailed activity information such as firing location, firing noise source, target location, target noise source, trajectory information, and number of shots fired between 0700-2200 local time and 2200-0700 local time

- Metrics (noise metrics and assessment period)
- Grid area (rectangular grid area defined by a length, a width and a spacing)

Similar to MRNMAP, the BNOISE computer generates a grid file which is a collection of noise levels at equally spaced points on a grid. The NMPLOT program uses the "grid" file to draw contours of equal CDNL for overlay onto base maps.

To assess noise effects, the USACHPPM has defined three noise zones to be considered in land use planning. The zones are described by the noise levels to which they are exposed, and based on sociological considerations, compatible land uses are recommended.

Noise Zone I (NZ I) includes all areas in which the PK_{15}(met) decibel level is less than 87 dB (for small arms), the A-weighted DNL (ADNL) is less than 65 dB (for aircraft), and the CDNL is less than 62 dB (for large arms and explosions). NZ I is usually the furthest zone from the noise source, and it basically includes all areas not in either of the next two zones. As a rule, this area is suitable for all types of land use.

Noise Zone II (NZ II) is the next furthest area away from the noise source where the PK_{15}(met) decibel level is between 87 and 104 dB, the ADNL is between 65 and 75 dB, or the CDNL is between 62 and 70 dB. The noise exposure here is considered significant, and the use of land in this zone should generally be limited to activities such as manufacturing, warehousing, transportation, and resource protection. Residential use is strongly discouraged; however, if the community determines that this land must be used for houses, there should be a requirement that NLR features be integrated into the design and construction of houses. Further details of NLR ideas and strategies are available from USACHPPM.

Noise Zone III (NZ III) is the area closest to the source of the noise where the PK_{15}(met) decibel level is greater than 104 dB, the ADNL is greater than 75 dB, or the CDNL is greater than 70 dB. The noise level is so severe that no noise-sensitive uses should be considered in this area.

One final zone is the more informal Land Use Planning Zone. This zone is at the upper end of NZ I and is defined by a CDNL of 57 to 62 dB or an ADNL of 60 to 65 dB. It accounts for the fact that some installations have seasonal variability in their operations (or several unusually busy days during certain times of the year), and that averaging those busier days over the course of a year (as with the DNL) effectively dilutes their impact. Showing this extra zone creates one more added buffer layer to encroachment, and it signals to planners that encroachment into this area is the beginning of where complaints may become an issue. It also signals that extra care should be taken when approving plans.

Table C-5 shows all of the noise zones by the respective noise levels.

Table C-5. Noise Zone Levels

Zone	Noise Limit Aviation ADNL in A-Weighted dB	Noise Limit Impulsive CDNL in C-Weighted dB
Land Use Planning Zone	60–65	57–62
Noise Zone I	< 65	< 62
Noise Zone II	65–75	62–70
Noise Zone III	> 75	> 70

Source: Army Regulation 200-1, Environmental Protection and Enhancement, 13 December 2007.

ADNL = A-Weighted DNL; CDNL = C-Weighted DNL; PK_{15}(met) = Single Event Peak Level exceeded by 15% of events; < = less than; > = greater then; N/A = Not Applicable

Although local conditions regarding the need for housing may require noise-sensitive land uses in NZ II, on or off base, this type of land use is strongly discouraged. The absence of viable alternative development options should be determined, and an evaluation should be conducted locally prior to local approvals, indicating that a demonstrated community need for the noise-sensitive land use would not be met if development were prohibited in NZ II.

Where the community determines that these uses must be allowed, measures to achieve an outdoor-to-indoor NLR of at least 25 to 30 dB in NZ II, from small arms and aviation noise, should be incorporated into building codes and contained in individual approvals. The NLR for communities subjected to large-caliber weapons and the weapons system noise is lacking scientific studies to accomplish the recommended NLR. For this reason, it is strongly discouraged that noise-sensitive land uses be allowed in NZ II where large-caliber weapons use occurs.

Normal permanent construction can be expected to provide a NLR of 20 dB for aircraft and small arms; thus, the reduction requirements are often stated as 5, 10, or 15 dB over standard construction, and they normally assume mechanical ventilation, upgraded Sound Transmission Class ratings in windows and doors, and closed windows year-round. Additional consideration should be given to modifying NLR levels based on peak noise levels or vibrations.

NLR criteria will not eliminate outdoor noise problems. However, building location and site planning and the design and use of berms and barriers can help mitigate outdoor noise exposure NLR, particularly from ground-level aircraft sources. Barriers are generally not effective in noise reduction for large arms such as artillery and armor or large explosions.

C.4.3 Construction Noise Modeling

Construction noise was modeled using the Roadway Construction Noise Model (RCNM) version 1.00, the Federal Highway Administration's (FHWA's) standard model for the prediction of construction noise (FHWA, 2006). The RCNM has the capability to model the types of construction equipment that are expected to be the dominant noise sources during construction associated with this action. The program uses a database of construction equipment source noise taken at a standard distance of 50 feet. Information on the noise level of each piece of equipment involved in construction is combined with data on what percentage of the time each piece of equipment would be running and the length of the workday to produce an equivalent noise level for the work site. The model adjusts for sound barriers that may reduce impact of the sound as well as a sound's being impulsive (banging), which increases the intrusiveness of the sound. The model yields L_{eq} and L_{max} at various distances and/or receptor locations.

C.5 NOISE IMPACTS MODELING RESULTS

C.5.1 Aircraft Noise Results

Subsonic Aircraft Noise Modeling Results. MR_NMAP was used to calculate the overall noise exposure for subsonic operations for Restricted Areas, MOAs/ATCAAs, and MTRs, and NOISEMAP for Creech AFB. The aircraft sorties were distributed uniformly within Restricted Areas and MOAs/ATCAAs, and normally across the MTRs.

C.5.1.1 Restricted Areas, MOAs/ATCAAs, and MTRs

Baseline: Table C-6 presents the resulting noise levels for Restricted Areas, MOAs/ATCAAs and MTRs (also depicted in Figure C-7). The Baseline Ldnmr values for Restricted Areas, MOAs/ATCAAs and MTRs were calculated to vary from less than 45 dB to 69 dB.

Alternatives 2 and 3: Table C-6 also presents the results for Alternatives 2 and 3 (also shown in Figure C-7).With a 30% increase in operations, the Ldnmr values for Restricted Areas, MOAs/ATCAAs and MTRs would be expected to vary from less than 45 dB to 70 dB, an average 1 dB increase. For example, the Ldnmr value within R-4806 would be expected to increase from 60 dB for Baseline to 61 dB for Alternatives 2 and 3.

Table C-6. Summary of Ldnmr Values for SUAs

SUA Name	Baseline	Alternative 2	Alternative 3
	L_{dnmr} (dBA)	L_{dnmr} (dBA) (Change)	L_{dnmr} (dBA) (Change)
R-4806	60	61 (+1)	61 (+1)
R-4807	66	67 (+1)	67 (+1)
R-4808	<45	46 (+1)	46 (+1)
R-4809	69	70 (+1)	70 (+1)
Caliente	67	68 (+1)	68 (+1)
Coyote	67	68 (+1)	68 (+1)
Elgin	60	61 (+1)	61 (+1)
Reveille	61	62 (+1)	62 (+1)
Sally	<45	<45 (+0)	<45 (+0)
VR-209	<45	<45 (+0)	<45 (+0)
VR-222	<45	<45 (+0)	<45 (+0)

C.5.1.2 Creech AFB

Baseline: The analysis of Creech AFB operations results in DNL contours of 65 to 85 dB plotted in increments of 5 dB for an average annual day condition (Figure C-7). The 65 dB contour extends approximately 2 NM to the southwest and southeast mostly due to transient Military and RQ-170 operations.

Alternatives 2 and 3: With a 30% increase in operations, the 65 dB contour would be expected to extend slightly over 2 NM to the southwest and southeast due to transient Military and RQ-170 operations and the overall increase in the number of operations.

Supersonic Aircraft Noise Modeling Results. Aircraft flight in excess of the speed of sound (Mach 1) generate sonic boom. The BOOMAP software was used to analyze the operational data for supersonic flights (sections 4 and 5) and generate the CDNL values associated with these operations.

C.5.1.3 Restricted Areas and MOAs/ATCAAs

Baseline: Table C-7 and Figure C-8 show the CDNL values associated with Baseline supersonic operations. For example, Table C-7 shows the CDNL values for the Baseline Condition vary from 51 dBC to 61 dBC. The number of sonic booms expected per day varies from 1 to 5.

Alternatives 2 and 3: Table C-7 and Figure C-8 also show the CDNL values associated with Alternatives 2 and 3.With a 30% increase in operations, the CDNL values would be expected to vary from 52 dBC to 62 dBC, an average 1 dBC increase. The number of sonic booms per day would be expected to increase for some of the SUAs and could vary from 1 to 6.

Table C-7. Summary of CDNL Values for SUA

SUA Name	Baseline		Alternative 2		Alternative 3	
	CDNL (dBC)	Booms per Day	CDNL(dBC) (Change)	Booms per Day (Change)	CDNL(dBC) (Change)	Booms per Day (Change)
R-4806	58	1	59 (+1)	2 (+1)	59	2 (+1)
R-4807	51	2	52 (+1)	2 (+0)	52	2 (+0)
R-4808	54	1	55 (+1)	1 (+0)	55	1 (+0)
R-4809	60	1	61 (+1)	2 (+1)	61	2 (+1)
Caliente	61	5	62 (+1)	6 (+1)	62	6 (+1)
Coyote	60	2	61 (+1)	3 (+1)	61	3 (+1)
Elgin	54	1	55 (+1)	1 (+0)	55	1 (+0)
Reveille	56	1	57 (+1)	1 (+0)	57	1 (+0)
Sally	57	1	58 (+1)	2 (+1)	58	2 (+1)

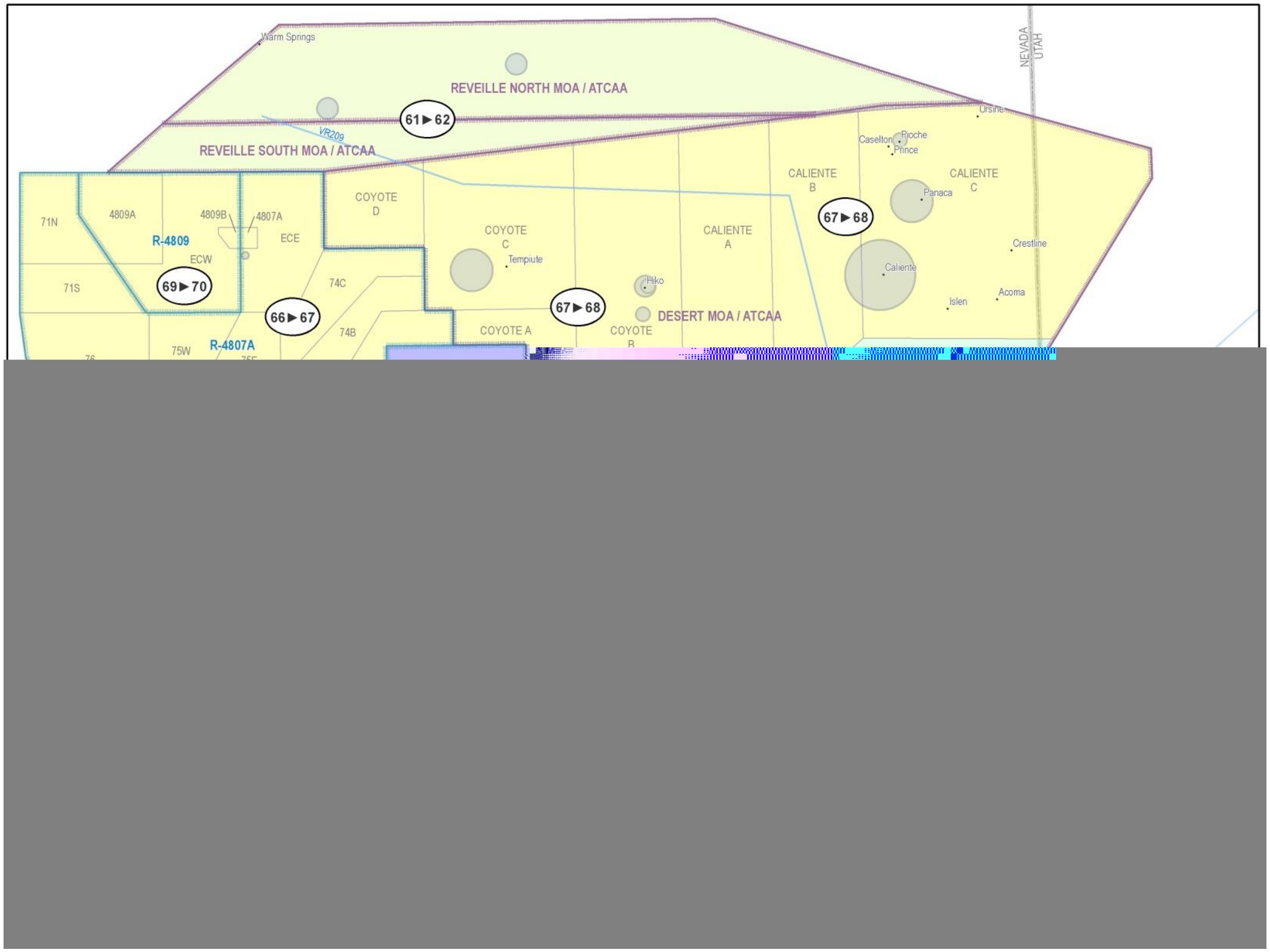


Figure C-7. Subsonic Noise Exposure Within the NTTR

In general, sonic booms may or may not reach the ground depending on environmental and flight conditions. Several factors influence the trajectory of a sonic boom and its magnitude on the ground, for example, aircraft altitude, temperature gradients, aircraft attitude, etc. Table C-8 shows, for selected aircraft, typical sonic boom peak overpressures that could be expected on the ground (in pounds per square foot) at various altitudes and Mach numbers.

Table C-8. Typical Sonic Boom Peak Overpressures (pounds per square foot)

Aircraft Type	Mach 1.1	Mach 1.2	Mach 1.3	Mach 1.4
10,000 feet AGL				
F-15	4.98	5.4	5.72	5.99
F-16	4.03	4.38	4.64	4.85
F-18	4.63	5.02	5.32	5.57
F-22*	5.02	5.48	5.82	6.1
F-35*	4.4	4.83	5.13	5.38
20,000 feet AGL				
F-15	2.68	2.87	3.04	3.17
F-16	2.16	2.32	2.45	2.56
F-18	2.48	2.66	2.8	2.93
F-22*	2.73	2.96	3.13	3.27
F-35*	2.4	2.61	2.77	2.9
30,000 feet AGL				
F-15	No Boom	1.9	1.99	2.07
F-16	No Boom	1.53	1.6	1.66
F-18	No Boom	1.74	1.82	1.89
F-22*	No Boom	1.99	2.09	2.18
F-35*	No Boom	1.78	1.87	1.95

* F-22 modeled as Fixed Wing Fighter of length 62.1 feet and weight 65,000 lbs.
* F-35 modeled as Fixed Wing Fighter of length 50.5 feet and weight 50,000 lbs.

Large Caliber Weapons Noise Modeling Results. The BNOISE computer program was used to analyze the operational data for large caliber weapons in sections 4 and 5, and to calculate the overall blast noise exposure in CDNL. The resulting noise levels are presented in Figure C-9. The 57, 62 and 70 dBC levels are reported consistent with AR 200-1 recommending the reporting of a Land Use Planning Zone (LUPZ) (57-62 dBC) and a Noise Zone I (less than 62 dBC) where noise-sensitive land uses such as housing, schools, and medical facilities need to be carefully managed, a Noise Zone II (62-70 dBC) where noise-sensitive land uses are normally not recommended and a Noise Zone III (70 dBC plus) where noise-sensitive land uses are not recommended.

<u>Baseline</u>: The CDNL contours for Baseline Conditions in Figure C-9 are generally centered around the most active target complexes. The 57 dBC contours extend approximately 2–3 NM from active target areas.

<u>Alternatives 2 and 3</u>: With an increase of 30% in large caliber munitions expenditure, the CDNL contours for Alternatives 2 and 3 would be expected to show a slight increase relative to Baseline conditions of approximately 1 dBC. The 57 dBC contours would be expected to continue to extend approximately 2–3 NM from active target areas.

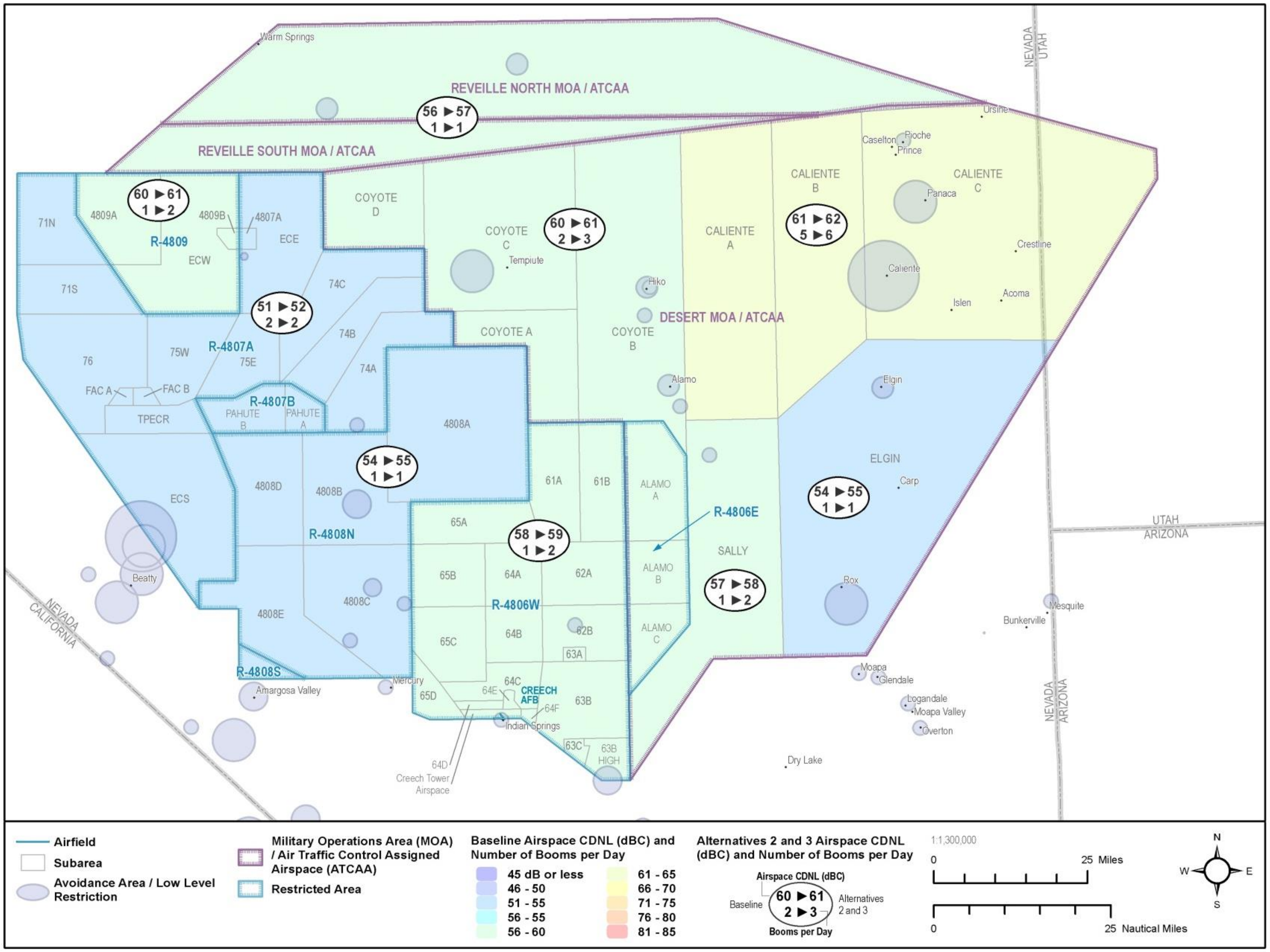


Figure C-8. Supersonic Noise Exposure Within the NTTR

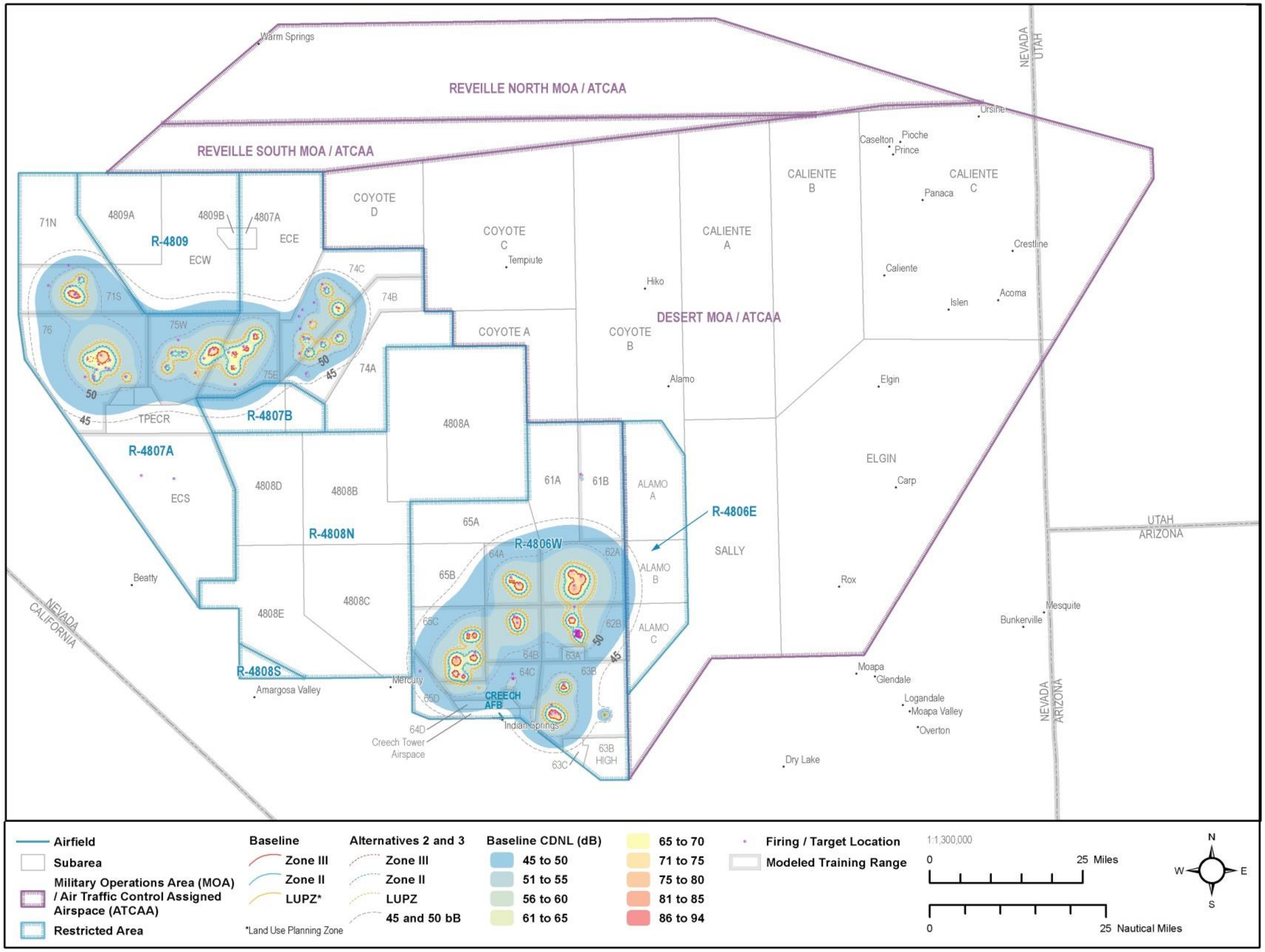


Figure C-9. Large Caliber Weapons Noise Exposure Within the NTTR

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