



APPENDIX C

NOISE



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ACRONYMS, ABBREVIATIONS, AND SYMBOLS

ADNL	A-weighted Day-Night Average Sound Level, as measured in decibels	L_{cdn}	C-weighted Day-Night Average Sound Level, as measured in decibels
AFB	Air Force Base	L_{dn}	Day-Night Average Sound Level, as measured in decibels
ANSI	American National Standards Institute	L_{dnmr} or DNL_{mr}	Onset-Rate Adjusted Monthly Day-Night Average Sound Level
ASA	Acoustical Society of America	LEIS	Legislative Environmental Impact Statement
CDNL or L_{cdn}	C-weighted Day-Night Average Sound Level	L_{eq}	Equivalent Sound Level
CHABA	Committee on Hearing, Bioacoustics and Biomechanics	L_{max}	Maximum Sound Level
CSEL	C-weighted Sound Exposure Level, as measured in decibels	L_{pk}	Peak Sound Level
dB	Decibels	MOA	Military Operating Area
dB(A) or dBA	A-Weighted Decibels	NLR	Noise Level Reduction
dB(C)	C-Weighted Decibels	NZ I, II, or III	Noise Zone I, II, or III
DLR	German Aerospace Center	OSHA	Occupational Safety and Health Administration
DNL	Day-Night Average Sound Level	PK₁₅(met)	Peak Noise Exceeded by 15 Percent of Firing Events
DoD	Department of Defense	psf	Pounds Per Square Foot
FAA	Federal Aviation Administration	RCNM	Roadway Construction Noise Model
FHWA	Federal Highway Administration	RPM	Revolutions per Minute
FICAN	Federal Interagency Committee on Aviation Noise	SEL	Sound Exposure Level
FICON	Federal Interagency Committee on Noise	SUA	Special Use Airspace
FICUN	Federal Interagency Committee on Urban Noise	USACHPPM	U.S. Army Center for Health Promotion and Preventive Medicine
Hz	Hertz	USEPA	U.S. Environmental Protection Agency
kHz	Kilohertz		
LBS	Pounds of Thrust		



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1 C.1 NOISE IMPACT ASSESSMENT METHODS

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

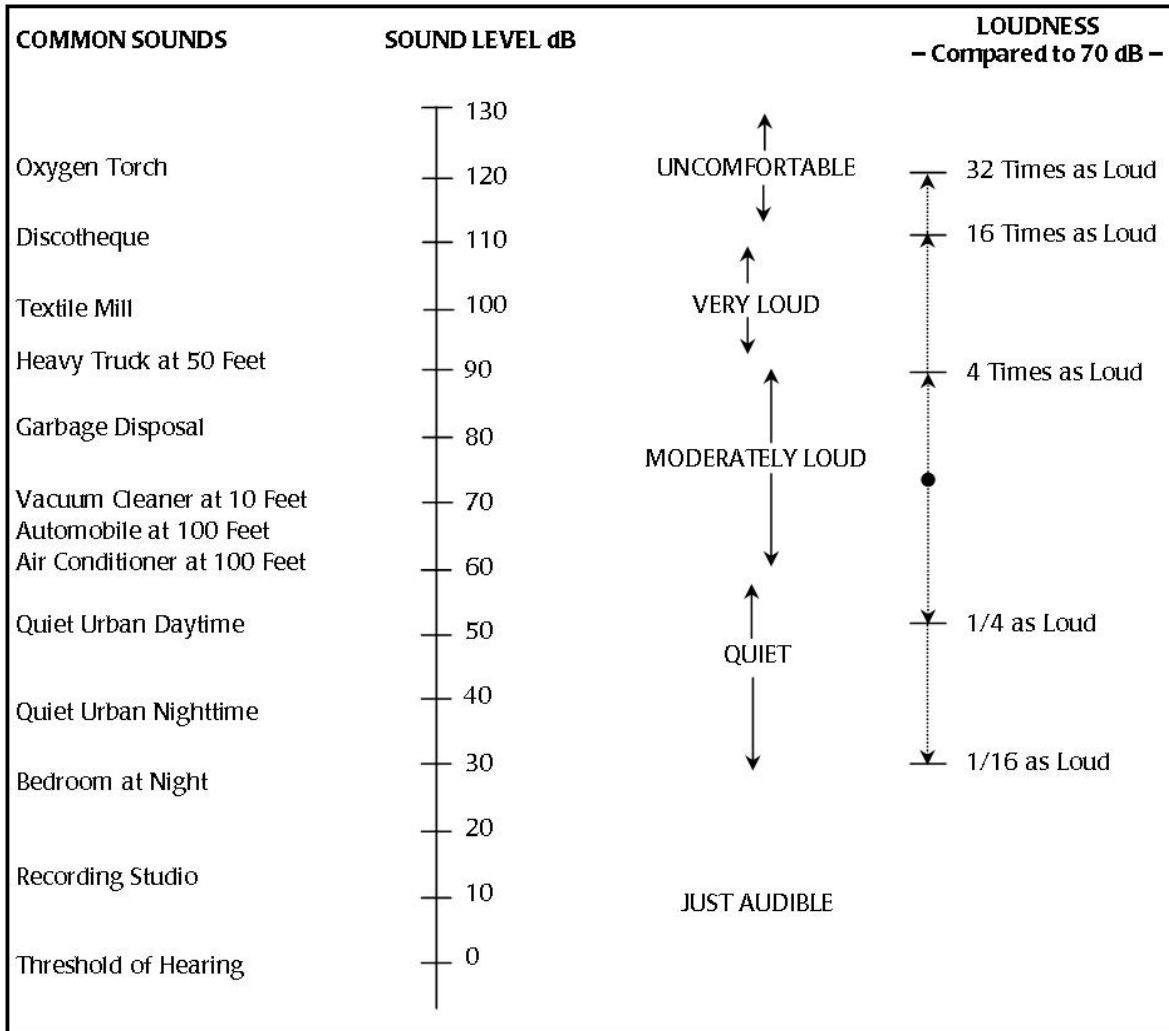
9 C.1.1 Characteristics of Sound

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

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

26 The threshold (level at which an effect starts) of human hearing is approximately 0 dB,
27 and the threshold of discomfort is approximately 120 dB. Under laboratory conditions,
28 differences in sound level of 1 dB can be detected by the human ear. In the community,
29 the smallest change in average noise level that can be detected is about 3 dB. A
30 change in sound level of about 10 dB is usually perceived by the average person as a
31 doubling (or halving) of the sound’s loudness, and this relation holds true for loud
32 sounds and quieter sounds. A decrease in sound level of 10 dB actually represents a
33 90-percent decrease in sound intensity but only a 50-percent decrease in perceived
34 loudness because of the nonlinear response of the human ear.

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



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

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

8
$$60 \text{ dB} + 60 \text{ dB} = 63 \text{ dB, and}$$

9
$$80 \text{ dB} + 80 \text{ dB} = 83 \text{ dB.}$$

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

12
$$60.0 \text{ dB} + 70.0 \text{ dB} = 70.4 \text{ dB.}$$

13 Sound pressure of what is perceived as being continuous sound actually varies greatly
14 over minute increments of time, so it is customary to deal with sound levels that
15 represent averages over time. Levels presented as instantaneous (i.e., as might be

1 read from the dial of a sound level meter) are based on averages of sound energy over
2 either 1/8 second (fast) or 1 second (slow). This distinction becomes important when
3 discussing sounds whose peak noise level lasts for only a short time, such as sonic
4 booms.

5 **Frequency.** The normal human ear can hear frequencies from about 20 hertz (Hz) to
6 about 20,000 Hz. It is most sensitive to sounds in the 1,000- to 4,000-Hz range. When
7 measuring community response to noise, it is common to adjust the frequency content
8 of the measured sound to correspond to the frequency sensitivity of the human ear.
9 This adjustment is called A-weighting (American National Standards Institute [ANSI],
10 1988). Sound levels that have been so adjusted are referred to as A-weighted and may
11 be denoted dBA or dB(A). However, because use of A-weighting to express sound
12 level is so prevalent, it can normally be assumed that dB is equivalent to dBA or dB(A).
13 In this LEIS, sound levels are reported in dB and are A-weighted unless otherwise
14 specified.

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

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

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

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

- 1 single vehicle driving by, and they usually last for only a few minutes at the most.
2 The annoyance caused by transient sounds is dependent upon both the
3 maximum sound level and the duration.
- 4 • **Impulsive Sound.** Impulsive sound is of short duration (typically less than one
5 second), high intensity, abrupt onset, rapid decay, and often a fast-changing
6 spectral composition. It is characteristically associated with such sources as
7 explosions, impacts, the discharge of firearms, the passage of supersonic aircraft
8 (sonic booms), and many industrial processes. Impulsive sound can be
9 particularly annoying because of the “startle factor” where the receiver has no
10 warning that exposure to a loud sound is imminent.

11 C.2 NOISE METRICS

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

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

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

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

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

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

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

27 **Day–Night Average Sound Level (DNL or L_{dn}).** Noise tends to be more intrusive at
28 night than during the day. This effect is accounted for by applying a 10-dB penalty to
29 events that occur after 10:00 PM and before 7:00 AM. DNL is similar to L_{eq} except DNL
30 has a nighttime penalty added. DNL is the community noise metric recommended by
31 the U.S. Environmental Protection Agency (USEPA) (USEPA, 1974) and has been
32 adopted by most federal agencies (Federal Interagency Committee on Noise [FICON],
33 1992). It has been widely accepted that DNL correlates well with community response
34 to noise (Schultz, 1978; Finegold et al., 1994). This correlation is presented in the
35 section titled “Noise Impacts on Humans.” Furthermore, DNL has also been proven
36 applicable to infrequent events (Fields and Powell, 1985) and to rural populations
37 exposed to sporadic military aircraft noise (Stusnick et al., 1992, 1993).

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

1 **Onset-Rate Adjusted Monthly Day–Night Average Sound Level.** The Onset-
 2 Adjusted Monthly Day–Night Average Sound Level is denoted as L_{dnmr} . Aircraft
 3 operations in military airspace (such as ranges, military operating areas [MOAs], military
 4 training routes, and Warning Areas) generate a noise environment somewhat different
 5 from other community noise environments. Overflights are sporadic, occurring at
 6 random times and varying from day to day and week to week. This situation differs from
 7 most community noise environments, where noise tends to be continuous or patterned.
 8 Individual military overflight events also differ from typical community noise events in
 9 that noise from a low-altitude, high-air-speed flyover can have a sudden onset. To
 10 represent these differences, the conventional DNL metric is adjusted to account for the
 11 “surprise” effect of the sudden onset of aircraft noise events on humans (Plotkin et al.,
 12 1987; Stusnick et al., 1992, 1993). For aircraft exhibiting a rate of increase in sound
 13 level (called onset rate) of from 15 to 150 dB per second, an adjustment or penalty
 14 ranging from 0 to 11 dB is added to the normal SEL. Onset rates above 150 dB per
 15 second require an 11 dB penalty, while onset rates below 15 dB per second require no
 16 adjustment. In addition, because of the irregular occurrences of aircraft operations, the
 17 number of average daily operations is determined by using the calendar month with the
 18 highest number of operations.

19 C.3 NOISE IMPACTS ON HUMANS

20 **Annoyance.** The primary effect of aircraft noise on exposed communities is one of
 21 annoyance. Noise annoyance is defined by the USEPA as any negative subjective
 22 reaction on the part of an individual or group (USEPA, 1974). Studies of community
 23 annoyance resulting from numerous types of environmental noise show that DNL
 24 correlates well with impact. Schultz (1978) showed a consistent relationship between
 25 DNL and percentage of the impacted population that was “highly annoyed” (9 or 10 on a
 26 scale of 1 to 10, with 10 being the most annoyed). A more recent study reaffirmed and
 27 updated this relationship (Finegold et al., 1994) (Table C-1). In general, correlation
 28 coefficients of 0.85 to 0.95 are found between the percentages of groups of people
 29 highly annoyed and the level of average noise exposure. The correlation coefficients for
 30 the annoyance of individuals are relatively low, however, on the order of 0.5 or less.
 31 This is not surprising, considering the varying personal factors that influence the manner
 32 in which individuals react to noise. Nevertheless, findings substantiate that, as a whole,
 33 communities’ level of annoyance to aircraft noise is represented fairly reliably using
 34 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

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

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

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

29 **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

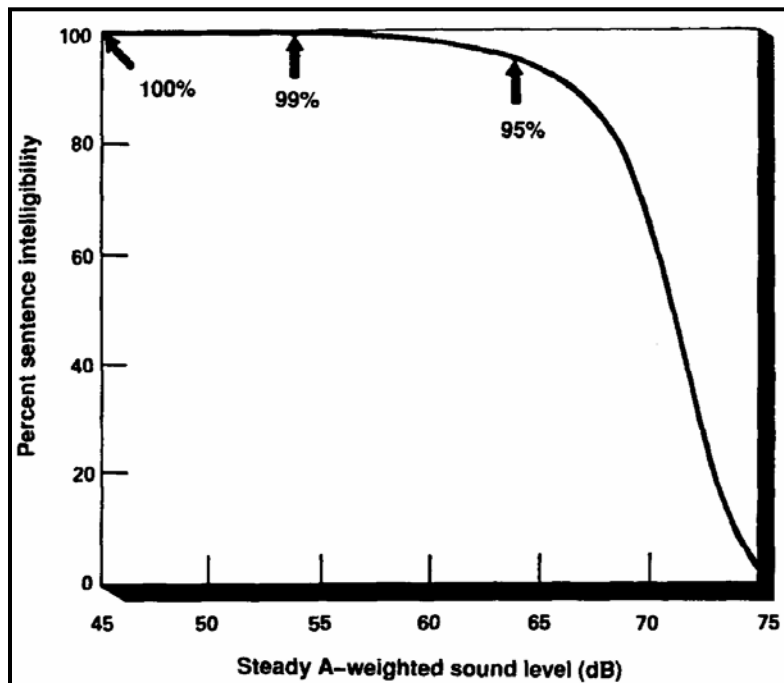
Source: CHABA, 1981

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

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

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

11 **U.S. Federal Criteria for Interior Noise.** In 1974, the USEPA identified a goal of an
 12 indoor 24-hour average sound level $L_{eq(24)}$ of 45 dB to minimize speech interference
 13 based on the intelligibility of sentences in the presence of a steady background noise
 14 (USEPA, 1974). Intelligibility pertains to the percentage of speech units correctly
 15 understood out of those transmitted, and specifies the type of speech material used, i.e.
 16 sentences or words. The curve displayed in Figure C-2 shows the effect of steady
 17 indoor background sound levels on sentence intelligibility. For an average adult with
 18 normal hearing and fluency in the language, steady background sound levels indoors of
 19 less than 45 dB L_{eq} are expected to allow 100-percent intelligibility of sentences.



20
 21 **Figure C-2. Speech Intelligibility Curve**

Source: USEPA, 1974

22 The curve shows 99-percent sentence intelligibility for background levels at a L_{eq} of
 23 54 dB, and less than 10-percent intelligibility for background levels above a L_{eq} of 73 dB.
 24 Note that the curve is especially sensitive to changes in sound level between 65 dB and
 25 75 dB—an increase of 1 dB in background sound level from 70 dB to 71 dB results in a

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

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

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

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

26 FICON produced a guidance document that provided an overview of the most pertinent
27 sleep disturbance research that had been conducted throughout the 1970s (FICON,
28 1992). Literature reviews and meta-analysis conducted between 1978 and 1989 made
29 use of the existing datasets that indicated the effects of nighttime noise on various
30 sleep-state changes and awakenings (Lukas, 1978; Griefahn, 1978; Pearsons et al.,
31 1989). FICON noted that various indoor A-weighted sound levels—ranging from 25 to
32 50 dB—were observed to be thresholds below which significant sleep effects were not
33 expected. Due to the large variability in the data, FICON did not endorse the reliability of
34 the results.

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

1 **Recent Sleep Disturbance Research—Field and Laboratory Studies.** It was noted in
2 the early sleep disturbance research that the controlled laboratory studies did not
3 account for many factors that are important to sleep behavior, such as habituation to the
4 environment and previous exposure to noise and awakenings from sources other than
5 aircraft noise. In the early 1990s, field studies were conducted to validate the earlier
6 laboratory work. The most significant finding from these studies was that an estimated
7 80 to 90 percent of sleep disturbances were not related to individual outdoor noise
8 events, but were instead the result of indoor noise sources and other non-noise-related
9 factors. The results showed that there was less of an effect of noise on sleep in real-life
10 conditions than had been previously reported from laboratory studies.

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

19 Based on the new information, FICAN updated its recommended dose-response curve
20 in 1997, depicted as the lower curve in Figure C-3. This figure is based on the results of
21 three field studies (Ollerhead, 1992; Fidell et al., 1994; Fidell et al., 1995a; Fidell et al.,
22 1995b), along with the datasets from six previous field studies.

23 The new relationship represents the higher end, or upper envelope, of the latest field
24 data. It should be interpreted as predicting the “maximum percent of the exposed
25 population expected to be behaviorally awakened” or the “maximum percent awakened”
26 for a given residential population. According to this relationship, a maximum of 3
27 percent of people would be awakened at an indoor SEL of 58 dB, compared to 10
28 percent using the 1992 curve. An indoor SEL of 58 dB is equivalent to outdoor SELs of
29 73 and 83 dB respectively assuming 15 and 25 dB noise level reduction from outdoor to
30 indoor with windows open and closed, respectively.

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

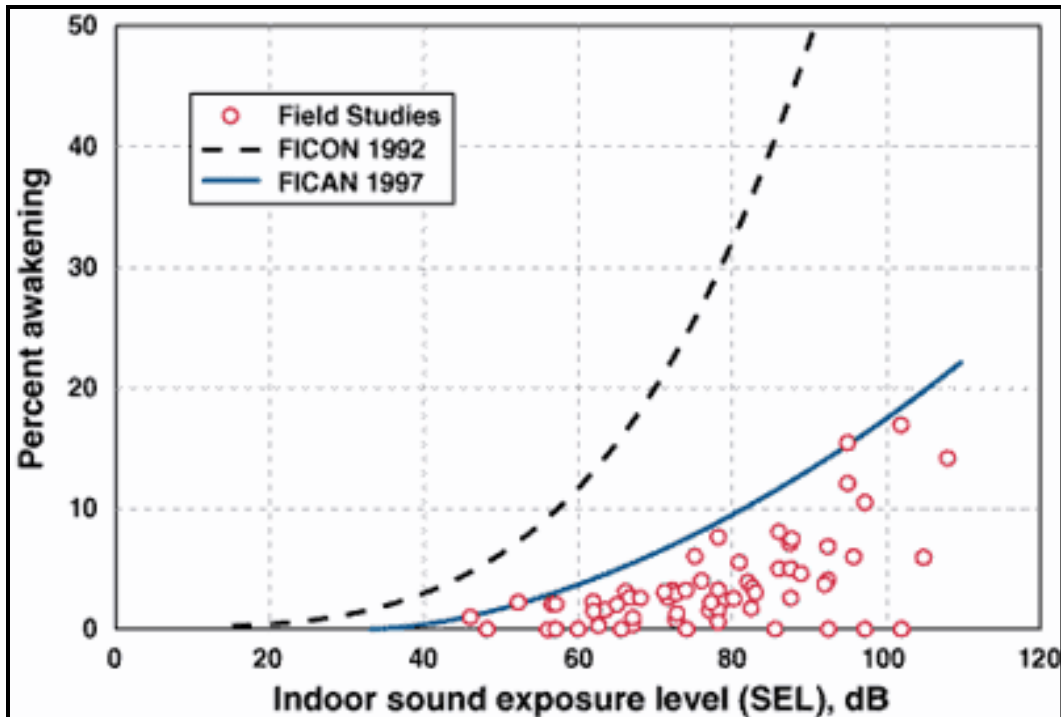


Figure C-3. FICAN's 1997 Recommended Sleep Disturbance Dose-Response Relationship

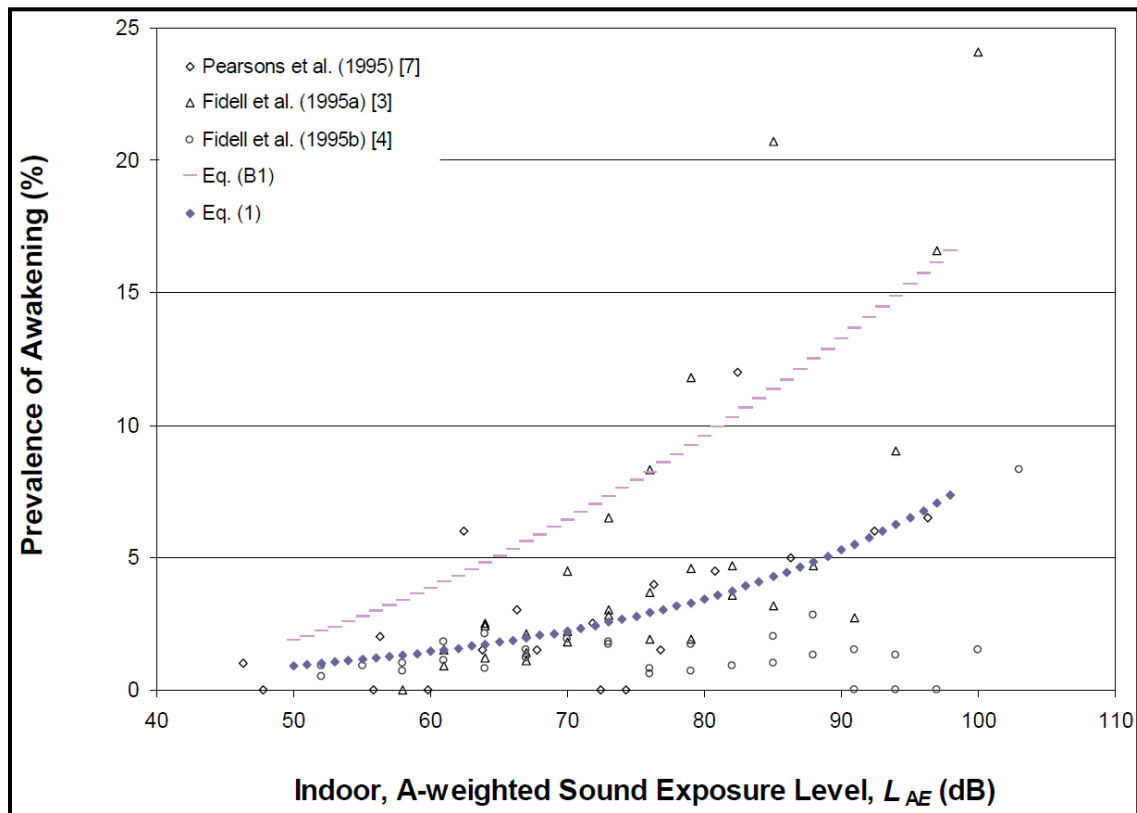
The FICAN 1997 curve is represented by the following equation:

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

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.

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



11 **Figure C-4. Plot of Sleep Awakening Data versus Indoor SEL**

12 Source: ANSI 2008

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

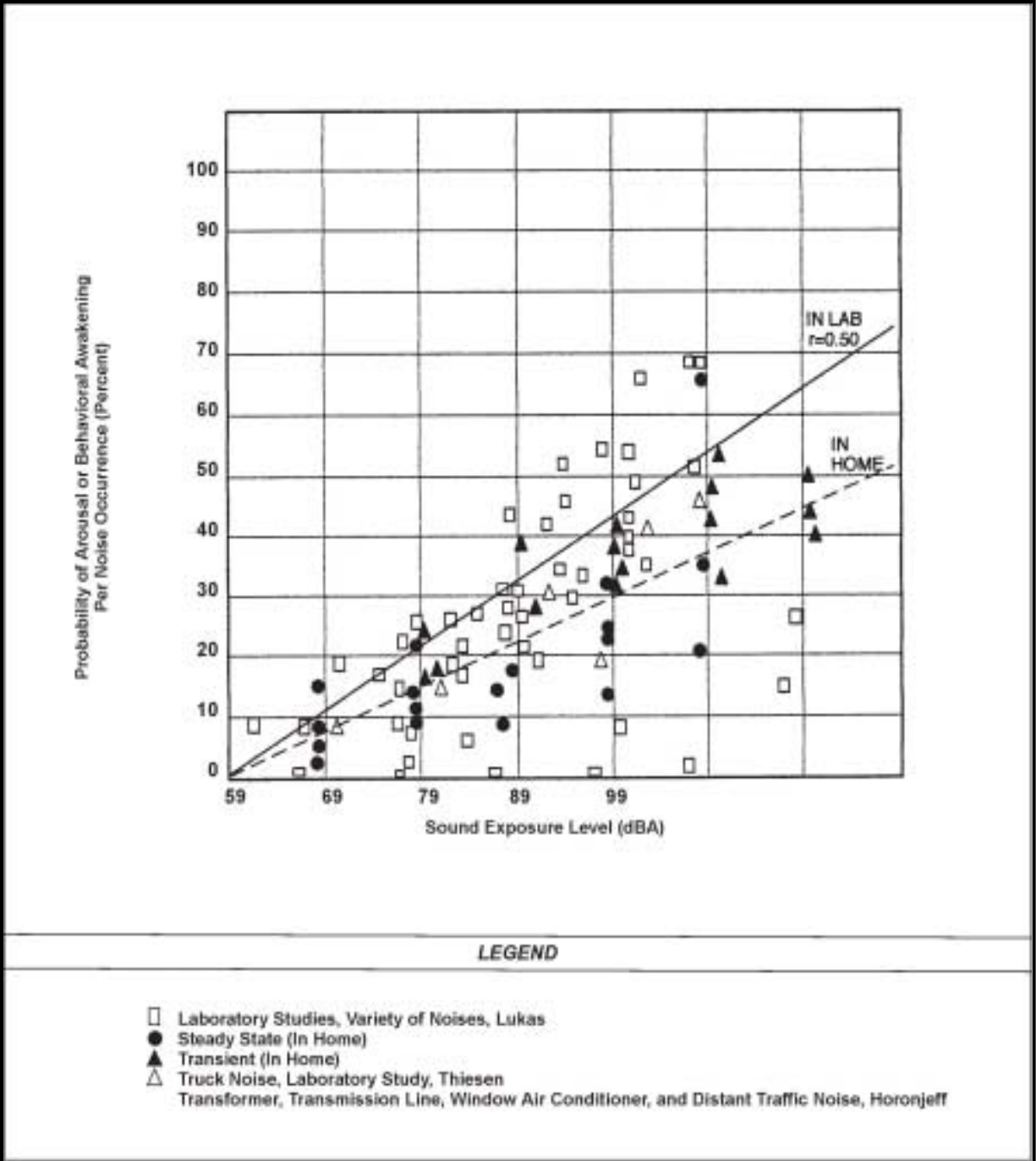
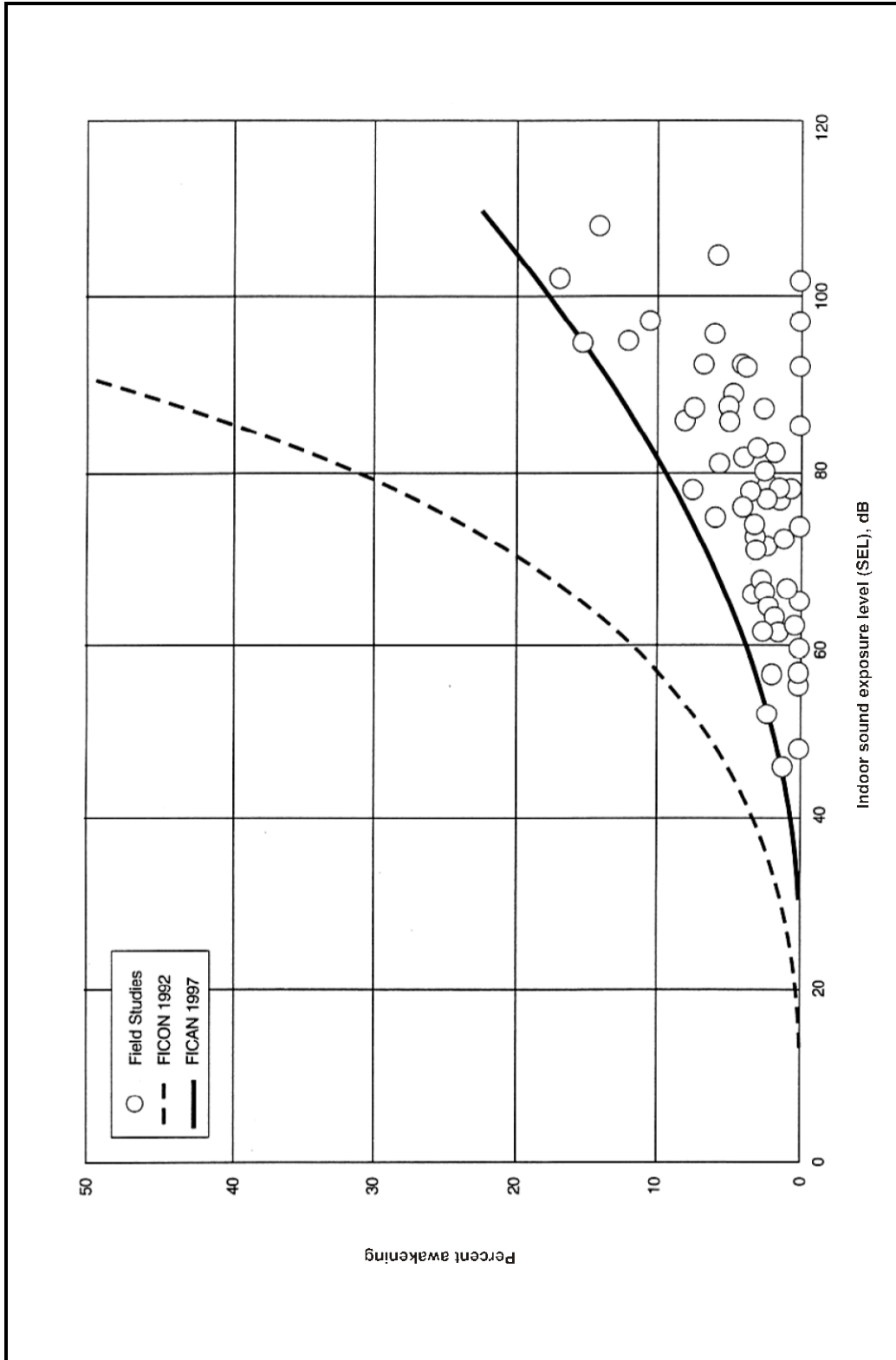


Figure C-5. Probability of Arousal or Behavioral Awakening in Terms of Sound Exposure Level

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2
3

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

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

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

21 It is important to note that the guidelines presented in Table C-3 are recommendations,
 22 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	Y ⁵ 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.

1 **Effects on Children.** The effect of aircraft noise on children is a controversial area.
 2 Certain studies indicate that, in certain situations, children are potentially more sensitive
 3 to noise compared to adults. For example, adults average roughly 10 percent better
 4 than young children on speech intelligibility tests in high noise environments (ASA,
 5 2000). Some studies indicate that noise negatively impacts classroom learning (Shield
 6 and Dockrell, 2008).

7 In response to noise-specific and other environmental studies, Executive Order 13045,
 8 *Protection of Children from Environmental Health Risks and Safety Risks* (1997),
 9 requires federal agencies to ensure that their policies, programs, and activities address
 10 environmental health and safety risks and to identify any disproportionate risks to

1 children. While the issue of noise impacts on children’s learning is not fully settled, in
2 June 2002 ANSI released a new classroom acoustics standard entitled “Acoustical
3 Performance Criteria, Design Requirements, and Guidelines for Schools” (ANSI
4 S12.60-2002). At present, complying with the standard is voluntary in most locations.
5 Essentially, the criteria states that when the noisiest hour is dominated by noise from
6 such sources as aircraft, the limits for most classrooms are an hourly average
7 A-weighted sound level of 40 dB, and the A-weighted sound level must not exceed
8 40 dB for more than 10 percent of the hour. For schools located near airfields, indoor
9 noise levels would have to be lowered by 35 to 45 dBA relative to outdoor levels
10 (ANSI, 2002).

11 ***Non-auditory Health Effects.*** Non-auditory health effects of long-term noise exposure,
12 where noise may act as a risk factor, have not been found to occur at levels below
13 those protective against noise-induced hearing loss (as described above). Most studies
14 attempting to clarify such health effects have found that noise exposure levels
15 established for hearing protection will also protect against any potential non-auditory
16 health effects, at least in workplace conditions. The lead paper at the National Institutes
17 of Health Conference on Noise and Hearing Loss, held on 22–24 January 1990 in
18 Washington, D.C., stated the following: “The non-auditory effects of chronic noise
19 exposure, when noise is suspected to act as one of the risk factors in the development
20 of hypertension, cardiovascular disease, and other nervous disorders, have never been
21 proven to occur as chronic manifestations at levels below these criteria (an average of
22 75 dBA for complete protection against hearing loss for an eight-hour day).” At the
23 1988 International Congress on Noise as a Public Health Problem, most studies
24 attempting to clarify such health effects did not find them at levels below the criteria
25 protective of noise-induced hearing loss, and even above these criteria, results
26 regarding such health effects were ambiguous. Consequently, it can be concluded that
27 establishing and enforcing exposure levels to protect against noise-induced hearing loss
28 would not only solve the noise-induced hearing loss problem but also any potential non-
29 auditory health effects in the work place (von Gierke, 1990).

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

36 The potential for noise to affect physiological health, such as the cardiovascular system,
37 has been speculated; however, no unequivocal evidence exists to support such claims
38 (Harris, 1997). Conclusions drawn from a review of health effect studies involving
39 military low-altitude flight noise, with its unusually high maximum levels and rapid rise in
40 sound level, have shown no correlation to cardiovascular disease (Schwartz and
41 Thompson, 1993). Since the aircraft fly predominantly at high altitudes, even less
42 concern exists for such health effects. Additional unsupported claims include flyover
43 noise that produces increased mortality rates, adverse effects on the learning ability of
44 middle- and low-apitude students, aggravation of post-traumatic stress syndrome,

1 increased stress, increase in admissions to mental hospitals, and adverse effects on
2 pregnant women and the unborn fetus (Harris, 1997). Harris' comments are based on a
3 report by The Health Council of The Netherlands (1996). That study discusses two
4 epidemiological studies that looked at the hearing abilities of children whose mothers
5 had been exposed to occupational noise during pregnancy. The results were
6 conditionally qualified by the committee concluding "...that equivalent sounds levels of
7 85 dB(A) or higher during an 8-hour working day appear to be detrimental to the hearing
8 of the unborn child," but then they also recommended that further research be
9 undertaken to verify that conclusion.

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

12 ***Aircraft Noise Effects on Structures.*** Normally, the most sensitive components of a
13 structure to airborne noise are the windows and, infrequently, the plastered walls and
14 ceilings. An evaluation of the peak sound pressures impinging on the structure is
15 normally sufficient to determine the possibility of damage. In general, at sound levels
16 above 130 dB, there is the possibility of the excitation of structural component
17 resonance. While certain frequencies (such as 30 Hz for window breakage) may be of
18 more concern than other frequencies, conservatively, only sounds lasting more than
19 1 second above a sound level of 130 dB are potentially damaging to structural
20 components (CHABA, 1977).

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

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

33 ***Sonic Boom Effects on Structures.*** Sonic booms are commonly associated with
34 structural damage. Most damage claims are for window panes, glass and plaster.
35 Table C-4 summarizes the threshold of damage that might be expected at various
36 overpressures. There is a large degree of variability in damage experience, and much
37 of the damage depends on the pre-existing condition of a structure. Breakage data for
38 glass, for example, spans a range of two to three orders of magnitude at a given
39 overpressure. While glass can suffer damage at low overpressures, as shown in
40 Table C-4, laboratory tests of glass (White, 1972) have shown that properly installed
41 window glass will not break at overpressures below 10 psf, even when subjected to
42 repeated booms. In general, structural damage from sonic booms should be expected
43 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.
	Bric-a-brac	Some nominally secure items can fall; e.g., large pictures, especially if fixed to party walls.

Source: Haber and Nakaki, 1989

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

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

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

19 **C.4 NOISE IMPACTS MODELING**

20 **C.4.1 Aircraft Noise**

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

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

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

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

- 28 • BASEOPS – The BaseOps program allows entry of runway coordinates, airfield
29 information, flight tracks, flight profiles (engine thrust settings, altitudes, speeds,
30 and pitch, yaw, roll and nacelle angles for tilt rotors and helicopters), numbers of
31 daily flight operations, and pre-flight and engine ground run-up spots and
32 operations.
- 33 • OMEGA10 – For fixed-wing and helicopters modeled using *NOISEMAP*, the
34 OMEGA10 program calculates SEL versus distance for each model of aircraft
35 from the *NOISEFILE* database, taking into consideration the specified speeds,
36 engine thrust settings, and environmental conditions appropriate to each type of
37 flight operation. The *NOISEFILE* database contains one-third octave band sound
38 data for pre-flight run-up and flight operations by most military aircraft and some
39 civil aircraft. The OMEGA10 output is used by *NOISEMAP* in subsequent
40 calculations.
- 41 • OMEGA11 - The OMEGA11 program calculates maximum A-weighted sound
42 levels from the *NOISEFILE* database for each model of aircraft taking into
43 consideration the engine thrust settings and environmental conditions

1 appropriate to ground engine maintenance run-up operations. Similar to the
2 OMEGA10 output, the OMEGA11 output is also used by NOISEMAP in
3 subsequent calculations.

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

12 **Supersonic Aircraft Noise Modeling** The BOOMAP model was used to model
13 supersonic noise. The tool is based on long-term sonic boom measurements of Air
14 Combat Maneuvers (ACM) in White Sands Proving Grounds, New Mexico (Plotkin et al.
15 1989); the eastern portion of the Goldwater Range, Arizona (Plotkin et al. 1992); the
16 Elgin MOA at Nellis AFB, Nevada (Frampton et al. 1993); and the western portion of the
17 Goldwater Range (Page et al. 1994). Analyses of these observations were developed
18 into the empirical BOOMAP model (Plotkin et al. 1992). BOOMAP, therefore, accounts
19 for the statistical variations in ACM maneuvers when computing C-weighted DNL
20 (CDNL) levels and the number of sonic booms per month on the ground underneath an
21 SUA. CDNL values are measured in C-weighted decibels and are denoted dBC.

22 **C.4.2 Munitions Noise**

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

- 28 • Firing and target areas (location, point or area distribution, and elevation)
- 29 • Activity data (activity name, site weather, and detailed activity information such
30 as firing location, firing noise source, target location, target noise source,
31 trajectory information, and number of shots fired between 0700-2200 local time
32 and 2200-0700 local time
- 33 • Metrics (noise metrics and assessment period)
- 34 • Grid area (rectangular grid area defined by a length, a width and a spacing)

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

38 To assess noise effects, the USACHPPM has defined three noise zones to be
39 considered in land use planning. The zones are described by the noise levels to which

1 they are exposed, and based on sociological considerations, compatible land uses are
2 recommended.

3 Noise Zone I (NZ I) includes all areas in which the $PK_{15}(\text{met})$ decibel level is less than
4 87 dB (for small arms), the A-weighted DNL (ADNL) is less than 65 dB (for aircraft), and
5 the CDNL is less than 62 dB (for large arms and explosions). NZ I is usually the
6 furthest zone from the noise source, and it basically includes all areas not in either of
7 the next two zones. As a rule, this area is suitable for all types of land use.

8 Noise Zone II (NZ II) is the next furthest area away from the noise source where the
9 $PK_{15}(\text{met})$ decibel level is between 87 and 104 dB, the ADNL is between 65 and 75 dB,
10 or the CDNL is between 62 and 70 dB. The noise exposure here is considered
11 significant, and the use of land in this zone should generally be limited to activities such
12 as manufacturing, warehousing, transportation, and resource protection. Residential
13 use is strongly discouraged; however, if the community determines that this land must
14 be used for houses, there should be a requirement that NLR features be integrated into
15 the design and construction of houses. Further details of NLR ideas and strategies are
16 available from USACHPPM.

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

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

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

1

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; PK₁₅(met) = Single Event Peak Level exceeded by 15% of events; < = less than; > = greater than; 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.

2 C.4.3 Construction Noise Modeling

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

1 C.5 NOISE IMPACTS MODELING RESULTS

2 C.5.1 Aircraft Noise Results

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

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

8 Baseline: Table C-6 presents the resulting noise levels for Restricted Areas,
9 MOAs/ATCAAs and MTRs (also depicted in Figure C-7). The Baseline Ldnmr values for
10 Restricted Areas, MOAs/ATCAAs and MTRs were calculated to vary from less than
11 45 dB to 69 dB.

12 Alternatives 2 and 3: Table C-6 also presents the results for Alternatives 2 and 3 (also
13 shown in Figure C-7). With a 30% increase in operations, the Ldnmr values for
14 Restricted Areas, MOAs/ATCAAs and MTRs would be expected to vary from less than
15 45 dB to 70 dB, an average 1 dB increase. For example, the Ldnmr value within R-4806
16 would be expected to increase from 60 dB for Baseline to 61 dB for Alternatives 2 and
17 3.

18 **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)

19 C.5.1.2 Creech AFB

20 Baseline: The analysis of Creech AFB operations results in DNL contours of 65 to 85 dB
21 plotted in increments of 5 dB for an average annual day condition (Figure C-7). The
22 65 dB contour extends approximately 2 NM to the southwest and southeast mostly due
23 to transient Military and RQ-170 operations.

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

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

8 **C.5.1.3 Restricted Areas and MOAs/ATCAAs**

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

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

18

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)

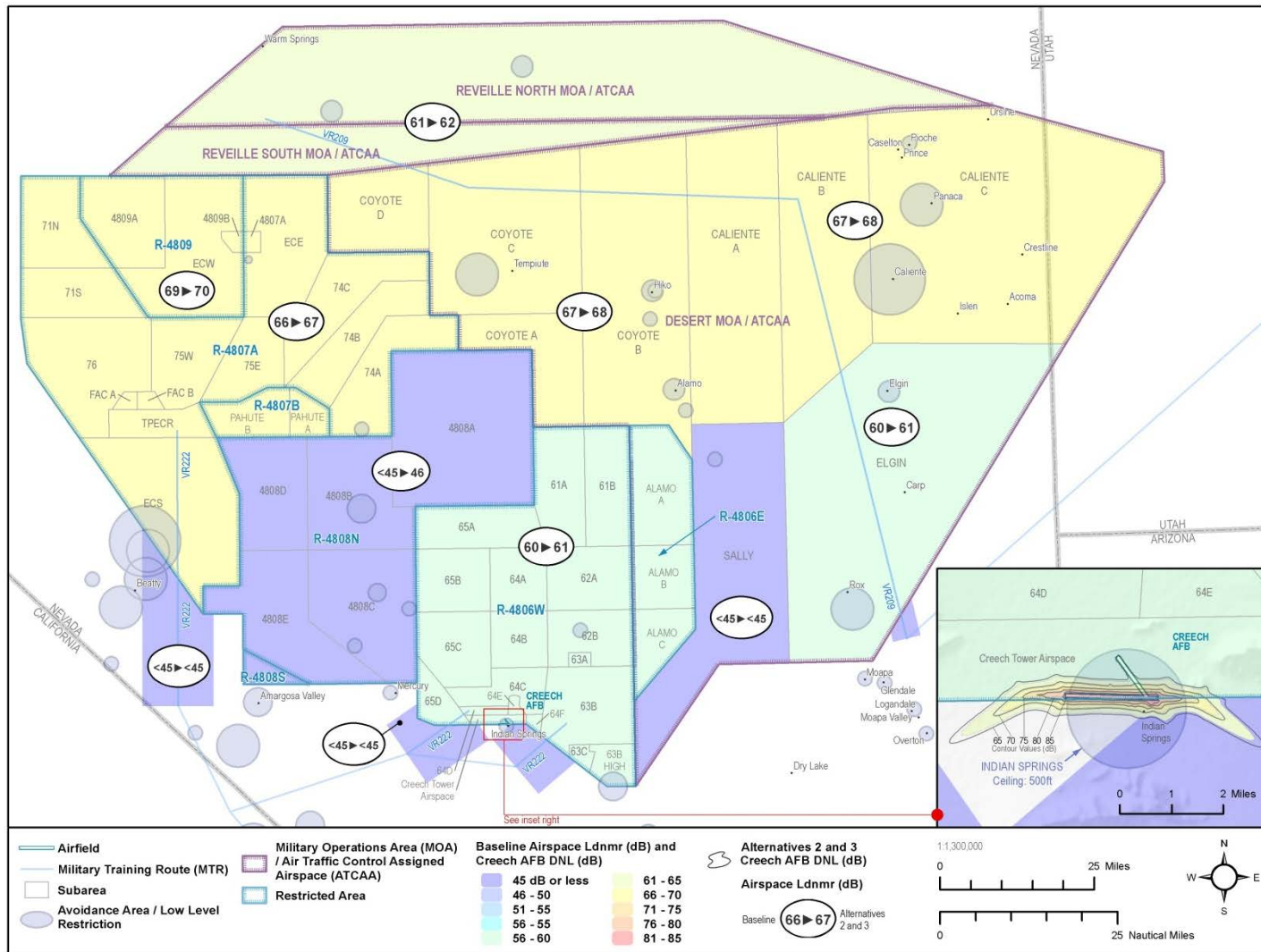


Figure C-7. Subsonic Noise Exposure Within the NTTR

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

7 **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.

8 **Large Caliber Weapons Noise Modeling Results.** The BNOISE computer program
 9 was used to analyze the operational data for large caliber weapons in sections 4 and 5,
 10 and to calculate the overall blast noise exposure in CDNL. The resulting noise levels are
 11 presented in Figure C-9. The 57, 62 and 70 dBC levels are reported consistent with AR
 12 200-1 recommending the reporting of a Land Use Planning Zone (LUPZ) (57-62 dBC)
 13 and a Noise Zone I (less than 62 dBC) where noise-sensitive land uses such as
 14 housing, schools, and medical facilities need to be carefully managed, a Noise Zone II
 15 (62-70 dBC) where noise-sensitive land uses are normally not recommended and a
 16 Noise Zone III (70 dBC plus) where noise-sensitive land uses are not recommended.

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

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

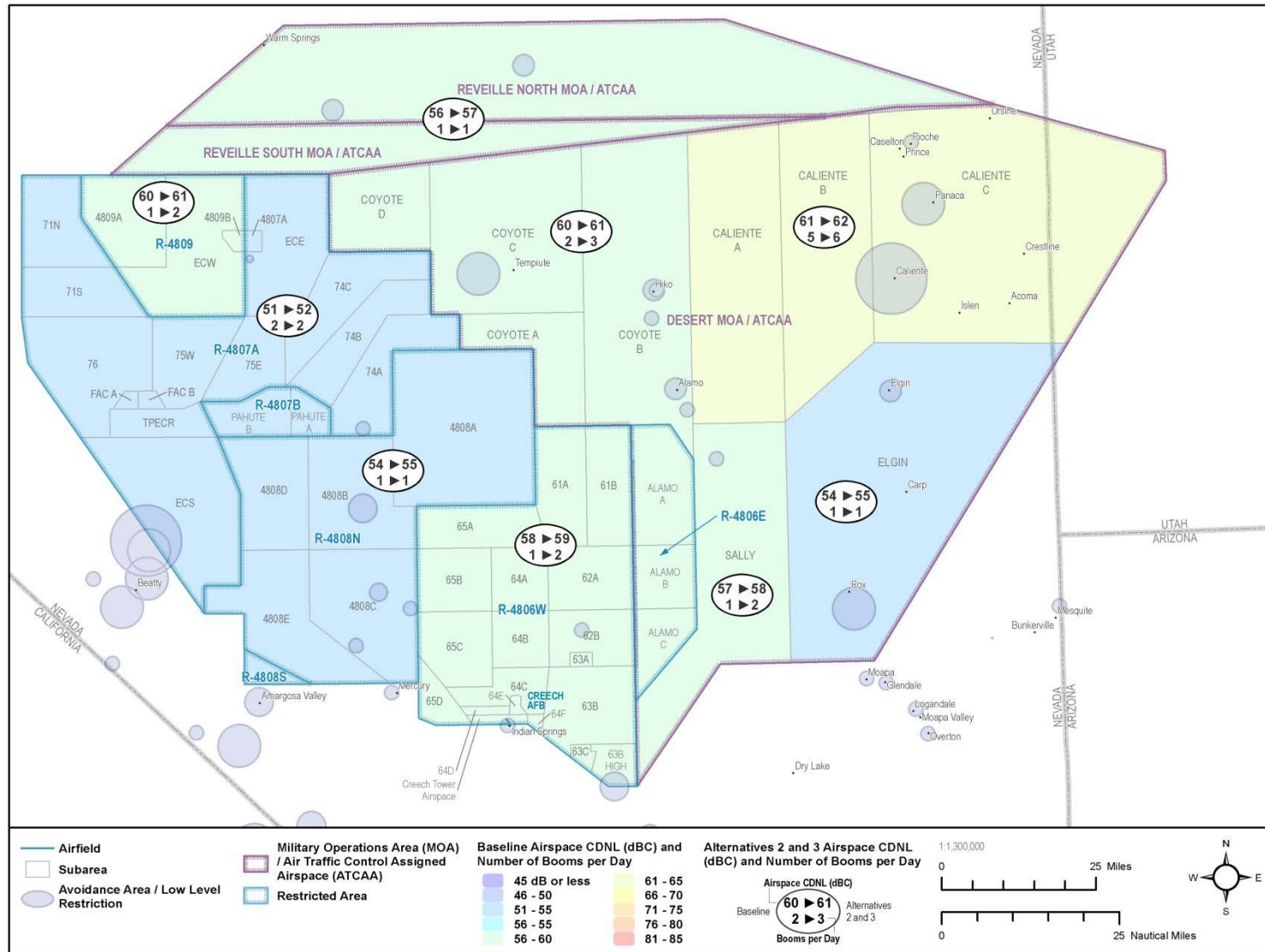


Figure C-8. Supersonic Noise Exposure Within the NTTR

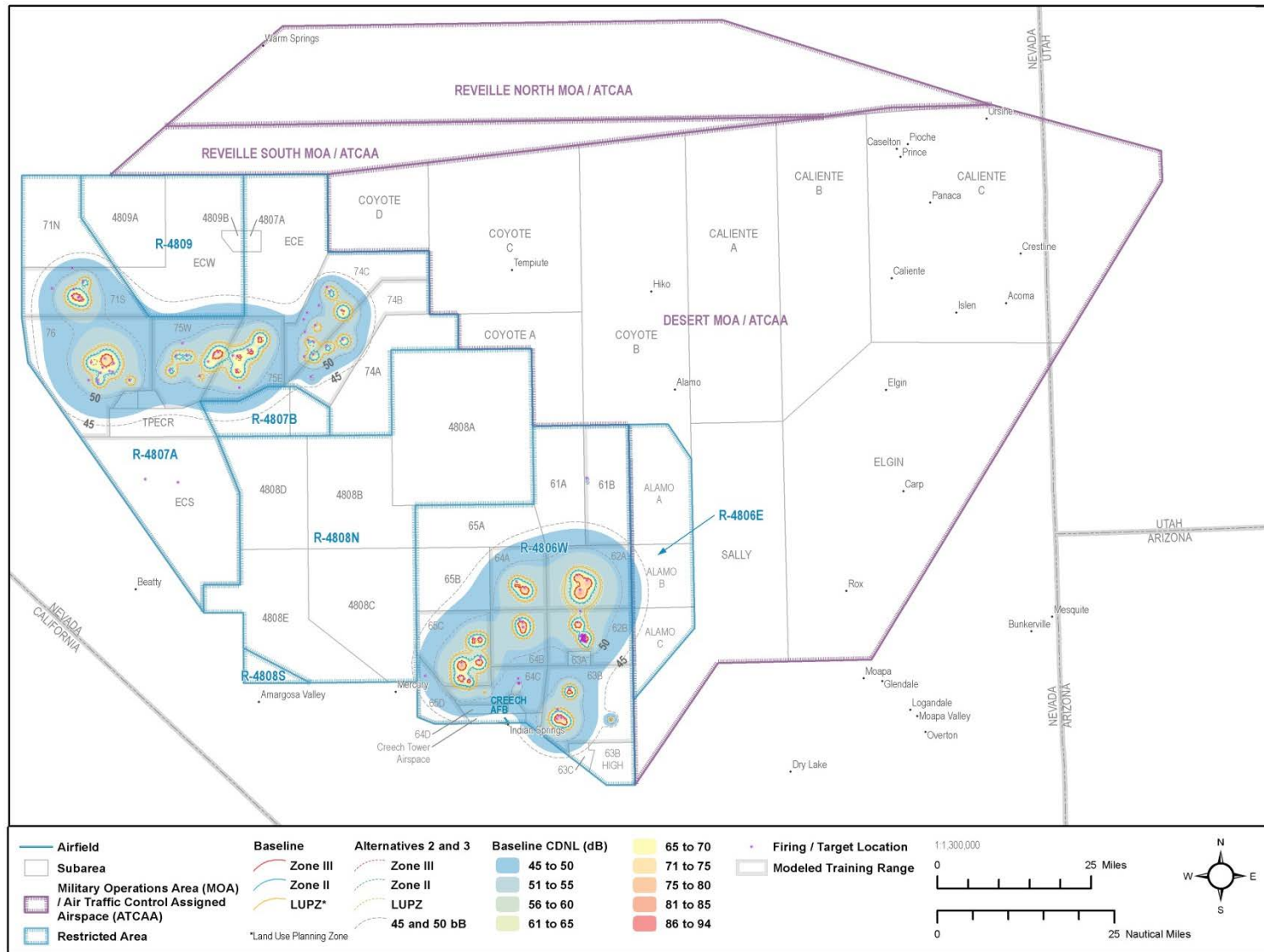


Figure C-9. Large Caliber Weapons Noise Exposure Within the NTTR

1 C.6 REFERENCES

- 2 Acoustical Society of America (ASA) Technical Committee on Architectural Acoustics, 2000.
3 Classroom Acoustics.
- 4 American National Standards Institute (ANSI), 1980. Sound Level Descriptors for Determination
5 of Compatible Land Use. American National Standards Institute Standard ANSI S3.231980.
- 6 American National Standards Institute (ANSI), 1988. Quantities and Procedures for Description
7 and Measurement of Environmental Sound, Part 1. American National Standards Institute
8 Standard ANSI S12.9-1988.
- 9 Armstrong Laboratories, 1991. Analysis of Measured Environmental Noise Levels: an
10 Assessment of the Effects of Airbase Operational Model Variables on Predicted Noise
11 Exposure Levels, AL-TR-1991-0097, June.
- 12 Committee on Hearing, Bioacoustics, and Biomechanics (CHABA), 1977. Guidelines for
13 Preparing Environmental Impact Statements on Noise. National Research Council, National
14 Academy of Sciences. Washington, D.C.
- 15 Committee on Hearing, Bioacoustics and Biomechanics (CHABA), 1981. Assessment of
16 Community Noise Response to High-Energy Impulsive Sounds. Report of Working Group
17 84, Committee on Hearing, Bioacoustics and Biomechanics, Assembly of Behavioral and
18 Social Sciences. National Research Council, National Academy of Sciences. Washington,
19 D.C.
- 20 Delaney, D. K., L. L. Pater, R. H. Melton, B. A. MacAllister, R. J. Dooling, B. Lohr, B. F. Brittan-
21 Powell, L. L. Swindell, T. A. Beaty, L. D. Carlile, and E. W. Spadgenske, 2002. Assessment
22 of Training Noise Impacts on the Red-cockaded Woodpecker: Final Report. February 2002.
- 23 Dooling, R. J., and M. L. Dent, 2001. "New Studies on Hair Cell Regeneration in Birds,"
24 *Acoustical Science and Technology*, Vol 22, No 2, 2001. Department of Psychology,
25 University of Maryland, College Park, Maryland.
- 26 Federal Highway Administration (FHWA), Office of Environmental Planning, 2006. Roadway
27 Construction Noise Model User's Guide. FHWA-HEP-05-054. January 2006
- 28 Federal Interagency Committee on Aircraft Noise (FICAN), 2000. FICAN Position on Research
29 into Effects of Aircraft Noise on Classroom Learning. September 2002.
- 30 Federal Interagency Committee on Aircraft Noise (FICAN), 2004. FICAN Report on
31 Relationship Between Aircraft Noise Reduction in Schools and Standardized Test Scores.
32 March 2004.
- 33 Federal Interagency Committee on Noise (FICON), 1992. Federal Agency Review of Selected
34 Airport Noise Analysis Issues. August 1992.

- 1 Federal Interagency Committee on Urban Noise (FICUN), 1980. Guidelines for Considering
2 Noise in Land-Use Planning and Control. Federal Interagency Committee on Urban Noise.
3 June 1980.
- 4 Fields, J. M., and C. A. Powell, 1985. A Community Survey of Helicopter Noise Annoyance
5 Conducted Under Controlled Noise Exposure Conditions. NASA TM-86400. March 1985.
- 6 Finegold, L. S., C. S. Harris, and H. E. von Gierke, 1994. Community Annoyance and Sleep
7 Disturbance: Updated Criteria for Assessing the Impacts of General Transportation Noise on
8 People. In *Noise Control Engineering Journal*, Vol 42, No 1, pp 25–30, January–February
9 1994.
- 10 Frampton, K., J. Lucas, and B. Cook, 1993. *Modeling the Sonic Boom Noise Environment in*
11 *Military Operations Areas*. AIAA-1993-4432, October 25–27, 1993.
- 12 Haber, J., and D. Nakaki, 1989. Sonic Boom Damage to Conventional Structures. HSD-TR-89-
13 001. April 1989.
- 14 Harris, C. S., 1997. The Effects of Noise on Health. Wright-Patterson AFB, OH. AL/OETR-
15 1997-0077.
- 16 Health Council of the Netherlands, 1996. Effects of Noise on Health, Chapter 3 of an edited
17 report on Noise and Health prepared by a committee of The Health Council of The
18 Netherlands. *Noise/News International*, September 1996.
- 19 Headquarters Department of the Army, 2007. Army Regulation 200-1, Environmental Protection
20 and Enhancement, 13 December 2007.
- 21 Kryter, K. D., 1984. Physiological, Psychological, and Social Effects of Noise. NASA Reference
22 Publication 1115, 446. July 1984.
- 23 Lucas, M., and P. Calamia, 1996. *Military Operations Area and Range Noise Model MRNMAP*
24 *User's Manual*. Wyle Report WR 94-12, June 1996.
- 25 Lucas, M. J., and K. Plotkin, 1988. ROUTEMAP Model for Predicting Noise Exposure from
26 Aircraft Operations on Military Training Routes. Final. Wright-Patterson AFB, OH. AAMRL.
27 AAMRL-TR-88-060.
- 28 Ludlow and Sixsmith, 1999. Long Term Effects of Military Jet Aircraft Noise Exposure During
29 Childhood on Hearing Threshold Levels. *Noise and Health*, Vol 5, pp 33–39.
- 30 Moulton, C. L., 1991. Air Force Procedure for Predicting Noise Around Airbases: Noise
31 Exposure Model (NOISEMAP). Technical Report AL-TR-1992-59.
- 32 Ollerhead J. B., C. J. Jones, R. E. Cadoux, A. Woodley, B. J. Atkinson, J. A. Horne, F.
33 Pankhurst, L. Reyner, K. I. Hume, F. Van, A. Watson, I. Diamond, P. Egger, D. Holmes, and
34 J. McKean, 1992. Report of a Field Study of Aircraft Noise and Sleep Disturbance.
35 Department of Transport, London, U.K.
- 36 Pearsons, K. S., D. S. Barber, and B. G. Tabachick, 1989. Analyses of the Predictability of
37 Noise-Induced Sleep Disturbance. USAF Report HSD-TR-89-029. October 1989.

- 1 Pearsons, K. S., R. L. Bennett, and S. Fidell, 1977. "Speech levels in various noise
2 environments," U.S. Environmental Protection Agency Report EPA-600/1-77-025.
- 3 Plotkin, K. J., L. C. Sutherland, and J. A. Molino, 1987. Environmental Noise Assessment for
4 Military Aircraft Training Routes, Volume II: Recommended Noise Metric. Wyle Research
5 Report WR 86-21. January 1987.
- 6 Plotkin, K. J., V. R. Desai, C. L. Moulton, M. J. Lucas, and R. Brown, 1989. Measurements of
7 Sonic Booms due to ACM Training at White Sands Missile Range. Wyle Research Report
8 WR 89-18.
- 9 Schultz, T. J., 1978. Synthesis of Social Surveys on Noise Annoyance. *Journal of the*
10 *Acoustical Society of America*, Vol 64, pp 377–405, August 1978.
- 11 Schwartze, S., and S. J. Thompson, 1993. Research on Non-Auditory Physiological Effects of
12 Noise Since 1988: Review and Perspectives. Proceedings of the 6th International Congress
13 on Noise as a Public Problem (I'NRETS), Nice, France, Vol 3.
- 14 Shield, B., and J. Dockrell, 2008. The Effects of Environmental and Classroom Noise on the
15 Academic Attainments of Primary School Children. *Journal of the Acoustical Society of*
16 *America*, Vol 123, No 1, pp 133–144, January 2008.
- 17 Stusnick, E., D. A. Bradley, J. A. Molino, and G. DeMiranda, 1992. The Effect of Onset Rate on
18 Aircraft Noise Annoyance. Volume 2: Rented Own-Home Experiment. Wyle Laboratories
19 Research Report WR 92-3. March 1992.
- 20 Stusnick, E., D. A. Bradley, M. A. Bossi, and D. G. Rickert, 1993. The Effect of Onset Rate on
21 Aircraft Noise Annoyance. Volume 3: Hybrid Own-Home Experiment. Wyle Laboratories
22 Research Report WR 93-22. December 1993.
- 23 Sutherland, L., 1989. Assessment of Potential Structural Damage from Low Altitude Subsonic
24 Aircraft. Wyle Laboratories Research Report WR 89-16. El Segundo, CA.
- 25 U.S. Army Center for Health Promotion and Preventative Medicine (USACHPPM), 2005.
26 Operational Noise Management. November 2005.
- 27 U.S. Environmental Protection Agency (USEPA), 1974. Information on Levels of Environmental
28 Noise Requisite to Protect the Public Health and Welfare with an Adequate Margin of
29 Safety. U.S. Environmental Protection Agency Report 550/9-74-004. March 1974.
- 30 U.S. Environmental Protection Agency (USEPA), 1982. *Guidelines for Noise Impact Analysis*.
31 Report No. 550/9-82-105. April 1982.
- 32 von Gierke, H. R., 1990. The Noise-Induced Hearing Loss Problem. NIH Consensus
33 Development Conference on Noise and Hearing Loss, Washington, D.C., 22–24 January
34 1990.
- 35 Wesler, J. E., 1977. Concorde Operations at Dulles International Airport. NOISEXPO '77,
36 Chicago, IL, March 1977.

- 1 White, R., 1972. Effects of Repetitive Sonic Booms on Glass Breakage. FAA Report FAA-RD-
- 2 72. April 1972.