Appendix E
Noise

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ACRONYMS AND ABBREVIATIONS

AGL	above ground level
ANSI	American National Standards Institute
ASA	Acoustical Society of America
ATV	all-terrain vehicle
BASH	bird/wildlife-aircraft strike hazard
BMP	best management practice
CHABA	Committee on Hearing, Bioacoustics and Biomechanics
CHCN	Committee of the Health Council of the Netherlands
dB	decibels
dB L_{pk}	decibels peak noise level
dBA	decibels measured on the A-weighted scale
DNL	day-night average sound level
DoD	U.S. Department of Defense
DOL	U.S. Department of Labor
DOT	U.S. Department of Transportation
EPA	U.S. Environmental Protection Agency
FAA	Federal Aviation Administration
FICAN	Federal Interagency Committee on Aircraft Noise
FICON	Federal Interagency Committee on Noise
FICUN	Federal Interagency Committee on Urban Noise
GIS	geographic information system
HE	high explosive
Hz	hertz
IN	inert
LAE	sound exposure level, a-weighted
lb	pounds
L_{dnmr}	onset rate–adjusted day-night average sound level
L_{eq}	equivalent continuous sound pressure level
L_{max}	maximum sound level
L_{pk}	peak noise level
MOA	Military Operations Area
MR_NMAP	MOA-Range NOISEMAP
MTR	Military Training Route
NATO	North Atlantic Treaty Organization
NIOSH	National Institute for Occupational Safety and Health
NIPTS	noise-induced permanent threshold shift
NPS	National Park Service
NRC/NAS	National Research Council/National Academy of Sciences
OSHA	Occupational Safety and Health Administration
PHL	potential hearing loss
PK 15	peak noise level exceeding only 15 percent of the time
psf	pounds per square foot
PTS	permanent threshold shift
SARNAM	Small Arms Range Noise Assessment Model
SEL	sound exposure level
TTS	temporary threshold shift
UCLA	University of California, Los Angeles
UK	United Kingdom
USARAK	U.S. Army Alaska
USFS	U.S. Forest Service
USFWS	U.S. Fish and Wildlife Service
WHO	World Health Organization

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APPENDIX E
NOISE

Appendix E provides a general noise primer to educate the reader on what constitutes noise, how it is measured, and the studies that were used in support of how and why noise is modeled.

Noise is generally described as unwanted sound. Unwanted sound can be based on objective effects (such as hearing loss or damage to structures) or subjective judgments (community annoyance). Noise analysis thus requires a combination of physical measurement of sound, physical and physiological effects, plus psycho- and socio-acoustic effects.

Section E.1 of this appendix describes how sound is measured and summarizes noise impacts in terms of community acceptability and land use compatibility. Section E.2 gives detailed descriptions of the effects of noise that lead to the impact guidelines presented in Section E.1. Section E.3 provides a description of the specific methods used to predict aircraft noise, including a detailed description of sonic booms.

E.1 NOISE DESCRIPTORS AND IMPACT

Aircraft operating in military airspace generate two types of sound. One is "subsonic" noise, which is continuous sound generated by the aircraft's engines and also by air flowing over the aircraft itself. The other is sonic booms (where authorized for supersonic), which are transient impulsive sounds generated during supersonic flight. These are quantified in different ways.

Section E.1.1 describes the characteristics used to describe sound. Section E.1.2 describes the specific noise metrics used for noise impact analysis. Section E.1.3 describes how environmental impact and land use compatibility are judged in terms of these quantities.

E.1.1 Quantifying Sound

Measurement and perception of sound involve two basic physical characteristics: amplitude and frequency. Amplitude is a measure of the strength of the sound and is directly measured in terms of the pressure of a sound wave. Because sound pressure varies in time, various types of pressure averages are usually used. Frequency, commonly perceived as pitch, is the number of times per second the sound causes air molecules to oscillate. Frequency is measured in units of cycles per second, or hertz (Hz).

Amplitude. The loudest sounds the human ear can comfortably hear have acoustic energy one trillion times the acoustic energy of sounds the ear can barely detect. Because of this vast range, attempts to represent sound amplitude by pressure are generally unwieldy. Sound is, therefore, usually represented on a logarithmic scale with a unit called the decibel (dB). Sound measured on the decibel scale is referred to as a sound level. The threshold of human hearing is approximately 0 dB, and the threshold of discomfort or pain is around 120 dB.

Because of the logarithmic nature of the decibel scale, sounds 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 increases by 3 dB, regardless of the initial sound level. Thus, 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.

Because the addition of sound levels behaves differently than that of ordinary numbers, such addition is often referred to as "decibel addition" or "energy addition." The latter term arises from the fact that the combination of decibel values consists of first converting each decibel value to its corresponding acoustic energy, then adding the energies using the normal rules of addition, and finally converting the total energy back to its decibel equivalent.

The difference in dB between two sounds represents the ratio of the amplitudes of those two sounds. Because human senses tend to be proportional (i.e., detect whether one sound is twice as big as another) rather than absolute (i.e., detect whether one sound is a given number of pressure units bigger than another), the decibel scale correlates well with human response.

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 for quieter sounds. A decrease in sound level of 10 dB actually represents a 90 percent decrease in sound *intensity* but only a 50 percent decrease in perceived *loudness* because of the nonlinear response of the human ear (similar to most human senses).

The one exception to the exclusive use of levels, rather than physical pressure units, to quantify sound is in the case of sonic booms. As described in Section E.3.2, sonic booms are coherent waves with specific characteristics. There is a long-standing tradition of describing individual sonic booms by the amplitude of the shock waves, in pounds per square foot (psf). This is particularly relevant when assessing structural effects as opposed to loudness or cumulative community response. In this environmental analysis, sonic booms are quantified by either dB or psf, as appropriate for the particular impact being assessed.

Frequency. The normal human ear can hear frequencies from about 20 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 (ANSI 1988). Sound levels that have been so adjusted are referred to as A weighted sound levels.

The audible quality of high thrust engines in modern military combat aircraft can be somewhat different than other aircraft, including (at high throttle settings) the characteristic nonlinear crackle of high thrust engines. The spectral characteristics of various noises are accounted for by A-weighting, which approximates the response of the human ear but does not necessarily account for quality. There are other, more detailed, weighting factors that have been applied to sounds. In the 1950s and 1960s, when noise from civilian jet aircraft became an issue, substantial research was performed to determine what characteristics of jet noise were a problem. The metrics Perceived Noise Level and Effective Perceived Noise Level were developed. These accounted for nonlinear behavior of hearing and the importance of low frequencies at high levels, and for many years airport/airbase noise contours were presented in terms of Noise Exposure Forecast, which was based on Perceived Noise Level and Effective Perceived Noise Level. In the 1970s, however, it was realized that the primary intrusive aspect of aircraft noise was the high noise level, a factor which is well represented by A-weighted levels and day–night average sound level (DNL). The refinement of Perceived Noise Level, Effective Perceived Noise Level, and Noise Exposure Forecast was not significant in protecting the public from noise.

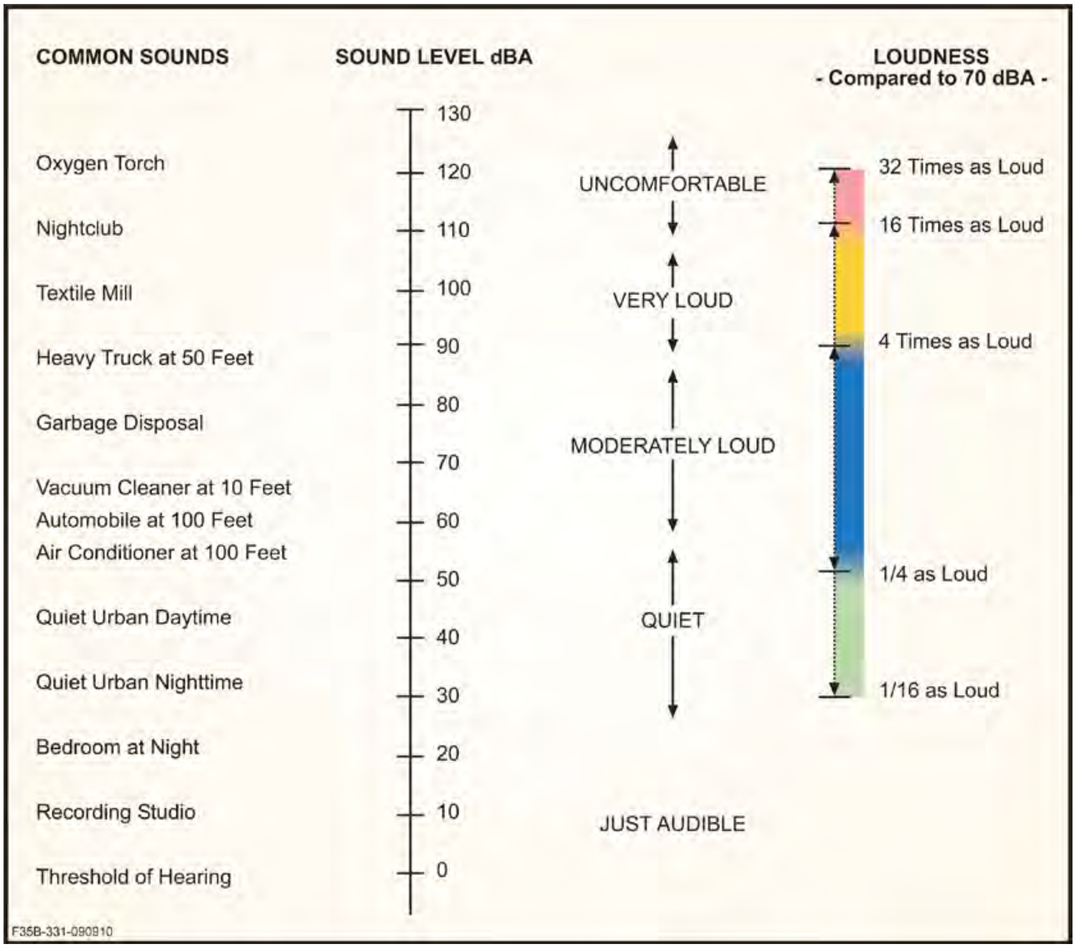
There has been continuing research on noise metrics and the importance of sound quality, sponsored by the U.S. Department of Defense (DoD) for military aircraft noise and by the Federal Aviation Administration (FAA) for civil aircraft noise. The metric L_{dnmr}, which is described later and accounts for the increased annoyance of rapid onset rate of sound, is a product of this long-term research.

The amplitude of A weighted sound levels is measured in dB. It is common for some noise analysts to denote the unit of A-weighted sounds by dBA. As long as the use of A-weighting is understood, there is no difference between dB or dBA: it is only important that the use of A-weighting be made clear. In this environmental analysis, A-weighted sound levels are reported as dB.

A-weighting is appropriate for continuous sounds, which are perceived by the ear. Impulsive sounds, such as sonic booms, are perceived by more than just the ear. When experienced indoors, there can be secondary noise from rattling of the building. Vibrations may also be felt. C-weighting (ANSI 1988) is applied to such sounds. This is a frequency weighting that is relatively flat over the range of human hearing (about 20 Hz to 20,000 Hz) that rolls off above 5,000 Hz and below 50 Hz. In this study, C-weighted sound levels are used for the assessment of sonic booms and other impulsive sounds. As with A-weighting, the unit is dB, but dBC is sometimes used for clarity. In this study, sound levels are reported in both A-weighting and C-weighting dBs, and C-weighted metrics are denoted when used.

Time Averaging. Sound pressure of a continuous sound varies greatly with 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 display of a sound level meter) are based on averages of sound energy over either 1/8 second (fast) or 1 second (slow). The formal definitions of fast and slow levels are somewhat complex, with details that are important to the makers and users of instrumentation. They may, however, be thought of as levels corresponding to the root mean-square sound pressure measured over the 1/8-second or 1-second periods.

The most common uses of the fast or slow sound level in environmental analysis is in the discussion of the maximum sound level that occurs from the action, and in discussions of typical sound levels. Figure E-1 is a chart of A-weighted sound levels from typical sounds. Some (air conditioner, vacuum cleaner) are continuous sounds whose levels are constant for some time. Some (automobile, heavy truck) are the maximum sound during a vehicle passby. Some (urban daytime, urban nighttime) are averages over some extended period. A variety of noise metrics have been developed to describe noise over different time periods. These are described in Section E.1.2.



Source: Derived from the *Handbook of Noise Control*, Harris 1979, FICAN 1997.

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

E.1.2 Noise Metrics

E.1.2.1 Maximum Sound Level

The highest A-weighted sound level measured during a single event in which the sound level changes value as time goes on (e.g., an aircraft overflight) is called the maximum A-weighted sound level or maximum sound level, for short. It is usually abbreviated by ALM, L_{max}, or L_{max}. The maximum sound level is important in judging the interference caused by a noise event with conversation, TV or radio listening, sleeping, or other common activities. Table E-1 reflects L_{max} values for typical aircraft associated with this assessment operating at the indicated flight profiles and power settings. Noise levels presented in Table E-1 reflect noise propagation through standard atmospheric conditions (70 degrees Fahrenheit and 59 percent relative humidity). Atmospheric conditions affect transmission loss, the degree to which noise attenuates over distance (e.g., through spreading of noise energy and absorption by air molecules. Noise levels may also vary from the numbers shown in Table E-1 due to location-specific variables such as refraction of sound waves as they travel through different air masses and reflection of sound waves off solid objects. Tactical ground vehicles are another source of military training noise. Table E-2 shows L_{max} level associated with operation tactical ground vehicles.

Table E-1. Representative Maximum Sound Levels (L_{max}) Associated With Aircraft Overflights

Aircraft (engine type)	Power Setting	Power Unit	Lmax Values (in dBA) At Varying Distances (In Feet)				
			500	1,000	2,000	5,000	10,000
Takeoff/Departure Operations (at 300 knots airspeed)							
A-10A	6200	NF	99.9	91.7	82.2	68.2	57.8
B-1	97.5%	RPM	126.5	118.3	109.9	98.3	88.7
F-15 (P220)	90%	NC	111.4	104.3	96.6	85	74.7
F-16 (P229)	93%	NC	113.7	106.2	98.1	86.1	75.7
F-22	100%	ETR	119.7	112.4	104.6	93	82.9
Landing/Arrival Operations (at 160 knots airspeed)							
A-10A	5225	NF	97	88.9	78.8	60.2	46.4
B-1	90%	RPM	98.8	91.9	84.5	72.8	62
F-15 (P220)	75%	NC	88.5	81.6	74.3	63.2	53.4
F-16 (P229)	83.5%	NC	92.6	85.5	77.8	66.1	55.6
F-22	43%	ETR	111.3	103.9	95.9	83.9	73.1

Key: Engine Unit of Power: RPM=Revolutions Per Minute; ETR=Engine Thrust Ratio; NC=Engine Core RPM; and NF=Engine Fan RPM.
Source: SELCalc2 (Flyover Noise Calculator), Using NoiseMap 6/7 and Maximum Omega10 Result as the defaults.

Table E-2. Representative Maximum Sound Levels (L_{max}) Associated With Tactical Ground Vehicles

Type	Distance (feet)	Speed (mph)	Noise Level (dB)
Stationary Stryker	20	0	78
Moving Stryker	60	50	85
Bradley Fighting Vehicle	98	20	80

Key: dB=Decibel; mph=Miles Per Hour.
Source: USARAK 2004.

E.1.2.2 Sound Exposure Level

Individual time-varying noise events have two main characteristics: a sound level that changes throughout the event and a period of time during which the event is heard. Although the maximum sound level reached during the event provides some measure of the intrusiveness of the event, it alone does not completely describe the total event. The period of time during which the sound is heard is also significant. The sound exposure level (abbreviated SEL or L_{AE} for A-weighted sounds) combines both of these characteristics into a single metric.

SEL is a composite metric that represents both the intensity of a sound and its duration. Mathematically, the mean square sound pressure is computed over the duration of the event, then multiplied by the duration in seconds, and the resultant product is turned into a sound level. It does not directly represent the sound level heard at any given time, but rather provides a measure of the net impact of the entire acoustic event. It has been well established in the scientific community that SEL measures this impact much more reliably than just the maximum sound level. Table E-3 shows SEL values corresponding to the aircraft and power settings reflected in Table E-1.

Because the SEL and the maximum sound level are both used to describe single events, there is sometimes confusion between the two, so the specific metric used should be clearly stated.

SEL can be computed for C-weighted levels (appropriate for impulsive sounds), and the results denoted CSEL or L_{CE}. SEL for A-weighted sound is sometimes denoted ASEL. Within this study, SEL is used for A weighted sounds and CSEL for C-weighted.

Table E-3. Representative Sound Exposure Levels (SEL)

Aircraft (engine type)	Power Setting	Power Unit	SEL Values (in dBA) At Varying Distances (In Feet)				
			500	1,000	2,000	5,000	10,000
Takeoff/Departure Operations (at 300 knots airspeed)							
A-10A	6200	NF	102.6	96.2	88.5	76.9	68.3
B-1	97.5%	RPM	129.5	123.1	116.5	107.3	99.3
F-15 (P220)	90%	NC	117.3	112	106.1	97	88.4
F-16 (P229)	93%	NC	116.5	110.8	104.6	95	86.3
F-22	100%	ETR	124.2	118.7	112.7	103.5	95.2
Landing/Arrival Operations (at 160 knots airspeed)							
A-10A	5225	NF	97.9	91.5	83.3	67	55
B-1	90%	RPM	103.4	98.3	92.7	83.4	74.4
F-15 (P220)	75%	NC	94.2	89.2	83.6	74.9	66.9
F-16 (P229)	83.5%	NC	97.4	92.1	86.3	76.9	68.2
F-22	43%	ETR	114.9	109.3	103.1	93.5	84.5

Key: Engine Unit of Power: RPM=Revolutions Per Minute; ETR=Engine Thrust Ratio; NC=Engine Core RPM; and NF=Engine Fan RPM.

Source: SELCalc2 (Flyover Noise Calculator), Using NoiseMap 6/7 and Maximum Omega10 Result as the defaults.

E.1.2.3 Equivalent Sound Level

For longer periods of time, total sound is represented by the equivalent continuous sound pressure 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, with L_{eq} being SEL over some time period normalized by that time.

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. Also, while L_{eq} is defined as an average, it is effectively a sum over that time period and is, thus, a measure of the cumulative impact of noise.

E.1.2.4 Day–Night Average Sound Level

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 pm and before 7 am. If L_{eq} is computed over a 24-hour period with this nighttime penalty applied, the result is the DNL. DNL is the community noise metric recommended by the U.S. Environmental Protection Agency (EPA) (EPA 1974) and has been adopted by most Federal agencies (FICON 1992). It has been well established that DNL correlates well with long-term community response to noise (Schultz 1978, Finegold et al. 1994). This correlation is presented in Section E.1.3 of this appendix.

DNL accounts for the total, or cumulative, noise impact at a given location, and for this reason is often referred to as a "cumulative" metric. It was noted earlier that, for impulsive sounds, such as sonic booms, C-weighting is more appropriate than A weighting. DNL computed with C-weighting is denoted CDNL or L_{Cdn}. This procedure has been standardized, and impact interpretive criteria similar to those for DNL have been developed (CHABA 1981).

E.1.2.5 Onset-Adjusted Monthly Day–Night Average Sound Level

Aircraft operations in military training airspace 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, in which 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 rather 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. The DNL is then determined in the same manner as for conventional aircraft noise events and is designated as onset rate–adjusted day-night average sound level (abbreviated L_{dnmr}).

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. The monthly average is denoted L_{dnmr}. Noise levels are calculated the same way for both DNL and L_{dnmr}. L_{dnmr} is interpreted by the same criteria as used for DNL.

E.1.2.6 Peak Noise Level

The peak noise level metric characterizes the strength of impulsive noise such as sonic boom peak overpressure or munitions detonations. Peak noise level can be expressed in pounds per square foot (psf) or in decibel version (dB L_{pk}). The units psf are most often used when relating boom amplitude to human or animal response, although the direct physical pressure, as reflected by the unit (dB L_{pk}) is most commonly used when assessing effects on structures. Peak noise levels are strongly affected by meteorological conditions such as humidity and temperature which vary over time. To account for the variability in peak noise levels due to meteorological effects, peak noise levels are generally specified as the level not exceeded for a certain percentage of the time. As an example, noise generated by detonation of a certain munitions type may exceed 115 dBP at a certain location only in the 15 percent of days with the most unfavorable meteorological conditions. The metric used to describe the peak noise level exceeding only 15 percent of the time is PK 15(met). Peak noise levels associated with several munitions noise events are provided in Table E-4 using the metric PK 15(met).

Table E-4. Peak Noise Level Associated With Munitions Noise Events

Munitions Type	Noise Level (in dB PK 15(met) at Lateral Distance From Firing Point (in miles)		
	1 mile	5 miles	10 miles
12-guage shotgun	80.0	59.0	51.0
30-06 rifle	86.0	64.5	56.0
60 mm mortar (inert round)	97.5	73.5	67.0
81 mm mortar (inert round)	99.0	75.0	68.5
120 mm mortar (inert round)	105.0	81.0	74.5
105 mm howitzer (inert round)	104.5	80.5	74.0
155 mm howitzer (inert round)	111.0	87.5	80.5
Mk-83/GBU-32 1,000 pound class bomb (high explosive)	144.0	120.0	113.5
Mk-81/SDB 250-pound class bomb (high explosive)	139.5	115.5	98.0

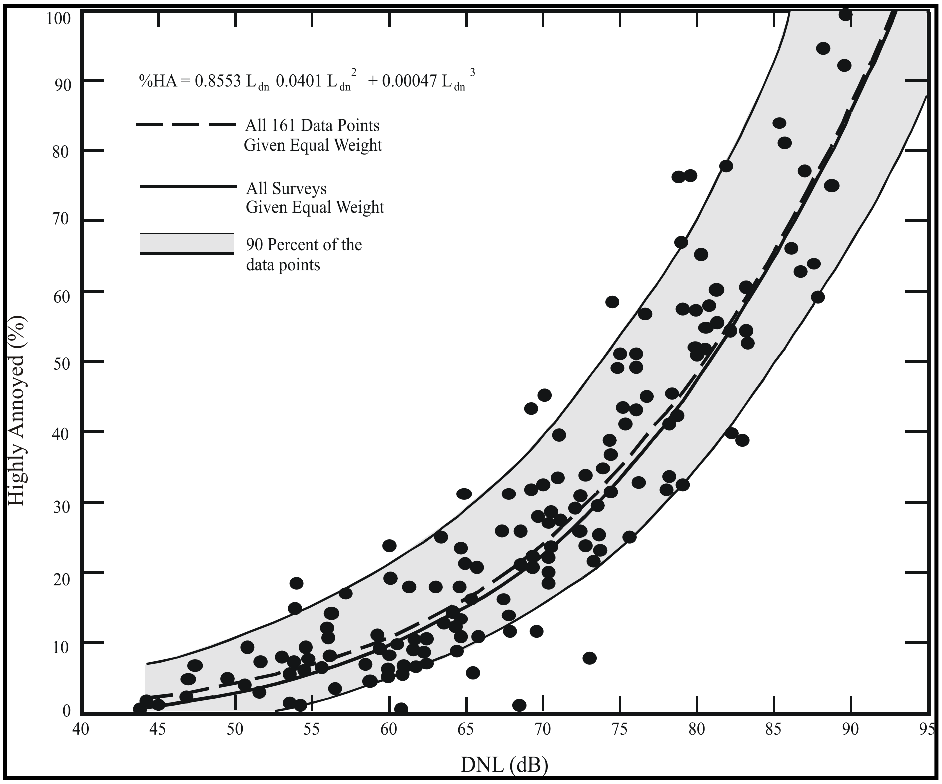
Note: Peak noise level estimates for shotgun and rifle calculated using Small Arms Range Noise Assessment Model version 2.6.2003-06-06; Peak noise levels associated with all other weapons calculated using BNOISE2 version 1.3.2003-07-03; noise levels rounded to the nearest 0.5 dB

E.1.3 Noise Impact

E.1.3.1 Community Reaction

Studies of long-term community annoyance to numerous types of environmental noise show that DNL correlates well with the annoyance. Schultz (1978) showed a consistent relationship between DNL and annoyance. Shultz's original curve fit (Figure E-2) shows that there is a remarkable consistency in results of attitudinal surveys which relate the percentages of groups of people who express various degrees of annoyance when exposed to different DNL.

Another study reaffirmed this relationship (Fidell et al. 1989). Figure E-3 shows an updated form of the curve fit (Finegold et al. 1994) in comparison with the original. The updated fit, which does not differ substantially from the original, is the current preferred form. 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. For example, individuals with autism are often very strongly affected by sudden noises (Tang et al. 2002). Persons with autism often report experiencing oversensitivity to noise and are often particularly sensitive to high-pitched or sudden onset noises (Grandin 1991). Nevertheless, findings substantiate that community annoyance to aircraft noise is represented quite reliably using DNL.



Source: Schultz 1978.

Figure E-2. Community Surveys of Noise Annoyance

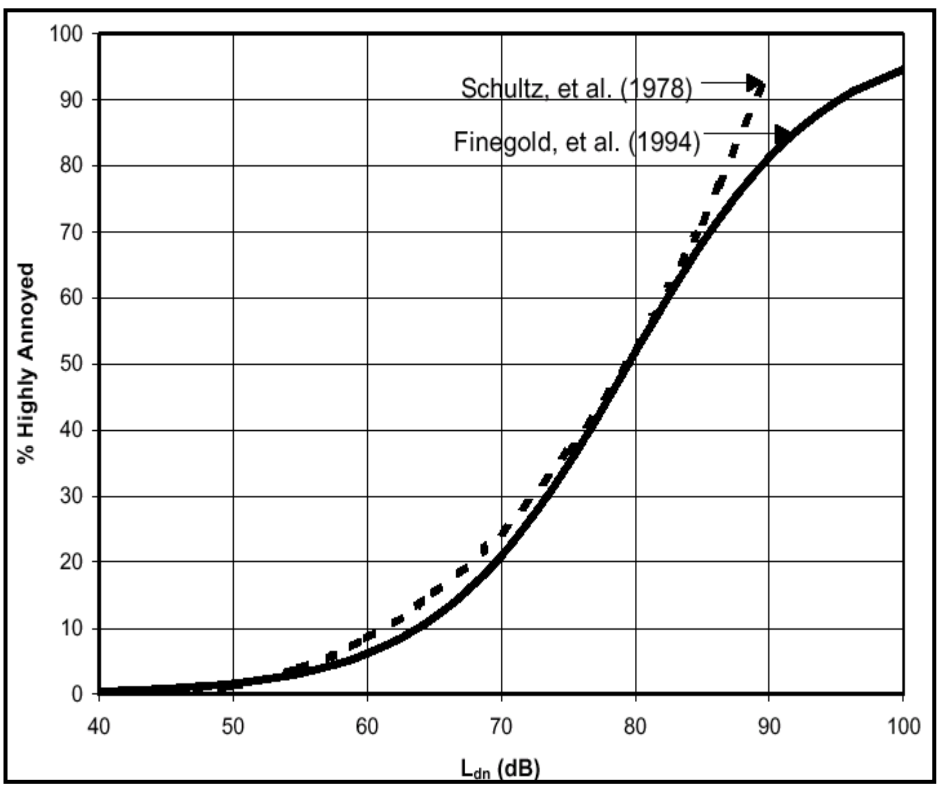


Figure E-3. Response of Communities to Noise; Comparison of Original (Schultz 1978) and Current (Finegold et al. 1994) Curve Fits

As noted earlier for SEL, DNL does not represent the sound level heard at any particular time, but rather represents the total 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 (ANSI 1980, 1988, 2005; EPA 1974; FICON 1992; FICUN 1980).

While DNL is the best metric for quantitatively assessing cumulative noise impact, it does not lend itself to intuitive interpretation by non-experts. Accordingly, it is common for environmental noise analyses to include other metrics for illustrative purposes. A general indication of the noise environment can be presented by noting the maximum sound levels which can occur and the number of times per day noise events will be loud enough to be heard. Use of other metrics as supplements to DNL has been endorsed by Federal agencies (FICON 1992).

The Schultz curve is generally applied to annual average DNL. In Section E.1.2, L_{dnmr} was described and presented as being appropriate for quantifying noise in military airspace. The Schultz curve is used with L_{dnmr} as the noise metric. L_{dnmr} is always equal to or greater than DNL, so impact is generally higher than would have been predicted if the onset rate and busiest-month adjustments were not accounted for.

There are several points of interest in the noise-annoyance relation. 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 do cause noise. Areas exposed to DNL above 65 dB are generally not considered suitable for residential use. The second is DNL of 55 dB, which was identified by EPA as a level "...requisite to protect the public health and welfare with an adequate margin of safety," (EPA 1974) which is essentially a level below which adverse impact is not expected. The third is DNL of 75 dB. This is the lowest level at which adverse health effects could be credible (EPA 1974). The very high annoyance levels correlated with DNL of 75 dB make such areas unsuitable for residential land use.

Sonic boom exposure is measured by C-weighting, with the corresponding cumulative metric being CDNL. Correlation between CDNL and annoyance has been established, based on community reaction to impulsive sounds (CHABA 1981). Values of the C weighted equivalent to the Schultz curve are different than that of the Schultz curve itself. Table E-5 shows the relation between annoyance, DNL, and CDNL.

Table E-5. Relation Between Annoyance, DNL and CDNL

DNL	% Highly Annoyed	CDNL
45	0.83	42
50	1.66	46
55	3.31	51
60	6.48	56
65	12.29	60
70	22.10	65

Key: CDNL = C-weighted day-night average sound level; DNL = day-night average sound level.

Interpretation of CDNL from impulsive noise is accomplished by using the CDNL versus annoyance values in Table E-5. CDNL can be interpreted in terms of an "equivalent annoyance" DNL. For example, CDNL of 52, 61, and 69 dB are equivalent to DNL of 55, 65, and 75 dB, respectively. If both continuous and impulsive noise occurs in the same area, impacts are assessed separately for each.

E.1.3.2 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, as outlined in Section E.1.3.1.

In June 1980, an ad hoc Federal Interagency Committee on Urban Noise published guidelines (FICUN 1980) relating DNL to compatible land uses. This committee was composed of representatives from DoD, Transportation, and Housing and Urban Development; EPA; and the Veterans Administration. Since the issuance of these guidelines, Federal agencies have generally adopted these guidelines for their noise analyses.

Following the lead of the committee, DoD and FAA adopted the concept of land-use compatibility as the accepted measure of aircraft noise effect. The FAA included the committee's guidelines in the Federal Aviation Regulations (DOT 1984). These guidelines are reprinted in Table E-6, along with the explanatory notes included in the regulation. Although these guidelines are not mandatory (note the footnote "*" in the table), they provide the best means for determining noise impact in airport communities. In general, residential land uses normally are not compatible with outdoor DNL values above 65 dB, and the extent of land areas and populations exposed to DNL of 65 dB and higher provides the best means for assessing the noise impacts of alternative aircraft actions. In some cases a change in noise level, rather than an absolute threshold, may be a more appropriate measure of impact.

Table E-6. Land Use Compatibility, Noise Exposure, and Accident Potential

Land Use		Accident Potential Zones			Noise Zones			
SLUCM No.	**Name**	**Clear Zone**	**APZ I**	**APZ II**	**65-69 dB**	**70-74 dB**	**75-79 dB**	**80+ dB**
10	**Residential**							
11	Household units							
11.11	Single units; detached	N	N	Y[1]	A[11]	B[11]	N	N
11.12	Single units; semidetached	N	N	N	A[11]	B[11]	N	N
11.13	Singe units; attached row	N	N	N	A[11]	B[11]	N	N
11.21	Two units; side-by-side	N	N	N	A[11]	B[11]	N	N
11.22	Two units; one above the other	N	N	N	A[11]	B[11]	N	N
11.31	Apartments; walk up	N	N	N	A[11]	B[11]	N	N
11.32	Apartments; elevator	N	N	N	A[11]	B[11]	N	N
12	Group quarters	N	N	N	A[11]	B[11]	N	N
13	Residential hotels	N	N	N	A[11]	B[11]	N	N
14	Mobile home parks or courts	N	N	N	N	N	N	N
15	Transient lodgings	N	N	N	A[11]	B[11]	C[11]	N
16	Other residential	N	N	N[1]	A[11]	B[11]	N	N
20	**Manufacturing**							
21	Food and kindred products; manufacturing	N	N[2]	Y	Y	Y[12]	Y[13]	Y[14]
22	Textile mill products; manufacturing	N	N[2]	Y	Y	Y[12]	Y[13]	Y[14]
23	Apparel and other finished products made from fabrics, leather, and similar materials; manufacturing	N	N	N[2]	Y	Y[12]	Y[13]	Y[14]
24	Lumber and wood products (except furniture); manufacturing	N	Y[2]	Y	Y	Y[12]	Y[13]	Y[14]
25	Furniture and fixtures; manufacturing	N	Y[2]	Y	Y	Y[12]	Y[13]	Y[14]
26	Paper and allied products; manufacturing	N	Y[2]	Y	Y	Y[12]	Y[13]	Y[14]
27	Printing, publishing, and allied industries	N	Y[2]	Y	Y	Y[12]	Y[13]	Y[14]
28	Chemicals and allied products; manufacturing	N	N	N[2]	Y	Y[12]	Y[13]	Y[14]

Table E-6. Land Use Compatibility, Noise Exposure, and Accident Potential *(continued)*

Land Use		Accident Potential Zones			Noise Zones			
SLUCM No.	**Name**	**Clear Zone**	**APZ I**	**APZ II**	**65-69 dB**	**70-74 dB**	**75-79 dB**	**80+ dB**
29	Petroleum refining and related industries	N	N	N	Y	Y[12]	Y[13]	Y[14]
30	**Manufacturing**							
31	Rubber and misc. plastic products, manufacturing	N	N[2]	N[2]	Y	Y[12]	Y[13]	Y[14]
32	Stone, clay and glass products; manufacturing	N	N[2]	Y	Y	Y[12]	Y[13]	Y[14]
33	Primary metal industries	N	N[2]	Y	Y	Y[12]	Y[13]	Y[14]
34	Fabricated metal products; manufacturing	N	N[2]	Y	Y	Y[12]	Y[13]	Y[14]
35	Professional, scientific, and controlling instruments; photographic and optical goods; watches and clocks; manufacturing	N	N	N[2]	Y	A	B	N
39	Miscellaneous manufacturing	N	Y[2]	Y[2]	Y	Y[12]	Y[13]	Y[14]
40	**Transportation, communications, and utilities**							
41	Railroad, rapid rail transit, and street railroad transportation	N[3]	Y[4]	Y	Y	Y[12]	Y[13]	Y[14]
42	Motor vehicle transportation	N[3]	Y	Y	Y	Y[12]	Y[13]	Y[14]
43	Aircraft transportation	N[3]	Y[4]	Y	Y	Y[12]	Y[13]	Y[14]
44	Marine craft transportation	N[3]	Y[4]	Y	Y	Y[12]	Y[13]	Y[14]
45	Highway and street right-of-way	N[3]	Y	Y	Y	Y[12]	Y[13]	Y[14]
46	Automobile parking	N[3]	Y[4]	Y	Y	Y[12]	Y[13]	Y[14]
47	Communications	N[3]	Y[4]	Y	Y	A[15]	B[15]	N
48	Utilities	N[3]	Y[4]	Y	Y	Y	Y[12]	Y[13]
49	Other transportation communications and utilities	N[3]	Y[4]	Y	Y	A[15]	B[15]	N
50	**Trade**							
51	Wholesale trade	N	Y[2]	Y	Y	Y[12]	Y[13]	Y[14]
52	Retail trade-building materials, hardware and farm equipment	N	Y[2]	Y	Y	Y[12]	Y[13]	Y[14]
53	Retail trade-general merchandise	N[2]	N[2]	Y[2]	Y	A	B	N
54	Retail trade-food	N[2]	N[2]	Y[2]	Y	A	B	N
55	Retail trade-automotive, marine craft, aircraft and accessories	N[2]	N[2]	Y[2]	Y	A	B	N
56	Retail trade-apparel and accessories	N[2]	N[2]	Y[2]	Y	A	B	N
57	Retail trade-furniture, home furnishings and equipment	N[2]	N[2]	Y[2]	Y	A	B	N
58	Retail trade-eating and drinking establishments	N	N	N[2]	Y	A	B	N
59	Other retail trade	N	N[2]	Y[2]	Y	A	B	N
60	**Services**							
61	Finance, insurance, and real estate services	N	N	Y[6]	Y	A	B	N
62	Personal services	N	N	Y[6]	Y	A	B	N
62.4	Cemeteries	N	Y[7]	Y[7]	Y	Y[12]	Y[13]	Y[14,2,1]
63	Business services	N	Y[8]	Y[8]	Y	A	B	N
64	Repair services	N	Y[2]	Y	Y	Y[12]	Y[13]	Y[14]
65	Professional services	N	N	Y[6]	Y	A	B	N
65.1	Hospitals, nursing homes	N	N	N	A*	B*	N	N
65.1	Other medical facilities	N	N	N	Y	A	B	N
66	Contract construction services	N	Y[6]	Y	Y	A	B	N

Table E-6. Land Use Compatibility, Noise Exposure, and Accident Potential *(continued)*

Land Use		Accident Potential Zones			Noise Zones			
SLUCM No.	**Name**	**Clear Zone**	**APZ I**	**APZ II**	**65-69 dB**	**70-74 dB**	**75-79 dB**	**80+ dB**
67	Governmental services	N[6]	N	Y[6]	Y*	A*	B*	N
68	Educational services	N	N	N	A*	B*	N	N
69	Miscellaneous services	N	N[2]	Y[2]	Y	A	B	N
70	**Cultural, entertainment and recreational**							
71	Cultural activities (including churches)	N	N	N[2]	A*	B*	N	N
71.2	Nature exhibits	N	Y[2]	Y	Y*	N	N	N
72	Public assembly	N	N	N	Y	N	N	N
72.1	Auditoriums, concert halls	N	N	N	A	B	N	N
72.11	Outdoor music shell, amphitheatres	N	N	N	N	N	N	N
72.2	Outdoor sports arenas, spectator sports	N	N	N	Y[17]	Y[17]	N	N
73	Amusements	N	N	Y[8]	Y	Y	N	N
74	Recreational activities (including golf courses, riding stables, water recreation)	N Y	Y[8,9,10]	Y	Y*	A*	B*	N
75	Resorts and group camps	N	N	N	Y*	Y*	N	N
76	Parks	N	Y[8]	Y[8]	Y*	Y*	N	N
79	Other cultural, entertainment, and recreation	N[9]	Y[9]	Y[9]	Y*	Y*	N	N
80	**Resources production and extraction**							
81	Agriculture (except livestock)	Y[16]	Y	Y	Y[18]	Y[19]	Y[20]	Y[20,21]
81.5 to 81.7	Livestock farming and animal breeding	N	Y	Y	Y[18]	Y[19]	Y[20]	Y[20,21]
82	Agricultural related activities	N	Y[5]	Y	Y[18]	Y[19]	N	N
83	Forestry activities and related services	N[5]	Y	Y	Y[18]	Y[19]	Y[20]	Y[20,21]
84	Fishing activities and related services	N[5]	Y[5]	Y	Y	Y	Y	Y
85	Mining activities and related services	N	Y[5]	Y	Y	Y	Y	Y
89	Other resources production and extraction	N	Y[5]	Y	Y	Y	Y	Y

1 Suggested maximum density of 1-2 dwelling units per acre possibly increased under a Planned Unit Development where maximum lot coverage is less than 20 percent.

2 Within each land use category, uses exist where further definition may be needed due to the variation of densities in people and structures. Shopping malls and shopping centers are considered incompatible in any APZ.

3 The placing of structures, buildings, or above ground utility lines in the clear zone is subject to severe restrictions. In a majority of the clear zones, these items are prohibited. See AFI 32-7063 and AFI 32-1026 for specific guidance.

4 No passenger terminals and no major above ground transmission lines in APZ I.

5 Factors to be considered: labor intensity, structural coverage, explosive characteristics, and air pollution.

6 Low-intensity office uses only. Meeting places, auditoriums, etc., are not recommended.

7 Excludes chapels.

8 Facilities must be low intensity.

9 Clubhouse not recommended.

10 Areas for gatherings of people are not recommended.

11a Although local conditions may require residential use, it is discouraged in DNL 65-69 dB and strongly discouraged in DNL 70-74 dB. An evaluation should be conducted prior to approvals, indicating that a demonstrated community need for residential use would not be met if development were prohibited in these zones, and that there are no viable alternative locations.

11b Where the community determines the residential uses must be allowed, measures to achieve outdoor to indoor NLR for DNL 65-69 dB and DNL 70-74 dB should be incorporated into building codes and considered in individual approvals.

11c NLR criteria will not eliminate outdoor noise problems. However, building location and site planning, and design and use of berms and barriers can help mitigate outdoor exposure, particularly from near ground level sources. Measures that reduce outdoor noise should be used whenever practical in preference to measures which only protect interior spaces.

Table E-6. Land Use Compatibility, Noise Exposure, and Accident Potential *(continued)*

12 Measures to achieve the same NLR as required for facilities in the DNL 65-69 dB range 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.

13 Measures to achieve the same NLR as required for facilities in the DNL 70-74 dB range 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.

14 Measures to achieve the same NLR as required for facilities in the DNL 75-79 dB range 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.

15 If noise sensitive, use indicated NLR; if not, the use is compatible.

16 No buildings.

17 Land use is compatible provided special sound reinforcement systems are installed.

18 Residential buildings require the same NLR required for facilities in the DNL 65-69 dB range.

19 Residential buildings require the same NLR required for facilities in the DNL 70-74 dB range.

20 Residential buildings are not permitted.

21 Land use is not recommended. If the community decides the use is necessary, hearing protection devices should be worn by personnel.

Key: SLUCM = Standard Land Use Coding Manual, U.S. Department of Transportation; Y = Yes; land use and related structures are compatible without restriction; N = No; land use and related structures are not compatible and should be prohibited; A, B, or C = Land use and related structures generally compatible; measures to achieve Noise Level Reduction of A (25 db), B (30 db), or C (35 db) should be incorporated into the design and construction of structures; A*, B*, or C* = Land use generally compatible with Noise Level Reduction. However, measures to achieve an overall noise level reduction do not necessarily solve noise difficulties and additional evaluation is warranted. See appropriate footnotes; * = The designation of these uses as "compatible" in this zone reflects individual Federal agency and program consideration of general cost and feasibility factors, as well as past community experiences and program objectives. Localities, when evaluating the application of these guidelines to specific situations, may have different concerns or goals to consider.

E.2 NOISE EFFECTS

The discussion in Section E.1.3 presented the global effect of noise on communities. The following sections describe particular noise effects. These effects include non-auditory health effects, annoyance, speech interference, sleep disturbance, noise-induced hearing impairment, noise effects on animals and wildlife, effects on property values, noise effects on structures, terrain, and cultural resources.

E.2.1 Annoyance

The primary effect of aircraft noise on exposed communities is one of annoyance. Noise annoyance is defined by the EPA as any negative subjective reaction on the part of an individual or group (EPA 1974). As noted in the discussion of DNL above, community annoyance is best measured by that metric.

Because the EPA Levels Document (EPA 1974) identified DNL of 55 dB as ". . . requisite to protect public health and welfare with an adequate margin of safety," it is commonly assumed that 55 dB should be adopted as a criterion for community noise analysis. From a noise exposure perspective, that would be an ideal selection. However, financial resources are generally not available to achieve that goal. Most agencies have identified DNL of 65 dB as a criterion which protects those most impacted by noise, and which can often be achieved on a practical basis (FICON 1992). This corresponds to about 12 percent of the exposed population being highly annoyed.

Although DNL of 65 dB is widely used as a benchmark for significant noise impact, and is often an acceptable compromise, it is not a statutory limit, and it is appropriate to consider other thresholds in particular cases. Local ordinances and regulations have been adopted by many municipal governments to prevent civilian development near military installations that would be incompatible with noise generated by military operations. The decision to adopt such measures, and the specific content of the ordinances and regulations, is up to the municipal government. In many cases, the 65 DNL noise contour line is adopted as the threshold level above which land use restrictions are invoked.

Community annoyance from sonic booms is based on CDNL, as discussed in Section E.1.3. These effects are implicitly included in the "equivalent annoyance" CDNL values in Table E-5, since those were developed from actual community noise impact.

E.2.2 Speech Interference

Speech interference associated with aircraft noise is a primary cause of annoyance to individuals on the ground. The disruption of routine activities such as radio or television listening, telephone use, or family conversation gives rise to frustration and irritation. The quality of speech communication is also important in classrooms, offices, and industrial settings and can cause fatigue and vocal strain in those who attempt to communicate over the noise. Speech is an acoustic signal characterized by rapid fluctuations in sound level and frequency pattern. It is essential for optimum speech intelligibility to recognize these continually shifting sound patterns. Not only does noise diminish the ability to perceive the auditory signal, but it also reduces a listener's ability to follow the pattern of signal fluctuation. In general, interference with speech communication occurs when intrusive noise exceeds about 60 dB (FICON 1992).

Indoor speech interference can be expressed as a percentage of sentence intelligibility among two people speaking in relaxed conversation approximately 3 feet apart in a typical living room or bedroom (EPA 1974). The percentage of sentence intelligibility is a non-linear function of the (steady) indoor background A-weighted sound level. Such a curve-fit yields 100 percent sentence intelligibility for background levels below 57 dB and yields less than 10 percent intelligibility for background levels above 73 dB. The function is especially sensitive to changes in sound level between 65 dB and 75 dB. As an example of the sensitivity, a 1 dB increase in background sound level from 70 dB to 71 dB yields a 14 percent decrease in sentence intelligibility. The sensitivity of speech interference to noise at 65 dB and above is consistent with the criterion of DNL 65 dB generally taken from the Schultz curve. This is consistent with the observation that speech interference is the primary cause of annoyance.

Classroom Criteria. 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 (e.g., 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 May 2009, the American National Standards Institute (ANSI) published a classroom acoustics standard entitled "Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools" (ANSI 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 35–45 dBA relative to outdoor levels (ANSI 2009).

E.2.3 Sleep Disturbance

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

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

An analysis sponsored by the Air Force summarized 21 published studies concerning the effects of noise on sleep (Pearsons et al. 1989). The analysis concluded that a lack of reliable in-home studies, combined with large differences among the results from the various laboratory studies, did not permit development of an acceptably accurate assessment procedure. The noise events used in the laboratory studies and in contrived in-home studies were presented at much higher rates of occurrence than would normally be experienced. None of the laboratory studies were of sufficiently long duration to determine any effects of habituation, such as that which would occur under normal community conditions. An extensive study of sleep interference in people's own homes (Ollerhead et al. 1992) showed very little disturbance from aircraft noise.

There is some controversy associated with these studies, so a conservative approach should be taken in judging sleep interference. Based on older data, the EPA identified an indoor DNL of 45 dB as necessary to protect against sleep interference (EPA 1974). Assuming an outdoor-to-indoor noise level reduction of 20 dB for typical dwelling units, this corresponds to an outdoor DNL of 65 dB as minimizing sleep interference.

A 1984 publication reviewed the probability of arousal or behavioral awakening in terms of SEL (Kryter 1984). Figure E-4, extracted from Figure 10.37 of Kryter (1984), indicates that an indoor SEL of 65 dB or lower should awaken less than 5 percent of those exposed. These results do not include any habituation over time by sleeping subjects. Nevertheless, this provides a reasonable guideline for assessing sleep interference and corresponds to similar guidance for speech interference, as noted above.

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.

The interim Federal Interagency Committee on Noise (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).

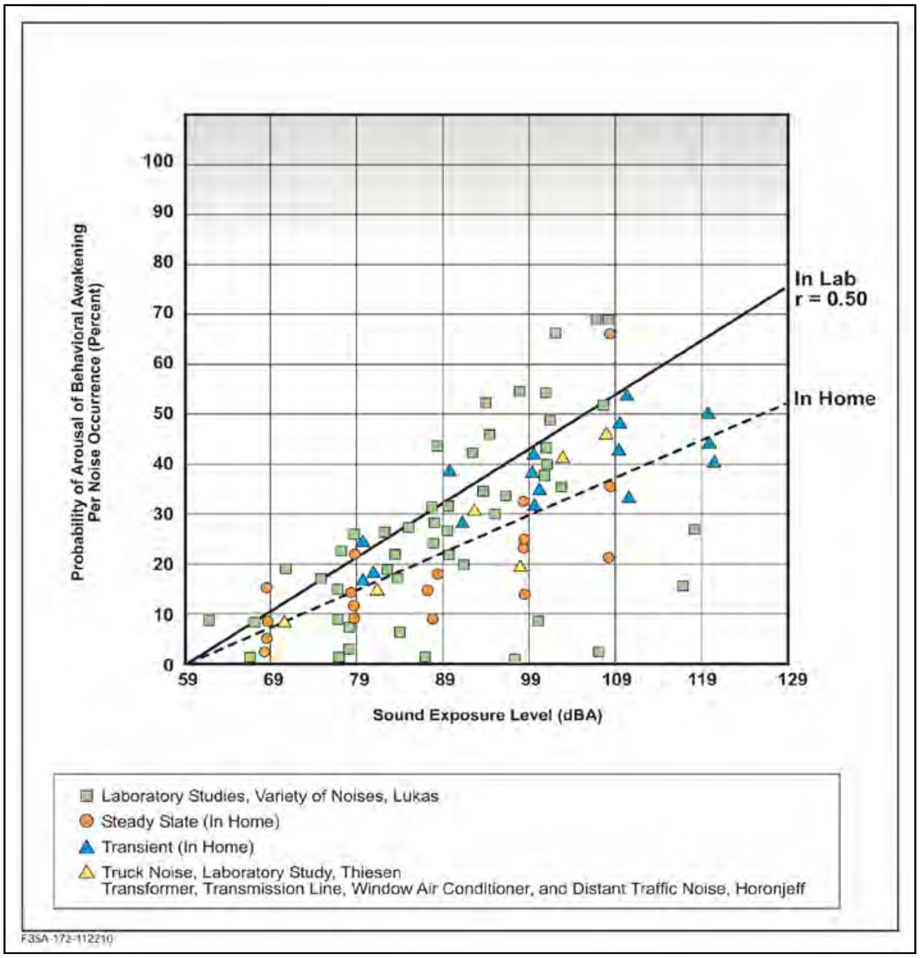


Figure E-4. Plot of Sleep Awakening Data versus Indoor SEL

Based on the new information, the Federal Interagency Committee on Aircraft Noise (FICAN) updated its recommended dose-response curve in 1997, depicted as the lower curve in Figure E-5. This figure is based on the results of three field studies (Ollerhead et al. 1992; Fidell et al. 1994; Fidell et al. 1995a and 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 SEL's of 73 and 83 dB respectively assuming 15 and 25 dB noise level reduction from outdoor to indoor with windows open and closed, respectively.

The FICAN 1997 curve is represented by the following equation:

Percent Awakenings = 0.0087 x [SEL – 30]1.79

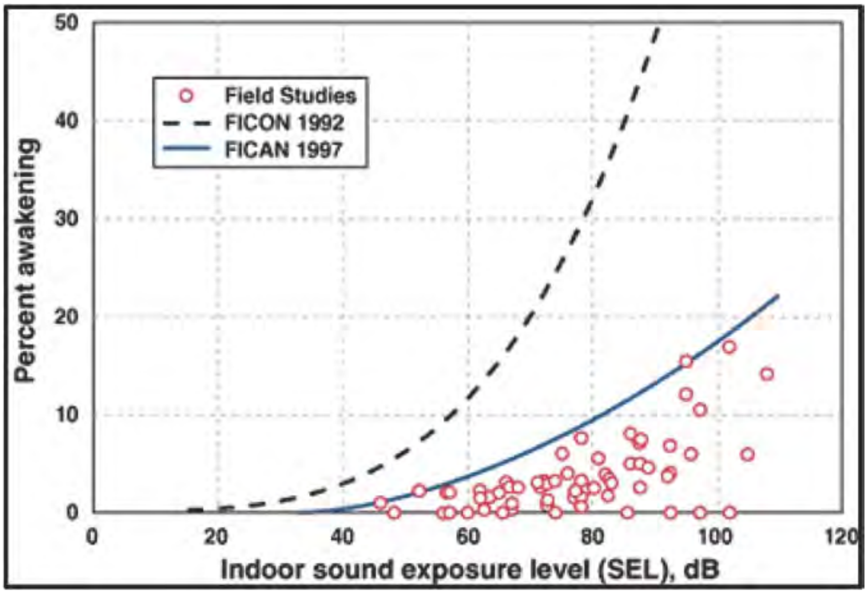


Figure E-5. FICAN's 1997 Recommended Sleep Disturbance Dose-Response Relationship

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 UK CAA 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.

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 E-6 depicts the awakenings data that form the basis and equations of ANSI (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 E-6 come from these studies. Unlike the FICAN curve, the ANSI 2008 curve represents the average of the field research data points.

In December 2008, FICAN recommended the use of this new estimation procedure for future analyses of behavioral awakenings from aircraft noise. 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 (2008).

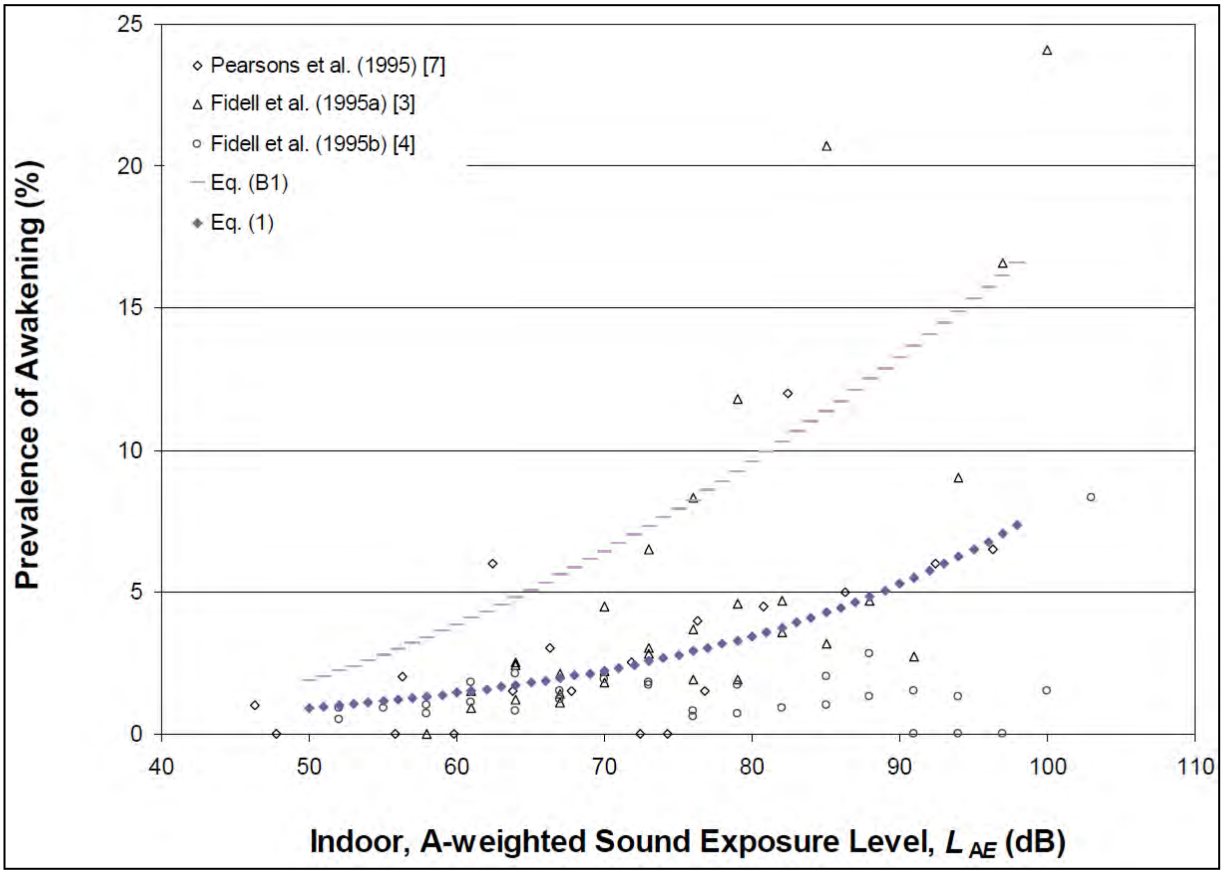


Figure E-6. Relation Between Indoor SEL and Percentage of Persons Awakened as Stated in ANSI/ASA S12.9-2008/Part 6

E.2.4 Noise-Induced Hearing Impairment

Residents in surrounding communities express concerns regarding the effects of aircraft noise on hearing. This section provides a brief overview of hearing loss caused by noise exposure. The goal is to provide a sense of perspective as to how aircraft noise (as experienced on the ground) compares to other activities that are often linked with hearing loss.

Hearing loss is generally interpreted as a decrease in the ear's sensitivity or acuity to perceive sound; i.e. a shift in the hearing threshold to a higher level. This change can either be a temporary threshold shift (TTS), or a permanent threshold shift (PTS) (Berger et al. 1995). TTS can result from exposure to loud noise over a given amount of time, yet the hearing loss is not necessarily permanent. An example of TTS might be a person attending a loud music concert. After the concert is over, the person may experience a threshold shift that may last several hours, depending upon the level and duration of exposure. While experiencing TTS, the person becomes less sensitive to low-level sounds, particularly at certain frequencies in the speech range (typically near 4,000 Hz). Normal hearing ability eventually returns, as long as the person has enough time to recover within a relatively quiet environment.

PTS usually results from repeated exposure to high noise levels, where the ears are not given adequate time to recover from the strain and fatigue of exposure. A common example of PTS is the result of working in a loud environment such as a factory. It is important to note that a temporary shift (TTS) can eventually become permanent (PTS) over time with continuous exposure to high noise levels. Thus, even if the ear is given time to recover from TTS, repeated occurrence of TTS may eventually lead to permanent hearing loss. The point at which a TTS results in a PTS is difficult to identify and varies with a person's sensitivity.

Considerable data on hearing loss have been collected and analyzed by the scientific/medical community. It has been well established that continuous exposure to high noise levels will damage human hearing (EPA 1978). The Occupational Safety and Health Administration (OSHA) regulation of 1971 standardizes the limits on workplace noise exposure for protection from hearing loss as an average level of 90 dB over an 8-hour work period or 85 dB over a 16-hour period (the average level is based on a 5 dB decrease per doubling of exposure time) (DOL 1971). Even the most protective criterion (no measurable hearing loss for the most sensitive portion of the population at the ear's most sensitive frequency, 4,000 Hz, after a 40-year exposure) is an average sound level of 70 dB over a 24-hour period.

The EPA established 75 dB for an 8-hour exposure and 70 dB for a 24-hour exposure as the average noise level standard requisite to protect 96 percent of the population from greater than a 5 dB PTS (EPA 1978). The National Academy of Sciences Committee on Hearing, Bioacoustics, and Biomechanics identified 75 dB as the minimum level at which hearing loss may occur (CHABA 1977). Finally, the World Health Organization (WHO) has concluded that environmental and leisure-time noise below an $L_{eq}24$ value of 70 dB "will not cause hearing loss in the large majority of the population, even after a lifetime of exposure" (WHO 2000).

E.2.4.1 Hearing Loss and Aircraft Noise

The 1982 EPA Guidelines report specifically addresses the criteria and procedures for assessing the noise-induced hearing loss in terms of the noise-induced permanent threshold shift (NIPTS), a quantity that defines the permanent change in hearing level, or threshold, caused by exposure to noise (EPA 1982). This effect is also described as potential hearing loss (PHL). Numerically, the NIPTS is the change in threshold averaged over the frequencies 0.5, 1, 2, and 4 kHz that can be expected from daily exposure to noise over a normal working lifetime of 40 years, with the exposure beginning at an age of 20 years. A grand average of the NIPTS over time (40 years) and hearing sensitivity (10 to 90 percentiles of the exposed population) is termed the Average NIPTS, or Ave NIPTS for short. The Ave NIPTS that can be expected for noise exposure as measured by the DNL metric is given in Table E-7.

For example, for a noise exposure of 80 dB DNL, the expected lifetime average value of NIPTS is 2.5 dB, or 6.0 dB for the 10th percentile. Characterizing the noise exposure in terms of DNL will usually overestimate the assessment of hearing loss risk as DNL includes a 10 dB weighting factor for aircraft operations occurring between 10 p.m. and 7 a.m. If, however, flight operations between the hours of 10 p.m. and 7 a.m. account for 5 percent or less of the total 24-hour operations, the overestimation is on the order of 1.5 dB.

Table E-7. Average NIPTS and 10th Percentile NIPTS as a Function of DNL

DNL	Ave. NIPTS dB*	10th Percentile NIPTS dB*
75–76	1.0	4.0
76–77	1.0	4.5
77–78	1.6	5.0
78–79	2.0	5.5

79–80	2.5	6.0
80–81	3.0	7.0
81–82	3.5	8.0
82–83	4.0	9.0
83–84	4.5	10.0
84–85	5.5	11.0
85–86	6.0	12.0
86–87	7.0	13.5
87–88	7.5	15.0
88–89	8.5	16.5
89–90	9.5	18.0

Note: *Rounded to the nearest 0.5 dB.

From a civilian airport perspective, the scientific community has concluded that there is little likelihood that the resulting noise exposure from aircraft noise could result in either a temporary or permanent hearing loss. Studies on community hearing loss from exposure to aircraft flyovers near airports showed that there is no danger, under normal circumstances, of hearing loss due to aircraft noise (Newman and Beattie 1985). The EPA criterion ($L_{eq}24$ = 70 dBA) can be exceeded in some areas located near airports, but that is only the case outdoors. Inside a building, where people are more likely to spend most of their time, the average noise level will be much less than 70 dBA (Eldred and von Gierke 1993). Eldred and von Gierke also report that "several studies in the U.S., Japan, and the U.K. have confirmed the predictions that the possibility for permanent hearing loss in communities, even under the most intense commercial take-off and landing patterns, is remote."

With regard to military airbases, as individual aircraft noise levels are increasing with the introduction of new aircraft, a 2009 DoD policy directive requires that hearing loss risk be estimated for the at risk population, defined as the population exposed to DNL greater than or equal to 80 dB and higher (DoD 2009). Specifically, DoD components are directed to "*use the 80 Day-Night A-Weighted (DNL) noise contour to identify populations at the most risk of potential hearing loss.*" This does not preclude populations outside the 80 DNL contour, i.e. at lower exposure levels, from being at some degree of risk of hearing loss. However, the analysis should be restricted to populations within this contour area, including residents of on-base housing. The exposure of workers inside the base boundary area should be considered occupational and evaluated using the appropriate DoD component regulations for occupational noise exposure.

With regard to military airspace activity, studies have shown conflicting results. A 1995 laboratory study measured changes in human hearing from noise representative of low-flying aircraft on Military Training Routes (MTRs) (Nixon et al. 1993). The potential effects of aircraft flying along MTRs is of particular concern because of maximum overflight noise levels can exceed 115 dB, with rapid increases in noise levels exceeding 30 dB per second. In this study, participants were first subjected to four overflight noise exposures at A-weighted levels of 115 dB to 130 dB. Fifty percent of the subjects showed no change in hearing levels, 25 percent had a temporary 5 dB *increase* in sensitivity (the people could hear a 5 dB wider range of sound than before exposure), and 25 percent had a temporary 5 dB decrease in sensitivity (the people could hear a 5 dB narrower range of sound than before exposure). In the next phase, participants were subjected to a single overflight at a maximum level of 130 dB for eight successive exposures, separated by 90 seconds or until a temporary shift in hearing was observed. The temporary hearing threshold shifts showed an increase in sensitivity of up to 10 dB.

In another study of 115 test subjects between 18 and 50 years old in 1999, temporary threshold shifts were measured after laboratory exposure to military low-altitude flight noise (Ising et al. 1999).

According to the authors, the results indicate that repeated exposure to military low-altitude flight noise with L_{max} greater than 114 dB, especially if the noise level increases rapidly, may have the potential to cause noise induced hearing loss in humans.

Aviation and typical community noise levels near airports are not comparable to the occupational or recreational noise exposures associated with hearing loss. Studies of aircraft noise levels associated with civilian airport activity have not definitively correlated permanent hearing impairment with aircraft activity. It is unlikely that airport neighbors will remain outside their homes 24 hours per day, so there is little likelihood of hearing loss below an average sound level of 75 dB DNL. Near military airbases, average noise levels above 75 dB may occur, and while new DoD policy dictates that NIPTS be evaluated, no research results to date have definitively related permanent hearing impairment to aviation noise.

E.2.5 Nonauditory Health Effects

Studies have been conducted to determine whether correlations exist between noise exposure and cardiovascular problems, birth weight, and mortality rates. The nonauditory effect of noise on humans is not as easily substantiated as the effect on hearing. Prolonged stress is known to be a contributor to a number of health disorders. Kryter and Poza (1980) state, "It is more likely that noise-related general ill-health effects are due to the psychological annoyance from the noise interfering with normal everyday behavior, than it is from the noise eliciting, because of its intensity, reflexive response in the autonomic or other physiological systems of the body." Psychological stresses may cause a physiological stress reaction that could result in impaired health. The National Institute for Occupational Safety and Health (NIOSH) and EPA commissioned the Committee on Hearing, Bioacoustics and Biomechanics (CHABA) in 1981 to study whether established noise standards are adequate to protect against health disorders other than hearing defects. CHABA's conclusion was that:

> Evidence from available research reports is suggestive, but it does not provide definitive answers to the question of health effects, other than to the auditory system, of long-term exposure to noise. It seems prudent, therefore, in the absence of adequate knowledge as to whether or not noise can produce effects upon health other than damage to auditory system, either directly or mediated through stress, that insofar as feasible, an attempt should be made to obtain more critical evidence.

Since the CHABA report, there have been further studies that suggest that noise exposure may cause hypertension and other stress-related effects in adults. Near an airport in Stockholm, Sweden, the prevalence of hypertension was reportedly greater among nearby residents who were exposed to energy averaged noise levels exceeding 55 dB and maximum noise levels exceeding 72 dB, particularly older subjects and those not reporting impaired hearing ability (Rosenlund et al. 2001). A study of elderly volunteers who were exposed to simulated military low-altitude flight noise reported that blood pressure was raised by L_{max} of 112 dB and high speed level increase (Michalak et al. 1990). Yet another study of subjects exposed to varying levels of military aircraft or road noise found no significant relationship between noise level and blood pressure (Pulles et al. 1990).

Most studies of nonauditory health effects of long-term noise exposure have found that noise exposure levels established for hearing protection will also protect against any potential nonauditory health effects, at least in workplace conditions. One of the best scientific summaries of these findings is contained in the lead paper at the National Institutes of Health Conference on Noise and Hearing Loss, held on 22 to 24 January 1990 in Washington, D.C.:

> The nonauditory 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 8-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, one comes to the conclusion that establishing and enforcing exposure levels protecting against noise-induced hearing loss would not only solve the noise-induced hearing loss problem, but also any potential nonauditory health effects in the work place" (von Gierke 1990).

Although these findings were specifically directed at noise effects in the workplace, they are equally applicable to aircraft noise effects in the community environment. Research studies regarding the nonauditory 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.

For example, two University of California, Los Angeles (UCLA) researchers apparently found a relationship between aircraft noise levels under the approach path to Los Angeles International Airport and increased mortality rates among the exposed residents by using an average noise exposure level greater than 75 dB for the "noise-exposed" population (Meacham and Shaw 1979). Nevertheless, three other UCLA professors analyzed those same data and found no relationship between noise exposure and mortality rates (Frerichs et al. 1980).

As a second example, two other UCLA researchers used this same population near LAX to show a higher rate of birth defects for 1970 to 1972 when compared with a control group residing away from the airport (Jones and Tauscher 1978). Based on this report, a separate group at the Center for Disease Control performed a more thorough study of populations near Atlanta's Hartsfield International Airport for 1970 to 1972 and found no relationship in their study of 17 identified categories of birth defects to aircraft noise levels above 65 dB (Edmonds et al. 1979).

In summary, there is no scientific basis for a claim that potential health effects exist for aircraft time average sound levels below 75 dB. 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 increase in cardiovascular disease (Schwarze and Thompson 1993). Additional claims that are unsupported include flyover noise producing increased mortality rates and increases in cardiovascular death, aggravation of post-traumatic stress syndrome, increased stress, increases in admissions to mental hospitals, and adverse affects on pregnant women and the unborn fetus (Harris 1997).

E.2.6 Performance Effects

The effect of noise on the performance of activities or tasks has been the subject of many studies. Some of these studies have established links between continuous high noise levels and performance loss. Noise-induced performance losses are most frequently reported in studies employing noise levels in excess of 85 dB. Little change has been found in low-noise cases. It has been cited that moderate noise levels appear to act as a stressor for more sensitive individuals performing a difficult psychomotor task. While the results of research on the general effect of periodic aircraft noise on performance have yet to yield definitive criteria, several general trends have been noted including:

- A periodic intermittent noise is more likely to disrupt performance than a steady-state continuous noise of the same level. Flyover noise, due to its intermittent nature, might be more likely to disrupt performance than a steady-state noise of equal level.
- Noise is more inclined to affect the quality than the quantity of work.

- Noise is more likely to impair the performance of tasks that place extreme demands on the worker.

E.2.7 Noise Effects on Children

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 policies, programs, and activities address environmental health and safety risks to identify any disproportionate risks to children.

A review of the scientific literature indicates that there has not been a tremendous amount of research in the area of aircraft noise effects on children. The research reviewed does suggest that environments with sustained high background noise can have variable effects, including noise effects on learning and cognitive abilities, and reports of various noise-related physiological changes.

E.2.7.1 Effects on Learning and Cognitive Abilities

In 2002 ANSI refers to studies that suggest that loud and frequent background noise can affect the learning patterns of young children (ANSI 2002). ANSI provides discussion on the relationships between noise and learning, and stipulates design requirements and acoustical performance criteria for outdoor-to-indoor noise isolation. School design is directed to be cognizant of, and responsive to surrounding land uses and the shielding of outdoor noise from the indoor environment. The ANSI acoustical performance criteria for schools include the requirement that the 1-hour-average background noise level shall not exceed 35 dBA in core learning spaces smaller than 20,000 cubic-feet and 40 dBA in core learning spaces with enclosed volumes exceeding 20,000 cubic-feet. This would require schools be constructed such that, in quiet neighborhoods indoor noise levels are lowered by 15 to 20 dBA relative to outdoor levels. In schools near airports, indoor noise levels would have to be lowered by 35 to 45 dBA relative to outdoor levels (ANSI 2002).

The studies referenced by ANSI to support the new standard are not specific to jet aircraft noise and the potential effects on children. However, there are references to studies that have shown that children in noisier classrooms scored lower on a variety of tests. Excessive background noise or reverberation within schools causes interferences of communication and can therefore create an acoustical barrier to learning (ANSI 2002). Studies have been performed that contribute to the body of evidence emphasizing the importance of communication by way of the spoken language to the development of cognitive skills. The ability to read, write, comprehend, and maintain attentiveness, are, in part, based upon whether teacher communication is consistently intelligible (ANSI 2002).

Numerous studies have shown varying degrees of effects of noise on the reading comprehension, attentiveness, puzzle-solving, and memory/recall ability of children. It is generally accepted that young children are more susceptible than adults to the effects of background noise. Because of the developmental status of young children (linguistic, cognitive, and proficiency), barriers to hearing can cause interferences or disruptions in developmental evolution.

Research on the impacts of aircraft noise, and noise in general, on the cognitive abilities of school-aged children has received more attention in the last 20 years. Several studies suggest that aircraft noise can affect the academic performance of schoolchildren. Although many factors could contribute to learning deficits in school-aged children (e.g., socioeconomic level, home environment, diet, sleep patterns), evidence exists that suggests that chronic exposure to high aircraft noise levels can impair learning. Specifically, elementary school children attending schools near New York City's two airports demonstrated lower reading scores than children living farther away from the flight paths (Green et al. 1982). Researchers have found that tasks involving central processing and language comprehension (such as reading, attention, problem solving, and memory) appear to be the most affected by noise (Evans and Lepore 1993, Evans et al. 1998). It has been demonstrated that chronic exposure of first- and second-grade children to aircraft noise can result in reading deficits and impaired speech perception (i.e., the ability to hear common, low-frequency [vowel] sounds but not high frequencies [consonants] in speech) (Evans and Maxwell 1997).

The Evans and Maxwell (1997) study found that chronic exposure to aircraft noise resulted in reading deficits and impaired speech perception for first- and second-grade children. Other studies found that children residing near the Los Angeles International Airport had more difficulty solving cognitive problems and did not perform as well as children from quieter schools in puzzle-solving and attentiveness (Bronzaft 1997, Cohen et al. 1980). Children attending elementary schools in high aircraft noise areas near London's Heathrow Airport demonstrated poorer reading comprehension and selective cognitive impairments (Haines et al. 2001a, 2001b). Similar studies involving the testing of attention, memory, and reading comprehension of school children located near airports showed that their tests exhibited reduced performance results compared to those of similar groups of children who were located in quieter environments (Evans et al. 1998, Haines et al. 1998). The Haines and Stansfeld study indicated that there may be some long-term effects associated with exposure, as one-year follow-up testing still demonstrated lowered scores for children in higher noise schools (Haines et al. 2001a, 2001b). In contrast, a 2002 study found that although children living near the old Munich airport scored lower in standardized reading and long-term memory tests than a control group, their performance on the same tests were equal to that of the control group once the airport was closed (Hygge et al. 2002).

Finally, although it is recognized that there are many factors that could contribute to learning deficits in school-aged children, there is increasing awareness that chronic exposure to high aircraft noise levels may impair learning. This awareness has led the WHO and a North Atlantic Treaty Organization (NATO) working group to conclude that daycare centers and schools should not be located near major sources of noise, such as highways, airports, and industrial sites (WHO 2000, NATO 2000).

E.2.7.2 Health Effects

Physiological effects in children exposed to aircraft noise and the potential for health effects have also been the focus of limited investigation. Studies in the literature include examination of blood pressure levels, hormonal secretions, and hearing loss.

As a measure of stress response to aircraft noise, authors have looked at blood pressure readings to monitor children's health. Children who were chronically exposed to aircraft noise from a new airport near Munich, Germany, had modest (although significant) increases in blood pressure, significant increases in stress hormones, and a decline in quality of life (Evans et al. 1998). Children attending noisy schools had statistically significant average systolic and diastolic blood pressure ($p<0.03$). Systolic blood pressure means were 89.68 mm for children attending schools located in noisier environments compared to 86.77 mm for a control group. Similarly, diastolic blood pressure means for the noisier environment group were 47.84 mm and 45.16 for the control group (Cohen et al. 1980).

Although the literature appears limited, studies focused on the wide range of potential effects of aircraft noise on school children have also investigated hormonal levels between groups of children exposed to aircraft noise compared to those in a control group. Specifically, two studies analyzed cortisol and urinary catecholamine levels in school children as measurements of stress response to aircraft noise (Haines et al. 2001b, 2001c). In both instances, there were no differences between the aircraft-noise-exposed children and the control groups.

Other studies have reported hearing losses from exposure to aircraft noise. Noise-induced hearing loss was reportedly higher in children who attended a school located under a flight path near a Taiwan airport, as compared to children at another school far away (Chen et al. 1997). Another study reported that hearing ability was reduced significantly in individuals who lived near an airport and were frequently exposed to aircraft noise (Chen and Chen 1993). In that study, noise exposure near the airport was reportedly uniform, with DNL greater than 75 dB and maximum noise levels of about 87 dB during overflights. Conversely, several other studies that were reviewed reported no difference in hearing ability between children exposed to high levels of airport noise and children located in quieter areas (Fisch 1977, Andrus et al. 1975, Wu et al. 1995).

E.2.8 Noise Effects on Domestic Animals and Wildlife

Hearing is critical to an animal's ability to react, compete, reproduce, hunt, forage, and survive in its environment. While the existing literature does include studies on possible effects of jet aircraft noise and sonic booms on wildlife, there appears to have been little concerted effort in developing quantitative comparisons of aircraft noise effects on normal auditory characteristics. Behavioral effects have been relatively well described, but the larger ecological context issues, and the potential for drawing conclusions regarding effects on populations, has not been well developed.

The following discussion provides an overview of the existing literature on noise effects (particularly jet aircraft noise) on animal species. The literature reviewed outlines those studies that have focused on the observations of the behavioral and in some cases physiological responses of animals to jet aircraft overflight and sonic booms.

The abilities to hear sounds and noise and to communicate assist wildlife in maintaining group cohesiveness and survivorship. Social species communicate by transmitting calls of warning, introduction, and others that are subsequently related to an individual's or group's responsiveness. Animal species differ greatly in their responses to noise. Noise effects on domestic animals and wildlife are classified as primary, secondary, and tertiary. Primary effects are direct, physiological changes to the auditory system, and most likely include the masking of auditory signals. Masking is defined as the inability of an individual to hear important environmental signals that may arise from mates, predators, or prey. There is some potential that noise could disrupt a species' ability to communicate or interfere with behavioral patterns (Manci et al. 1988; Warren et al. 2006), however this would be a greater concern for continuous or near-continuous noise sources (e.g., compressors, near busy highway) than for intermittent, brief exposures such as military jet overflight. Increased noise levels reduce the distance and area over which acoustic signals can be perceived by animals (Barber et al. 2009). Although the effects are likely temporary, aircraft noise may cause masking of auditory signals within exposed faunal communities.

Animals rely on hearing to avoid predators, obtain food, and communicate and attract other members of their species. Aircraft noise may mask or interfere with these functions. Other primary effects, such as eardrum rupture or temporary and permanent hearing threshold shifts, are unlikely given the noise levels produced by aircraft overflights. Secondary effects may include nonauditory effects such as stress and hypertension; behavioral modifications; interference with mating or reproduction; and impaired ability to obtain adequate food, cover, or water. Tertiary effects are the direct result of primary and secondary effects. These include population decline and habitat loss. Most of the effects of noise are mild enough to be undetectable as variables of change in population size or population growth against the background of normal variation (Bowles 1995). Other environmental variables (e.g., predators, weather, changing prey base, ground-based disturbance) also influence secondary and tertiary effects and confound the ability to identify the ultimate factor in limiting productivity of a certain nest, area, or region (Smith et al. 1988). Overall, the literature suggests that species differ in their response to various types, durations, and sources of noise (Manci et al. 1988; Radle 2007; NPS 2011) and that response of unconfined wildlife and domestic animals to aircraft overflight under most circumstances has minimal biological significance.

Considerable research has been conducted on the effects of aircraft noise on the public and the potential for adverse ecological impacts. These studies were largely completed in response to the increase in air travel and the introduction of supersonic commercial jet aircraft (e.g., the Concorde). According to Manci et al. (1988), the foundation of information created from that focus did not necessarily correlate or provide information specific to the impacts to wildlife in areas overflown by aircraft at supersonic speed or at low altitudes. A 1996 review revealed that aircraft noise plays a minor role in disturbance to animals when separated from the optical stimuli and uses examples of nearly soundless paragliders causing panic flights (Kempf and Hüppop 1996). This research indicated that sonic booms and jet aircraft noise can cause startle responses, but do not result in severe consequences and that severity of response depends upon previous exposure. These authors felt that aside from the rare panic flights causing accidents, negative consequences of aircraft noise *per se* on individuals and populations are not proven (Kempf and Hüppop 1996). Similarly, the Air Force has conducted many studies and defines a startle or startle response as the sequence of events that occurs when an animal is surprised, including behavioral responses (muscular flinching, alerting and running) and physiological changes (e.g., elevated heart rate and other physiologic changes) (Air Force 1994). The startle is a natural response that helped the ancestors of domestic stock avoid predators. If the behavioral component of the startle is uncontrolled, particularly if the animal runs or jumps without concern for its safety, it is often called a panic. Completely uncontrolled panics are rare in mammals (Air Force 1994).

Pepper et al. (2003) suggest that many past studies were inconclusive and based on relatively small sample sizes and that more work is needed to determine if noise adversely impacts wildlife. Research into the effects of noise on wildlife often presents conflicting results because of the variety of factors and variables that can affect and/or interfere with the determination of the actual effects that human-produced noise is having on any given animal (Radle 2007).

Many scientific studies have investigated the effects of aircraft noise on wildlife, and some have focused on wildlife "flight" due to noise. Apparently, animal responses to aircraft are influenced by many variables related to the aircraft, including its size, speed, proximity (both height above the ground and lateral distance), engine noise, color, flight profile, and radiated noise. The type of aircraft (e.g., fixed-wing versus rotary-wing [helicopter]) and characteristics of the overflight may also produce different levels of disturbance (e.g., one-way pass overhead in level flight versus circling and approaching more closely), with varying animal responses (Smith et al. 1988). Consequently, it is difficult to generalize animal responses to noise disturbances across species.

Periodic literature reviews have concluded that, while behavioral observation studies were relatively limited, a general behavioral reaction in animals from exposure to aircraft noise/overflight ranges from performing a visual scan to alerting to a startle response (Manci et al. 1988; Bowles 1995; NPS 2011). The intensity and duration of the startle response appears to be dependent on the species, whether there is a group or an individual; what the individuals are doing (e.g., initial stages of pair bonding versus brooding eggs versus communally roosting); and whether there have been previous exposures. Responses range from movement of the head in the apparent direction of the noise source, to alerting, and in rarer cases to flight. In the case of large mammals responses range from alerting to running. More severe responses such as trampling, bunching, or stampeding have been documented, generally with confined animals, Manci et al. (1988) reported that the literature indicated that avian species may be more sensitive to aircraft noise than mammals. In addition to flight, other concerns with regard to impact from noise disturbance on wildlife or livestock include the following possible responses and effects:

- Possible injury due to trampling or uncontrolled running or flight
- Increased expenditure of energy, particularly during critical periods (e.g., breeding, winter)
- Decreased time spent on life functions (e.g., seeking food or mates)

- Temporary masking of auditory signals from other animals of the same species, predators, or prey (e.g., noise could prevent an animal from hearing the approach of a predator)
- Damage to eggs or nestlings if a bird is startled from its nest
- Temporary exposure of eggs or young in nest to environmental conditions or predation if a parent flees
- Temporary increased risk of predation if startled animals flee from nests, roosts, or other protective cover

Although the above-listed concerns have been raised in the literature and examples have been documented, studies of unconfined wildlife and domestic animals to overflight by military jet aircraft at 500 feet AGL or higher have not shown measurable changes in population size or reproductive success at the population level or other significant biological impact under normal conditions.

E.2.8.1 Domestic Animals

Although some studies report that the effects of aircraft noise on domestic animals is inconclusive, a majority of the literature reviewed indicates that domestic animals exhibit some behavioral responses to military overflights, but generally seem to habituate to the disturbances over a period of time. Significant adverse responses are infrequently documented and these generally occur under unusual circumstances.

Bowles et al. (1990) reviewed 209 aircraft noise claims files against the Air Force. Within that sample the major source of loss was panics induced in naïve animals, and secondarily losses due to reproductive failure and failure to gain weight properly. These claims spanned a 32-year period and were remarkably infrequent compared to the number of flight-miles logged over rural areas. Claims found to be legitimate by Air Force examiners cost the Air Force less than $24,000 per year nationwide, and over 62 percent of this cost could be attributed to a single claim for animals that escaped after stampeding away from aircraft. Bowles et al. (1990) concluded that the economic loss is small; however, the concerns about damage effects are political in nature. Large effects might be noted in cases where animals were previously stressed, such as by long periods of adverse weather conditions, or poor management practices, or by genetic predisposition. In these cases, it is very difficult to separate what effect may be attributed to the pre-stressor and what may be attributed to aircraft activity per se (Bowles et al. 1990).

Mammals in particular appear to react to noise at sound levels higher than 90 dB, with responses including a startle response, alerting, freezing (i.e., becoming temporarily stationary), and fleeing from the sound source. A startle response is a sequence of physiological and behavioral events that once helped animals avoid predators (Bowles et al. 1990). Because large, domestic animals normally control their movements even when frightened, and because they habituate quickly to aircraft noise (even to the noise of low-altitude, high-speed aircraft overflights), panic-related responses are rare. They are most common in horses and least common in dairy cattle, which are exposed to frequent human disturbance and are bred for docility. Some studies have reported primary and secondary effects of chronic exposure, including reduced milk production and rate of milk release, increased glucose concentrations, decreased levels of hemoglobin, increased heart rate, and a reduction in thyroid activity. These latter effects appear to represent a small percentage of the findings occurring in the literature. Effects on weight gain, milk yield, productivity, and fertility are either nonexistent based on current information or undocumented, although they are frequently the subject of public debate (Bowles et al. 1990).

Some reviewers have indicated that earlier studies and claims by farmers linking adverse effects of aircraft noise on livestock did not necessarily provide clear-cut evidence of cause and effect (Cottereau 1978). Many studies conclude that there is no evidence that aircraft overflights affect feed intake, growth, or production rates in domestic animals (Air Force 1994).

Cattle. In response to concerns about overflight effects on pregnant cattle, milk production, and cattle safety, the Air Force prepared a handbook for environmental protection that summarizes the literature on the impacts of low-altitude flights on livestock (and poultry), and includes specific case studies conducted in numerous airspaces across the country. Adverse effects have been found in a few studies, but have not been reproduced in other similar studies. One such study, conducted in 1983, suggested that two of 10 cows in late pregnancy aborted after showing rising estrogen and falling progesterone levels. These increased hormonal levels were reported as being linked to 59 aircraft overflights. The remaining eight cows showed no changes in their blood concentrations and calved normally (Air Force 1994). A similar study reported that abortions occurred in three out of five pregnant cattle after exposing them to flyovers by six different aircraft (Air Force 1994). Another study suggested that feedlot cattle could stampede and injure themselves when exposed to low-level overflights (Air Force 1994).

A majority of the studies reviewed suggest that there is little or no effect of aircraft noise on cattle. Studies documenting adverse effects on domestic animals have been limited. A number of studies (Parker and Bayley 1960; Kovalcik and Sottnik 1971) investigated the effects of jet aircraft noise and sonic booms on the milk production of dairy cows. Through the compilation and examination of milk production data from areas exposed to jet aircraft noise and sonic booms, it was determined that milk yields were not affected by jet aircraft noise. This was particularly evident in cows that had been previously exposed to jet aircraft noise.

One study examined the causes of 1,763 abortions in Wisconsin dairy cattle over a one-year time period and found that none of the abortions were associated with aircraft disturbances (Air Force 1993). In 1987, a researcher contacted seven livestock operators for production data, and no effects of low-altitude and supersonic flights were noted. Three out of 43 cattle previously exposed to low-altitude flights showed a startle response to an F/A-18 aircraft flying overhead at 500 feet above ground level (AGL) at 400 knots by running less than 10 meters. They resumed normal activity within one minute (Air Force 1993). In 1983, another researcher found that helicopters caused more reaction than other low-level aircraft overflights (Air Force 1994). A 1964 study also found that helicopters flying 30 to 60 feet overhead did not affect milk production and pregnancies of 44 cows and heifers (Air Force 1994).

Additionally, Beyer reported that five pregnant dairy cows in a pasture did not exhibit fright-flight tendencies or have their pregnancies disrupted after being overflown by 79 low-altitude helicopter flights and four low-altitude, subsonic jet aircraft flights (Air Force 1994). A 1956 study found that the reactions of dairy and beef cattle to noise from low-altitude, subsonic aircraft were similar to those caused by paper blowing about, strange persons, or other moving objects (Air Force 1994).

In a report to Congress, the U.S. Forest Service (USFS) concluded that "evidence both from field studies of wild ungulates and laboratory studies of domestic stock indicate that the risks of damage are small (from aircraft approaches of 50 to 100 meters), as animals take care not to damage themselves (USFS 1992). If animals are overflown by aircraft at altitudes of 50 to 100 meters, there is no evidence that mothers and young are separated, that animals collide with obstructions (unless confined) or that they traverse dangerous ground at too high a rate." These varied study results suggest that, although the confining of cattle could magnify animal response to aircraft overflight, there is no proven cause-and-effect link between startling cattle from aircraft overflights and abortion rates or lower milk production.

Horses. Horses have also been observed to react to overflights of jet aircraft. Several of the studies reviewed reported a varied response of horses to low-altitude aircraft overflights. Observations made in 1966 and 1968 noted that some horses galloped in response to jet flyovers (Air Force 1993). Strong reactions were observed, but no injuries sustained, when pregnant horses were exposed to very low-altitude aircraft overflights (50 meters or lower, most flights with sound levels over 95 dBA) and helicopters hovering 20 meters overhead (Air Force 1994). Although horses were observed noticing the overflights, it did not appear to affect either survivability or reproductive success.

LeBlanc et al. (1991) studied the effects of simulated aircraft noise over 100 dBA and visual stimuli on pregnant mares shortly before parturition. They specifically focused on any changes in pregnancy success, behavior, cardiac function, hormonal production, and rate of habituation. Their findings reported observations of "flight-fright" reactions, which caused increases in heart rates and serum cortisol concentrations. Levels of anxiety and mass body movements were the highest after initial exposure, but no horses injured themselves or their fetuses. Intensities of responses decreased with continued exposures, indicating habituation. There were no differences in pregnancy success when compared to a control group. Interestingly, the mares in LeBlanc's study exposed to overflight noise only habituated much more rapidly than mares exposed to the visual stimulus from an overflight as well as the noise.

Swine. Generally, the literature findings for swine appear to be similar to those reported for cows and horses. While there are some effects from aircraft noise reported in the literature, these effects are minor. Studies of continuous noise exposure (i.e., six hours or 72 hours of constant exposure) reported influences on short-term hormonal production and release. Additional constant exposure studies indicated the observation of stress reactions, hypertension, and electrolyte imbalances (Dufour 1980). A study by Bond et al. (1963) demonstrated no adverse effects on the feeding efficiency, weight gain, ear physiology, or thyroid and adrenal gland condition of pigs subjected to aircraft noise. Observations of heart rate increase were recorded and it was noted that cessation of the noise resulted in the return to normal heart rates. Conception rates and offspring survivorship did not appear to be influenced by exposure to aircraft noise.

Similarly, long-term exposure of pigs to recorded aircraft noise at levels of 100 dB to 135 dB from weaning to slaughter had only minor effects on the rate of feed utilization, weight gain, food intake, and reproduction rates, and there were no injuries or inner ear changes observed (Manci et al. 1988; Gladwin et al. 1988).

Domestic Fowl. Effects of low-altitude overflights (below 1,000 feet) generally had negligible effects on domestic fowl (Air Force 1994). The paper did recognize that given certain circumstances, adverse effects can be serious. Some of the effects can be panic reactions, reduced productivity, and effects on marketability (e.g., bruising of the meat).

The typical reaction of domestic fowl after exposure to sudden, intense noise is a short-term startle response. The reaction ceases as soon as the stimulus is ended, and within a few minutes all activity returns to normal. More severe responses are possible depending on the number of birds, the frequency of exposure, and environmental conditions. Large crowds of confined birds and birds not previously exposed are more likely to pile up in response to a noise stimulus (Air Force 1994). According to studies and interviews with growers, it is typically the previously unexposed birds that incite panic crowding, and the tendency to do so is markedly reduced within five exposures to the stimulus (Air Force 1994). This suggests that the birds habituate relatively quickly. Egg productivity was not adversely affected by infrequent noise bursts, even at exposure levels as high as 120 to 130 dBA.

Between 1956 and 1988, there were 100 recorded claims against the Navy for alleged damage to domestic fowl. The number of claims averaged three per year, with peak numbers of claims following publications of studies on the topic in the early 1960s (Air Force 1994). Many of the claims were disproved or did not have sufficient supporting evidence. The claims were filed for the following alleged damages: 55 percent for panic reactions, 31 percent for decreased production, 6 percent for reduced hatchability, 6 percent for weight loss, and less than 1 percent for reduced fertility (Air Force 1994).

Turkeys. The review of the existing literature suggests that there has not been a concerted or widespread effort to study the effects of aircraft noise on commercial turkeys. One study involving turkeys examined the differences between simulated versus actual overflight aircraft noise, turkey responses to the noise, weight gain, and evidence of habituation (Bowles et al. 1990). Findings from the study suggested that turkeys habituated to jet aircraft noise quickly, that there were no growth rate differences between the experimental and control groups, and that there were some behavioral differences that increased the difficulty in handling individuals within the experimental group.

Low-altitude overflights were shown to cause confined turkey flocks to occasionally pile up and experience high mortality rates due to the aircraft noise and a variety of disturbances unrelated to aircraft (Air Force 1994).

E.2.8.2 Wildlife

Studies on the effects of overflights and sonic booms on wildlife have been focused mostly on avian species and ungulates such as caribou and bighorn sheep. Few studies have been conducted on small terrestrial mammals, reptiles, amphibians, and carnivorous mammals. Chronic exposures are rarely relevant to wildlife because high levels and sustained levels of human-made noise are rare outside urban areas or industrial facilities (Bowles 1995). Guidelines that protect human hearing can reasonably be expected to also protect terrestrial wildlife because they are based on studies of laboratory animals. Susceptibility varies with species, but models currently in use are conservative (Bowles 1995). Generally, species that live entirely below the surface of the water have received little study due to the fact they do not experience the same level of sound as terrestrial species (NPS 1994).

E.2.8.3 Mammals

Terrestrial Mammals. Sound levels above about 90 dB may be associated with a number of behaviors such as retreat from the sound source, freezing (becoming motionless), or a strong startle response (Manci et al. 1988). Studies of terrestrial mammals have shown that sustained exposure to noise levels of 120 dBA or more can damage mammals' hearing, and levels of 95 dBA can cause adverse physiological changes (Manci et al. 1988).

It has been speculated that repeated aircraft overflight (e.g., surveillance flights along a pipeline) could affect large carnivores such as grizzly bears by causing changes in home ranges, foraging patterns, and breeding behavior (Dufour 1980). However, these possible effects have not been borne out in subsequent studies. Although wolves have been frightened by low-altitude flights that were 25 to 1,000 feet off the ground, wolves have been found to adapt to aircraft overflights and noise as long as they were not being hunted from aircraft (Dufour 1980). A literature review by Larkin et al. (1996) determined that wolves were the least disturbed of any of the large mammals by low-level overflights. Incidental observations of wolves and bears exposed to fixed-wing aircraft and helicopters indicated a stronger reaction to helicopters than to fixed-wing aircraft, and that wolves were less disturbed by helicopters than were wild ungulates, while individual grizzly bears showed the greatest response of any animal species observed (Larkin et al. 1996; Manci et al. 1988); although response to overflight by grizzly bears varied from individual to individual (Dufour 1980).

Wild ungulates (such as American bison, caribou, bighorn sheep) appear to be more sensitive to noise disturbance than domestic livestock (Manci et al. 1988; Weisenberger et al. 1996; Bleich et al. 1990, 1994; White et al. 1993). Behavioral reactions may be related to the past history of exposure to such things as humans and aircraft. Behavioral responses can range from mild to severe. Mild responses include head raising, body shifting, or turning to orient toward the aircraft. Moderate responses to disturbance may be nervous behaviors, such as trotting a short distance. Escape behavior would represent a typical severe response, but it is rarely observed in response to overflight above 500 feet AGL that does not include circling.

Both the visual aspect and peak noise level (L_{pk}) of overflights diminish rapidly with increasing altitude of overflight. Similarly, wildlife responses diminish with increasing altitude of overflight (or increasing slant distance, which is a combination of aircraft height AGL and the horizontal distance from the animal for an aircraft not directly overhead). A National Park Service study (Anderson and Horonjeff 1992) described the relationship between increasing altitude or slant distances and diminution of sound levels. Very large reductions in sound levels (on the order of 15 to 25 dB) are experienced as altitude or slant distance increases from 125 feet to 1,000 feet. Increases from 1,000 to 2,000 feet altitude would produce smaller but still moderate to substantial reductions (on the order of 4 to 8 dB). Between 2,000 and 7,000 feet AGL, 1,000-foot increases in distance produce considerably smaller reductions in sound levels (on the order of 3 to 5 dB), and above 7,000 feet AGL, each 1,000-foot increase in altitude results in only very small reductions in sound level (Anderson and Horonjeff 1992).

Reported wildlife responses to overflight are largely behavioral and short-term. Some short-term physiological changes (e.g., increased heart rate) have also been measured. Andersen et al. (1996) studied the response of radio-collared moose to large-scale ground and aerial military training exercises. They found temporary increases in heart rate that returned to normal soon (within 10 to 20 minutes or less) after the exposure. Animal flight responses were greater in response to approach by humans than to approach by equipment, including aircraft, possibly due to perception of humans as predators. Overflight of F-16 jets flying at 150 meters AGL (less than 500 feet AGL) did not elicit any heart rate or activity response from a moose, while skiers and walkers were flushing moose at approach distances of 200 to 400 meters (650 to 1,300 feet). Home ranges were temporarily displaced approximately 1.4 kilometers during the exercises, which involved 6,000 personnel, several hundred pieces of mechanized equipment including battle tanks and all-terrain vehicles (ATVs), a squadron of transport helicopters, and four jet fighter squadrons. Larkin et al. (1996) found that moose showed a much greater indifference to aircraft than caribou, and this was equally true of animals encountered in the open or in partial cover. Moose that reacted by running from the aircraft were in most cases cows with young calves.

It has been shown that exposure to low-altitude overflights can also result in increased heart rates in mule deer, elk, and bighorn sheep. Weisenberger et al. (1996) measured the heart rate responses of captive bighorn sheep (*Ovis canadensis*) and mule deer (*Odocoileus hemionus*) to simulated aircraft noise ranging from 92 to 112 dB. For both species, heart rates increased following the simulated aircraft noise, but returned to normal levels within 60–180 seconds. Behavioral responses were relatively rare, and the animals returned to normal behavior within four to five minutes. Furthermore, the animals exhibited decreased responses to increased exposure, suggesting habituation. A study reported possible effects on bighorn sheep energetic reserves through changes in food intake when helicopters were within 500 meters of animals (Bowles 1995). Authors observed that bighorn sheep alerted more while eating in the presence of helicopters than when undisturbed. They concluded that frequent alerting affected food intake. Krausman et al. (1998) studied the response of bighorn sheep in a 790-acre enclosure to frequent F-16 overflights at 395 feet AGL. Heart rates increased above preflight level during 7 percent of the overflights but returned to normal within 120 seconds. No behavioral response by the bighorn sheep was observed during the overflights.

Lawler et al. (2004) reported on a study of the effects of military jet overflights on Dall sheep (*Ovis dalli*) under the Yukon 1 and 2 Military Operations Areas (MOAs) in Alaska. The study could find no difference in population trends, productivity, survival rates, behavior, or habitat use between areas mitigated and not mitigated for low-level military aircraft (Air Force 1997). In the mitigated area of the Yukon MOAs, flights are restricted to above 5,000 feet AGL during the lambing season. In their wildlife best management practice (BMP) recommendations, Churchill and Holland (2003) suggest for bighorn and stone sheep (*Ovis dalli stonei*) that chronic aircraft exposure reduces foraging efficiency and habitat utilization and can impact growth and survival. They recommend limiting helicopter and fixed-wing aircraft to above 1,312 feet (400 meters) AGL and 6,562 feet (2,000 meters) horizontal distance from all sheep habitats, with no circling and no direct approaches.

A study of barren ground caribou (*Rangifer tarandus granti*) in Alaska documented only mild short-term behavioral reactions of caribou to military overflights in the Yukon MOAs (Lawler et al. 2005). A large portion of the Fortymile Caribou Herd calves underneath the Yukon MOAs. Lawler et al. (2005) concluded that military overflights did not cause any calf deaths, nor did cow-calf pairs exhibit increased movement in response to the overflights. Maier et al. (1998) found that cow-calf pairs of the Delta Caribou Herd exposed to low-altitude overflights in existing MOAs moved about 2.5 kilometers more per day than those not exposed (Maier et al. 1998). Other studies found that post-calving caribou were more sensitive to the effects of aircraft noise disturbance than other environmentally stressed caribou (e.g., during low forage productivity years, winter or insect seasons) (White et al. 1993; Wolfe et al. 2000). However, given the low energy costs of observable behavioral responses, the instantaneous energy cost is minimal and would not measurably increase the daily energy expenditure even if animals were overflown repeatedly (White et al. 1993; Reimers and Colman 2006). White et al. (1993) found that caribou responded to increasing simulated daily sound doses from low-flying military jets with linear increases in activity, daily energy costs, and metabolic rates, and that the response was statistically significant for post-calving females, but increases were small and they projected no biologically significant decrease in fecundity or herd productivity. They nonetheless recommended that early post-calving caribou not be subjected to repeated low-altitude jet aircraft overflights because indirect, longer-term effects were unknown (White et al. 1993). Magoun et al. (2003) identified that maintaining a floor of 2,000 feet (625 meters) AGL for all military jet aircraft over caribou calving grounds would "eliminate most of the stronger-level reactions of caribou to military jet aircraft (startle reactions, trotting, and running) especially if speeds…did not exceed 500 knots between 2,000 feet AGL and 5,000 feet (1,562 meters) AGL." In their wildlife BMP recommendations, Churchill and Holland (2003) advise limiting helicopter and fixed-wing aircraft to above 1,312 feet (400 meters) AGL and 6,562 feet (2,000 meters) horizontal distance from birthing/rearing habitats.

Observations of caribou in Alaska exposed to fixed-wing aircraft and helicopters showed running and panic reactions occurred when overflights were at an altitude of 200 feet AGL or less. The reactions decreased with increased altitude of overflights, and for overflights higher than 500 feet in altitude, the panic reactions stopped. Also, smaller groups reacted less strongly than larger groups.

Using various aircraft and during several seasons, Murphy et al. (1993) found that instantaneous reactions of the Delta Caribou Herd to overflights were mild, seldom involved movement, and did not suggest that the animals were panicking or exhibiting predator response behaviors. They did observe that modifications of activity budgets, activity cycles, and daily movements were evident for caribou exposed to overflights. During post-calving, treatment animals traveled significantly farther than did control animals, and these results indicate that the presence of newborn calves in June may cause female caribou to respond more strongly to disturbance than at other times of the year. Also, F-15s, which were the loudest aircraft in the study, caused stronger reactions than did the other types of aircraft. They could not completely attribute the variability in duration of reactions or the distance moved in response to overflights to varying noise exposure alone, however. Reactions seemed to vary by the activity the animal was doing and by the individual. They attributed some of the individual variation in behavior to habituation and decided that caribou in that herd either have habituated or, at least, have had the opportunity to habituate to aircraft disturbance (Murphy et al. 1993). The increased movement observed during post-calving probably was of low energetic cost but may have moved the animals into suboptimal habitat or increased the chance of encountering a predator. This study also looked at how overflights altered caribou activity in different seasons and found time budgets during two of the three sampling periods were affected. During late winter, no differences in the activity budgets of caribou that had been recently overflown were detected, whereas differences were apparent during post-calving and the insect season, both seasons of overall increased activity levels (Murphy et al. 1993).

Although few studies have been conducted on the response of wild ungulates to sonic booms, these disturbances appear to have little to no adverse effect. Workman et al. (1992) studied the physiological and behavioral responses of captive pronghorn, elk (*Cervus elaphus*), and bighorn sheep to sonic booms. All three species exhibited an increase in heart rate lasting from 30 to 90 seconds in response to their first exposure to a sonic boom. Behaviorally, the animals responded to their first exposure to a sonic boom by running a short distance (less than 30 feet reported for elk). After successive sonic booms, the heart-rate response decreased greatly and the animals remained alert, but did not run. The authors suggested the animals became habituated in response to successive exposures.

E.2.8.4 Birds

Auditory research conducted on birds indicates that they fall between reptiles and mammals relative to hearing sensitivity. According to Dooling (1978), within the range of 1,000 to 5,000 Hz, birds show a level of hearing sensitivity similar to that of the more sensitive mammals. In contrast to mammals, bird auditory sensitivity falls off at a greater rate with increasing and decreasing frequencies. Observational evidence as well as studies examining aircraft-bird strikes indicate that birds routinely nest, roost, and forage near airports. Aircraft noise in the vicinity of commercial airports apparently does not inhibit bird presence and use.

E.2.8.5 Raptors

Considerable research attention has been paid to the potential adverse effects of aircraft overflight on raptors, given their habits of nesting and perching in elevated, exposed places such as cliff ledges and treetops, their status as high-level predators, and depressed population sizes of many species due to eggshell thinning and other metabolic effects related to exposure to pesticides through the food chain. There has been a concern that high-noise events (e.g., from a low-altitude aircraft overflight) may cause raptors to engage in escape or avoidance behaviors, such as flushing from perches or nests (Ellis et al. 1991). Concerns have been expressed that these activities could impose an energy cost on the birds that, over the long term, could affect survival or growth. In addition, the birds may spend less time engaged in necessary activities like feeding, preening, or caring for their young because they spend time in noise-avoidance activity. However, the long-term significance of noise-related impacts is less clear. For these concerns to be borne out, disturbance would need to be frequent enough for the energy costs to be cumulatively substantial and there would need to be a lack of habituation over time. Several studies on nesting raptors have indicated that birds become habituated to aircraft overflights and that long-term reproductive success is not affected by exposure to overflight (Grubb and King 1991; Ellis et al. 1991; Palmer et al. 2003; Andersen et al. 1989; Trimper et al. 1998).

In a literature review of raptor responses to aircraft overflight/noise, Manci et al. (1988) found that most raptors did not show a negative response to overflights. When negative responses were observed, they were predominantly associated with rotary-winged aircraft or jet aircraft that were repeatedly passing within 0.5 miles (0.8 kilometers) or less of a nest. Many raptor-aircraft studies have been conducted since then and several are reviewed below.

In Alaska, Palmer et al. (2003) found small differences in nest attendance and time-activity budgets between undisturbed nesting peregrine falcons (*Falco peregrinus*) and those that were overflown by military aircraft within 500 feet; however, the differences were not correlated with specific overflights nor did they affect reproductive success. Furthermore, Palmer et al. did not observe a difference in nest provisioning rates between disturbed and undisturbed nests.

Ellis et al. (1991) estimated the effects of low-level military jet aircraft and mid- to high-altitude sonic booms (both actual and simulated) on several nesting raptor species. No incidents of reproductive failure were observed, and site reoccupancy rates were high (95 percent) the following year. Overflights by military jet aircraft (mostly A-7 Corsair IIs and A-10 Thunderbolts) within 60 meters (195 feet) of the birds most often evoked only minimal behavioral response, although they occasionally caused birds to fly from perches or eyries (Ellis et al. 1991). Jet passes greater than 500 meters (1,625 feet) from the birds consistently failed to elicit significant responses. Several researchers found that ground-based activities, such as operating chainsaws or an intruding human, were more disturbing to raptors than aircraft (White and Thurow 1985; Grubb and King 1991; Delaney et al. 1999). Red-tailed hawks (*Buteo jamaicensis*) and osprey (*Pandion haliaetus*) appeared to readily habituate to regular aircraft overflights (Andersen et al. 1989; Trimper et al. 1998).

Bald Eagle. The effects of aircraft overflight on the bald eagle (*Haliaeetus leucocephalus*) have been studied relatively well compared to most wildlife species. Bald eagle behavioral responses, varying from altering posture to taking flight and/or departing the area, have been associated with overflights of jets, helicopters, and light planes (Grubb and Bowerman 1997).

Overall, there have been no reports of reduced reproductive success or physiological risks to bald eagles exposed to aircraft overflights or other types of military noise and habituation behavior was observed in several studies (Fraser et al. 1985; Stalmaster and Kaiser 1997; Grubb and Bowerman 1997; Brown et al. 1999). Most researchers have documented that pedestrians and helicopters were more disturbing to bald eagles than fixed-wing aircraft, including military jets (Fraser et al. 1985; Grubb and King 1991; Grubb and Bowerman 1997). Recorded responses to 779 events involving military jet aircraft at median distances of 500 meters ranged from no response (67 percent), an alert posture (29 percent), taking flight (3 percent) or temporarily departing the immediate area (1 percent). Median approach distance for the few instances of eagles taking flight was 200 meters. There was considerably more reaction to helicopters than to jets or light planes (Grubb and King 1991; Grubb and Bowerman 1997). In their 1997 study, Grubb and Bowerman recommended a buffer of 1,968 feet (600 meters) around bald eagle nests for all aircraft during the breeding season.

One study of wintering bald eagles observed that 47 percent flushed when approached closer than 984 feet (300 meters) with Army helicopters; however, few eagles flushed in response to helicopter traffic staying over 300 meters in the same areas (Stalmaster and Kaiser 1997). The National Bald Eagle Management Guidelines recommend aircraft avoid overflights within 1,000 feet of nests during the breeding season, and that aircraft corridors are located no closer than 1,000 feet vertical or horizontal distance from communal roost sites (USFWS 2007).

Golden Eagle. In their guidelines for aerial surveys, USFWS (Pagel et al. 2010) summarized past studies by stating that most golden eagles respond to survey aircraft (fixed-wing and helicopters) by remaining on their nests, and continuing to incubate or roost. Surveys take place generally as close as 10 to 20 meters from cliffs (including hovering less than 30 seconds if necessary to count eggs) and no farther than 200 meters from cliffs depending on safety (Pagel et al. 2010).

Grubb et al. (2007) experimented with multiple exposures to two helicopter types and concluded that flights with a variety of approach distances (800, 400, 200, and 100 meters) had no effect on golden eagle nesting success or productivity rates within the same year, or on rates of renewed nesting activity the following year, when compared to the corresponding figures for the larger population of nonmanipulated nest sites (Grubb et al. 2007). They found no significant, detrimental, or disruptive responses in 303 helicopter passes near eagles. In 227 AH-64 Apache helicopter experimental passes (considered twice as loud as a civilian helicopter also tested) at test distances of 0–800 meters from nesting golden eagles, 96 percent resulted in no more response than watching the helicopter pass. No greater reactions occurred until after hatching when individual golden eagles exhibited five flattening and three flying behaviors at three nest sites. The flight responses occurred at approach distances of 200 meters or less. No evidence was found of an effect on subsequent nesting activity or success, despite many of the helicopter flights occurring during early courtship and nest repair, when fidelity to the nest site is weakest. None of these responding pairs failed to successfully fledge young, except for one nest that fell later in the season. Excited, startled, and avoidance reactions were never observed. Nonattending eagles or those perched away from the nests were more likely to fly than attending eagles, but also with less potential consequence to nesting success (Grubb et al. 2007). Golden eagles appeared to become less responsive with successive exposures. Grubb et al. (2007) suggest that much of helicopter sound energy may be at a lower frequency than golden eagles can hear, thus reducing expected impacts. Grubb et al. (2007) found no relationship between helicopter sound levels and corresponding eagle ambient behaviors or limited responses, which occurred throughout recorded test levels (76.7–108.8 dB, unweighted). The authors thought that the lower than expected behavioral responses may have been partially due to the fact that the golden eagles in the area appeared acclimated to the current high levels of outdoor recreational, including aviation, activities. Based on the results of this study, the authors recommended reduction of existing buffers around nest sites to 100 meters (325 feet) for helicopter activity.

Richardson and Miller (1997) reviewed buffers as protection for raptors against disturbance from ground-based human activities. No consideration of aircraft activity was included. They stressed a clear line of sight as an important factor in a raptor's response to a particular disturbance, with visual screening allowing a closer approach of humans without disturbing a raptor. A geographic information system (GIS)-assisted viewshed approach combined with a designated buffer zone distance was found to be an effective tool for reducing potential disturbance to golden eagles from ground-based activities (Richardson and Miller 1997). They summarized recommendations that included a median 0.5-mile (800-meter) buffer (range = 200–1,600 meters, n = 3) to reduce human disturbances (from ground-based activities such as rock climbing, shooting, vehicular activity) around active golden eagle nests from February 1 to August 1 based on an extensive review of other studies (Richardson and Miller 1997). Physical characteristics (i.e., screening by topography or vegetation) are important variables to consider when establishing buffer zones based on raptors' visual and auditory detection distances (Richardson and Miller 1997).

Osprey. A 1998 study by Trimper et al. in Goose Bay, Labrador, Canada, focused on the reactions of nesting osprey to military overflights by CF-18 Hornets (a Canadian twin-engine jet attack aircraft similar to the F/A-18 Hornet used by the U.S. Navy and Marine Corps). Reactions varied from increased alertness and focused observation of planes to adjustments in incubation posture. No overt reactions (e.g., startle response, rapid nest departure) were observed as a result of an overflight. Young nestlings crouched as a result of any disturbance until 1 to 2 weeks prior to fledging. Helicopters, human presence, float planes, and other ospreys elicited the strongest reactions from nesting ospreys. These responses included flushing, agitation, and aggressive displays. Adult ospreys showed high nest occupancy rates during incubation regardless of external influences.

The osprey observed occasionally stared in the direction of the flight before it was audible to the observers. The birds may have become habituated to the noise of the flights; however, overflights were strictly controlled during the experimental period. Strong reactions to float planes and helicopters may have been due to the slower flight and therefore longer duration of visual stimuli rather than noise-related stimuli.

Red-Tailed Hawk. Andersen et al. (1989) investigated the effects of low-level helicopter overflights (0.3 miles [500 meters] AGL and below to 98 feet [30 meters] AGL) and habituation on red-tailed hawk nests at two Army installations. Naïve hawks (i.e., not previously exposed to helicopter flights) exhibited flushing at much greater distances (mean 100 meters) than did hawks at the same locations when overflights were repeated the next year (mean distance of 17 meters and 10 meters for the two installations). Flushing occurred at similar percentages of total nests both years. The overflights did not appear to affect nesting success in either study group. These findings were consistent with the belief that red-tailed hawks habituate to low-level overflight, even during the nesting period.

E.2.8.6 Songbirds

The effect of overflight activity on songbirds has historically received little attention at least partially because most songbirds rely on concealment of nests in vegetation cover to avoid predation and are thus not exposed to the visual aspect of overflight. Additionally some species show a high tolerance to human presence, urban noise and disturbance.

Songbirds were observed to become silent prior to the onset of a sonic boom (F-111 jets), followed by "raucous discordant cries" for a few seconds. There was a return to normal singing within 10 seconds after the boom (Higgins 1974). The silence of the birds coincided with the arrival of a seismic signal propagated through the ground 4 to 8seconds prior to the audible boom. Ravens responded to sonic booms by emitting protestation calls, flapping their wings, and soaring, returning to normal behavior within a few minutes.

It has been observed that songbirds are not driven any great distance from a favored food source by a nonspecific disturbance, such as aircraft overflights (USFS 1992). Data analyzed from 7 years found that military helicopter noise had no detectable influence on reproductive performance of the California gnatcatcher (a small songbird that is federally listed as threatened) on Naval Air Station Miramar and that nest success was equally likely in quiet and noisy areas (Hunsaker 2006). Hunsaker found that elevation, vegetation age class, and other habitat variables influenced nesting area choice more than the sound environment for this bird. A series of studies focused on busy multilane highways has indicated that road noise has a negative effect on bird populations (particularly during breeding) in a variety of species (Kaseloo 2005) that diminishes with distance from the highway. In contrast to noise from jet overflight, which is generally intermittent, noise from busy highways is nearly continuous, which magnifies adverse effects such as masking or interference with communication.

A study conducted cooperatively between the DoD and the USFWS assessed the response of the red-cockaded woodpecker to a range of military training noise events, including artillery, small arms, helicopter, and maneuver noise (Pater et al. 1999). The study did not address overflight except by helicopters. The findings suggested that the red-cockaded woodpecker can successfully acclimate to military noise events depending on the noise level. During noise events the birds responded by flushing from their nest cavities, increasing flushes proportionately with closer noise sources. In all cases, however, the birds returned to their nests within a relatively short period of time (usually within 12 minutes). Additionally, the noise exposure did not result in any mortality or statistically detectable changes in reproductive success (Pater et al. 1999). Red-cockaded woodpeckers did not flush when artillery simulators were more than 122 meters away and SEL noise levels were 70 dBA.

E.2.8.7 Waterbirds

In their review, Manci et al. (1988) noted that aircraft can be particularly disturbing to waterfowl. The USFWS *Waterfowl Management Handbook* (Korschgen and Dahlgren 1992) lists "loud noise" as caused by aircraft as the top disturbance category for waterfowl. Overflight visual aspects may be more important (Owen 1973 in Dahlgren and Korschgen 1992). Eagles and other natural disturbances, boats, and hunting interrupted waterfowl behavior in greater percentages than aircraft (Ward et al. 1994; Korschgen and Dahlgren 1992).

Studies of waterfowl responses to overflight have shown (1) temporary behavior, including taking flight; (2) responses decreasing in magnitude as overflight elevation increases; and (3) rapid resumption of the behaviors exhibited prior to the overflight (e.g., Komenda-Zehnder et al. 2003). Helicopters generally create a greater response at a given altitude than do fixed-wing aircraft, including military jets (Ward et al. 1994). Several studies showed that migratory waterfowl (e.g., ducks and geese) expend more energy when exposed to repeated aircraft overflights, at least in the short term, which affects the birds' energy balance (Bowles 1995; Korschgen et al. 1985). Waterfowl are sensitive to disturbance because of their aggregation into large flocks during their molting and staging prior to migration. When at rest, the flocks are typically in waterbodies or wetlands exposed to the open sky and subject to aerial and ground predation. Taking flight is their defense against either types of predation. Waterfowl flocks seem to be as sensitive as their most responsive individual in the flock, so that larger flocks would have a greater chance of responding than small ones (Bowles 1995).

A variety of studies have indicated that migratory waterfowl exposed to overflights by aircraft and helicopters did not habituate to overflight (Bowles 1995; Komenda-Zehnder et al. 2003; Jensen 1990). However, most birds returned to normal behavior within several minutes after disturbance. Due to the danger to aircraft and aircrews posed by potential collisions with waterfowl and other flocking birds, the bird/wildlife-aircraft strike hazard (BASH) has received much attention by the military. BASH programs exist at every air installation and areas where low-level aircraft flight training takes place (e.g., MTRs), and have locations of seasonal concentrations of waterfowl identified and guidance for pilots with regard to elevational or lateral separation from these sites at specific seasons and times of day to avoid or minimize the potential for collision. This avoidance in turn reduces the potential for disturbance of migratory waterfowl concentrations by military aircraft overflight.

Conomy et al. (1998) suggested that responses of waterfowl to aircraft noise may be species-specific or differ by species groups (Komenda-Zehnder et al. 2003). Conomy et al. (1998) found that black ducks (*Anas rubripes*) exposed to noise under experimental conditions were able to habituate to aircraft noise, while wood ducks (*Aix sponsa*) were not. Black ducks exhibited a significant decrease in startle response to actual and simulated jet aircraft noise over a 17-day period, but wood duck response did not decrease uniformly following initial exposure. Some bird species appear to be more sensitive to aircraft noise at different times of the year.

Many waterfowl studies have involved brant (*Branta bernicla*), primarily during staging or molting periods, and their sensitivity to disturbance. The Alaska molt period is from June through August, and sources of stress that cause a temporal disruption of normal foraging activity could result in abnormal or incomplete molt (Taylor 1993). On an autumn staging ground in Alaska (i.e., prior to fall migration), 75 percent of brant and only 9 percent of Canada geese (*Branta canadensis*) flew in response to aircraft overflights of several types of commercial fixed-wing and rotary-wing aircraft for 356 overflights over 4 years (Ward et al. 1999).

Experiments with helicopter overflights found that disturbance-related behavioral responses by brant are greatest within 984 to 1,968 feet (300–600 meters) altitude range and aircraft would have to fly above 3,510 feet (1,070 meters) to have no significant effect on brant (Jensen 1990). Miller et al. (1994) used a simulation model designed to study the effects of helicopter disturbance on behavioral and energetic response of molting brant in Alaska and found that flying above 2,493 feet (760 meters) in a Bell 206 or 3,002 feet (915 meters) in a Bell 412 along any flight line would greatly reduce aircraft impacts. The disturbance distances given in the literature indicate that birds can be more sensitive in undisturbed regions, in very high concentrations, when molting, or when breeding in colonies (Komenda-Zehnder et al. 2003). The latter researchers found that overflights of wintering waterbirds at a very high speed, such as of military jets, are less disturbing than overflights at slower speeds. Ward et al. (1999) suggested that lateral distance, independent of aircraft type or noise, between aircraft and flock was the most important parameter in predicting response to overflights; they recommended aircraft travel greater than a mile (1.6 kilometers) from the shoreline of the lagoon they studied. Although mean response of brant and Canada geese generally was inversely proportional to aircraft altitude, there was a greater response to aircraft at 1,000 to 2,500 feet AGL than at lower or higher altitudes (Ward et al. 1999). Ward et al. (2000) speculate that the anomalous response was due to reduction of noise transmission from low-flying aircraft to the ground resulting from upward deflection of sound caused by typically windy conditions at the site.

Snow geese (*Chen caerulescens*) were more easily disturbed by aircraft prior to fall migration than at the beginning of the nesting season (Belanger and Bedard 1989). High levels of disturbance may have harmful energetic consequences on fall staging snow geese (Belanger and Bedard 1990). More than two disturbances per hour that cause the birds to leave a feeding area and return to a roost may cause an energy deficit that no behavioral compensatory mechanism (e.g., night feeding) can counterbalance.

The USFWS recommends avoidance of low-level flights below 1,600 feet AGL during the nesting and post-nesting molt of adult waterfowl (April 15 through August 1) over large river systems used by nesting ducks, geese, and swans.

Black et al. (1984) studied the effects of low-altitude (primarily over 500 feet AGL) military training flights with sound levels from 55 to 100 dBA on wading bird colonies (i.e., great egret, snowy egret, tricolored heron, and little blue heron). The training flights involved three or four F-16 aircraft and occurred once or twice per day. This study concluded that the reproductive activity—including nest success, nestling survival, and nestling chronology—was independent of F-16 overflights. Dependent variables were more strongly related to ecological factors, including location and physical characteristics of the colony and climatology.

Kushlan (1979) did not observe any negative effects on wading bird colonies (i.e., rookeries) when circling fixed-wing aircraft conducted surveys within 200 feet AGL; 90 percent of the 220 observations indicated no reactions to overflight or heads turning from the birds. Another 6 percent stood up, 3 percent walked from the nest, and 2 percent flushed (but were without active nests) and returned within 5 minutes (Kushlan 1979). Apparently, nonnesting wading birds had a slightly higher incidence of reacting to overflights than nesting birds. Colony distribution of wading birds appeared to be most directly correlated to available wetland community types and was found to be distributed randomly with respect to MTRs. These results suggest that presence of wading bird species was most closely linked to habitat availability and that they were not affected by low-level military overflights (Air Force 2000).

Burger (1986) studied the response of migrating shorebirds to human disturbance in two New Jersey estuaries and found that shorebirds did not fly in response to aircraft overflights, but did flush in response to more localized intrusions (i.e., humans and dogs on the beach).

Burger (1981) also studied the effects of overflight noise from John F. Kennedy Airport in New York on herring gulls (*Larus argentatus*) that nested less than 1 kilometer from the airport. The study compared the response of the birds to overflight by conventional subsonic jetliners (Boeing 707, 727, 747) and the supersonic Concorde, a passenger jet formerly used for supersonic transatlantic flight that was well-known for the noise and vibration produced on takeoff and landing approach when flying subsonically. Noise levels over the nesting colony were recorded as 85 to 100 dBA on approach and 94 to 105 dBA on takeoff for most aircraft, including conventional jetliners. Generally, there did not appear to be any adverse effects of takeoff and landing noise on nesting birds caused by conventional jetliners. No sonic booms were heard in this study because flight in the vicinity of the airport was all subsonic. However, birds flushed when a Concorde flew directly overhead (producing 116 dBA sound and ground vibrations) and birds engaged in significantly more aggressive behavior once they returned to the colony compared with the normal conditions, including breaking eggs. The adverse response was attributed to fighting among birds from neighboring territories returning to the nesting colony after being simultaneously flushed when the Concorde flew overhead. Groups of gulls tended to loaf in the area of the nesting colony, and these resting birds were not disturbed when conventional jetliners flew overhead but all took flight when the Concorde flew overhead, which occurred only once or twice daily (Burger 1981).

Few studies show responses of waterbirds to sonic booms. One widely cited report discussed by Manci et al. (1988) was inconclusive regarding the cause of the reproductive failure of a colony of sooty terns (*Sterna fuscata*) on the Dry Tortugas in 1969 as to whether behavioral response of adults to sonic booms from extremely low-flying military jets (less than 100 meters AGL) or overgrowth of island vegetation were causal factors (Gladwin et al. 1988). Actions were taken to curb planes breaking the sound barrier within range of the Tortugas, and much of the excess vegetation was cleared. In mid-May 1970, the birds appeared to be having a normal nesting season. Laboratory tests of exposure of eggs to sonic booms and other impulsive noises (Bowles et al. 1991; Bowles et al. 1994; Cogger and Zegarra 1980) failed to show adverse effects on the hatching of eggs. A structural analysis (Ting et al. 2002) showed that even under extraordinary circumstances, sonic booms would not damage an avian egg.

E.2.8.8 Fish

The effects of overflight noise on fish have not received extensive study, but conclusions regarding their expected responses have involved inference based upon known physiologies and behavioral traits of these taxa (Gladwin et al. 1988). Transmission of sound from air to water takes place under limited conditions but sound is conducted very efficiently in water. Most of the literature on fish hearing relates to intense impulse sounds generated in the water (e.g., from pile driving) which has limited applicability to sound generated by aircraft overflight. Variables affecting what noise levels the new MOAs will experience include the type of aircraft, altitude, speed, and power level in addition to the characteristics of the water surface and amount of background noise present in the aquatic environment.

Fish in their native habitat would not be affected at the sound levels associated with military aircraft overflight as low as 500 feet AGL. Salmon are hearing generalists with their best hearing sensitivity at low frequencies (below 300 Hz) where they can detect particle motion induced by low frequency sound at high intensities (Amoser and Ladich 2005; Popper and Hastings 2009). The sound intensity required for salmon hearing is not approached by projected in-water sound levels associated with military jet overflight. Studies of Atlantic salmon conclude that they are unlikely to detect sounds originating in air (Hawkins and Johnstone 1978). This is partially attributable to the limited transmission of sound from air into water, background noise in water, and limitations on fish hearing. The literature includes one study that looked specifically at trout and salmon eggs after exposure during a critical phase of development to a variety of simulated sonic boom overpressures similar to those produced by military airplanes. Comparisons with control groups of eggs spawned at the same time indicated that the sonic boom exposure caused no increase in egg or fish fry mortality (Rucker 1973).

E.2.9 Summary

Some physiological/behavioral responses such as increased hormonal production, increased heart rate, and reduction in milk production have been described in a small percentage of studies. A majority of the studies focusing on these types of effects have reported short-term or no effects.

The relationships between physiological effects and how species interact with their environments have not been thoroughly studied. Therefore, the larger ecological context issues regarding physiological effects of jet aircraft noise (if any) and resulting behavioral pattern changes are not well understood.

Animal species exhibit a wide variety of responses to noise. It is therefore difficult to generalize animal responses to noise disturbances or to draw inferences across species, as reactions to jet aircraft noise appear to be species-specific. Consequently, some animal species may be more sensitive than other species and/or may exhibit different forms or intensities of behavioral responses. For instance one study suggests that wood ducks appear to be more sensitive and more resistant to acclimation to jet aircraft noise than Canada geese. Similarly, wild ungulates seem to be more easily disturbed than domestic animals.

The literature does suggest that common responses include the “startle” or “fright” response and, ultimately, habituation. It has been reported that the intensities and durations of the startle response decrease with the numbers and frequencies of exposures, suggesting no long-term adverse effects. The majority of the literature suggests that domestic animal species (cows, horses, chickens) and wildlife species exhibit adaptation, acclimation, and habituation after repeated exposure to jet aircraft noise and sonic booms.

Animal responses to aircraft noise appear to be somewhat dependent on, or influenced by, the size, shape, speed, proximity (vertical and horizontal), engine noise, color, and flight profile of planes. Helicopters also appear to induce greater intensities and durations of disturbance behavior as compared to fixed-wing aircraft. Some studies showed that animals that had been previously exposed to jet aircraft noise exhibited greater degrees of alarm and disturbance to other objects creating noise, such as boats, people, and objects blowing across the landscape. Other factors influencing response to jet aircraft noise may include wind direction, speed, and local air turbulence; landscape structures (i.e., amount and type of vegetative cover); and, in the case of bird species, whether the animals are in the incubation/nesting phase.

E.2.10 Property Values

There are a number of factors that affect property values, which makes predicting impacts difficult. Factors directly related to the property, such as size, improvements, and location of the property, as well as current conditions in the real estate market, interest rates, and housing sales in the area are more likely to have a direct adverse impact on property values. Several studies have analyzed property values as they relate to military and civilian aircraft noise. In one study, a regression analysis of property values as they relate to aircraft noise at two military installations was conducted (Fidell et al. 1996). This study found that, while aircraft noise at these installations may have had minor impacts on property values, it was difficult to quantify that impact. Other factors such, as the quality of the housing near the installations and the local real estate market, had a larger impact on property values. Therefore, the regression analysis was not able to predict the impact of aircraft noise on the property values of two comparable properties.

Another study analyzed 33 other studies attempting to quantify the impact of noise on property values (Nelson 2003). The result of the study supports the idea that the potential for an adverse impact on property values as a result of aircraft noise exists and estimates that the value of a specific property could be discounted between 0.5 and 0.6 percent per decibel when compared to a similar property that is not impacted by aircraft noise. Additional data indicates that the discount for property values as a result of noise would be higher for noise levels above 75 dB DNL.

E.2.11 Noise Effects on Structures

E.2.11.1 Subsonic Aircraft Noise

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 one second above a sound level of 130 dB are potentially damaging to structural components (CHABA 1977). A study directed specifically at low-altitude, high-speed aircraft showed that there is little probability of structural damage from such operations (Sutherland 1989). One finding in that study is that sound levels at damaging frequencies (e.g., 30 Hz for window breakage or 15 to 25 Hz for whole-house response) 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 within the dwelling, such as hanging pictures, dishes, plaques, and bric-a-brac. Window panes 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 incompatible with residential land use. Thus assessments of noise exposure levels for compatible land use should also be protective of noise-induced secondary vibrations.

E.2.11.2 Sonic Booms

Sonic booms are commonly associated with structural damage. Most damage claims are for brittle objects, such as glass and plaster. Table E-8 summarizes the threshold of damage that might be expected at various overpressures. There is a large degree of variability in damage experience, and much 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. At 1 psf, the probability of a window breaking ranges from one in a billion (Sutherland 1989) to one in a million (Hershey and Higgins 1976). These damage rates are associated with a combination of boom load and glass condition. At 10 psf, the probability of breakage is between one in a hundred and one in a thousand. 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, but in the real world glass is not in pristine condition.

Damage to plaster occurs at similar ranges to glass damage. Plaster has a compounding issue in that it will often crack due to shrinkage while curing, or from stresses as a structure settles, even in the absence of outside loads. Sonic boom damage to plaster often occurs when internal stresses are high from these factors.

Some degree of damage to glass and plaster should thus be expected whenever there are sonic booms, but usually at the low rates noted above. In general, structural damage from sonic booms should be expected only for overpressures above 10 psf.

Table E-8. 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; more in ceilings; over door frames; 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	Those 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 show that 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, 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.

E.2.12 Noise Effects on Structure and Terrain

E.2.12.1 Subsonic Aircraft Noise

Members of the public often believe that noise from low-flying aircraft can cause avalanches or landslides by disturbing fragile soil or snow structures in mountainous areas. There are no known instances of such effects, and it is considered improbable that such effects will result from routine, subsonic aircraft operations.

E.2.12.2 Sonic Booms

In contrast to subsonic noise, sonic booms are considered to be a potential trigger for snow avalanches. Avalanches are highly dependent on the physical status of the snow, and do occur spontaneously. They can be triggered by minor disturbances, and there are documented accounts of sonic booms triggering avalanches. Switzerland routinely restricts supersonic flight during avalanche season. Landslides are not an issue for sonic booms. There was one anecdotal report of a minor landslide from a sonic boom generated by the Space Shuttle during landing, but there is no credible mechanism or consistent pattern of reports.

E.2.12.3 Noise Effects on Historical and Archaeological Sites

Because of the potential for increased fragility of structural components of historical buildings and other historical sites, aircraft noise may affect such sites more severely than newer, modern structures. Most scientific studies of the effects of noise and vibration on historic properties have considered potential impacts on standing architecture. For example, the FAA published a study of potential impacts resulting from vibrations caused by the noise of subsonic Concorde overflights on five historic properties, including a restored plantation house, a stone bridge and tollhouse, and other structures (Hershey, Kevala, and Burns 1975). This study analyzed the breakage probabilities of structural elements that might be considered susceptible to vibration, such as window glass, mortar, and plaster. The results indicated that, with the exception of some already cracked window glass, there was no practical risk of noise-induced vibration damage to any of these structures.

Some studies of the effects of overflights—both subsonic and supersonic—on archaeological structures and other types of sites also have been published. Battis examined the effects of low-altitude overflights of B-52, RF-4C, and A-7 aircraft on standing walls at Long House Ruin in northeastern Arizona (Battis 1988). The motion levels observed during all passes were well below a conservative threshold for vibration in ancient structures, a level of 1.3 millimeters per second, established by two previous studies. Battis concluded that vibration associated with aircraft overflights at speeds and altitudes similar to those measured in his study had/would have no significant damaging effect on Long House and similar sites.

Two Air Force-sponsored studies have included research into potential effects of supersonic overflight on "nonstructural" archaeology and unconventional structures. One study included historic buildings, prehistoric structures, water tanks, archaeological cave/shelter sites and rock art, and seismically sensitive areas such as avalanche and mud/rock slide areas (Sutherland, Brown, and Goerner 1990). That study compared overpressure associated with different types of aircraft in supersonic flight at different altitudes with failure or damage stress values for these types of sites. The authors concluded that overpressures generated by supersonic overflight were well below established damage thresholds. Subsonic operations—which were not included in this study—would be even less likely to cause damage.

Battis also completed a study that examined the potential for damage by sonic booms to rock shelter and petroglyph sites located within the Valentine MOA in Texas (Battis 1983). The Texas State Historic Preservation Office helped design and participated in this study, which involved taking measurements at a rock shelter site and at a field of petroglyphs-bearing boulders during supersonic overflights. The peak overpressure for booms generated during supersonic operations over the Valentine MOA was 5.2 psf. The lower limit (the least amount of pressure needed) for damaging rock was measured in the laboratory at 2.1 × 104 psf, 4,000 times the peak overpressure measured during the study.

Air Force National Environment Policy Act documents have examined the potential impacts on historic properties that might result from subsonic and supersonic overflights. In 1995, the Air Force published the Environmental Assessment for Continued Supersonic Operations in the Black Mountain Supersonic Corridor and the Alpha/Precision Impact Range Area. Eligible and potentially eligible cultural resources in the area of potential effect include petroglyph and pictograph panels located on a variety of rock types, historic adobe and non-adobe structures with standing walls, and historic mines (which contain tunnels) and wells. The report concludes that supersonic low-altitude flights have occurred over these corridors for 25 years or more and have resulted in no significant impacts on cultural resources. The California SHPO agreed, and during National Historic Preservation Act Section 106 review of this undertaking, concurred with the Air Force's finding that continued supersonic overflights would have no effect on historic properties.

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

E.3 NOISE MODELING

E.3.1 Subsonic Aircraft Noise

An aircraft in subsonic flight generally emits noise from two sources: the engines and flow noise around the airframe. Noise generation mechanisms are complex and, in practical models, the noise sources must be based on measured data. The Air Force has developed a series of computer models and aircraft noise databases for this purpose. The models include NOISEMAP (Moulton 1992) for noise around airbases, and MOA-Range NOISEMAP (MR_NMAP) (Lucas and Calamia 1996) for use in MOAs, ranges, and low-level training routes. These models use the NOISEFILE database developed by the Air Force. NOISEFILE data includes SEL and L_{max} as a function of speed and power setting for aircraft in straight flight.

Noise from an individual aircraft is a time-varying continuous sound. It is first audible as the aircraft approaches, increases to a maximum when the aircraft is near its closest point, then diminishes as it departs. The noise depends on the speed and power setting of the aircraft and its trajectory. The models noted above divide the trajectory into segments whose noise can be computed from the data in NOISEFILE. The contributions from these segments are summed.

MR_NMAP was used to compute noise levels in the airspace. The primary noise metric computed by MR_NMAP was Ldnmr averaged over each airspace. Supporting routines from NOISEMAP were used to calculate SEL and L_{max} for various flight altitudes and lateral offsets from a ground receiver position. Sound intensity at a point on the ground, is also affected by several environmental factors, such as, atmospheric conditions and properties of the terrain being overflown.

E.3.2 Sonic Booms

When an aircraft moves through the air, it pushes the air out of its way. At subsonic speeds, the displaced air forms a pressure wave that disperses rapidly. At supersonic speeds, the aircraft is moving too quickly for the wave to disperse, so it remains as a coherent wave. This wave is a sonic boom. When heard at the ground, a sonic boom consists of two shock waves (one associated with the forward part of the aircraft, the other with the rear part) of approximately equal strength and (for fighter aircraft) separated by 100 to 200 milliseconds. When plotted, this pair of shock waves and the expanding flow between them have the appearance of a capital letter "N," so a sonic boom pressure wave is usually called an "N-wave." An N-wave has a characteristic "bang-bang" sound that can be startling. Figure E-7 shows the generation and evolution of a sonic boom N-wave under the aircraft. Figure E-8 shows the sonic boom pattern for an aircraft in steady supersonic flight. The boom forms a cone that is said to sweep out a “carpet” under the flight track.

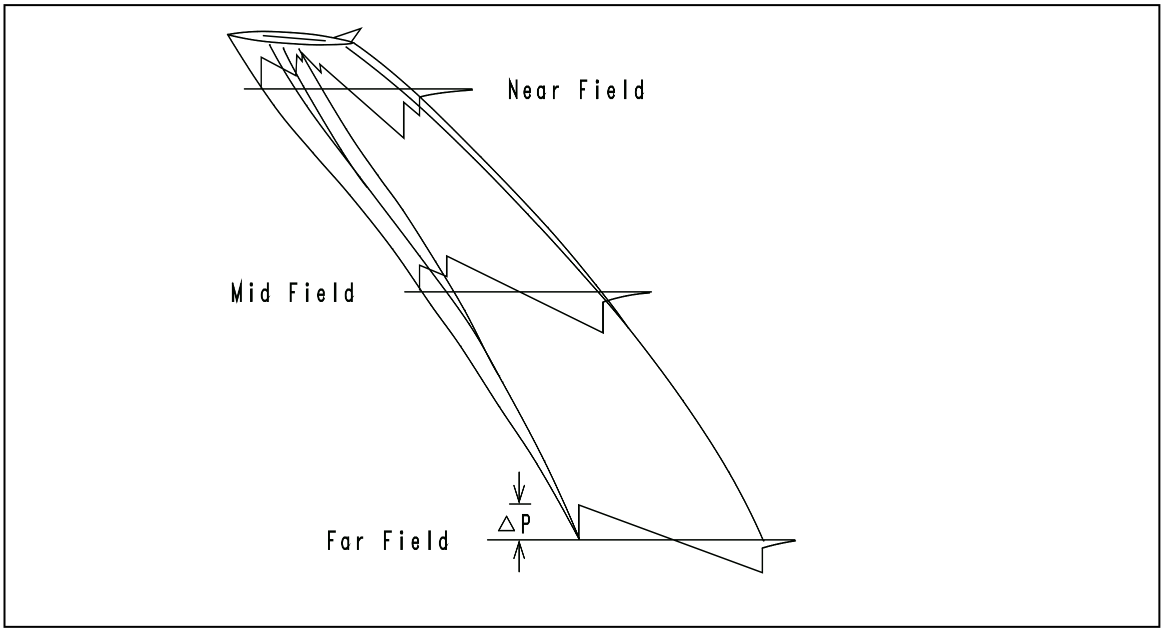


Figure E-7. Sonic Boom Generation and Evolution to N-Wave

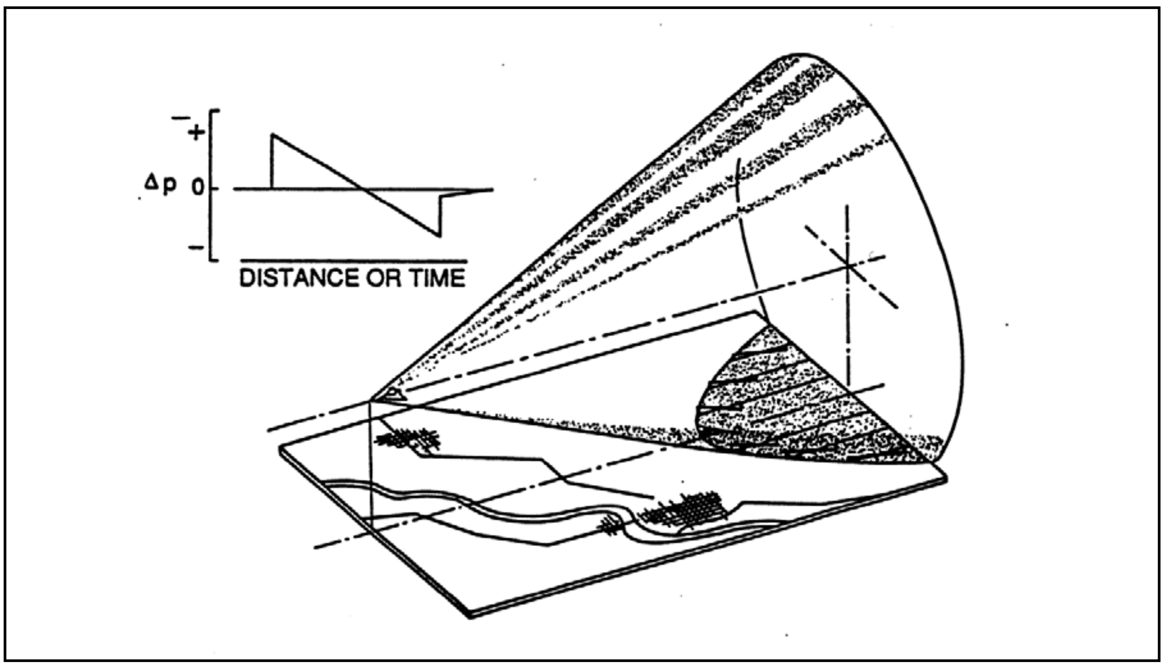


Figure E-8. Sonic Boom Carpet in Steady Flight

The complete ground pattern of a sonic boom depends on the size, shape, speed, and trajectory of the aircraft. Even for a nominally steady mission, the aircraft must accelerate to supersonic speed at the start, decelerate back to subsonic speed at the end, and usually change altitude. Figure E-9 illustrates the complexity of a nominal full mission.

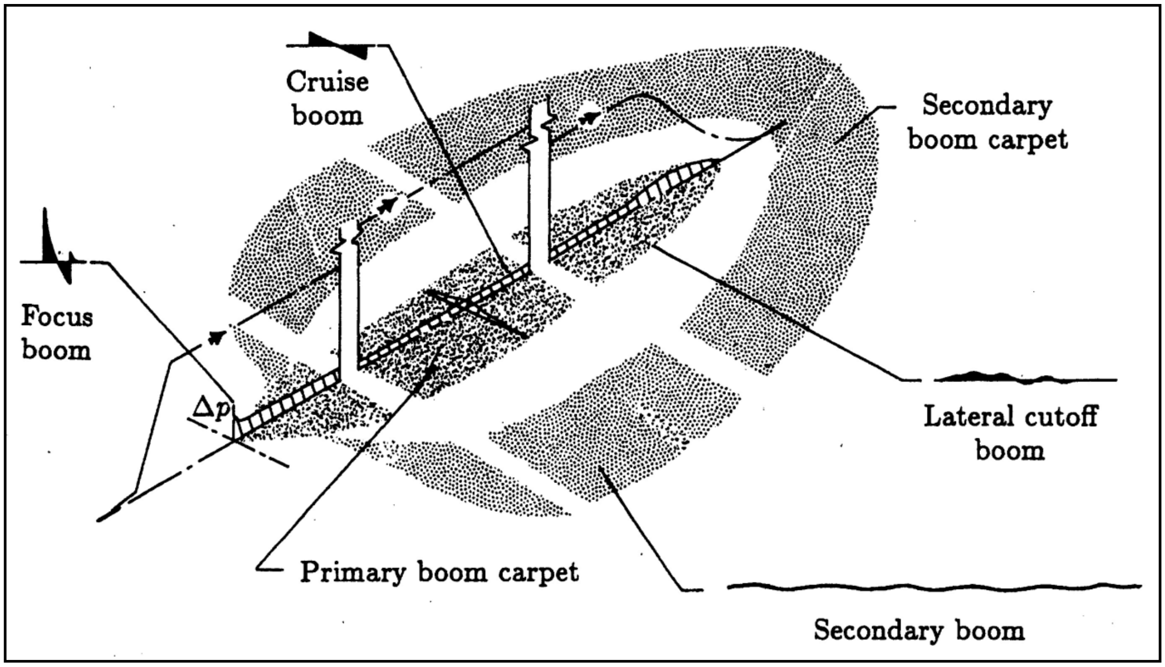


Figure E-9. Complex Sonic Boom Pattern for Full Mission

The Air Force's PCBoom4 computer program (Plotkin and Grandi 2002) can be used to compute the complete sonic boom footprint for a given single event, accounting for details of a particular maneuver.

Supersonic operations for the proposed action and alternatives are, however, associated with air combat training, which cannot be described in the deterministic manner that PCBoom4 requires. Supersonic events occur as aircraft approach an engagement, break at the end, and maneuver for advantage during the engagement. Long time cumulative sonic boom exposure, CDNL, is meaningful for this kind of environment.

Long-term sonic boom measurement projects have been conducted in four supersonic air combat training airspaces: White Sands, 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). These studies included analysis of schedule and air combat maneuvering instrumentation data and supported development of the 1992 BOOMAP model (Plotkin et al. 1992). The current version of BOOMAP (Frampton et al. 1993, Plotkin 1996) incorporates results from all four studies. Because BOOMAP is directly based on long-term measurements, it implicitly accounts for such variables as maneuvers, statistical variations in operations, atmosphere effects, and other factors.

Figure E-10 shows a sample of supersonic flight tracks measured in the air combat training airspace at White Sands (Plotkin et al. 1989). The tracks fall into an elliptical pattern aligned with preferred engagement directions in the airspace. Figure E-11 shows the CDNL contours that were fit to six months of measured booms in that airspace. The subsequent measurement programs refined the fit, and demonstrated that the elliptical maneuver area is related to the size and shape of the airspace (Frampton et al. 1993). BOOMAP quantifies the size and shape of CDNL contours, and also numbers of booms per day, in air combat training airspaces. That model was used for prediction of cumulative sonic boom exposure in this analysis.

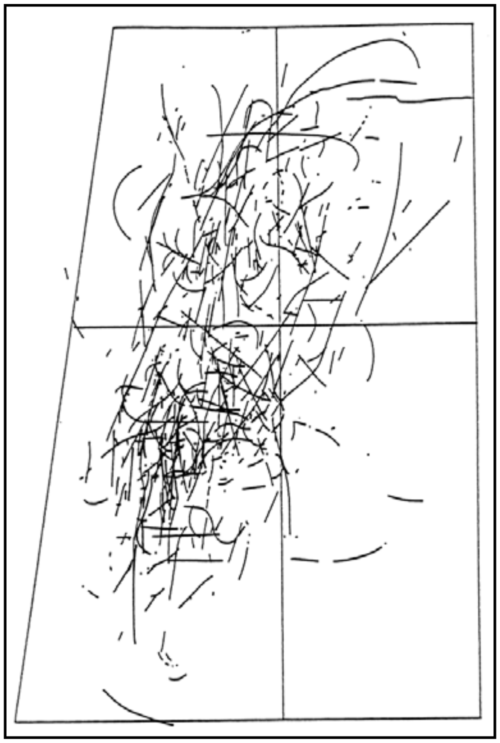


Figure E-10. Supersonic Flight Tracks in Supersonic Air Combat Training Airspace

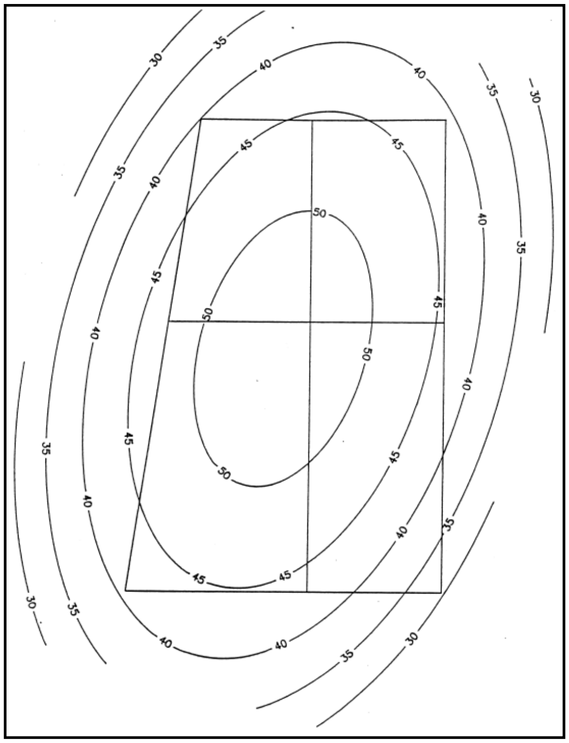


Figure E-11. Elliptical CDNL Contours in Supersonic Air Combat Training Airspace

E.3.3 Munitions Noise

The programs BNOISE2 and Small Arms Range Noise Assessment Model (SARNAM) calculate noise levels generated by large arms and small arms, respectively. Large arms are defined as being weapons firing rounds 20 mm or larger, while small arms are defined as weapons firing projectiles less than 20 mm in diameter. Both BNOISE2 and SARNAM calculate munitions noise based on recorded noise levels for several weapon and projectile types using a series of noise propagation algorithms. Calculations include the muzzle blast as well as the shockwave generated by the projectile, which often travels at faster than the speed of sound. The programs are capable of generating several noise metrics including CDNL and peak noise level.

E.4 LARGE ARMS MUNITIONS NOISE MODELING AT JPARC RANGES

The BNOISE2 noise model was used to assess large arms munitions noise levels at the DTA and YTA under baseline conditions and under several action alternatives. Munitions usage data used in noise modeling are listed in Table E-9 and Table E-10 for Donnelly Training Area/R-2202 and Yukon Training Area/R-2205, respectively. Table E-9 and Table E-10 first list numbers of round fired annually under representative baseline conditions and then list numbers of rounds that would be fired annually under action alternatives.

Representative baseline munitions data are based on reported 2010 Army and Air Force munitions usage as adjusted to reflect expected growth if no further actions are taken. The baseline numbers reflect an expected increase in the number of annual Red Flag exercises to six, the number proposed in the Alaska MOA EIS (Air Force 1997). The tables below also reflect a conservative estimate of increased munitions usage by Army units once all unit beddown actions are complete.

Table E-9. Munitions Usage at DTA Under Baseline Conditions and Action Alternatives

Donnelly Training Area/R-2202 Noise Modeling Inputs			Baseline		BAX Restricted Area – Alternatives A and B		RLOD – Alternatives A and B
			Rounds used in the DTA	Rounds used in the BAX	Rounds used in the DTA	Rounds used in the BAX	Rounds used in R-2202
Air-to-Ground	Cannon	20 mm (IN)	3,388	0	0	3,388	3,388
Air-to-Ground	Cannon	20 mm (HE)	9,788	0	9,788	0	9,788
Air-to-Ground	Cannon	25 mm (IN)	0	0	0	0	0
Air-to-Ground	Cannon	25 mm (HE)	4,788	0	4,788	0	4,788
Air-to-Ground	Cannon	30 mm (IN)	0	0	0	1600	0
Air-to-Ground	Cannon	30 mm (HE)	22,063	0	22,063	0	22,063
Air-to-Ground	Missile/ Rocket	2.75" FFAR (IN)	99	0	99	0	99
Air-to-Ground	Missile/ Rocket	2.75" FFAR (HE)	244	0	4	240	244
Air-to-Ground	Missile/ Rocket	AGM-65 (HE)	60	0	60	0	60
Air-to-Ground	Missile/ Rocket	AGM-65 (IN)	26	0	8	18	26
Air-to-Ground	Inert Bombs	BDU-33 (45 lb)	334	0	334	0	334
Air-to-Ground	Inert Bombs	BDU-45 (500 lb)	64	0	64	0	64
Air-to-Ground	Inert Bombs	BDU-50 (500 lb)	150	0	150	0	150
Air-to-Ground	Inert Bombs	BDU-56 (2,000 lb)	113	0	113	0	113
Air-to-Ground	Inert Bombs	GBU-10 (2,000 lb)	123	0	123	0	123
Air-to-Ground	Inert Bombs	GBU-12 (500 lb)	76	0	76	0	76
Air-to-Ground	Inert Bombs	GBU-16 (1,000 lb)	44	0	44	0	44
Air-to-Ground	Inert Bombs	GBU-24 (2,000 lb)	49	0	49	0	49
Air-to-Ground	Inert Bombs	GBU-30 (500 lb)	1	0	1	0	1
Air-to-Ground	Inert Bombs	GBU-31 (2,000 lb)	40	0	40	0	40
Air-to-Ground	Inert Bombs	GBU-32 (1,000 lb)	26	0	26	0	26
Air-to-Ground	Inert Bombs	GBU-38 (500 lb)	125	0	125	0	125
Air-to-Ground	Inert Bombs	Mark-83 (1,000 lb)	9	0	9	0	9
Air-to-Ground (Continued)	Live Bombs	SDB (250 lb)	200	0	200	0	200
Air-to-Ground (Continued)	Live Bombs	GBU-12 (500 lb)	76	0	76	0	76
Air-to-Ground (Continued)	Live Bombs	GBU-31 (2,000 lb)	25	0	25	0	25
Air-to-Ground (Continued)	Live Bombs	GBU-32 (1,000 lb)	70	0	70	0	200
Air-to-Ground (Continued)	Live Bombs	GBU-38 (500 lb)	38	0	38	0	38
Air-to-Ground (Continued)	Live Bombs	Mark-82 (500 lb)	243	0	243	0	243
Air-to-Ground (Continued)	Live Bombs	Mark-83 (1,000 lb)	125	0	125	0	125
Air-to-Ground (Continued)	Live Bombs	Mark-84 (2,000 lb)	40	0	40	0	40
Ground-to-Ground	Mortars	60 mm (IN)	922	0	135	787	922
Ground-to-Ground	Mortars	60 mm (HE)	486	0	486	0	486
Ground-to-Ground	Mortars	81 mm (IN)	459	0	0	459	459
Ground-to-Ground	Mortars	81 mm (HE)	218	0	218	0	218
Ground-to-Ground	Mortars	120 mm (IN)	1,197	0	48	1,149	1,197
Ground-to-Ground	Mortars	120 mm (HE)	779	0	779	0	779
Ground-to-Ground	Artillery	105 mm (IN)	161	0	0	161	161
Ground-to-Ground	Artillery	105 mm (HE)	2,635	0	2,635	0	2,635
Ground-to-Ground	Artillery	155 mm (IN)	117	0	0	117	117
Ground-to-Ground	Artillery	155 mm (HE)	1,615	0	1,615	0	1,615
Ground-to-Ground	Other	TOW missile (IN)	9	0	3	6	9
Ground-to-Ground	Other	AT4 rocket (HE)	50	0	50	0	50
Ground-to-Ground	Other	Dragon Missile (HE)	1	0	1	0	1
Ground-to-Ground	Other	MLRS (IN)	2	0	2	0	2
Ground-to-Ground	Other	Stryker 105 mm (IN)	502	3,186	502	3,186	3,688
Ground-to-Ground	Other	Abrams 120 mm (HE)	8	0	8	0	8
Explosive Charges	Black Powder	0.139 lb charge	1,617	0	1,617	0	1,617
Explosive Charges	Black Powder	0.055 lb charge	16	0	16	0	16
Explosive Charges	Black Powder	0.110 lb charge	330	0	330	0	330
Explosive Charges	Black Powder	0.088 lb charge	1,044	0	1,044	0	1,044
Explosive Charges	C-4	1.25 lb charge	2,012	0	2,012	0	2,012

Table E-10. Munitions Usage at YTA Under Baseline Conditions and Action Alternatives

Yukon Training Area/R-2205 Noise Modeling Inputs			Baseline		R-2205 Expansion – Alternative A	
			Rounds used in the YTA	Rounds used in the DMPTR	Rounds used in the YTA	Rounds used in the DMPTR
Air-to-Ground	Cannon	20 mm (IN)	9,144	0	0	9,144
Air-to-Ground	Cannon	20 mm (HE)	23,113	0	23,113	0
Air-to-Ground	Cannon	25 mm (IN)	750	0	225	525
Air-to-Ground	Cannon	25 mm (HE)	75	0	75	0
Air-to-Ground	Cannon	30 mm (IN)	28,950	0	5,675	23,275
Air-to-Ground	Cannon	30 mm (HE)	4,300	0	4,300	0
Air-to-Ground	Missile/ Rocket	2.75” FFAR (IN)	1,540	0	462	1,078
Air-to-Ground	Missile/ Rocket	2.75” FFAR (HE)	118	0	118	0
Air-to-Ground	Missile/ Rocket	AGM-65 (HE)	0	0	0	0
Air-to-Ground	Missile/ Rocket	AGM-65 (IN)	0	0	0	0
Air-to-Ground (Continued)	Inert Bombs	BDU-33 (45 lb)	784	0	784	0
Air-to-Ground (Continued)	Inert Bombs	BDU-45 (500 lb)	34	0	34	0
Air-to-Ground (Continued)	Inert Bombs	BDU-50 (500 lb)	248	0	248	0
Air-to-Ground (Continued)	Inert Bombs	BDU-56 (2,000 lb)	95	0	95	0
Air-to-Ground (Continued)	Inert Bombs	GBU-10 (2,000 lb)	3	0	3	0
Air-to-Ground (Continued)	Inert Bombs	GBU-12 (500 lb)	156	0	156	0
Air-to-Ground (Continued)	Inert Bombs	GBU-16 (1,000 lb)	5	0	5	0
Air-to-Ground (Continued)	Inert Bombs	GBU-24 (2,000 lb)	0	0	0	0
Air-to-Ground (Continued)	Inert Bombs	GBU-30 (500 lb)	0	0	0	0
Air-to-Ground (Continued)	Inert Bombs	GBU-31 (2,000 lb)	15	0	15	0
Air-to-Ground (Continued)	Inert Bombs	GBU-32 (1,000 lb)	0	0	0	0
Air-to-Ground (Continued)	Inert Bombs	GBU-38 (500 lb)	9	0	9	0
Air-to-Ground (Continued)	Inert Bombs	Mark-83 (1,000 lb)	0	0	0	0
Air-to-Ground (Continued)	Live Bombs	SDB (250 lb)	0	0	0	0
Air-to-Ground (Continued)	Live Bombs	GBU-12 (500 lb)	33	0	33	0
Air-to-Ground (Continued)	Live Bombs	GBU-31 (2,000 lb)	0	0	0	0
Air-to-Ground (Continued)	Live Bombs	GBU-32 (1,000 lb)	0	0	0	0
Air-to-Ground (Continued)	Live Bombs	GBU-38 (500 lb)	0	0	0	0
Air-to-Ground (Continued)	Live Bombs	Mark-82 (500 lb)	531	0	531	0
Air-to-Ground (Continued)	Live Bombs	Mark-83 (1,000 lb)	20	0	20	0
Air-to-Ground (Continued)	Live Bombs	Mark-84 (2,000 lb)	45	0	45	0
Ground-to-Ground	Mortars	60 mm (IN)	2,048	0	140	1,908
Ground-to-Ground	Mortars	60 mm (HE)	1,244	0	1,244	0
Ground-to-Ground	Mortars	81 mm (IN)	1,979	0	365	1,614
Ground-to-Ground	Mortars	81 mm (HE)	327	0	327	0
Ground-to-Ground	Mortars	120 mm (IN)	3,532	0	296	3,236
Ground-to-Ground	Mortars	120 mm (HE)	1,091	0	1,091	0
Ground-to-Ground, Cont’d	Artillery	105 mm (IN)	0	0	0	0
Ground-to-Ground, Cont’d	Artillery	105 mm (HE)	0	0	0	0
Ground-to-Ground, Cont’d	Artillery	155 mm (IN)	361	0	0	361
Ground-to-Ground, Cont’d	Artillery	155 mm (HE)	2,160	0	2,160	0
Ground-to-Ground, Cont’d	Artillery	165 mm M135 (HE)	89	0	89	0
Ground-to-Ground, Cont’d	Other	TOW missile (IN)	0	0	0	0
Ground-to-Ground, Cont’d	Other	AT4 rocket (HE)	0	0	0	0
Ground-to-Ground, Cont’d	Other	Dragon Missile (HE)	0	0	0	0
Ground-to-Ground, Cont’d	Other	MLRS (IN)	0	0	0	0
Ground-to-Ground, Cont’d	Other	Stryker 105 mm (IN)	0	4,880	0	4,880
Ground-to-Ground, Cont’d	Other	Abrams 120 mm (HE)	187	0	187	0
Ground-to-Ground, Cont’d	Other	C-4 1.25 lb charge	180	0	180	0

Key: AGM=air-to-ground missile; BAX=battle area complex; BDU=bomb dummy unit; DMPTR=digital multipurpose training range; DTA=Donnelly Training Area; FFAR=folding fin aerial rocket; GBU=guided bomb unit; HE=high explosive; IN=inert; JCALF=joint combined arms live fire; lb=pounds; MLRS=multiple launch rocket system; mm-millimeter; RLOD=realistic live ordnance delivery; SDB=small diameter bomb; TOW=tube-launched, optically-tracked, wire command data link; YTA= Yukon Training Area

Table E-9 and Table E-10 list munitions usage for each action alternative that would alter the number or location of munitions firing. Under both BAX Restricted Area action alternatives, certain inert munitions types that had not been permitted under baseline conditions would now be permitted at the BAX because of the presence of restricted airspace. An estimated 70 percent of the baseline inert munitions used annually of those type newly permitted was modeled as shifting from DTA to the BAX under the BAX action alternatives. Under the RLOD action alternatives, the number of air-to-ground munitions used annually would increase relative to baseline conditions. Only inert munitions are permitted at Blair Lakes Range and therefore, under both RLOD action alternatives, all high-explosive munitions would be used at DTA. Under the proposal to expand R-2205, inert munitions types that had not been permitted at the DMPTR under baseline conditions would be permitted. Similar to the BAX Restricted Area proposal, an estimated 70 percent of baseline inert munitions used annually was modeled as shifting to the DMPTR from other YTA ranges.

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