NOISE SUPPORTING DOCUMENTATION

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ACRONYMS AND ABBREVIATIONS

ACEL	A-weighted sound exposure level
AGL	above ground level
ANSI	American National Standards Institute
CDNL or L_{Cdn}	C-weighted day-night average noise level
CHABA	Committee on Hearing, Bioacoustics, and Biomechanics
CNEL	Community Noise Equivalent Level
dB	decibels
dBA	A-weighted decibels
DAF	Department of the Air Force
DLR	German Aerospace Center
DNL	day-night average sound level
DoD	Department of Defense
EPA	U.S. Environmental Protection Agency
FAA	Federal Aviation Administration
FICAN	Federal Interagency Committee on Aviation Noise
FICON	Federal Interagency Committee on Noise
Hz	Hertz
HYENA	Hypertension and Exposure to Noise Near Airports
L	Threshold level
L_{dn}	day-night average sound level (symbol)
L_{dnmr}	onset-rate adjusted monthly day-night average sound level
L_{eq}	equivalent noise level
$L_{eq(h)}$	hourly equivalent noise levels
$L_{eq(24)}$	24-hour equivalent noise level
L_{max}	maximum noise level
L_{pk}	peak sound pressure level
MOA	Military Operating Area
MTR	Military Training Route
NA	Number-of-events above
NDI	Noise Depreciation Index
NIOSH	National Institute for Occupational Safety and Health
OR	odds ratio
PK_{15}(met)	peak noise exceeded by 15 percent of firing events
PTS	permanent threshold shift
RANCH	Road Traffic and Aircraft Noise Exposure and Children's Cognition and Health
SEL	sound exposure level
SIL	speech interference level
SUA	Special Use Airspace
TA	time-above

TTS	temporary threshold shift
U.S.	United States
USFWS	U.S. Fish and Wildlife Service
WHO	World Health Organization

1.0 NOISE SUPPORTING INFORMATION

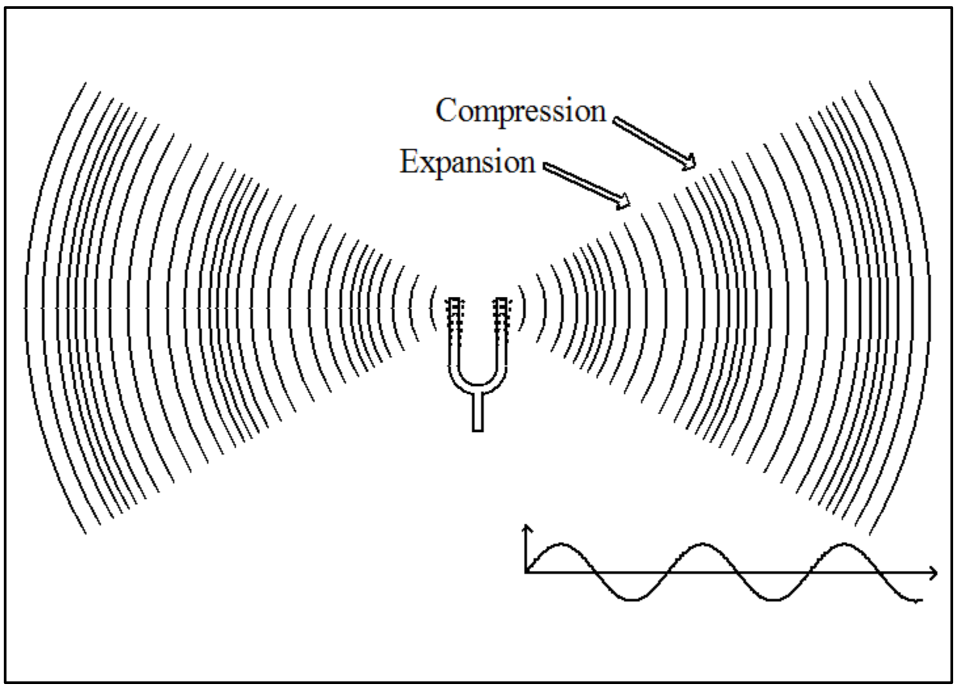
This document describes sound and noise potential effects on the human and natural environment and includes analyses of the potential effects of noise, focusing on effects on humans and addressing effects on property values, terrain, structures, and animals.

1.1 BASICS OF SOUND

The following three subsections describe sound waves and decibels (dB), sounds levels and types of sounds, and workplace noise.

1.1.1 Sound Waves and Decibels

Sound consists of minute vibrations that travel through the air and are sensed by the human ear. Figure 1 is a sketch of sound waves from a tuning fork. The waves move outward as a series of crests where the air is compressed and troughs where the air is expanded. The height of the crests and the depth of the troughs are the amplitude, or sound pressure, of the wave. The pressure determines its energy, or intensity. The number of crests or troughs that pass a given point each second is called the frequency of the sound wave.



Source: (Wyle Laboratories, 1970))

Figure 1. Sound Waves from a Vibrating Tuning Fork

The measurement and human perception of sound involves three basic physical characteristics: intensity, frequency, and duration.

- *Intensity* is a measure of the acoustic energy of the sound and is related to sound pressure. The greater the sound pressure, the more energy carried by the sound and the louder the perception of that sound.

- *Frequency* determines how the pitch of the sound is perceived. Low-frequency sounds are characterized as rumbles or roars, while high-frequency sounds are typified by sirens or screeches.
- *Duration* is the length of time the sound can be detected.

As shown in Figure 1, the sound from a tuning fork spreads out uniformly as it travels from the source. The spreading causes the sound's intensity to decrease with increasing distance from the source. For a source such as an aircraft in flight, the sound level will decrease by approximately 6 dB for every doubling of the distance. For a busy highway, the sound level will decrease by 3 to 4.5 dB for every doubling of distance.

As sound travels from the source, the air absorbs the sound. The amount of absorption depends on the frequency composition of the sound, the temperature, and the level of humidity. High-frequency sound is absorbed more in colder and drier conditions than in hot and wet conditions. Sound is also affected by wind and temperature gradients, terrain (elevation and ground cover), and structures.

The loudest sounds that can be comfortably heard by the human ear have intensities a trillion times higher than those of sounds barely heard. Because of this vast range, it is unwieldy to use a linear scale to represent the intensity of sound. As a result, a logarithmic unit known as the dB is used to represent the intensity of a sound. Such a representation is called a sound level. A sound level of 0 dB is approximately the threshold of human hearing and is barely audible under extremely quiet listening conditions. Normal speech has a sound level of approximately 60 dB. Sound levels greater than 120 dB begin to be felt inside the human ear as discomfort. Sound levels between 130 and 140 dB are felt as pain (Berglund and Lindvall, 1995).

Because of the logarithmic nature of the dB unit, sound levels cannot simply be added or subtracted and are somewhat cumbersome to handle mathematically. However, some simple rules 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. For example:

$$60 \text{ dB} + 60 \text{ dB} = 63 \text{ dB}$$

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

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

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

Because the addition of sound levels is different than that of ordinary numbers, this process is often referred to as "decibel addition."

The minimum change in the sound level of individual events that an average human ear can detect is approximately 3 dB. On average, a person perceives a change in sound level of approximately 10 dB as a doubling (or halving) of the sound's loudness. This relation holds true for loud and quiet 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 the human ear does not respond linearly.

Sound frequency is measured in terms of cycles per second or hertz (Hz). The normal ear of a young person can detect sounds that range in frequency from approximately 20 to 20,000 Hz. As a person ages, the ability to hear high-frequency sounds is lost. Not all sounds in this wide range of frequencies are heard equally. Human hearing is most sensitive to frequencies in the 1,000- to 4,000-Hz range. The notes on a piano range from just over 27 to 4,186 Hz, with middle C equal to 261.6 Hz. Most sounds (including a single note on a piano) are not simple pure tones like the tuning fork in Figure 1 but contain a mix, or spectrum, of many frequencies.

Sounds with different spectra are perceived differently even if the sound levels are the same. Weighting curves have been developed to correspond to the sensitivity and perception of different types of sound. A-weighting and C-weighting are the two most common weightings. A-weighting puts emphasis on the 1,000- to 4,000-Hz range.

1.1.2 Sound Levels and Types of Sound

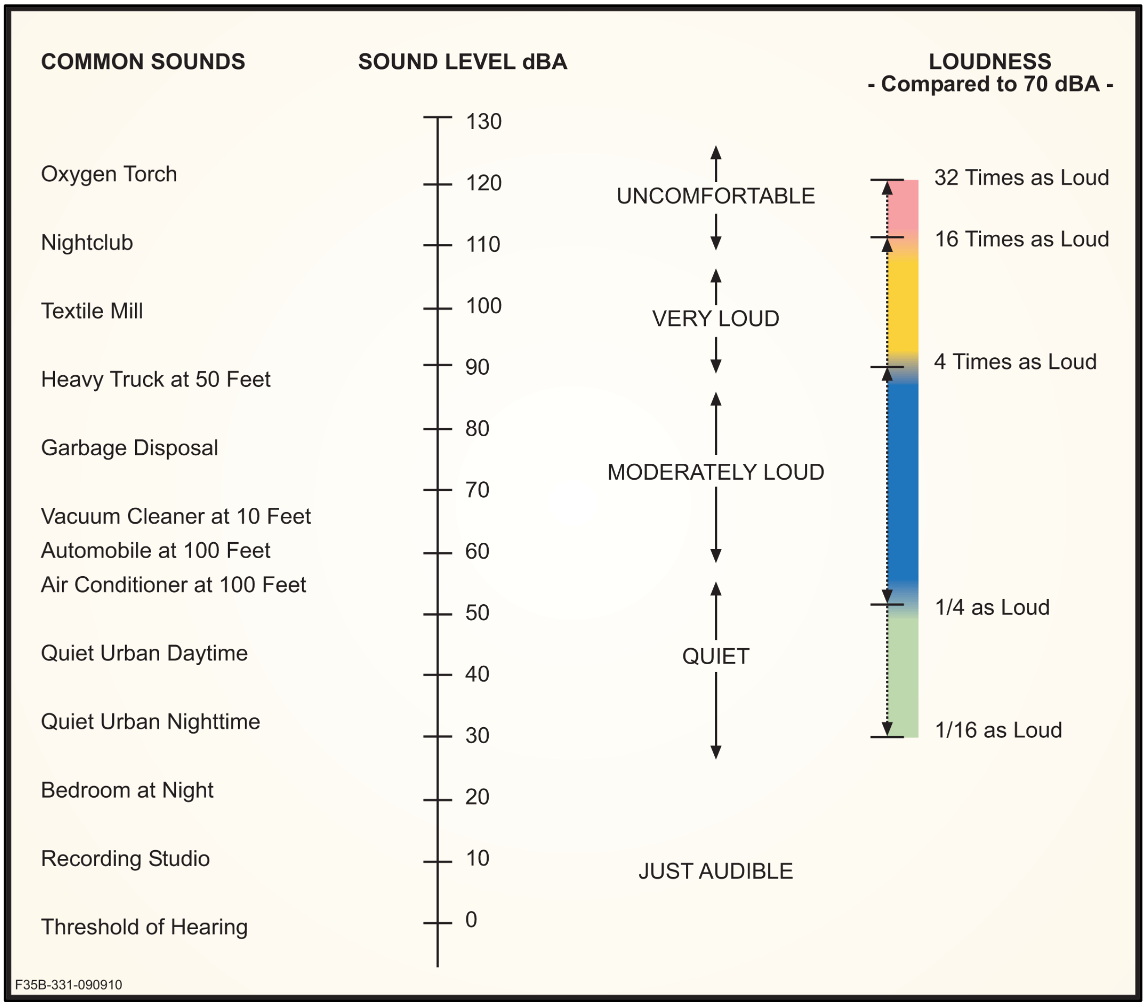
Most environmental sounds are measured using A-weighting. These sounds are measured in A-weighted decibels (dBA), and sometimes the unit dBA or dB(A) is denoted rather than dB. When the use of A-weighting is understood, the term "A-weighted" is often omitted and the unit dB is used. Unless otherwise stated, dB units refer to dBA.

Sound becomes noise when it is unwelcome and interferes with normal activities, such as sleep or conversation. Noise is unwanted sound. Noise can become an issue when its level exceeds the ambient or background sound level. Ambient noise in urban areas typically varies from 60 to 70 dB but can be as high as 80 dB in the center of a large city. Quiet suburban neighborhoods experience ambient noise levels around 45 to 50 dB (U.S. Environmental Protection Agency [EPA], 1978).

Figure 2 shows dBA levels from common noise sources. Some sources, like an air conditioner and vacuum cleaner, are continuous sounds with levels that are constant for some time. Other sources, like the automobile and heavy truck, are the maximum sound during an intermittent event like a vehicle pass-by. Some sources, like "urban daytime" and "urban nighttime," are averages over extended periods. A variety of noise metrics have been developed to describe noise over different time periods. These are detailed in Section 1.2.

Aircraft noise consists of two major types of sound events: flight (including takeoffs, landings, and flyovers) and stationary, such as engine maintenance run-ups. The former is intermittent and the latter primarily continuous. Noise from aircraft overflights typically occurs beneath main approach and departure paths, in local air traffic patterns around the airfield, and in areas near aircraft parking ramps and staging areas. As aircraft climb, the noise received on the ground drops to lower levels, eventually fading into the background or ambient levels.

Impulsive noises are generally short, loud events. Their single-event duration is usually less than one second. Examples of impulsive noises are small-arms gunfire, hammering, pile driving, metal impacts during rail yard shunting operations, and riveting. Examples of high-energy impulsive sounds are quarry/mining explosions, demolition, and industrial processes that use high explosives, military ordnance (e.g., armor, artillery and mortar fire, and bombs), explosive ignition of rockets and missiles, and any other explosive source where the equivalent mass of dynamite exceeds 25 grams (American National Standards Institute [ANSI], 1996).



Sources: (Harris, 1979; Federal Interagency Committee on Aviation Noise [FICAN], 1997).

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

1.1.3 Workplace Noise

In 1972, the National Institute for Occupational Safety and Health (NIOSH) published a criteria document with a recommended exposure limit of 85 dB as an eight-hour time-weighted average. This exposure limit was reevaluated in 1998 when NIOSH made recommendations that went beyond conserving hearing by focusing on the prevention of occupational hearing loss (NIOSH, 1998). Following the reevaluation, using a new risk assessment technique, NIOSH published another criteria document in 1998 that reaffirmed the 85-dB recommended exposure limit (NIOSH, 1998). Active-duty and reserve components of the Department of the Air Force (DAF) as well as civilian employees and contracted personnel working on DAF bases must comply with Department of the Air Force Instruction (DAFI) 48-127, *Occupational Noise and Hearing Conservation Program*, Department of Defense (DoD) Instruction 6055.12, *DoD Hearing Conservation Program*, and Title 29 of the Code of Federal Regulations Section 1910.95, *Occupational Noise Exposure*. Per DAFI 48-127, the Hearing Conservation Program is designed to protect workers from the harmful effects of hazardous noise by identifying all areas where workers are exposed to hazardous noise. The following are main components of the program:

- Identify noise hazardous areas or sources and ensure these areas are clearly marked.
- Use engineering controls as the primary means of eliminating personnel exposure to potentially hazardous noise. All practical design approaches to reduce noise levels to below hazardous levels by engineering principles shall be explored. Priorities for noise control resources shall be assigned based on the applicable risk assessment code. Where engineering controls are undertaken, the design objective shall be to reduce steady-state levels to less than 85 dBA, regardless of personnel exposure time, and to reduce impulse noise levels to less than 140 dB peak sound pressure level (L_{pk}).
- Ensure workers with an occupational exposure to hazardous noise complete an initial/reference audiogram within 30 days from the date of the workers' initial exposure to hazardous noise.
- Ensure new equipment being considered for purchase has the lowest sound emission levels that are technologically and economically possible and compatible with performance and environmental requirements; Title 42 United States Code Section 4914, *Public Health and Welfare, Noise Control, Development of Low-Noise Emission Products*, applies.
- Education and training regarding potentially noise-hazardous areas and sources, use and care of hearing-protective devices, the effects of noise on hearing, and the Hearing Conservation Program.

1.2 NOISE METRICS

Noise metrics quantify sounds so they can be compared with each other, and with their effects, in a standard way. The simplest metric is the A-weighted level, which is appropriate by itself for constant noise such as an air conditioner. Aircraft noise varies with time. During an aircraft overflight, noise starts at the background level, rises to a maximum level as the aircraft flies close to the observer, then returns to the background as the aircraft recedes into the distance. This is shown in Figure 3, which also indicates two metrics (i.e., maximum noise level [L_{max}] and sound exposure level [SEL]) that are described below. Over time, there can be a number of events, which are not all the same.

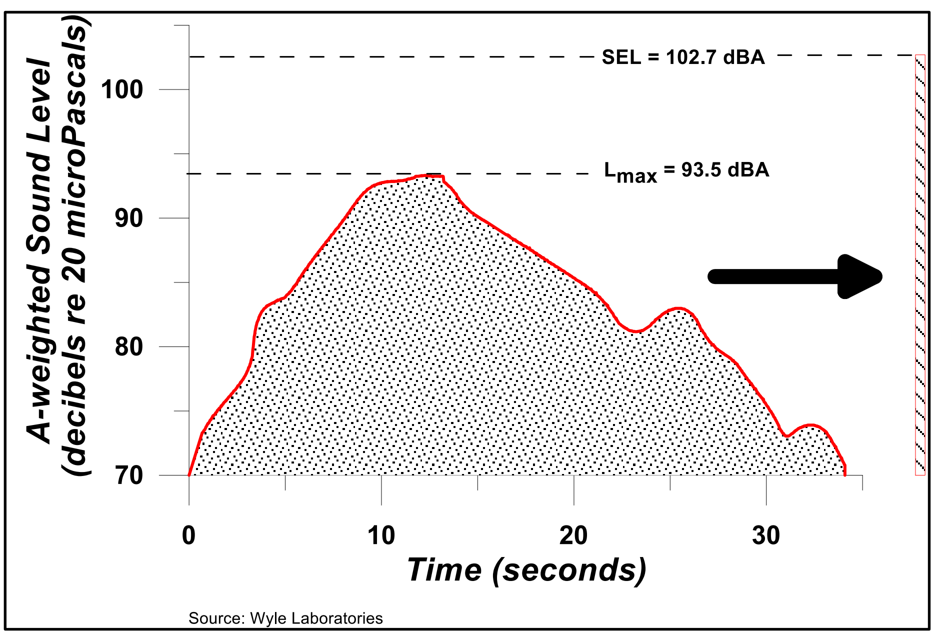


Figure 3. Example Time History of Aircraft Noise Flyover

There are a number of metrics that can be used to describe a range of situations, from a particular individual event to the cumulative effect of all noise events over a long time. This section describes the metrics relevant to environmental noise analysis.

1.2.1 Single Events

1.2.1.1 Maximum Noise Level

The highest dBA measured during a single event in which the sound changes with time is called the maximum sound level (L_{max}). The L_{max} is depicted for a sample event in Figure 3.

The L_{max} is the maximum level that occurs over a fraction of a second. For aircraft noise, the "fraction of a second" is one-eighth of a second, denoted as "fast" response on a sound level measuring meter (ANSI, 2013). Slowly varying or steady sounds are generally measured over one second, denoted "slow" response. L_{max} is important in judging if a noise event will interfere with conversation, TV or radio listening, or other common activities. Although it provides some measure of the event, it does not fully describe the noise, because it does not account for how long the sound is heard. Table 1 reflects L_{max} values for common aircraft types operating at the indicated flight profiles and power settings.

Table 1. Representative Instantaneous L_{max}[a]

Aircraft (Engine Type)	Power Setting	Power Unit	L_{max} (in dBA) at Varying Altitudes (in Feet)				
			500	1,000	2,000	5,000	10,000
Takeoff/Departure Operations[b]							
A-10A	6,200	NF RPM	100	92	82	68	58
B-1	97.5%	RPM	113	105	97	84	72
F-15 (PW220)	90%	NC RPM	111	104	97	85	75
F-16 (PW229)	93%	NC RPM	114	106	98	86	76
F-22	100%	ETR	120	112	105	93	83
F-35A	100%	ETR	119	111	103	91	81
Landing/Arrival Operations[c]							
A-10A	5,225	NF RPM	97	89	79	60	46
B-1	90%	RPM	104	97	89	76	65
F-15 (PW220)	75%	NC RPM	91	84	77	65	56
F-16 (PW229)	83.5%	NC RPM	93	86	78	66	56
F-22	43%	ETR	111	104	96	84	73
F-35A	40%	ETR	100	93	85	73	62

[a] Power settings indicated may not be comparable across aircraft, all numbers are rounded, and power settings are typical but not constant for departure/arrival operations.
[b] All departure aircraft modeled without afterburner.
[c] All landing/arrival aircraft modeled with "parallel-interpolation" power setting for gear down configuration (unless otherwise noted).
Key: % = percent; dBA = A-weighted decibels; ETR = engine thrust request; L_{max} = maximum sound level; NC = engine core; NF = engine fan; RPM = revolutions per minute

Source: SELCALC3 using standard weather conditions of 59 degrees Fahrenheit and 70 percent relative humidity.

1.2.1.2 Peak Sound Pressure Level

The L_{pk} is the highest instantaneous level measured by a sound level measurement meter. The L_{pk} is typically measured every 20 microseconds and usually based on unweighted or linear response of the meter. A- or C-weighting is not applied. It is used to describe individual impulsive events such as sonic boom and blast noise. Because blast noise varies from shot to shot and varies with meteorological (weather) conditions, the DoD usually characterizes L_{pk} by the metric PK_{15}(met), which is the L_{pk} exceeded

15 percent of the time. The "met" notation refers to the metric accounting for varied meteorological or weather conditions.

1.2.1.3 Sound Exposure Level

The SEL combines both the intensity of a sound and its duration. For an aircraft flyover, the SEL includes the maximum and all lower noise levels produced as part of the overflight, together with how long each part lasts. It represents the total sound energy in the event. Figure 3 indicates the SEL for an example event, representing it as if all the sound energy were contained within one second.

Because aircraft noise events last more than a few seconds, the SEL value is larger than L_{max}. It does not directly represent the sound level heard at any given time but rather the entire event. The SEL provides a much better measure of aircraft flyover noise exposure than L_{max} alone. Table 2 shows SEL values corresponding to the aircraft and power settings reflected in Table 1.

Table 2. Representative Sound Exposure Level[a]

Aircraft (Engine Type)	Power Setting	Power Unit	SEL (in dBA) at Varying Altitudes (in Feet)				
			500	1,000	2,000	5,000	10,000
Takeoff/Departure Operations[b, c]							
A-10A	6,200	NF RPM	105	99	91	80	71
B-1	97.5%	RPM	119	113	106	96	86
F-15 (PW220)	90%	NC RPM	120	115	109	100	91
F-16 (PW229)	93%	NC RPM	119	114	107	98	89
F-22	100%	ETR	127	121	115	106	98
F-35A	100%	ETR	125	119	113	103	95
Landing/Arrival Operations[d]							
A-10A	5,225	NF RPM	98	92	83	67	55
B-1	90%	RPM	111	105	98	88	79
F-15 (PW220)	75%	NC RPM	99	94	88	79	71
F-16 (PW229)	83.5%	NC RPM	97	92	86	77	68
F-22	43%	ETR	115	109	103	94	85
F-35A	40%	ETR	107	102	95	86	76

[a] Power settings indicated may not be comparable across aircraft, that all numbers are rounded, and power settings are typical but not constant for departure/arrival operations.
[b] Takeoff/departure modeled at 160 knots airspeed for SEL purposes.
[c] All departure aircraft modeled without afterburner.
[d] All landing/arrival aircraft modeled at 160 knots airspeed for SEL purposes.
Key: % = percent; dBA = A-weighted decibels; ETR = engine thrust request; NC = engine core; NF = engine fan; RPM = revolution(s) per minute; SEL = sound exposure level
Source: SELCALC3 using standard weather conditions of 59 degrees Fahrenheit and 70 percent relative humidity.

1.2.2 Cumulative Events

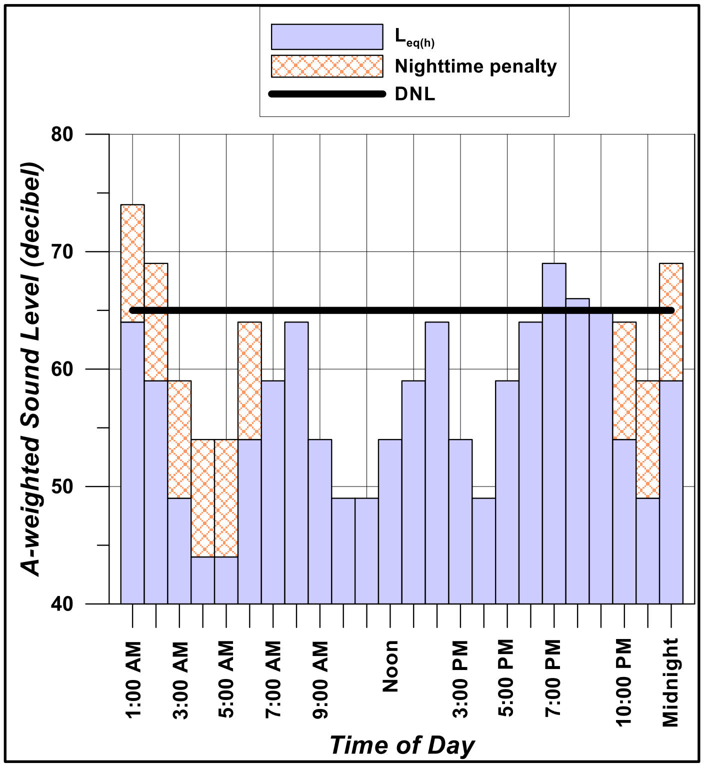
1.2.2.1 Equivalent Noise Level

Equivalent noise level (L_{eq}) is a "cumulative" metric that combines a series of noise events over a period of time. L_{eq} is the sound level that represents the dB average SEL of all sounds in the time period. Just as the SEL has proven to be a good measure of a single event, L_{eq} has proven to be a good measure of series of events during a given time period.

The time period of an L_{eq} measurement is usually related to some activity and is given along with the value. The time period is often shown in parenthesis (e.g., 24-hour equivalent noise level [$L_{eq(24)}$]). The

L_{eq} from 7:00 a.m. to 3:00 p.m., which can be denoted as $L_{eq(SD)}$, describes exposure to noise during a typical 8-hour school day.

An example of $L_{eq(24)}$ using notional hourly equivalent noise levels ($L_{eq(h)}$) for each hour of the day as an example is shown in Figure 4. The $L_{eq(24)}$ for this example is 61 dB.



Source: (Wyle Laboratories)

Figure 4. Example of $L_{eq(24)}$, Day-Night Average Sound Level Computed from Hourly Equivalent Sound Levels

1.2.2.2 Day-Night Average Sound Level

Day-night average sound level (DNL) (with the mathematical symbol for DNL denoted L_{dn}) is a cumulative metric that accounts for all noise events in a 24-hour period. However, unlike $L_{eq(24)}$, DNL contains a nighttime noise penalty. To account for our increased sensitivity to noise at night, DNL applies a 10-dB penalty to events during the nighttime period, defined as 10:00 p.m. to 7:00 a.m. The notations DNL and L_{dn} are both used for DNL and are equivalent.

For airports and military airfields outside of California, DNL represents the average sound level for annual average daily aircraft events. An example of DNL using notional $L_{eq(h)}$ for each hour of the day as an example is shown in Figure 4. Note the $L_{eq(h)}$ for the hours between 10:00 p.m. and 7:00 a.m. have a 10-dB penalty assigned. A graphical representation comparing DNL to SEL is provided in Figure 5. The DNL for this example is 65 dB. The ranges of DNL that occur in various types of communities are shown in Figure 6. Under a flight path at a major airport, the DNL may exceed 80 dB, while rural areas may experience DNL less than 45 dB.

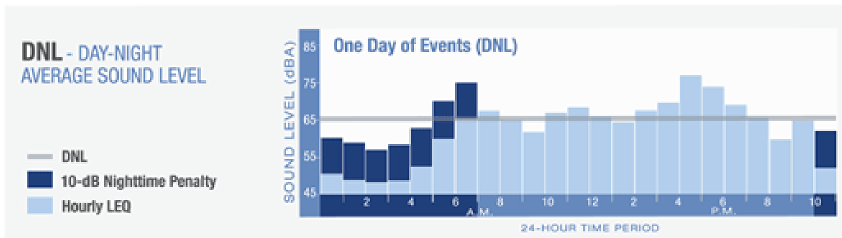
Aviation Noise

Fundamentals of Noise and Sound

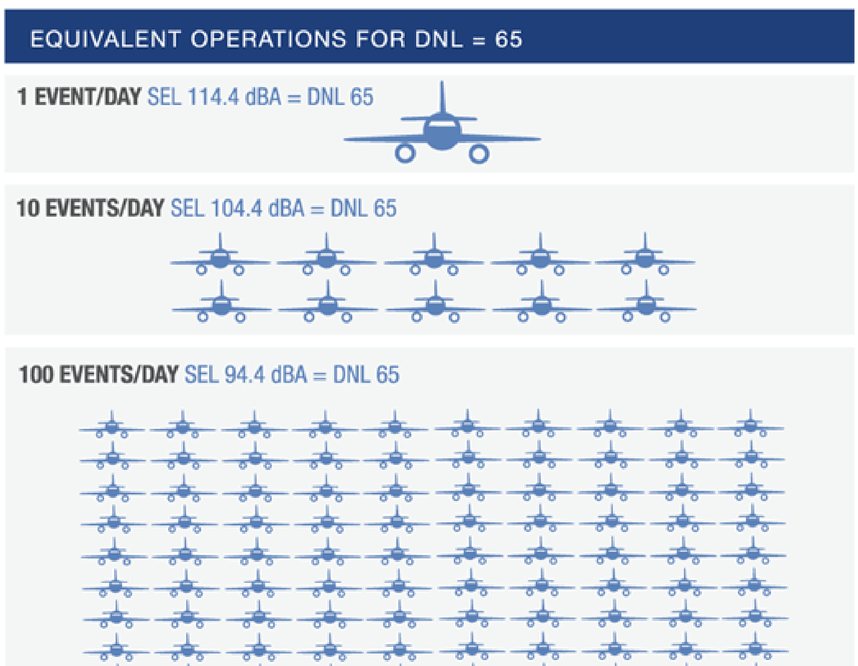
Community Response to Noise

FAA History of Noise

Finally, the **day-night average sound level (DNL)** noise metric is used to reflect a person's cumulative exposure to sound over a 24-hour period, expressed as the noise level for the average day of the year on the basis of annual aircraft operations. The DNL noise metric provides a mechanism to describe the effects of environmental noise in a simple and uniform way. DNL is the standard noise metric used for all FAA studies of aviation noise exposure in airport communities. (For more on DNL, see FAA History of Noise.) DNL and the closely related CNEL metric used in California are both similar to LEQ, but they differ in how noise is treated during the evening and nighttime.

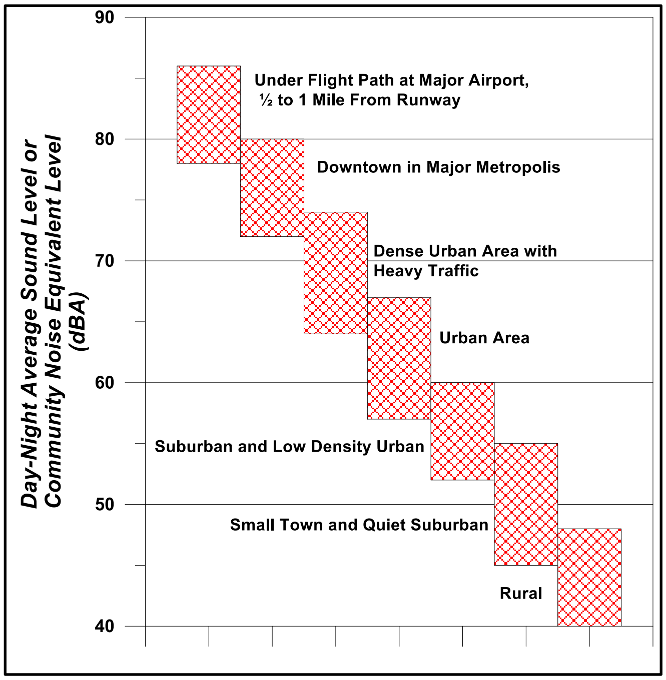


Because DNL takes into account both the amount of noise from each aircraft operation as well as the total number of operations flying throughout the day, there are many ways in which aircraft noise can add up to a specific DNL. Small numbers of relatively loud operations can result in the same DNL as large numbers of relatively quiet operations.



Source: (FAA, 2018)

Figure 5. Graphical Representation of Day-Night Average Sound Level Versus Sound Exposure Level



Source: (DoD, 1978)

Figure 6. Typical Day-Night Average Sound Level Ranges in Various Types of Communities

The dB summation nature of these metrics causes the noise levels of the loudest events to control the 24-hour average. As a simple example, consider a case in which only one aircraft overflight occurs during the daytime over a 24-hour period, creating a sound level of 100 dB for 30 seconds. During the remaining 23 hours, 59 minutes, and 30 seconds of the day, the ambient sound level is 50 dB. The DNL for this 24-hour period is 65.9 dB. As a second example, assume that 10 such 30-second overflights occur during daytime hours during the next 24-hour period, with the same ambient sound level of 50 dB during the remaining 23 hours and 55 minutes of the day. The DNL for this 24-hour period is 75.5 dB. The averaging of noise over a 24-hour period does not ignore the louder single events and tends to emphasize both the sound levels and number of those events.

A feature of the DNL metric is that a given DNL value could result from a very few noisy events or many quieter events. For example, 1 overflight at 90 dB creates the same DNL as 10 overflights at 80 dB.

It is worth noting the differences between the terms “operation” and “sortie,” which are often both used in environmental documentation to describe the frequency of aircraft events. A sortie consists of a single military aircraft flight from the initial takeoff through the final landing and includes all activities that occur during that flight. An operation is an event, such as a landing or takeoff that occurs during the flight. A single sortie includes at least two operations—an initial takeoff and final landing—and may include additional operations conducted as part of additional practice approaches. Aircraft performing additional practice approaches conduct one operation during the landing portion and another operation as they depart the airfield to line up for the next approach.

DNL does not represent a level heard at any given time but represent long-term exposure. Scientific studies have found good correlation between the percentages of groups of people highly annoyed and the level of average noise exposure measured in DNL (Schultz, 1978; EPA, 1978).

1.2.2.3 Community Noise Equivalent Level

In the state of California, the Community Noise Equivalent Level (CNEL) noise metric is used instead of the DNL metric as a basis for land use recommendations. The CNEL metric is identical to the DNL metric except that it also adds a 5 dBA penalty to noise events that occur between 7:00 p.m. and 10:00 p.m. (in addition to the 10 dB penalty that is added to events between 10:00 p.m. and 7:00 a.m. in calculation of DNL). Land use recommendations are the same for CNEL and the equivalent DNL numeric value.

1.2.2.4 Onset Rate-Adjusted Monthly Day-Night Average Sound Level

Military aircraft utilizing Special Use Airspace (SUA) such as Military Training Routes (MTRs), Military Operations Areas (MOAs), and Restricted Areas/ranges generate a noise environment that is somewhat different from that around airfields. Rather than the regularly occurring operations at airfields, activity in SUA is highly sporadic. It is often seasonal, ranging from 10 per hour to less than 1 per week. 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, with rates of up to 150 dB per second.

The cumulative daily noise metric devised to account for the “surprise” effect of the sudden onset of aircraft noise events on humans and the sporadic nature of SUA activity is the onset rate-adjusted day-night average sound level (L_{dnmr}). Onset rates between 15 and 150 dB per second require an adjustment of 0 to 11 dB to the event’s SEL, while onset rates less than 15 dB per second require no adjustment to the event’s SEL (Stusnick et al., 1992). The term “monthly” in L_{dnmr} refers to the noise assessment being conducted for the month with the most operations or sorties—the so-called busiest month.

1.2.3 Supplemental Metrics

1.2.3.1 Number-of-Events Above a Threshold Level

The number-of-events above (NA) metric gives the total number of events that exceed a noise threshold level (L) during a specified period of time. Combined with the selected threshold, the metric is denoted number-of-events above a threshold level. The threshold can be either SEL or L_{max}, and it is important that this selection is shown in the nomenclature. When labeling a contour line or point of interest, NAL is followed by the number of events in parentheses. For example, where 10 events exceed an SEL of 90 dB over a given period of time, the nomenclature would be NA90SEL(10). Similarly, for L_{max} it would be NA90L_{max}(10). The period of time can be an average 24-hour day, daytime, nighttime, school day, or any other time period appropriate to the nature and application of the analysis.

The NA metric is a supplemental metric. It is not supported by the amount of science behind DNL/CNEL, but it is valuable in helping describe noise to the community. A threshold level and metric are selected that best meet the need for each situation. An L_{max} threshold is normally selected to analyze speech interference, while an SEL threshold is normally selected for analysis of sleep disturbance.

The NA metric is the only supplemental metric that combines single-event noise levels with the number of aircraft operations. In essence, it answers the question of how many aircraft (or range of aircraft) fly over a given location or area at or above a selected threshold noise level.

1.2.3.2 Time-Above-a Specified Level

The time-above (TA) metric is the total time, in minutes, that the A-weighted noise level is at or above a threshold. Combined with the "L," it is denoted time-above a threshold level. The TA can be calculated over a full 24-hour annual average day, the 15-hour daytime and 9-hour nighttime periods, a school day, or any other time period of interest, provided there is operational data for that time.

The TA is a supplemental metric, used to help understand noise exposure. It is useful for describing the noise environment in schools, particularly when assessing classroom or other noise-sensitive areas for various scenarios. The TA can be shown as contours on a map similar to the way DNL contours are drawn.

The TA helps describe the noise exposure of an individual event or many events occurring over a given time period. When computed for a full day, the TA can be compared alongside the DNL to determine the sound levels and total duration of events that contribute to the DNL. The TA analysis is usually conducted along with NA analysis, so the results show not only how many events occur but also the total duration of those events above the threshold.

1.3 NOISE EFFECTS

Noise is of concern because of potential adverse effects. The following subsections describe how noise can affect communities and the environment and how those effects are quantified. The specific topics discussed are as follows:

- Annoyance
- Land use compatibility
- Speech interference
- Sleep disturbance
- Noise-induced hearing impairment
- Nonauditory health effects
- Performance effects
- Noise effects on children
- Property values
- Noise-induced vibration effects on structures and humans
- Noise effects on terrain
- Noise effects on historical and archaeological sites
- Effects on domestic animals and wildlife

The discussion of noise effects references documents that provide a comprehensive overview of knowledge on each topic. Some of the documents referenced were written several decades ago but remain accurate and relevant today.

1.3.1 Annoyance

With the introduction of jet aircraft in the 1950s, it became clear that aircraft noise annoyed people and was a significant problem around airports. Early studies, such as those of Rosenblith et al. (1953) and

Stevens et al. (1953), showed that effects depended on the quality of the sound, its level, and the number of flights. Over the next 20 years, considerable research was performed refining this understanding and setting guidelines for noise exposure. In the early 1970s, the EPA published its “Levels Document” (EPA, 1974) that reviewed the factors that affected communities. DNL was identified as an appropriate noise metric, and threshold criteria were recommended.

Threshold criteria for annoyance were identified from social surveys, where people exposed to noise were asked how noise affects them. Surveys provide direct real-world data on how noise affects actual residents.

Surveys in the early years had a range of designs and formats and needed some interpretation to find common ground. In 1978, Schultz showed that the common ground was the number of people “highly annoyed,” defined as the upper 28 percent range of whatever response scale a survey used (Schultz, 1978). With that definition, he was able to show a remarkable consistency among the majority of the surveys for which data were available. The result of his study relating DNL to individual annoyance measured by percent highly annoyed is shown in Figure 7.

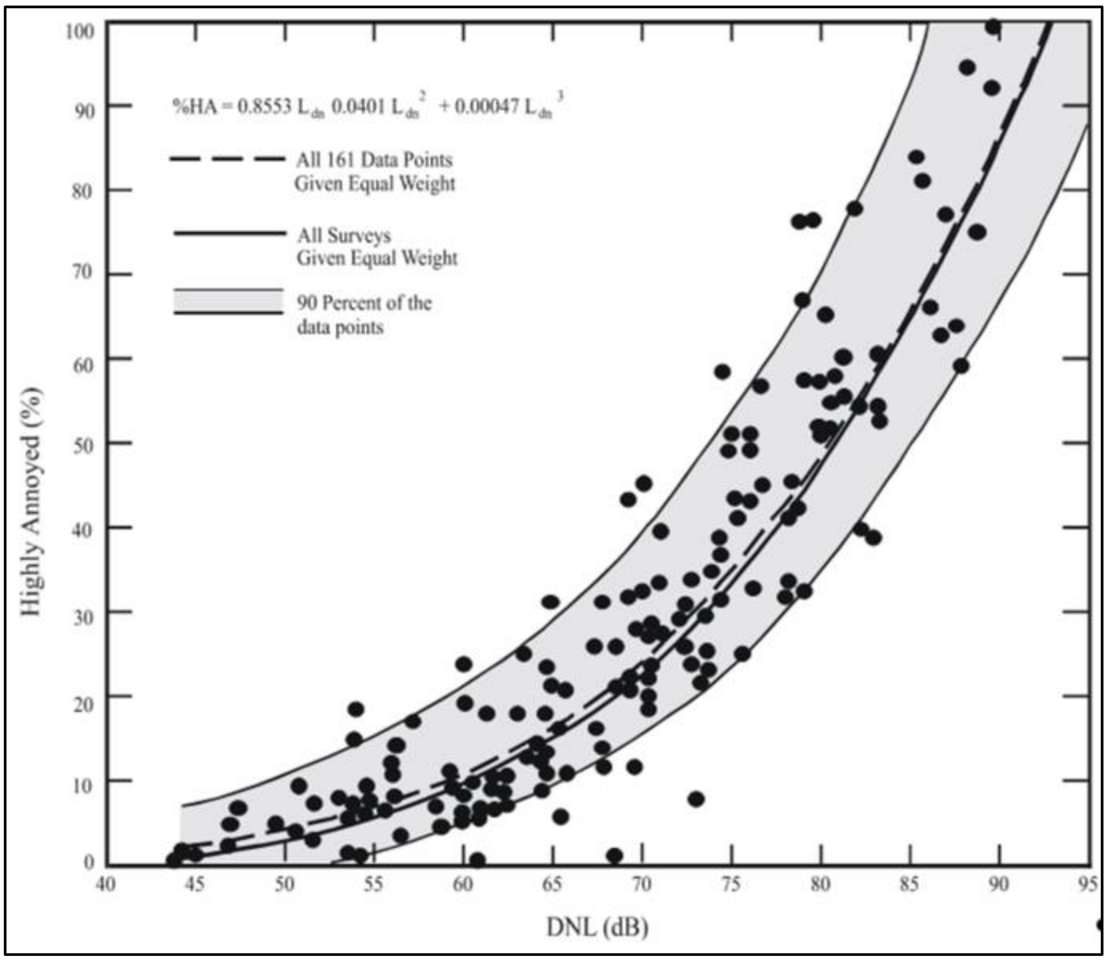


Figure 7. Schultz Curve Relating Noise Annoyance to Day-Night Average Sound Level (Schultz, 1978)

Schultz’s original synthesis included 161 data points. Revised fits of the Schultz dataset are compared with an expanded set of 400 data points collected through 1989 (Finegold et al., 1994) in Figure 8. The new form is the preferred form in the United States, endorsed by the Federal Interagency Committee on

Aviation Noise (FICAN) (FICAN, 1997). Other forms have been proposed, such as that of Fidell and Silvati (2004) but have not gained widespread acceptance.

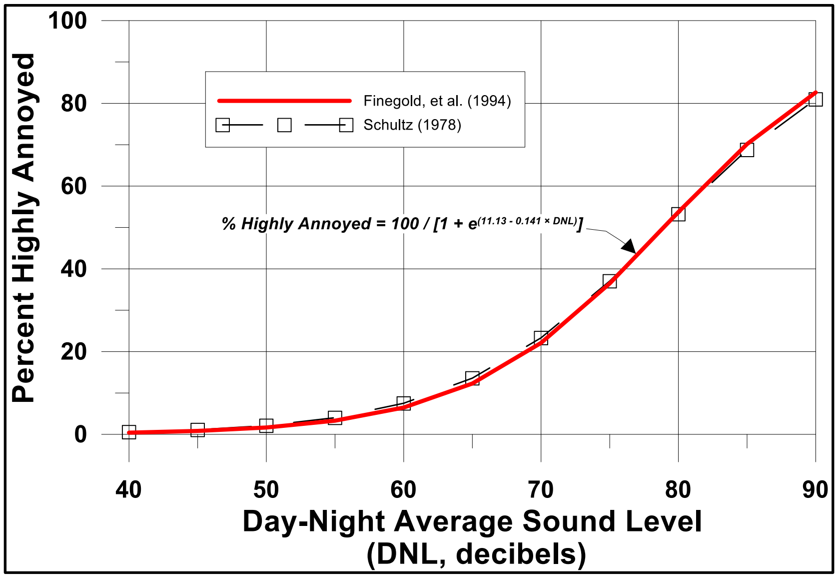


Figure 8. Response of Communities to Noise; Comparison of Original Schultz (1978) With Finegold et al. (1994)

When the goodness of fit of the Schultz curve is examined, the correlation between groups of people is high, in the range of 85 to 90 percent. The correlation between individuals is lower, 50 percent or less. This is not surprising, given the personal differences between individuals. The surveys underlying the Schultz curve include results that show that annoyance to noise is also affected by nonacoustical factors. Newman and Beattie (1985) divided the nonacoustical factors into the emotional and physical variables shown in Table 3.

Table 3. Nonacoustic Variables Influencing Aircraft Noise Annoyance

Emotional Variables
Feeling About the Necessity or Preventability of the Noise
Judgment of the Importance and Value of the Activity That Is Producing the Noise
Activity at the Time an Individual Hears the Noise
Attitude About the Environment
General Sensitivity to Noise
Belief About the Effect of Noise on Health
Feeling of Fear Associated With the Noise
Physical Variables
Type of Neighborhood
Time of Day
Season
Predictability of the Noise
Control Over the Noise Source
Length of Time Individual Is Exposed to a Noise

Schreckenberg and Schuemer (2010) recently examined the importance of some of these factors on short-term annoyance. Attitudinal factors were identified as having an effect on annoyance. In formal regression analysis, however, sound level (in L_{eq}) was found to be more important than attitude.

A recent study by Plotkin et al. (2011) examined updating DNL to account for these factors. It was concluded that the data requirements for a general analysis were much greater than most existing studies. It was noted that the most significant issue with DNL is that it is not readily understood by the public and that supplemental metrics such as TA and NA were valuable in addressing attitude when communicating noise analysis to communities (DoD, 2009a).

A factor that is partially nonacoustical is the source of the noise. Miedema and Vos (1998) presented synthesis curves for the relationship between DNL and percentage "annoyed" and percentage "highly annoyed" for three transportation noise sources. Different curves were found for aircraft, road traffic, and railway noise. Table 4 summarizes their results. Comparing the updated Schultz curve suggests that the percentage of people highly annoyed by aircraft noise may be higher than previously thought.

As noted by the World Health Organization (WHO), however, even though aircraft noise seems to produce a stronger annoyance response than road traffic, caution should be exercised when interpreting synthesized data from different studies (WHO, 1999).

Table 4. Percent Highly Annoyed for Different Transportation Noise Sources

DNL (dB)	%HA			
	Miedema and Vos (1998)			Schultz Combined
	Air	Road	Rail	
55	12	7	4	3
60	19	12	7	6
65	28	18	11	12
70	37	29	22	22
75	48	40	36	36

Key: %HA = percent highly annoyed; dB = decibels; DNL = day-night average sound level
Source: (Miedema and Vos, 1998)

The Noise Related Annoyance Cognition and Health study found larger percentages of surveyed Germans being highly annoyed by aircraft noise than were found in previous studies (Wothge et al., 2017). The study was conducted in a part of Germany where aircraft noise was the subject of ongoing controversy, and study authors acknowledge that this factor could have resulted in increased responsiveness to noise. In a 2018 review of selected noise issues, FICAN stated that there are large differences between communities in responsiveness to noise (FICAN, 2018). The FICAN review does not endorse the findings of any new studies as being universally applicable, nor does it recommend alteration of noise impact thresholds.

Current Federal Aviation Administration (FAA) noise policy is informed by the noise-to-annoyance dose-response curve known as the "Schultz curve," but the FAA is considering creating an updated national dose-response curve based on results of the Neighborhood Environmental Survey completed in February 2021. The survey, which includes responses from over 10,000 people living near 20 representative airports, found a higher percentage of people described themselves as "highly annoyed" at a given DNL than would be predicted by the "Schultz curve." The FAA is considering a wide variety of cultural, economic, and scientific factors prior to making any policy changes based on the survey results (FAA, 2021, 2022).

Consistent with WHO recommendations, the Federal Interagency Committee on Noise (FICON) considered the Schultz curve to be the best source of dose information to predict community response to noise but recommended further research to investigate the differences in perception of noise from different sources (FICON, 1992).

Where applicable, sonic boom exposure is assessed cumulatively with C-weighted day-night average noise level (CDNL). Correlation between CDNL and annoyance has been established, based on community reaction to impulsive sounds (Committee on Hearing, Bioacoustics, and Biomechanics, [CHABA] 1981). Values of the C-weighted equivalent to the Schultz curve are different than that of the Schultz curve itself. Table 5 shows the relation between annoyance, DNL, and CDNL.

Interpretation of CDNL from impulsive noise is accomplished by using the CDNL versus annoyance values in Table 3. 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.

Table 5. Relationship Between Annoyance, Day-Night Average Sound Level, and C-Weighted Day-Night Average Sound Level

DNL	%HA	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: %HA = percent highly annoyed; CDNL = C-weighted day-night average noise level; DNL = day-night average sound level

1.3.2 Land Use Compatibility

As noted previously, 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 previously, the best noise exposure metric for this correlation is the DNL or L_{dnmr} for military overflights (DoD 2009a). Impulsive noise can be assessed by relating CDNL to an "equivalent annoyance" DNL, as outlined in Section 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 the Departments of Defense, 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, the DoD adopted the concept of land use compatibility as the accepted measure of aircraft noise effect. DAF guidelines are presented in Table 6, along with the explanatory notes included in the regulation.

Table 7 lists the equivalent compatibility recommendation promulgated under 14 Code of Federal Regulations Part 150. These guidelines are not mandatory (note the footnote in the table); rather, they are recommendations to provide the best means for determining noise impact for communities adjacent to bases. Again, these are recommendations only; it is up to the city/county zoning and planning entities to determine what land uses are compatible and how they will deal with incompatibilities (e.g., what type of development is allowed, instituting residential buyouts, or whether noise attenuation efforts will be done in residential units). In general, residential land uses normally are not compatible with outdoor DNL values greater than 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 6. Department of the Air Force Land Use Compatibility Recommendations

Land Uses		Suggested Land Use Compatibility				
SLUCM No.	**Category**	**DNL 65–69 dB**	**DNL 70–74 dB**	**DNL 75–79 dB**	**DNL 80–84 dB**	**DNL > 85 dB**
10	Residential					
11	Household Units	N[a]	N[a]	N	N	N
11.11	Single Units: Detached	N[a]	N[a]	N	N	N
11.12	Single Units: Semi-Detached	N[a]	N[a]	N	N	N
11.13	Single Units: Attached Row	N[a]	N[a]	N	N	N
11.21	Two Units: Side by Side	N[a]	N[a]	N	N	N
11.22	Two Units: One Above the Other	N[a]	N[a]	N	N	N
11.31	Apartments: Walk-Up	N[a]	N[a]	N	N	N
11.32	Apartment: Elevator	N[a]	N[a]	N	N	N
12	Group Quarters	N[a]	N[a]	N	N	N
13	Residential Hotels	N[a]	N[a]	N	N	N
14	Mobile Home Parks or Courts	N	N	N	N	N
15	Transient Lodgings	N[a]	N[a]	N[a]	N	N
16	Other Residential	N[a]	N[a]	N	N	N
20	Manufacturing					
21	Food and Kindred Products; Manufacturing	Y	Y[b]	Y[c]	Y[d]	N
22	Textile Mill Products; Manufacturing	Y	Y[b]	Y[c]	Y[d]	N
23	Apparel and Other Finished Products; Products Made from Fabrics, Leather, and Similar Materials; Manufacturing	Y	Y[b]	Y[c]	Y[d]	N
24	Lumber and Wood Products (Except Furniture); Manufacturing	Y	Y[b]	Y[c]	Y[d]	N

Table 6. Department of the Air Force Land Use Compatibility Recommendations

Land Uses		Suggested Land Use Compatibility				
SLUCM No.	**Category**	**DNL 65–69 dB**	**DNL 70–74 dB**	**DNL 75–79 dB**	**DNL 80–84 dB**	**DNL > 85 dB**
25	Furniture and Fixtures; Manufacturing	Y	Y[b]	Y[c]	Y[d]	N
26	Paper and Allied Products; Manufacturing	Y	Y[b]	Y[c]	Y[d]	N
27	Printing, Publishing, and Allied Industries	Y	Y[b]	Y[c]	Y[d]	N
28	Chemicals and Allied Products; Manufacturing	Y	Y[b]	Y[c]	Y[d]	N
29	Petroleum Refining and Related Industries	Y	Y[b]	Y[c]	Y[d]	N
30	Manufacturing					
31	Rubber and Miscellaneous Plastic Products; Manufacturing	Y	Y[b]	Y[c]	Y[d]	N
32	Stone, Clay, and Glass Products; Manufacturing	Y	Y[b]	Y[c]	Y[d]	N
33	Primary Metal Products; Manufacturing	Y	Y[b]	Y[c]	Y[d]	N
34	Fabricated Metal Products; Manufacturing	Y	Y[b]	Y[c]	Y[d]	N
35	Professional, Scientific, and Controlling Instruments; Photographic and Optical Goods; Watches and Clocks	Y	25[e]	30	N	N
39	Miscellaneous Manufacturing	Y	Y[b]	Y[c]	Y[d]	N
40	Transportation, Communication, and Utilities					
41	Railroad, Rapid Rail Transit, and Street Railway Transportation	Y	Y[b]	Y[c]	Y[d]	N
42	Motor Vehicle Transportation	Y	Y[b]	Y[c]	Y[d]	N
43	Aircraft Transportation	Y	Y[b]	Y[c]	Y[d]	N
44	Marine Craft Transportation	Y	Y[b]	Y[c]	Y[d]	N
45	Highway and Street Right-of-Way	Y	Y	Y	Y	N
46	Automobile Parking	Y	Y	Y	Y	N
47	Communication	Y	25	30	N	N
48	Utilities	Y	Y[b]	Y[c]	Y[d]	N

Table 6. Department of the Air Force Land Use Compatibility Recommendations

Land Uses		Suggested Land Use Compatibility				
SLUCM No.	**Category**	**DNL 65–69 dB**	**DNL 70–74 dB**	**DNL 75–79 dB**	**DNL 80–84 dB**	**DNL > 85 dB**
49	Other Transportation, Communication, and Utilities	Y	25	30	N	N
50	Trade					
51	Wholesale Trade	Y	Y[b]	Y[c]	Y [(d)]	N
52	Retail Trade – Building Materials, Hardware, and Farm Equipment	Y	25	30	Y[d]	N
53	Retail Trade – Including Shopping Centers, Discount Clubs, Home Improvement Stores, Electronics Superstores, etc.	Y	25	30	N	N
54	Retail Trade – Food	Y	25	30	N	N
55	Retail Trade – Automotive, Marine Craft, Aircraft, and Accessories	Y	25	30	N	N
56	Retail Trade – Apparel and Accessories	Y	25	30	N	N
57	Retail Trade – Furniture, Home, Furnishings, and Equipment	Y	25	30	N	N
58	Retail Trade – Eating and Drinking Establishments	Y	25	30	N	N
59	Other Retail Trade	Y	25	30	N	N
60	Services					
61	Finance, Insurance, and Real Estate Services	Y	25	30	N	N
62	Personal Services	Y	25	30	N	N
62.4	Cemeteries	Y	Y[b]	Y[c]	Y[d,f]	Y[f, g]
63	Business Services	Y	25	30	N	N
63.7	Warehousing and Storage	Y	Y[b]	Y[c]	Y[d]	N
64	Repair Services	Y	Y[b]	Y[e]	Y[d]	N
65	Professional Services	Y	25	30	N	N
65.1	Hospitals, Other Medical Facilities	25	30	N	N	N
65.16	Nursing Homes	N[a]	N[a]	N	N	N
66	Contract Construction Services	Y	25	30	N	N
67	Government Services	Y[a]	25	30	N	N

Table 6. Department of the Air Force Land Use Compatibility Recommendations

Land Uses		Suggested Land Use Compatibility				
SLUCM No.	Category	DNL 65–69 dB	DNL 70–74 dB	DNL 75–79 dB	DNL 80–84 dB	DNL > 85 dB
68	Educational Services	25	30	N	N	N
68.1	Childcare Services, Child Development Centers, and Nurseries	25	30	N	N	N
69	Miscellaneous Services	Y	25	30	N	N
69.1	Religious Activities (Including Places of Worship)	Y	25	30	N	N
70	Cultural, Entertainment, and Recreational					
71	Cultural Activities	25	30	N	N	N
71.2	Nature Exhibits	Y[a]	N	N	N	N
72	Public Assembly	Y	N	N	N	N
72.1	Auditoriums, Concert Halls	25	30	N	N	N
72.11	Outdoor Music Shells, Amphitheaters	N	N	N	N	N
72.2	Outdoor Sports Arenas, Spectator Sports	Y[h]	Y[h]	N	N	N
73	Amusements	Y	Y	N	N	N
74	Recreational Activities (Including Golf Courses, Riding Stables, Water Recreation)	Y	25	30	N	N
75	Resorts and Group Camps	Y	25	N	N	N
76	Parks	Y	25	N	N	N
79	Other Cultural, Entertainment, and Recreation	Y	25	N	N	N
80	Resource Production and Extraction					
81	Agriculture (Except Livestock)	Y[i]	Y[j]	Y[k]	Y[f,k]	Y[f,k]
81.5-81.7	Agriculture – Livestock Farming Including Grazing and Feedlots	Y[i]	Y[j]	N	N	N
82	Agriculture-Related Activities	Y[i]	Y[j]	Y[k]	Y[f,k]	Y[f,k]
83	Forestry Activities	Y[i]	Y[j]	Y[k]	Y[f,k]	Y[f,k]
84	Fishing Activities	Y	Y	Y	Y	Y
85	Mining Activities	Y	Y	Y	Y	Y

Table 6. Department of the Air Force Land Use Compatibility Recommendations

Land Uses		Suggested Land Use Compatibility				
SLUCM No.	**Category**	**DNL 65–69 dB**	**DNL 70–74 dB**	**DNL 75–79 dB**	**DNL 80–84 dB**	**DNL > 85 dB**
89	Other Resource Production or Extraction	Y	Y	Y	Y	Y

[a] No, with exceptions. The land use and related structures are generally incompatible. However, the following general notes apply: Although local conditions regarding the need for housing may require residential use in these zones, residential use is discouraged where 65 to 69 dB DNL occur and strongly discouraged where 70 to 74 dB DNL occur. The absence of viable alternative development options should be determined, and an evaluation should be conducted locally prior to local approvals indicating that a demonstrated community need for the residential use would not be met if development were prohibited in these zones. Existing residential development is considered as pre-existing, nonconforming land uses.
Where the community determines that these uses must be allowed, measures to achieve outdoor-to-indoor noise level reduction (NLR) of at least 25 dB in areas where 65 to 69 dB DNL occur and 30 dB in areas where 70 to 74 dB DNL occur should be incorporated into building codes and be considered in individual approvals; for transient housing, an NLR of at least 35 dB should be incorporated in areas with noise at 75 to 79 dB DNL.
Normal permanent construction can be expected to provide an NLR of 20 dB; thus, the reduction requirements are often stated as 5, 10, or 15 dB over standard construction and normally assume mechanical ventilation, upgraded sound transmission class ratings in windows and doors, and closed windows year-round. Additional consideration should be given to modifying NLRs based on peak noise levels or vibrations.
NLR criteria will not eliminate outdoor noise problems. However, building location, site planning, design, and use of berms and barriers can help mitigate outdoor noise exposure particularly from ground-level sources. Measures that reduce noise at a site should be used wherever practical in preference to measures that only protect interior spaces.
[b] Yes, with restrictions. The land use and related structures generally are compatible. However, measures to achieve NLR of 25 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.
[c] Yes, with restrictions. The land use and related structures generally are compatible. However, measures to achieve NLR of 30 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.
[d] Yes, with restrictions. The land use and related structures generally are compatible. However, measures to achieve NLR of 35 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.
[e] The numbers 25, 30, or 35 refer to NLR. NLR (outdoor to indoor) is achieved through the incorporation of noise attenuation into the design and construction of a structure. Land use and related structures are generally compatible; however, measures to achieve NLR of 25, 30, or 35 must be incorporated into design and construction of structures. However, measures to achieve an overall noise reduction do not necessarily solve noise difficulties outside the structure and additional evaluation is warranted. Also, see notes indicated by superscripts where they appear with one of these numbers. If project or proposed development is noise-sensitive, use indicated NLR; if not, land use is compatible without NLR.
[f] Yes, with restrictions. The land use and related structures generally are compatible. However, land use that involves outdoor activities is not recommended, but if the community allows such activities, hearing-protection devices should be worn when noise sources are present. Long-term exposure (multiple hours per day over many years) to high noise levels can cause hearing loss in some unprotected individuals.
[g] Yes, with restrictions. The land use and related structures generally are compatible. However, buildings are not permitted.
[h] Yes, with restrictions. The land use and related structures generally are compatible. However, land use is compatible provided special sound reinforcement systems are installed.
[i] Yes, with restrictions. The land use and related structures generally are compatible. However, residential buildings require an NLR of 25.
[j] Yes, with restrictions. The land use and related structures generally are compatible. However, residential buildings require an NLR of 30.
[k] Yes, with restrictions. The land use and related structures generally are compatible. However, residential buildings are not permitted.
Key: > = greater than; dB = decibels; DNL = day-night average sound level; N = No, land use and related structures are not compatible and should be prohibited; SLUCM = Standard Land Use Coding Manual, U.S. Department of Transportation; Y = Yes, land use and related structures compatible without restrictions.

Table 7. Federal Aviation Administration Land Use Compatibility Recommendations

Land Use	Yearly Day-Night Average Sound Level (L_{dn}) in dBs					
	Below 65	65–70	70–75	75–80	80–85	Over 85
Residential						
Residential, Other Than Mobile Homes and Transient Lodgings	Y	N[a]	N[a]	N	N	N
Mobile Home Parks	Y	N	N	N	N	N
Transient Lodgings	Y	N[a]	N[a]	N[a]	N	N
Public Use						
Schools	Y	N[a]	N[a]	N	N	N
Hospitals and Nursing Homes	Y	25	30	N	N	N
Churches, Auditoriums, and Concert Halls	Y	25	30	N	N	N
Governmental Services	Y	Y	25	30	N	N
Transportation	Y	Y	Y[b]	Y[c]	Y[d]	Y[d]
Parking	Y	Y	Y[b]	Y[c]	Y[d]	N
Commercial Use						
Offices, Business, and Professional	Y	Y	25	30	N	N
Wholesale and Retail – Building Materials, Hardware, and Farm Equipment	Y	Y	Y[b]	Y[c]	Y[d]	N
Retail Trade – General	Y	Y	25	30	N	N
Utilities	Y	Y	Y[b]	Y[c]	Y[d]	N
Communication	Y	Y	25	30	N	N
Manufacturing and Production						
Manufacturing, General	Y	Y	Y[b]	Y[c]	Y[d]	N
Photographic and Optical	Y	Y	25	30	N	N
Agriculture (Except Livestock) and Forestry	Y	Y[f]	Y[g]	Y[h]	Y[h]	Y[h]
Livestock Farming and Breeding	Y	Y[f]	Y[g]	N	N	N
Mining and Fishing, Resource Production, and Extraction	Y	Y	Y	Y	Y	Y
Recreational						
Outdoor Sports Arenas and Spectator Sports	Y	Y[e]	Y[e]	N	N	N
Outdoor Music Shells, Amphitheaters	Y	N	N	N	N	N
Nature Exhibits and Zoos	Y	Y	N	N	N	N
Amusements, Parks, Resorts, and Camps	Y	Y	Y	N	N	N
Golf Courses, Riding Stables, and Water Recreation	Y	Y	25	30	N	N

*The designations contained in this table do not constitute a federal determination that any use of land covered by the program is acceptable or unacceptable under federal, state, or local law. The responsibility for determining the acceptable and permissible land uses and the relationship between specific properties and specific noise contours rests with the local authorities. FAA determinations under part 150 are not intended to substitute federally determined land uses for those determined to be appropriate by local authorities in response to locally determined needs and values in achieving noise compatible land uses.

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

[a] Where the community determines that residential or school uses must be allowed, measures to achieve outdoor to indoor Noise Level Reduction (NLR) of at least 25 dB and 30 dB should be incorporated into building codes and be considered in individual

Table 7. Federal Aviation Administration Land Use Compatibility Recommendations

approvals. Normal residential construction can be expected to provide a NLR of 20 dB, thus, the reduction requirements are often stated as 5, 10 or 15 dB over standard construction and normally assume mechanical ventilation and closed windows year-round. However, the use of NLR criteria will not eliminate outdoor noise problems.
[b] Measures to achieve NLR 25 dB must be incorporated into the design and construction of portions of these buildings where the public is received, office areas, noise-sensitive areas or where the normal noise level is low.
[c] Measures to achieve NLR of 30 dB must be incorporated into the design and construction of portions of these buildings where the public is received, office areas, noise-sensitive areas or where the normal noise level is low.
[d] Measures to achieve NLR 35 dB must be incorporated into the design and construction of portions of these buildings where the public is received, office areas, noise-sensitive areas or where the normal level is low.
[e] Land use compatible provided special sound reinforcement systems are installed.
[f] Residential buildings require an NLR of 25.
[g] Residential buildings require an NLR of 30.
[h] Residential buildings not permitted.
Key: dB = decibels; FAA = Federal Aviation Administration; Y (Yes) = Land Use and related structures compatible without restrictions; N (No) = Land Use and related structures are not compatible and should be prohibited; NLR = Noise Level Reduction (outdoor to indoor) to be achieved through incorporation of noise attenuation into the design and construction of the structure

1.3.3 Speech Interference

Speech interference from noise is a primary cause of annoyance for communities. Disruption of routine activities such as radio or television listening, telephone use, or conversation leads to frustration and annoyance. The quality of speech communication is important in classrooms and offices. In the workplace, speech interference from noise can cause fatigue and vocal strain in those who attempt to talk over the noise. People working or engaged in recreation outdoors are exposed to higher noise levels and, therefore, are more likely to experience speech interference. In schools, it can impair learning.

There are two measures of speech comprehension:

- *Word intelligibility* – the percentage of words spoken and understood. This might be important for students in the lower grades who are learning the English language, particularly students for whom English is a second language.
- *Sentence intelligibility* – the percent of sentences spoken and understood. This might be important for high school students and adults who are familiar with the language and who do not necessarily have to understand each word to understand sentences.

1.3.3.1 U.S. Federal Criteria for Interior Noise

In 1974, EPA identified a goal of an indoor $L_{eq(24)}$ of 45 dB to minimize speech interference based on sentence intelligibility and the presence of steady noise (EPA, 1974). The effect of steady indoor background sound levels on sentence intelligibility is shown in Figure 9. For an average adult with normal hearing and fluency in the language, steady background indoor sound levels of less than 45 dB L_{eq} are expected to allow 100 percent sentence intelligibility.

The curve in Figure 9 shows 99 percent intelligibility at L_{eq} less than 54 dB and less than 10 percent greater than 73 dB. Recalling that L_{eq} is dominated by louder noise events, the EPA $L_{eq(24)}$ goal of 45 dB generally ensures that sentence intelligibility will be high most of the time.

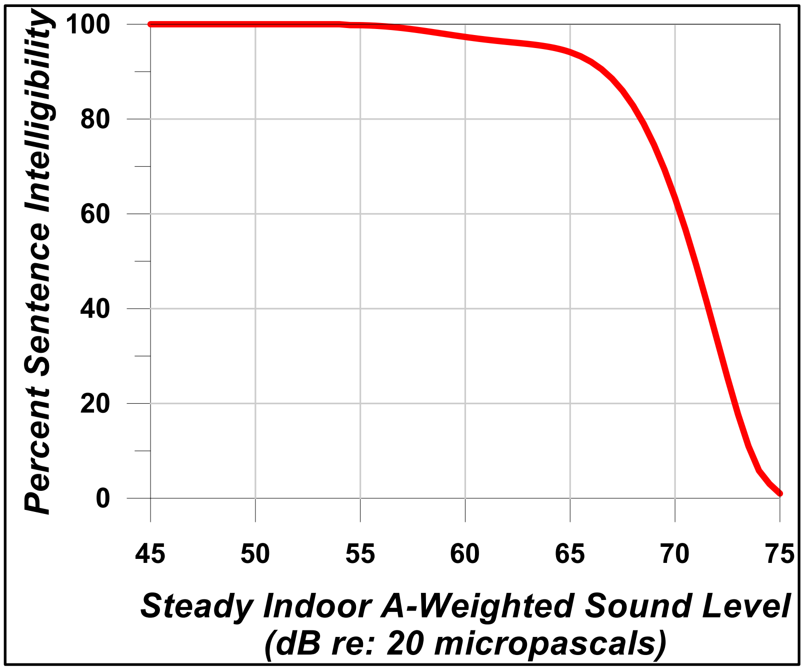


Figure 9. Speech Intelligibility Curve (Digitized from EPA, 1974)

1.3.3.2 Classroom Criteria

For teachers to be understood, their regular voice must be clear and uninterrupted. Background noise must be below the teacher's voice level. Intermittent noise events that momentarily drown out the teacher's voice need to be kept to a minimum. It is, therefore, important to evaluate the steady background level, the level of voice communication, and the single-event level due to aircraft overflights that might interfere with speech.

Lazarus (1990) found that for listeners with normal hearing and fluency in the language, complete sentence intelligibility can be achieved when the signal-to-noise ratio (i.e., a comparison of the level of the sound to the level of background noise) is in the range of 15 to 18 dB. The ANSI classroom noise standard (ANSI, 2020) and American Speech-Language-Hearing Association guidelines concur, recommending at least a 15-dB signal-to-noise ratio in classrooms (ASLHA, 1995). If the teacher's voice level is at least 50 dB, the background noise level must not exceed an average of 35 dB. The National Research Council of Canada (Bradley, 1993) and the WHO (1999) agree with this criterion for background noise.

Most aircraft noise is not continuous. It consists of individual events like the one shown in Figure 3. Because speech interference in the presence of aircraft noise is caused by individual aircraft flyover events, a time-averaged metric alone, such as L_{eq}, is not necessarily appropriate. In addition to the background level criteria described previously, single-event criteria that account for those noisy events are also needed.

A 1984 study by Wyle for the Port Authority of New York and New Jersey recommended using "speech interference level" (SIL) for classroom noise criteria (Sharp and Plotkin, 1984). SIL is based on the L_{max} in the frequency range that most affects speech communication (500 to 2,000 Hz). The study identified an SIL of 45 dB as the goal. This would provide 90 percent word intelligibility for the short time periods during aircraft overflights. While SIL is technically the best metric for speech interference, it can be approximated by an L_{max} value. An SIL of 45 dB is equivalent to an A-weighted L_{max} of 50 dB for aircraft noise (Wesler, 1986).

In 1998, researchers also concluded that an L_{max} criterion of 50 dB would result in 90 percent word intelligibility (DoD, 2013a). Bradley (1985) recommends SEL as a better indicator. His work indicates that 95 percent word intelligibility would be achieved when indoor SEL did not exceed 60 dB. For typical flyover noise, this corresponds to an L_{max} of 50 dB. While the WHO (1999) only specifies a background L_{max} criterion, it also notes the SIL frequencies, and that interference can begin at around 50 dB.

The United Kingdom Department for Education and Skills established in its classroom acoustics guide a 30-minute time-averaged metric of $L_{eq(30min)}$ for background levels and the metric of $L_{A1,30min}$ for intermittent noises, at thresholds of 30 to 35 and 55 dB, respectively. $L_{A1,30min}$ represents the dBA that is exceeded 1 percent of the time (in this case, during a 30-minute teaching session) and is generally equivalent to the L_{max} metric (UKDfES, 2003).

Table 8 summarizes the criteria discussed. Other than the FAA (1985) 45 dB L_{max} criterion, they are consistent with a limit on indoor background noise of 35 to 40 dB L_{eq} and a single-event limit of 50 dB L_{max}. It should be noted that these limits were set based on students with normal hearing and no special needs. At-risk students may be adversely affected at lower sound levels.

Table 8. Indoor Noise Level Criteria Based on Speech Intelligibility

Source	Metric/Level (dB)	Effects and Notes
FAA (1985)	$L_{eq(during\ school\ hours)}$ = 45 dB	Federal assistance criteria for school sound insulation; supplemental single-event criteria may be used.
DoD (2013a), Sharp and Plotkin (1984), Wesler (1986)	L_{max} = 50 dB / SIL 45	Single event level permissible in the classroom.
WHO (1999)	L_{eq} = 35 dB L_{max} = 50 dB	Assumes average speech level of 50 dB and recommends signal-to-noise ratio of 15 dB.
ANSI (2020)	L_{eq} = 35 dB, based on room volume (e.g., cubic feet)	Acceptable background level for continuous and intermittent noise.
UKDfES (2003)	$L_{eq(30min)}$ = 30 – 35 dB L_{max} = 55 dB	Minimum acceptable in classroom and most other learning environs.

Key: ANSI = American National Standards Institute; dB = decibels; DoD = Department of Defense; FAA = Federal Aviation Administration; L_{eq} = equivalent noise level; L_{max} = maximum noise level; SIL = speech interference level; UKDfES = United Kingdom Department for Education and Skills; WHO = World Health Organization

1.3.4 Sleep Disturbance

Sleep disturbance or delay is a major concern for communities exposed to aircraft noise at night. A number of studies have attempted to quantify the effects of noise on sleep. This section provides an overview of the major noise-induced sleep disturbance studies. Emphasis is on studies that have influenced U.S. federal noise policy. The studies have been separated into two groups:

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

1.3.4.1 Initial Studies

The relationship between noise and sleep disturbance is complex and not fully understood. The disturbance depends not only on the depth of sleep and the noise level but also on the nonacoustic factors cited for annoyance. The easiest effect to measure is the number of arousals or awakenings from noise events. Therefore, much of the literature has focused on predicting the percentage of the population that will be awakened at various noise levels.

FICON's 1992 review of airport noise issues (FICON, 1992) included an overview of relevant research conducted through the 1970s. Literature reviews and analyses were conducted from 1978 through 1989 using existing data (Griefahn, 1978; Lukas, 1978; Pearsons et al., 1989). Because of large variability in the data, FICON did not endorse the reliability of those results.

FICON did recommend, however, an interim dose-response curve—awaiting future research—that predicted the percent of the population expected to be awakened as a function of the exposure to SEL. This curve was based on research conducted for the DAF (Finegold, 1994). The data included most of the research performed up to that point and predicted a 10 percent probability of awakening when exposed to an interior SEL of 58 dB. The data used to derive this curve were primarily from controlled laboratory studies. Other studies conducted in this time period found lower percent probabilities of awakening. For example, Kryter (1984) indicates that an interior SEL of 65 dB or lower should awaken less than 5 percent of those exposed.

1.3.4.2 Recent Sleep Disturbance Research – Field and Laboratory Studies

It was noted that early sleep laboratory studies did not account for some important factors. These included habituation to the laboratory, previous exposure to noise, and awakenings from noise other than aircraft. In the early 1990s, field studies in people's homes were conducted to validate the earlier laboratory work conducted in the 1960s and 1970s. The field studies of the 1990s found that 80 to 90 percent of sleep disturbances were not related to outdoor noise events but rather to indoor noises and non-noise factors. The results showed that, in real-life conditions, there was less of an effect of noise on sleep than had been previously reported from laboratory studies. Laboratory sleep studies tend to show more sleep disturbance than field studies because people who sleep in their own homes are used to their environment and, therefore, do not wake up as easily (FICAN, 1997).

1.3.4.3 Federal Interagency Committee on Aviation Noise

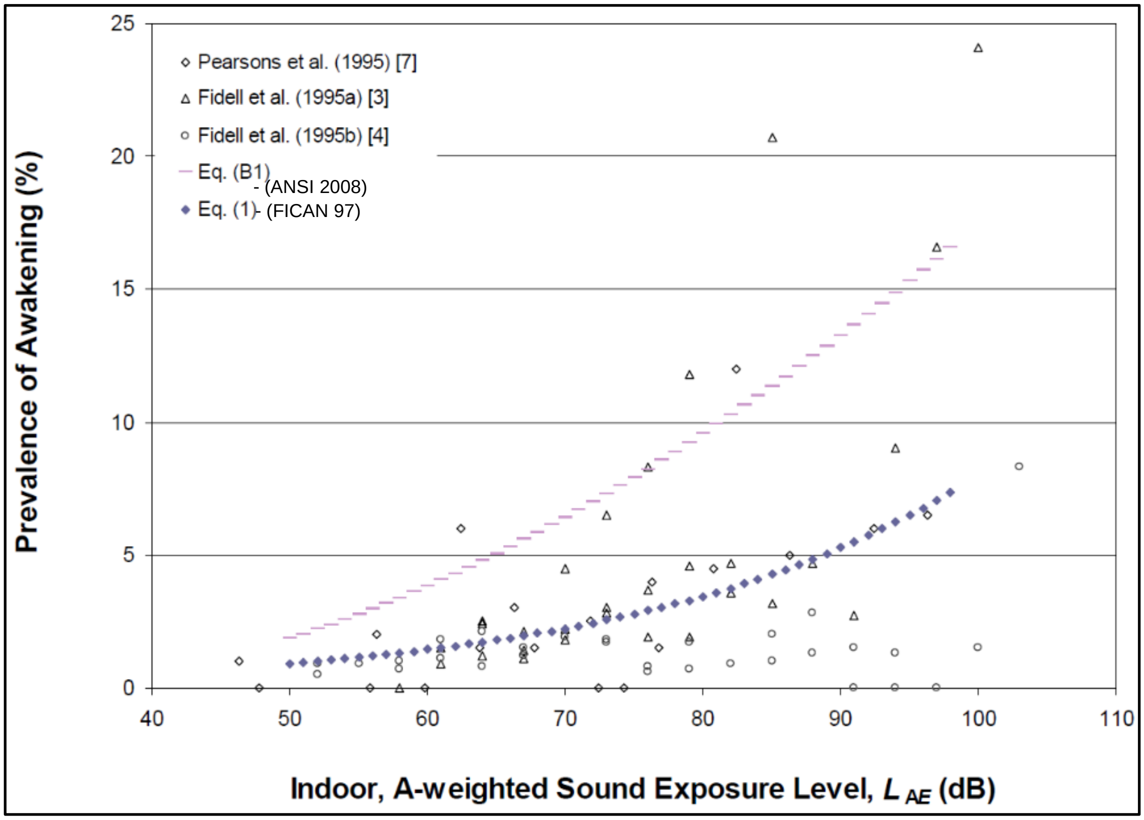
Based on this new information, in 1997, FICAN recommended a dose-response curve to use instead of the earlier 1992 FICON curve (FICAN, 1997). FICAN's curve, the red dashed line, which is based on the results of three field studies shown in Figure 10 (Ollerhead et al., 1992; Fidell et al., 1994, 1995a, 1995b), along with the data from six previous field studies.

The 1997 FICAN curve represents the upper envelope of the latest field data. It predicts the maximum percent awakened for a given residential population. According to this curve, a maximum of 3 percent of people would be awakened at an indoor SEL of 58 dB. An indoor SEL of 58 dB is equivalent to an outdoor SEL of 83 dB, with the windows closed (73 dB with windows open).

1.3.4.4 Number of Events and Awakenings

It is reasonable to expect that sleep disturbance is affected by the number of events. The German Aerospace Center (i.e., DLR Laboratory) conducted an extensive study focused on the effects of nighttime aircraft noise on sleep and related factors (Basner et al., 2004). The DLR study was one of the largest studies to examine the link between aircraft noise and sleep disturbance. It involved both laboratory and in-home field research phases. The DLR investigators developed a dose-response curve that predicts the number of aircraft events at various values of L_{max} expected to produce one additional awakening over the course of a night. The dose-effect curve was based on the relationships found in the field studies.

A different approach was taken by an ANSI standards committee (ANSI, 2008). The committee used the average of the data shown in Figure 10 (i.e., the blue dashed line) rather than the upper envelope, to predict average awakening from one event. Probability theory is then used to project the awakening from multiple noise events. In 2018, the standard containing this prediction method was withdrawn in part because it "may be in error and have overestimated numbers of expected awakenings" (ANSI-ASA, 2018).



Source: (DoD, 2009b)

Figure 10. Sleep Disturbance Dose-Response Relationship

Currently, there are no established criteria for evaluating sleep disturbance from aircraft noise, although recent studies have suggested a benchmark of an outdoor SEL of 90 dB as an appropriate tentative criterion when comparing the effects of different operational alternatives. The corresponding indoor SEL would be approximately 25 dB lower (at 65 dB) with doors and windows closed, and approximately 15 dB lower (at 75 dB) with doors or windows open. Persons sleeping outdoors or in tents experience overflight noise without the benefit of structural sound attenuation and would have higher probabilities of sleep disturbance. According to the ANSI (2008) standard, the probability of awakening from a single aircraft event at this level is between 1 and 2 percent for people habituated to the noise sleeping in bedrooms with windows closed, and 2 to 3 percent with windows open. The probability of the exposed population awakening at least once from multiple aircraft events at noise levels of 90-dB SEL is provided in Table 9.

The standard describing this assessment method has been withdrawn, as was noted previously. In December 2008, FICAN recommended the use of the ANSI (2008) standard. FICAN also recognized that more research is underway by various organizations, and that work may result in changes to FICAN's position. Until that time, FICAN recommends the use of the ANSI (2008) standard (FICAN, 2008).

Table 9. Probability of Awakening from the Number of Events Above a 90-Decibel Sound Exposure Level

Number of Aircraft Events at 90-dB SEL for Average 9-Hour Night	Minimum Probability of Awakening at Least Once (Percent)	
	Windows Closed	Windows Open
1	1	2
3	4	6
5	7	10
9 (1 per hour)	12	18
12 (2 per hour)	22	33
27 (3 per hour)	32	45

Key: dB = decibels; SEL = sound exposure level
Source: (DoD, 2009b)

1.3.4.5 Summary

Sleep disturbance research still lacks the details to accurately estimate the population awakened for a given noise exposure. The procedure described in the ANSI (2008) standard and endorsed by FICAN is based on probability calculations that have not yet been scientifically validated. While this procedure certainly provides a much better method for evaluating sleep awakenings from multiple aircraft noise events, the estimated probability of awakenings can only be considered approximate.

1.3.5 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.

1.3.5.1 Hearing Threshold Shifts

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).

A TTS can result from exposure to loud noise over a given amount of time. An example of TTS might be a person attending a loud music concert. After the concert is over, there can be a threshold shift that may last several hours. 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 eventually returns, if the person has enough time to recover within a relatively quiet environment.

A PTS usually results from repeated exposure to high noise levels, where the ears are not given adequate time to recover. A common example of PTS is the result of regularly working in a loud factory. A TTS can eventually become a PTS over time with repeated exposure to high noise levels. 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.

1.3.5.2 Criteria for Permanent Hearing Loss

It has been well established that continuous exposure to high noise levels will damage human hearing (EPA, 1978). A large amount of data on hearing loss have been collected, largely for workers in manufacturing industries, and analyzed by the scientific/medical community. The Occupational Health and Safety Administration regulation of 1971 places the limit on workplace noise exposure at an average level of 90 dB over an 8-hour work period or 85 dB over a 16-hour period (U.S. Department of Labor, 1971). Some hearing loss is still expected at those levels. The most protective criterion, with no measurable hearing loss after 40 years of exposure, is an average sound level of 70 dB over a 24-hour period.

EPA established 75-dB eight-hour equivalent noise level ($L_{eq(8)}$) and 70 dB $L_{eq(24)}$ as the average noise level standard needed 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 lowest level at which hearing loss may occur (CHABA, 1977). The WHO 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, 1999).

1.3.5.3 Hearing Loss and Aircraft Noise

The 1982 EPA Guidelines for Noise Impact Analysis (EPA, 1982) addresses noise-induced hearing loss in terms of the noise-induced permanent threshold shift (NIPTS). This defines the permanent change in hearing caused by exposure to noise. Numerically, the NIPTS is the change in threshold that can be expected from daily exposure to noise over a normal working lifetime of 40 years. A grand average of the NIPTS over time and hearing sensitivity is termed the average NIPTS. The average NIPTS that can be expected for noise measured by the $L_{eq(24)}$ metric is given in Table 10 and assumes exposure to the full outdoor noise throughout 24 hours. When inside a building, the exposure will be less (Eldred and von Gierke, 1993).

The average NIPTS is estimated as an average over all people exposed to the noise. The actual value of NIPTS for any given person will depend on their physical sensitivity to noise—some will experience more hearing loss than others. The EPA guidelines provide information on this variation in sensitivity in the form of the NIPTS exceeded by 10 percent of the population, which is included in Table 10 in the "10th Percentile NIPTS dB" column (EPA, 1982). For individuals exposed to $L_{eq(24)}$ of 80 dB, the most sensitive of the population would be expected to show degradation to their hearing of 7 dB over time.

Table 10. Average Noise-Induced Permanent Threshold Shift and 10th Percentile Noise-Induced Permanent Threshold Shift as a Function of $L_{eq(24)}$

$L_{eq(24)}$	Ave. NIPTS dB[a]	10th Percentile NIPTS dB[a]
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

Table 10. Average Noise-Induced Permanent Threshold Shift and 10th Percentile Noise-Induced Permanent Threshold Shift as a Function of $L_{eq(24)}$

$L_{eq(24)}$	Ave. NIPTS dB[a]	10th Percentile NIPTS dB[a]
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

[a] Rounded to the nearest 0.5 dB
Key: Ave. NIPTS = average noise-induced permanent threshold shift; dB = decibels; DNL = day-night average sound level; $L_{eq(24)}$ = 24-hour equivalent sound level
Source: (DoD, 2013b)

To put these numbers in perspective, changes in hearing level of less than 5 dB are generally not considered noticeable or significant. Furthermore, there is no known evidence that a NIPTS of 5 dB is perceptible or has any practical significance for the individual. Finally, the variability in audiometric testing is generally assumed to be ± 5 dB (EPA, 1974). The scientific community has concluded that noise exposure from civil airports has little chance of causing permanent hearing loss (Newman and Beattie, 1985). For military airbases, DoD policy requires that hearing risk loss be estimated for population exposed to $L_{eq(24)}$ of 80 dB or higher (DoD, 2013b), including residents of on-base housing. Exposure of workers inside the base boundary is assessed using DoD regulations for occupational noise exposure.

Noise in low-altitude military airspace, especially along MTRs where L_{max} can exceed 115 dB, is of concern. That is the upper limit used for occupational noise exposure (e.g., U.S. Department of Labor, 1971). One laboratory study (Ising et al., 1999) concluded that events with L_{max} greater than 114 dB have the potential to cause hearing loss. Another laboratory study of participants exposed to levels between 115 and 130 dB (Nixon et al., 1993), however, showed conflicting results. For an exposure to four events across that range, half the subjects showed no change in hearing, one quarter showed a temporary 5 dB decrease in sensitivity, and a quarter showed a temporary 5 dB increase in sensitivity. For exposure to eight events of 130 dB, subjects showed an increase in sensitivity of up to 10 dB (Nixon et al., 1993).

1.3.5.4 Summary

Aviation noise levels are not comparable to the occupational noise levels associated with hearing loss of workers in manufacturing industries. There is little chance of hearing loss at levels less than 75 dB DNL. Noise levels equal to or greater than 75 dB DNL can occur near military airbases, and DoD policy specifies that NIPTS be evaluated when exposure exceeds 80 dB $L_{eq(24)}$ (DoD, 2009c). There is some concern about L_{max} exceeding 115 dB in low-altitude military airspace, but no research results to date have definitively related permanent hearing impairment to aviation noise. Because hearing loss risk increases with multiple exposures to very loud sounds, risk is lower where very loud sounds occur only infrequently.

1.3.6 Nonauditory Health Effects

1.3.6.1 Stress-Related Effects

Prolonged stress is known to be a contributor to a number of health disorders. Some studies have found a connection between aircraft noise and blood pressure (e.g., Michalak et al., 1990; Rosenlund et al., 2001), while others have not (e.g., Pulles et al., 1990).

Kryter and Poza (1980) noted, "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."

The connection from annoyance to stress to health issues requires careful experimental design. Some highly publicized reports on health effects have, in fact, been rooted in poorly done science. Meecham and Shaw (1979) apparently found a relation between noise levels and mortality rates in neighborhoods under the approach path to Los Angeles International Airport. When the same data were analyzed by others (Frerichs et al., 1980), no relationship was found. Jones and Tauscher (1978) found a high rate of birth defects for the same neighborhood. But when the Centers for Disease Control performed a more thorough study near Atlanta's Hartsfield International Airport, no relationships were found for levels greater than 65 dB (Edmonds et al., 1979).

A carefully designed study, Hypertension and Exposure to Noise Near Airports (HYENA), was conducted around six European airports from 2002 through 2006 (Jarup et al., 2005, 2008). There were 4,861 subjects, aged between 45 and 70. Blood pressure was measured, and questionnaires were administered for health, socioeconomic, and lifestyle factors, including diet and physical exercise. Hypertension was defined by the WHO blood pressure thresholds (WHO, 2003). Noise from aircraft and highways was predicted from models.

The HYENA results were presented as an odds ratio (OR). An OR of 1 means there is no added risk, while an OR of 2 would mean risk doubles. An OR of 1.14 was found for nighttime aircraft noise, measured by L_{night}, the L_{eq} for nighttime hours. For daytime aircraft noise, measured by $L_{eq(16)}$, the OR was 0.93. For road traffic noise, measured by the full day $L_{eq(24)}$, the OR was 1.1.

Note that OR is a statistical measure of change, not the actual risk. Risk itself and the measured effects were small and not necessarily distinct from other events. Haralabidis et al. (2008) reported an increase in systolic blood pressure of 6.2 millimeters of mercury for aircraft noise, and an increase of 7.4 millimeters of mercury for other indoor noises such as snoring.

It is interesting that aircraft noise is a factor only at night, while traffic noise is a factor for the full day. Aircraft noise results varied among the six countries so that the result is pooled across all data. Traffic noise results were consistent across the six countries.

One notable conclusion from a 2013 study of the HYENA data (Babisch et al., 2013) states there is some indication that noise level is a stronger predictor of hypertension than annoyance. That is not consistent with the idea that annoyance is a link in the connection between noise and stress. Babisch et al. (2012) present interesting insights on the relationship of the results to various modifiers.

Two studies examined the correlation of aircraft noise with hospital admissions for cardiovascular disease. Hansell et al. (2013) examined neighborhoods around London's Heathrow Airport. Correia et al. (2013) examined neighborhoods around 89 airports in the United States. Both studies included areas of various noise levels. They found associations that were consistent with the HYENA results. The authors of these studies noted that further research is needed to refine the associations and the causal interpretation with noise or possible alternative explanations. Rhee et al. (2008) found a significant association between military helicopter noise and the prevalence of hypertension but no significant effect due to exposure to fighter jet (fixed wing) noise, also noting that more research is needed to better understand the observed effects (Rhee et al., 2008).

Associations between aircraft noise and negative mental health outcomes has been the subject of several studies in recent years. Analysis of cross-sectional data of 15,010 Germans by Beutel et al. (2016) found significant associations between noise and increased prevalence of anxiety and depression. The authors acknowledge that annoyance due to aircraft noise could not be related directly to the negative outcomes but establish that it was a major source of annoyance in the sample.

In a 2018 review of selected aviation noise research, FICAN stated that, based on a large number of studies on the subject, chronic road traffic noise has nonacoustic (cardiovascular) health effects, but there is a need for more and better-designed studies before a similar conclusion can be reached for aircraft noise. High road-traffic noise levels have been associated by several studies with an increased risk of hypertension (Dzhambov et al., 2017; Hahad et al., 2019) and stroke for people over the age of 64 (Sørensen et al., 2011). Recent studies provide novel insights into mechanisms of vascular damage attributed to noise (Münzel et al., 2018a, 2018b). The accumulated evidence to support an association between aircraft noise and nonauditory health impacts (Münzel et al., 2014; Willich et al., 2006) is considered by FICAN to be less strong.

In 2018, van Kempen et al. conducted a systematic review of literature on cardiovascular and metabolic effects of noise at the behest of the WHO (van Kempen et al., 2018). The quality of evidence available supporting associations between noise and a variety of potential noise impacts in hundreds of published studies was rated based on risk of bias, inconsistency, indirectness, imprecision, publication bias, strength of association, exposure-response gradient, and possible confounding in multiple categories of studies. For example, the reviewers judged the overall quality of evidence for an association between aircraft noise and prevalence of hypertension to be "low" due primarily to a "serious" risk of bias and inconsistency of data and a "small" strength of association in the cross-sectional and cohort studies considered. The quality of evidence to support an association between aircraft noise and prevalence of ischemic heart disease, as well as mortality due to ischemic heart disease, was judged to be "very low" or "low" for the cross-sectional and cohort studies considered. The association between aircraft noise and the prevalence of stroke was found to be "very low," while the evidence supporting association with mortality due to stroke was judged to be "moderate." The quality of evidence supporting and associations between aircraft noise and the prevalence of diabetes was judged to be "very low" while the association with the incidence of diabetes was judged to be "low." Evidence of an association between aircraft noise and the risk of obesity, as quantified using body mass index, was found to be "low," while the quality of evidence supporting an association with increased waist circumference was found to be "moderate."

A 2017 literature review by the International Civil Aviation Organization titled "Aviation Noise: State of the Science" concluded that "There is a good biological plausibility by which noise may affect health in terms of impacts on the autonomic system, annoyance and sleep disturbance. Studies are suggestive of impacts on cardiovascular health especially hypertension, but limited and inconclusive with respect to quantification of these, with a relatively small number of studies conducted to date. More studies are needed to better define exposure –response relationships, the relative importance of night versus daytime noise and the best noise metrics for health studies (e.g., number of aircraft noise events versus average noise level)" (Basner et al., 2017).

1.3.6.2 Vestibular Health Effects

The vestibular system is network of canals adjacent to the inner ear that assist in providing a sense of balance. Common causes of vestibular health issues, whose most common symptoms are dizziness or vertigo, include aging, certain medicines (as a side effect), infection of the middle ear, and head injuries (John Hopkins Medicine, 2024). In recent years, several studies have been conducted on the potential for exposure to very intense and/or very long-duration noise to negatively affect the vestibular system. For example, vestibular system effects have been found in rats after six hours of exposure to 120 dB at 500-4,000 Hertz (Stewart et al., 2020). A study conducted in 2012 showed vestibular effects in mice after extremely long duration noise (i.e., a month of non-stop noise exposure at 70 dB and 100 Hertz) (Tamura, et al., 2012). Although animal studies provide an indication of potential for similar effects in humans, applicability to human systems is not clear. Human studies have focused primarily on correlations between demonstrated vestibular effects and uncontrolled exposures to hazardous noise levels in a workplace environment over several years. For example, a study of workers in India exposed to 108 dB sound pressure level five days a week for more than eight years found an increased incidence of vestibular issues (Bayat et al., 2021). However, a large study of 17,245 veterans found no support for the hypothesis that Ménière's Disease (a common manifestation of vestibular damage) was causally related to previous acoustic trauma or noise-induced hearing loss (Segal et al., 2003). At this time, available literature does not support a causal connection between short-lived noise at levels commonly associated with aircraft overflight and vestibular effects.

1.3.6.3 Summary

The current state of scientific knowledge cannot yet support inference of a causal or consistent relationship between aircraft noise exposure and nonauditory health consequences for exposed residents. The large-scale HYENA study and the recent studies by Hansell et al. (2013) and Correia et al. (2013) offer indications, but it is not yet possible to establish a quantitative cause and effect based on the currently available scientific evidence. These summary conclusions are supported by extensive reviews of recent literature conducted by several groups (FICAN, 2018; van Kempen et al., 2018; Basner et al., 2017). Similarly, additional research on the potential effects of noise on the vestibular system is needed to determine if there are causal connections between short-lived noise at levels commonly associated with aircraft overflights and changes or effects to the vestibular system.

1.3.7 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 found links between continuous high noise levels and performance loss. Noise-induced performance losses are most frequently reported in studies where noise levels are greater than 85 dB. Little change has been found in low-noise cases. 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 the following:

- 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 workers.

1.3.8 Noise Effects on Children

Recent studies on school children indicate a potential link between aircraft noise and both reading comprehension and learning motivation. The effects may be small but may be of particular concern for children who are already scholastically challenged.

1.3.8.1 Effects on Learning and Cognitive Abilities

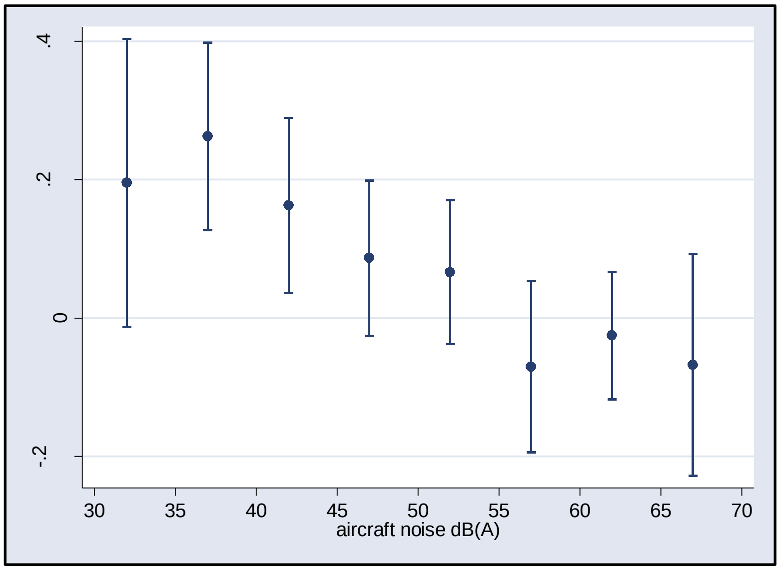
Early studies in several countries (Cohen et al., 1973, 1980, 1981; Bronzaft and McCarthy, 1975; Green et al., 1982; Evans et al., 1998; Haines et al., 2002; Lercher et al., 2003) showed lower reading scores for children living or attending school in noisy areas than for children away from those areas. In some studies, noise-exposed children were less likely to solve difficult puzzles or more likely to give up.

More recently, the Road Traffic and Aircraft Noise Exposure and Children's Cognition and Health (RANCH) study (Stansfeld et al., 2005; Clark et al., 2006) compared the effect of aircraft and road traffic noise on over 2,000 children in three countries. This was the first study to derive exposure-effect associations for a range of cognitive and health effects and the first to compare effects across countries.

The study found a linear relation between chronic aircraft noise exposure and impaired reading comprehension and recognition memory. No associations were found between chronic road traffic noise exposure and cognition. Conceptual recall and information recall surprisingly showed better performance in high road-traffic noise areas. Neither aircraft noise nor road-traffic noise affected attention or working memory (Stansfeld et al., 2005; Clark et al., 2006).

RANCH's result relating noise to reading comprehension is shown in Figure 11. Reading falls below average (a Z-score of 0) at L_{eq} greater than 55 dB, as shown in the figure. Because the relationship is linear, reducing exposure at any level should lead to improvements in reading comprehension.

A six-year follow-up to the RANCH study designed to examine long-term effects of aircraft noise found that children exposed to aircraft noise during primary school had increased noise annoyance but only nonsignificant negative association with reading comprehension (Clark et al., 2013). The authors of the study felt that the lack of statically significant association between noise and reading comprehension was a result of smaller sample size (i.e., 461 children) available for follow-up.



Sources: (Stansfeld et al., 2005, Clark et al., 2006)

Figure 11. Road Traffic and Aircraft Noise Exposure and Children's Cognition and Health Study Reading Scores Varying With L_{eq}

FICAN funded a pilot study to assess the relationship between aircraft noise reduction and standardized test scores (Eagan et al., 2004; FICAN, 2007). The study evaluated whether abrupt aircraft noise reduction within classrooms, from either airport closure or sound insulation, was associated with improvements in test scores. Data were collected in 35 public schools near three airports in Illinois and Texas. The study used several noise metrics. While the findings of this study are valid, the study make use of computed indoor levels, making it hard to compare with the outdoor levels used in most other studies.

The FICAN study found a significant association between noise reduction and a decrease in failure rates for high school students, but not middle or elementary school students. There were some weaker associations between noise reduction and an increase in failure rates for middle and elementary schools. Overall, the study found that the associations observed were similar for children with or without learning difficulties and between verbal and math/science tests. As a pilot study, it was not expected to obtain final answers but provided useful indications (FICAN, 2007).

A study of school occupants exposed to 55 dB DNL and higher near the top 46 U.S. airports found associations between aircraft noise levels and scores on standardized tests in third through fifth grades after accounting for school factors and demographics (National Academies of Sciences, Engineering, and Medicine, 2014). It was shown that schools with good sound insulation have better test scores than those with less insulation. The study showed a greater effect of noise on the performance of non-disadvantaged students than on disadvantaged students, but study analysis does not provide rationale for this result. The study provides further support to the hypothesis that elevated background noise levels are negatively associated with student performance.

Case studies at 11 schools near Los Angeles International Airport identified factors at the individual classroom, student, and teacher level that influence the degree to which noise impacts student achievement (National Academies of Sciences, Engineering, and Medicine, 2017). Classroom observations showed that the most common sources of distraction for students was other students (51 percent) followed by "other" non-aircraft events (30 percent). Even though no in-class distractions were directly attributed to individual aircraft noise events, teachers at schools where DNL exceeded 55 dB were more likely to report perceived interference with student attention, concentration, and performance.

While many factors can 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 to conclude that daycare centers and schools should not be located near major sources of noise, such as highways, airports, and industrial sites (WHO, 1999). The awareness has also led to the classroom noise standard discussed previously (ANSI, 2020).

1.3.8.2 Health Effects

A number of studies, including some of the cognitive studies discussed previously, have examined the potential for effects on children's health. Health effects include annoyance, psychological health, coronary risk, stress hormones, sleep disturbance and hearing loss.

Annoyance. Chronic noise exposure causes annoyance in children (Bronzaft and McCarthy, 1975; Evans et al., 1995). Annoyance among children tends to be higher than for adults, and there is little habituation (Haines et al., 2001a). The RANCH study found annoyance may play a role in how noise affects reading comprehension (Clark et al., 2005).

Psychological health. Lercher et al. (2002) found an association between noise and teacher ratings of psychological health but only for children with biological risk defined by low birth weight and/or premature birth. Haines et al. (2001b) found that children exposed to aircraft noise had higher levels of psychological distress and hyperactivity. Stansfeld et al. (2009) replicated the hyperactivity result but not distress.

As with studies of adults, the evidence suggests that chronic noise exposure is probably not associated with serious psychological illness, but there may be effects on well-being and quality of life. Further research is needed, particularly on whether hyperactive children are more susceptible to stressors such as aircraft noise.

Coronary risk. The HYENA study discussed previously indicated a possible relation between noise and hypertension in older adults. Cohen et al. (1980, 1981) found some increase in blood pressure among school children, but within the normal range and not indicating hypertension. Hygge et al. (2002) found mixed effects. The RANCH study found some effect for children at home and at night, but not at school. Overall, the evidence for noise effects on children's blood pressure is mixed, and less certain than for older adults. A systematic literature review conducted by van Kempen et al. in 2018 judged the overall quality of evidence based on several factors present in available studies on a variety of potential noise impacts (van Kempen et al., 2018). They judged the overall quality of evidence supporting an association between children's blood pressure and aircraft noise experienced at home or at school to be "very low." Similarly, the quality of evidence supporting an association between aircraft noise at home as well as at school and a change in children's blood pressure was also found to be "very low."

Stress hormones. Some studies investigated hormonal levels between groups of children exposed to aircraft noise compared to those in a control group. Two studies analyzed cortisol and urinary catecholamine levels in school children as measurements of stress response to aircraft noise (Haines et al., 2001a, 2001b). In both instances, there were no differences between the aircraft noise-exposed children and the control groups.

Sleep disturbance. A substudy of RANCH in a Swedish sample used sleep logs and the monitoring of rest/activity cycles to compare the effect of road traffic noise on child and parent sleep (Öhrström et al., 2006). An exposure-response relationship was found for sleep quality and daytime sleepiness for children. While this suggests effects of noise on children's sleep disturbance, it is difficult to generalize from one study.

Hearing loss. A few studies have examined hearing loss from exposure to aircraft noise. Noise-induced hearing loss for children who attended a school located under a flight path near a Taiwan airport was greater than for 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 greater than 75 dB DNL and L_{max} were approximately 87 dB during overflights. Conversely, several other studies reported no difference in hearing ability between children exposed to high levels of airport noise and children located in quieter areas (Andrus et al., 1975; Fisch, 1977; Wu et al., 1995). It is not clear from those results whether children are at higher risk than adults, but the levels involved are higher than those desirable for learning and quality of life.

Ludlow and Sixsmith (1999) conducted a cross-sectional pilot study to examine the hypothesis that military jet noise exposure early in life is associated with raised hearing thresholds. The authors concluded that there were no significant differences in audiometric test results between military personnel who as children had lived in or near stations where fast jet operations were based and a similar group who had no such exposure as children.

1.3.9 Property Values

Noise can affect the value of homes. Economic studies of property values based on selling prices and noise have been conducted to find a direct relation.

The value-noise relation is usually presented as the Noise Depreciation Index (NDI) or Noise Sensitivity Depreciation Index, the percent loss of value per dB (measured by the DNL metric). An early study by Nelson (1978) at three airports found an NDI of 1.8 to 2.3 percent per dB. Nelson also noted a decline in NDI over time, which he theorized could be due to either a change in population or the increase in commercial value of the property near airports. Crowley (1978) reached a similar conclusion. A larger study by Nelson (1980) looking at 18 airports found an NDI from 0.5 to 0.6 percent per dB.

In a review of property value studies, Newman and Beattie (1985) found a range of NDI from 0.2 to 2 percent per dB. They noted that many factors other than noise affected values.

Fidell et al. (1996) studied the influence of aircraft noise on actual sale prices of residential properties in the vicinity of a military base in Virginia and one in Arizona. They found no meaningful effect on home values. Their results may have been due to non-noise factors, especially the wide differences in homes between the two study areas.

Recent studies of noise effects on property values have recognized the need to account for non-noise factors. Nelson (2004) analyzed data from 33 airports and discussed the need to account for those factors and the need for careful statistics. His analysis showed an NDI from 0.3 to 1.5 percent per dB, with an average of approximately 0.65 percent per dB. Nelson (2007) and Andersson et al. (2013) discuss statistical modeling in more detail.

Enough data are available to conclude that aircraft noise has a real effect on property values. This effect falls in the range of 0.2 to 2 percent per dB, with the average on the order of 0.5 percent per dB. The actual value varies from location to location and is very often small compared to non-noise factors.

1.3.10 Noise-Induced Vibration Effects on Structures and Humans

High noise levels can cause buildings to vibrate. If high enough, building components can be damaged. The most sensitive components of a building are the windows, followed by plaster walls and ceilings. Possibility of damage depends on the peak sound pressures and the resonances of the building. An evaluation of the peak sound pressures impinging on the structure is normally sufficient to determine the possibility of damage. In general, sound levels greater than 130 dB (unweighted) can potentially result in structural damage (CHABA, 1977). Normal aircraft operations would be expected to be at sound levels lower than 130 dB, so even low-altitude heavy-aircraft flyovers would not result in structural damage (Sutherland, 1990). 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 an unweighted sound level of 130 dB are potentially damaging to structural components (von Gierke and Ward, 1991).

The sound from an aircraft overflight travels from the exterior to the interior of the house in one of two ways: through the solid structural elements and directly through the air. The sound transmission through a wall constructed with a brick exterior, stud framing, interior finish wall, and absorbent material in the cavity is shown in Figure 12. The sound transmission starts with noise impinging on the wall exterior. Some of this sound energy will be reflected away and some will make the wall vibrate. The vibrating wall radiates sound into the airspace, which in turn sets the interior finish surface vibrating, with some energy lost in the airspace. This surface then radiates sound into the dwelling interior. As shown in the figure, vibrational energy also bypasses the air cavity by traveling through the studs and edge connections.

Noise-induced structural vibration may cause annoyance to dwelling occupants because of induced secondary vibrations, or “rattle,” of objects within the dwelling—hanging pictures, dishes, plaques, and bric-a-brac. Loose windowpanes may also vibrate noticeably when exposed to high levels of airborne noise, causing homeowners to fear breakage. In general, rattling occurs at peak unweighted sound levels that last for several seconds at levels greater than 110 dB, which is well above that considered normally compatible with residential land use. Thus, assessments of noise exposure levels for compatible land use will also be protective of noise-induced rattle.

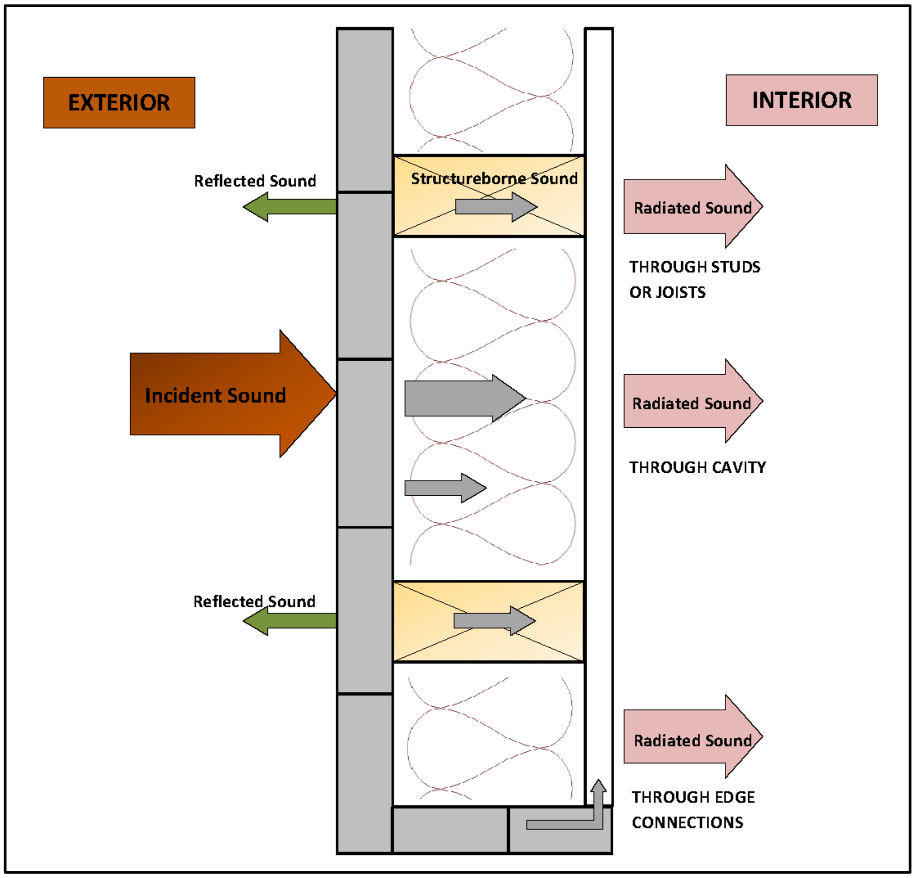


Figure 12. Depiction of Sound Transmission Through Built Construction

In the assessment of vibration on humans, the following factors determine if a person will perceive and possibly react to building vibrations:

- Type of excitation: steady-state, intermittent, or impulsive vibration
- Frequency of the excitation. International Organization for Standardization standard 2631-2 (ISO, 2003) recommends a frequency range of 1 to 80 Hz for the assessment of vibration on humans
- Orientation of the body with respect to the vibration
- The use of the occupied space (i.e., residential, workshop, hospital)
- Time of day

Table 11 lists the whole-body vibration criteria from International Organization for Standardization 2631-2 for one-third octave frequency bands from 1 to 80 Hz.

Table 11. Vibration Criteria for the Evaluation of Human Exposure to Whole-Body Vibration

Frequency (Hertz)	Root Mean Square Acceleration (in Meters per Second Squared)		
	Combined Criteria Base Curve	Residential Night	Residential Day
1.00	0.0036	0.0050	0.0072
1.25	0.0036	0.0050	0.0072
1.60	0.0036	0.0050	0.0072
2.00	0.0036	0.0050	0.0072

Table 11. Vibration Criteria for the Evaluation of Human Exposure to Whole-Body Vibration

Frequency (Hertz)	Root Mean Square Acceleration (in Meters per Second Squared)		
	Combined Criteria Base Curve	Residential Night	Residential Day
2.50	0.0037	0.0052	0.0074
3.15	0.0039	0.0054	0.0077
4.00	0.0041	0.0057	0.0081
5.00	0.0043	0.0060	0.0086
6.30	0.0046	0.0064	0.0092
8.00	0.0050	0.0070	0.0100
10.00	0.0063	0.0088	0.0126
12.50	0.0078	0.0109	0.0156
16.00	0.0100	0.0140	0.0200
20.00	0.0125	0.0175	0.0250
25.00	0.0156	0.0218	0.0312
31.50	0.0197	0.0276	0.0394
40.00	0.0250	0.0350	0.0500
50.00	0.0313	0.0438	0.0626
63.00	0.0394	0.0552	0.0788
80.00	0.0500	0.0700	0.1000

Source: (ISO, 2003)

1.3.11 Noise Effects on Terrain

It has been suggested that noise levels associated with low-flying aircraft may affect the terrain under the flight path by disturbing fragile soil or snow, especially in mountainous areas, causing landslides or avalanches. There are no known instances of such events. It is improbable that such effects would result from routine subsonic aircraft operations.

1.3.12 Noise Effects on Historical and Archaeological Sites

Noise that does not exceed 130 dB in any one-third-octave frequency band and last for more than one second does not typically have the potential to damage structures in good repair (CHABA, 1977). The term "frequency bands" refers to noise energy in a certain range of frequencies and is similar in concept to frequency bands employed on home stereo equalizers to control relative levels of bass and treble. Noise energy in certain frequency bands has increased potential to vibrate and/or damage structures. Noise exceeding 130 dB in any one-third-octave frequency band and lasting for more than one second of that intensity and duration does not occur except on the flightline immediately adjacent to jet aircraft.

Noise-induced structural vibration and secondary vibrations (i.e., "rattle") of objects within structures can occur during loud overflights, as was noted in scoping comments. Rattling of objects such as dishes, hanging pictures, and loose windowpanes can cause residents to fear damage. Rattling objects have the potential to contribute to annoyance along with other potential noise effects (e.g., speech interference, sleep disturbance). Various studies have been completed to document the impact of noise. For example, one study involved measurements of noise and vibration in a restored plantation house, originally built in 1795. It is located 1,500 feet from the centerline at the departure end of Runway 19L at Washington Dulles International Airport. The aircraft measured was the Concorde. There was special concern for the building's windows because roughly half of the 324 panes were original. No instances of structural damage were found. Interestingly, despite the high levels of noise during Concorde takeoffs, the induced structural vibration levels were actually less than those induced by touring groups and vacuum cleaning (Wesler, 1977).

As for conventional structures, noise exposure levels for normally compatible land uses should also be protective of historic and archaeological sites. Unique sites should, of course, be analyzed for specific exposure.

1.3.13 Effects on Domestic Animals and Wildlife

Domestic animals and wildlife have different hearing thresholds, frequency response, and tolerance characteristics than do humans. There is a large difference in response even among different animal species. Evaluation of noise impacts on wildlife using metrics primarily intended for human impact should be done with caution and makes evaluation of impacts on wildlife even more difficult. As such, evaluations in this document have been based primarily on historical response to sounds rather than to absolute sound levels.

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 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 relationships between potential auditory/physiological effects and species interactions with their environments are not well understood. Manci et al. (1988), assert that the consequences that physiological effects may have on behavioral patterns are vital to understanding the long-term effects of noise on wildlife. Questions regarding the effects (if any) on predator-prey interactions, reproductive success, and intra-inter-specific behavior patterns remain.

The following discussion provides an overview of the existing literature on noise effects (particularly jet aircraft noise) on animal species. The literature reviewed here involves those studies that have focused on the observations of the behavioral effects that jet aircraft have on animals.

A great deal of research was conducted in the 1960s and 1970s 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 as a result of the introduction of supersonic jet aircraft. According to Manci et al. (1988), the foundation of information created from that focus does not necessarily correlate or provide information specific to the impacts to wildlife in areas overflown by aircraft at supersonic speed or at low altitudes.

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 other types 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 could interfere with behavioral patterns (Manci et al., 1988). Although the effects are likely temporal, aircraft noise may cause masking of auditory signals within exposed faunal communities (Barber et al., 2009). Animals rely on hearing to avoid predators, obtain food, and communicate with, 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 not as likely given the subsonic noise levels produced by aircraft overflights. Increased noise levels may also reduce the distance and area over which acoustic signals can be perceived by animals. Barber et al. (2009) reviewed a broad range of findings that indicated the potential severity of noise threats to diverse taxa, and recent studies that document substantial changes in foraging and anti-predator behavior, reproductive success, density, and community structure in response to noise. It was concluded that effective management of protected areas must include noise assessment, and research is needed to further quantify the ecological consequences of chronic noise exposure in terrestrial environments. Although the effects are likely temporary, aircraft noise may cause masking of auditory signals within exposed faunal communities (Barber et al., 2009).

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 and include population decline and habitat loss. Most of the effects of noise are mild enough that they may never be detectable 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). Many scientific studies have investigated the effects of aircraft noise on wildlife, and some have focused on wildlife “flight” due to noise. Animal responses to aircraft are influenced by many variables, including 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 rotor wing [helicopter]) and type of flight mission may also produce different levels of disturbance, with varying animal responses (Smith et al., 1988). Consequently, it is difficult to generalize animal responses to noise disturbances across species.

One result of the Manci et al. (1988) literature review was the conclusion that, while behavioral observation studies were relatively limited, a general behavioral reaction in animals from exposure to aircraft noise is the startle response. The intensity and duration of the startle response appears to be dependent on which species is exposed, whether there is a group or an individual, and whether there have been some previous exposures. Responses range from flight, trampling, stampeding, jumping, or running to movement of the head in the apparent direction of the noise source. Manci et al. (1988) reported that the literature indicated that avian species may be more sensitive to aircraft noise than mammals.

1.3.13.1 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. Mammals in particular appear to react to noise at sound levels higher than 90 dB, with responses including the startle response, freezing (i.e., becoming temporarily stationary), and fleeing from the sound source. Many studies on domestic animals suggest that some species appear to acclimate to some forms of sound disturbance (Manci et al., 1988). Some studies have reported such primary and secondary effects as 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 existing literature.

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). In contrast, many studies conclude that there is no evidence that aircraft overflights affect feed intake, growth, or production rates in domestic animals.

Cattle

In response to concerns about overflight effects on pregnant cattle, milk production, and cattle safety, the DAF prepared a handbook for environmental protection that summarized 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 2 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. A similar study reported abortions occurred in three out of five pregnant cattle after exposing them to flyovers by six different aircraft. Another study suggested that feedlot cattle could stampede and injure themselves when exposed to low-level overflights (DAF, 1994a).

A majority of the studies reviewed suggests that there is little or no effect of aircraft noise on cattle. Studies presenting adverse effects to 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 boom events, it was determined that milk yields were not affected. This was particularly evident in those cows that had been previously exposed to jet aircraft noise.

A study examined the causes of 1,763 abortions in Wisconsin dairy cattle over a one-year time period, and none were associated with aircraft disturbances (DAF, 1993). In 1987, researchers contacted seven livestock operators for production data, and no effects of low-altitude and supersonic flights were noted. Of the 43 cattle previously exposed to low-altitude flights, 3 showed a startle response to an F/A-18 aircraft flying overhead at 500 feet above ground level (AGL) and 400 knots by running less than 10 meters. They resumed normal activity within one minute (DAF, 1994a). In 1983, researchers found that helicopters caused more reaction than other low-aircraft overflights and that the helicopters at 30 to 60 feet overhead did not affect milk production and pregnancies of 44 cows in a 1964 study (DAF, 1994a).

Additionally, the 1983 study reported that 5 pregnant dairy cows in a pasture did not exhibit fright-flight tendencies or disturb their pregnancies after being overflown by 79 low-altitude helicopter flights and 4 low-altitude, subsonic jet aircraft flights (DAF 1994a). 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 (DAF, 1994a).

In a report to Congress, the U.S. Forest Service 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 horses galloped in response to jet flyovers (DAF, 1993). Bowles (1995) cites Kruger and Erath as observing horses exhibiting intensive flight reactions, random movements, and biting/kicking behavior. However, no injuries or abortions occurred, and there was evidence that the mares adapted somewhat to the flyovers over the course of a month (DAF, 1994a). Although horses were observed noticing the overflights, it did not appear to affect either survivability or reproductive success. There was also some indication that habituation to these types of disturbances was occurring.

LeBlanc et al. (1991) studied the effects of F-14 jet aircraft noise on pregnant mares. 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. The mares, however, did habituate to the noise. Levels of anxiety and mass body movements were the highest after initial exposure, with intensities of responses decreasing thereafter. There were no differences in pregnancy success when compared to a control group.

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., 6 hours, 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 observed aircraft noise. Observations of heart rate increase were recorded, noting 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, simulated aircraft noise at levels of 100 to 135 dB had only minor effects on the rate of feed utilization, weight gain, food intake, or reproduction rates of boars and sows exposed, and there were no injuries or inner ear changes observed (Gladwin et al., 1988; Manci et al., 1988).

Domestic Fowl

According to a 1994 position paper by the DAF on effects of low-altitude overflights (below 1,000 feet) on domestic fowl, overflight activity has negligible effects (DAF, 1994b). 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 caused during "pile-up" situations).

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 birds, and birds not previously exposed, are more likely to pile up in response to a noise stimulus (DAF, 1994b). 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 (DAF, 1994b). 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 dB.

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. 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 (DAF, 1994b).

1.3.13.2 Wildlife

Studies on the effects of overflights on wildlife have been focused mostly on avian species and ungulates such as caribou and bighorn sheep. Few studies have been conducted on marine mammals, small terrestrial mammals, reptiles, amphibians, and carnivorous mammals. Generally, species that live entirely below the surface of the water have also been ignored due to the fact they do not experience the same level of sound as terrestrial species (NPS, 1994).

Wild ungulates appear to be much more sensitive to noise disturbance than domestic livestock. This may be due to previous exposure to disturbances. One common factor appears to be that low-altitude flyovers seem to be more disruptive in terrain where there is little cover (Manci et al., 1988).

Terrestrial Mammals

Early studies of terrestrial mammals have shown that noise exceeding 120 dBA repeatedly over a 10-hour period can damage mammals' ears, and levels at 95 dBA for 8 minutes can cause temporary loss of hearing acuity. Noise from aircraft has affected other large carnivores by causing changes in home ranges, foraging patterns, and breeding behavior. One study recommended that aircraft not be allowed to fly at altitudes below 2,000 feet AGL over important grizzly and polar bear habitat. Wolves have been frightened by low-altitude flights that were 25 to 1,000 feet AGL. However, wolves have been found to adapt to aircraft overflights and noise as long as they were not being hunted from aircraft (Dufour, 1980). The effects of individual short-lived noise exposure events on hearing are less predictable. Bowles (1995) indicated that acute exposure to noise was known to damage animals' hearing at peak levels over 140 to 150 dB in the frequency range heard best by humans.

Wild ungulates (American bison, caribou, bighorn sheep) appear to be much more sensitive to noise disturbance than domestic livestock (Weisenberger et al., 1996). Behavioral reactions may be related to the history of disturbances by such things as humans and aircraft. In 1998, Krausman et al. found that aircraft flying over bighorn sheep at 410 feet (125 meters) did not cause an alteration of heart rates or behavior that suggested the aircraft created a negative effect on the sheep population. However, heart rate increased above preflight levels in 21 of 149 overflights but returned to preflight levels within 120 seconds. When F-16 aircraft flew over the enclosure, the noise levels created did not alter behavior or use of habitat or increase heart rates to the detriment of the sheep in the enclosure (Krausman et al., 1998). In contrast, a 1994 study concluded that mountain sheep have been found to respond dramatically to helicopter disturbance. Mountain sheep did not habituate or become sensitized to repeated helicopter overflights (Bleich et al., 1994). The consequences of disturbing mountain sheep, such as altering use of habitat, increasing susceptibility to predation, or increasing nutritional stress, need additional study. Research into the effects on bighorn sheep of frequent flight activities and supersonic flight is limited (Idaho Department of Fish and Game, 2010; Lawler et al. 2004). Common reactions of reindeer kept in an enclosure exposed to aircraft noise disturbance were a slight startle response, rising of the head, pricking ears, and scenting of the air. Panic reactions and extensive changes in behavior of individual animals were not observed. 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 or less. The reactions decreased with increased altitude of overflights, and with more than 500 feet in altitude, the panic reactions stopped. Also, smaller groups reacted less strongly than larger groups. One negative effect of the running and avoidance behavior is increased expenditure of energy. For a 90-kilogram animal, the calculated expenditure due to aircraft harassment is 64 kilocalories per minute when running and 20 kilocalories per minute when walking. When conditions are favorable, this expenditure can be counteracted with increased feeding; however, during harsh winter conditions, this may not be possible. Incidental observations of wolves and bears exposed to fixed-wing aircraft and helicopters in the northern regions suggested that wolves are less disturbed than wild ungulates, while grizzly bears showed the greatest response of any animal species observed (Weisenberger et al., 1996).

It has been proven that low-altitude overflights do induce stress in animals. Increased heart rates, an indicator of excitement or stress, have been found in pronghorn antelope, elk, and bighorn sheep. As such reactions occur naturally as a response to predation, infrequent overflights may not, in and of themselves, be detrimental. However, flights at high frequencies over a long period of time may cause harmful effects. The consequences of this disturbance, while cumulative, are not additive. It may be that aircraft disturbance may not cause obvious and serious health effects, but coupled with a harsh winter, it may have an adverse impact. Research has shown that stress induced by other types of disturbances produces long-term decreases in metabolism and hormone balances in wild ungulates.

Behavioral responses can range from mild to severe. Mild responses include head raising, body shifting, or turning to orient toward the aircraft. Moderate disturbance may be nervous behaviors, such as trotting a short distance. Escape is the typical severe response.

1.3.13.3 Birds

Auditory research conducted on birds indicates that they fall between the reptiles and the 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 sensitivity falls off at a greater rate to increasing and decreasing frequencies. Passive observations and studies examining aircraft bird strikes indicate that birds nest and forage near airports. Aircraft noise in the vicinity of commercial airports apparently does not inhibit bird presence and use.

High noise events (like a low-altitude aircraft overflight) may cause birds to engage in escape or avoidance behaviors, such as flushing from perches or nests (Ellis et al., 1991). These activities impose an energy cost on the birds that, over the long term, may 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. Some birds may even respond to overflights by adjusting their nesting patterns. However, the long-term significance of noise-related impacts is less clear. Several studies on nesting raptors have indicated that birds become habituated to aircraft overflights and that long-term reproductive success is not affected (Ellis et al., 1991; Grubb and King, 1991). Threshold noise levels for significant responses range from 62 dB for Pacific black brant to 85 dB for crested tern (Brown, 1990; Ward and Stehn, 1990).

Manci et al. (1988) reported a reduction in reproductive success in some small territorial passerines (i.e., perching birds or songbirds) after exposure to low-altitude overflights. However, it has been observed that passerines are not driven any great distance from a favored food source by a nonspecific disturbance, such as aircraft overflights (USFS, 1992). Further study may be warranted.

A cooperative study between the DoD and the U.S. Fish and Wildlife Service (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 project findings show that the red-cockaded woodpecker successfully acclimates to military noise events. Depending on the noise level that ranged from innocuous to very loud, the birds responded by flushing from their nest cavities. When the noise source was closer and the noise level was higher, the number of flushes increased proportionately. 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 SELs were 70 dB.

Raptors

In a literature review of raptor responses to aircraft 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 rotor-winged aircraft or jet aircraft that were repeatedly passing within 0.5 mile of a nest.

Short-term behavior responses were also noted. Overflights at a distance of 150 meters or less produced few significant responses and no severe responses. Typical responses consisted of crouching or, very rarely, flushing from the perch site. Significant responses were most evident before egg laying and after young were "well grown." Incubating or brooding adults never burst from the nest, thus preventing egg breaking or knocking chicks out of the nest. Jet passes and sonic booms often caused noticeable alarm; however, significant negative responses were rare and did not appear to limit productivity or reoccupancy. Due to the locations of some of the nests, some birds may have been habituated to aircraft noise. There were some test sites located at distances far from zones of frequent military aircraft usage, and the test stimuli were often closer, louder, and more frequent than would be likely for a normal training situation (Ellis et al., 1991).

Manci et al. (1988) noted that a female northern harrier was observed hunting on a bombing range in Mississippi during bombing exercises. The harrier was apparently unfazed by the exercises, even when a bomb exploded within 200 feet. In a similar case of habituation/nondisturbance, a study on the Florida snail-kite stated the greatest reaction to overflights (approximately 98 dB) was "watching the aircraft fly by." No detrimental impacts to distribution, breeding success, or behavior were noted.

Bald eagle. A study by Grubb and King (1991) on the reactions of the bald eagle to human disturbances showed that terrestrial disturbances elicited the greatest response, followed by aquatic (i.e., boats) and aerial disturbances. The disturbance regime of the area where the study occurred was predominantly characterized by aircraft noise. The study found that pedestrians consistently caused responses that were greater in both frequency and duration. Helicopters elicited the highest level of aircraft-related responses. Aircraft disturbances, although the most common form of disturbance, resulted in the lowest levels of response. This low response level may have been due to habituation; however, flights less than 170 meters away caused reactions similar to other disturbance types. Ellis et al. (1991) showed that eagles typically respond to the proximity of a disturbance, such as a pedestrian or aircraft within 100 meters, rather than the noise level. In a 1986 study, researchers noted that reactions of bald eagles to commercial jet flights, although minor (e.g., looking), were twice as likely to occur when the jets passed at a distance of 0.5 mile or less (Manci et al., 1988). They also noted that helicopters were 4 times more likely to cause a reaction than a commercial jet and 20 times more likely to cause a reaction than a propeller plane.

The USFWS advised Cannon Air Force Base that flights at or below 2,000 feet AGL from October 1 through March 1 could result in adverse impacts to wintering bald eagles (USFWS, 1998). However, Fraser et al. (1985) suggested that raptors habituate to overflights rapidly, sometimes tolerating aircraft approaches of 65 feet or less.

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 and rotary wing) 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 exposure 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 to 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 flatten and three fly 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. None of these responding pairs failed to successfully fledge young, except for one nest that fell later in the season. Excited, startled, 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. 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 to 108.8 dB, unweighted). The authors thought that the lower-than-expected behavioral responses may be partially due to the fact that the golden eagles in the area appear acclimated to the current high levels of outdoor recreational activities, including aviation. 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 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 to 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 study by Trimper et al. (1998) in Goose Bay, Labrador, Canada, focused on the reactions of nesting osprey to military overflights by CF-18 Hornets. 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 one to two 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 osprey 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 been habituated to the noise of the flights; however, overflights were strictly controlled during the experimental period. Strong reactions to float planes and helicopter 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) conducted a study that investigated the effects of low-level helicopter overflights on 35 red-tailed hawk nests. Some of the nests had not been flown over prior to the study. The hawks that were naïve (i.e., not previously exposed) to helicopter flights exhibited stronger avoidance behavior (9 of 17 birds flushed from their nests) than those that had experienced prior overflights. 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 air traffic, even during the nesting period.

Migratory Waterfowl

Fleming et al. (1996) conducted a study of caged American black ducks and found that noise had negligible energetic and physiologic effects on adult waterfowl. Measurements included body weight, behavior, heart rate, and enzymatic activity. Experiments also showed that adult ducks exposed to high noise events acclimated rapidly and showed no effects.

The study also investigated the reproductive success of captive ducks, which indicated that duckling growth and survival rates at Piney Island, North Carolina, were lower than those at a background location. In contrast, observations of several other reproductive indices (i.e., pair formation, nesting, egg production, and hatching success) showed no difference between Piney Island and the background location. Potential effects on wild duck populations may vary, as wild ducks at Piney Island have presumably acclimated to aircraft overflights. It was not demonstrated that noise was the cause of adverse impacts. A variety of other factors, such as weather conditions, drinking water and food availability and variability, disease, and natural variability in reproduction, could explain the observed effects. Fleming noted that drinking water conditions (particularly at Piney Island) deteriorated during the study, which could have affected the growth of young ducks. Further research would be necessary to determine the cause of any reproductive effects (Fleming et al., 1996).

Another study by Conomy et al. (1998) exposed previously unexposed ducks to 71 noise events per day that equaled or exceeded 80 dB. It was determined that the proportion of time black ducks reacted to aircraft activity and noise decreased from 38 percent to 6 percent in 17 days and remained stable at 5.8 percent thereafter. In the same study, the wood duck did not appear to habituate to aircraft disturbance. This supports the notion that animal response to aircraft noise is species specific. Because a startle response to aircraft noise can result in flushing from nests, migrants and animals living in areas with high concentrations of predators would be the most vulnerable to experiencing effects of lowered birth rates and recruitment over time. Species that are subjected to infrequent overflights do not appear to habituate to overflight disturbance as readily.

Black brant studied in the Alaska Peninsula were exposed to jets and propeller aircraft, helicopters, gunshots, people, boats, and various raptors. Jets accounted for 65 percent of all the disturbances. Humans, eagles, and boats caused a greater percentage of brant to take flight. There was markedly greater reaction to Bell-206-B helicopter flights than fixed-wing, single-engine aircraft (Ward et al., 1986).

The presence of humans and low-flying helicopters in the Mackenzie Valley North Slope area did not appear to affect the population density of Lapland longspurs, but the experimental group was shown to have reduced hatching and fledging success and higher nest abandonment. Human presence appeared to have a greater impact on the incubating behavior of the black brant, common eider, and Arctic tern than fixed-wing aircraft (Gunn and Livingston, 1974).

Gunn and Livingston (1974) found that waterfowl and seabirds in the Mackenzie Valley and North Slope of Alaska and Canada became acclimated to float plane disturbance over the course of three days. Additionally, it was observed that potential predators (bald eagle) caused a number of birds to leave their nests. Nonbreeding birds were observed to be more reactive than breeding birds. Waterfowl were affected by helicopter flights, while snow geese were disturbed by Cessna 185 flights. The geese flushed when the planes were less than 1,000 feet compared to higher flight elevations. An overall reduction in flock sizes was observed. It was recommended that aircraft flights be reduced in the vicinity of premigratory staging areas.

Manci et al. (1988) reported that waterfowl were particularly disturbed by aircraft noise. The most sensitive appeared to be snow geese. Canada geese and snow geese were thought to be more sensitive than other animals such as turkey vultures, coyotes, and raptors (Edwards et al., 1979).

Wading and Shorebirds

Black et al. (1984) studied the effects of low-altitude (less than 500 feet AGL) military training flights with sound levels from 55 to 100 dB on wading bird colonies (i.e., great egret, snowy egret, tricolored heron, and little blue heron). The training flights involved three or four aircraft, which 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.

Another study on the effects of circling fixed-wing aircraft and helicopter overflights on wading bird colonies found that at altitudes of 195 to 390 feet, there was no reaction in nearly 75 percent of the 220 observations. Approximately 90 percent displayed no reaction or merely looked toward the direction of the noise source. 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, 1978). Apparently, nonnesting wading birds had a slightly higher incidence of reacting to overflights than nesting birds. Seagulls observed roosting near a colony of wading birds in another study remained at their roosts when subsonic aircraft flew overhead (Burger, 1981). Colony distribution 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 wading bird species presence was most closely linked to habitat availability and that they were not affected by low-level military overflights (DAF, 2000).

Burger (1986) studied the response of migrating shorebirds to human disturbance 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) studied the effects of noise from John F. Kennedy International Airport in New York on herring gulls that nested less than 1 kilometer from the airport. Noise levels over the nesting colony were 85 to 100 dB on approach and 94 to 105 dB on takeoff. Generally, there did not appear to be any prominent adverse effects of subsonic aircraft on nesting, although some birds flushed when the Concorde flew overhead and, when they returned, engaged in aggressive behavior. Groups of gulls tended to loaf in the area of the nesting colony, and these birds remained at the roost when the Concorde flew overhead. Up to 208 of the loafing gulls flew when supersonic aircraft flew overhead. These birds would circle around and immediately land in the loafing flock (DAF, 2000).

Burger (1981) observed no effects of subsonic aircraft on herring gulls in the vicinity of John F. Kennedy International Airport. The Concorde aircraft did cause more nesting gulls to leave their nests (especially in areas of higher density of nests), causing the breakage of eggs and the scavenging of eggs by intruder prey. Clutch sizes were observed to be smaller in areas of higher-density nesting (presumably due to the greater tendency for panic flight) than in areas where there were fewer nests.

1.3.13.4 Fish, Reptiles, Amphibians, and Invertebrates

The effects of overflight noise on fish, reptiles, amphibians, and invertebrates have not been well studied, but conclusions regarding their expected responses have involved speculation based upon known physiologies and behavioral traits of these taxa (Gladwin et al., 1988; Manci et al., 1988). Per studies summarized in (Manci et al., 1988), fish have not been found to be sensitive to in-air noise, showing at most a slight startle response. Although studies of longer periods of noise exposure have documented effects on invertebrate behavior and reproductive success, brief, intermittent noise exposure did not appear to negatively affect the invertebrate species studied. Most of the limited number of studies on noise impacts to reptiles and amphibians examined noise exposure over much longer periods of time than would occur for an overflight. Short-term behavioral responses in reptiles and amphibians have included freezing and emergence at inappropriate times, but it is unclear if these were due more to vibrations or the noise itself (Bowles, 1995). During and after an overflight, individuals may remain "frozen" for a brief period, and frogs may cease breeding calls. In instances where the frogs do not freeze, overflight noise may mask breeding calls for about a 1- to 2-minute period. If overflight noise/vibrations prompt emergences during the dry season, species that use auditory cues (i.e., thunder) to emerge from burrows may deplete energy reserves and become dehydrated. Another study from 2005 concluded that certain species of acoustically active, pond-dwelling frogs decrease their call rate when exposed to airplane flyby or motorcycle engine playbacks. This finding suggests that frogs changed their calling behavior to avoid acoustic masking (Sun & Narins, 2005).

1.3.13.5 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, wood ducks appear to be more sensitive and more resistant to acclimation to jet aircraft noise than Canada geese in one study. 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. Military training situations in which similar noise-producing exercises are carried out in the same habitat at frequent intervals may therefore affect locally breeding wildlife less than less-frequent or less-predictable activities (Larkin et. al, 1996).

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.

1.4 NOISE MODELING METHODOLOGY

1.4.1 Installation Vicinity

Analyses of aircraft noise exposure around military airfield facilities are normally accomplished by using the NoiseMap suite of computer programs (Czech & Plotkin, 1998). The latest NoiseMap package of computer programs consists of BaseOps Version 7, OMEGA10, OMEGA11, NoiseMap Version 7.3, NMPlot, and the latest issue of NOISEFILE. NOISEFILE is the DoD noise database originating from noise measurements of controlled flyovers at prescribed power, speed, and drag configurations for many models of aircraft (Downing, 2016). The data input module BaseOps allows the user to enter the runway coordinates, airfield information, flight tracks, and flight profiles along each track by each aircraft, numbers of flight operations, run-up coordinates, run-up profiles, and run-up operations (Wasmer & Maunsell, 2006a). After the operational parameters are defined, NoiseMap and the supporting programs OMEGA10 and OMEGA11 calculate DNL values on a grid of ground locations on and around the facility (Mohlman, 1983). The NMPlot program draws contours of equal DNL (Wasmer & Maunsell, 2006b). NoiseMap also has the flexibility of calculating sound metrics (e.g., SEL, DNL) at specified points so that noise values at representative locations around an airfield can be described in more detail. NoiseMap has the capability to account for the effects of terrain on noise propagation using local topographic and ground cover data. In accordance with DAF standard practice, noise levels are calculated for average conditions as measured during the month with acoustically median conditions.

The OA-1K is a variant of the Air Tractor AT-802 aircraft. This family of aircraft are not included in either the DoD NOISEFILE or the FAA reference noise databases. However, the European Union Aviation Safety Agency does have a certification dataset of noise levels for both the AT-802 and T-6 aircraft, which is in the NOISEFILE database (European Union Aviation Safety Agency, 2024). These certification levels are for departures under International Civil Aviation Organization, Annex 16, Volume 1, Chapter 10 requirements. Table 12 shows the European Union Aviation Safety Agency certification Effective Perceived Noise Levels for these two single propellor aircraft.

Table 12. Comparison of European Union Aviation Safety Agency Certification Noise Levels for the Selection of the Surrogate for OA-1K

Aircraft	Engine Thrust (per engine)	Aircraft Gross Weight	Operation Type	Effective Perceived Noise Level (dB)	Source
Air Tractor AT-802	1,434 horsepower	16,000 pounds	Take-Off (Chapter 10 requirements)	84.4	European Union Aviation Safety Agency
T-6	1,100 horsepower	6,300 pounds	Take-Off (Chapter 10 requirements)	80.3	NOISEFILE

Key: dB = decibels

The T-6 is the most similar aircraft to the AT-802 in the NOISEFILE database, but it only has a 1,100-horsepower turboprop engine. However, the Effective Perceived Noise Level for the AT-802 is 4.1 dBA higher than the T-6 for the Chapter 10 Take-Off requirement. To avoid an under estimation of the noise for the OA-1K, this difference in Effective Perceived Noise Level levels was used to generate an estimated NOISEFILE dataset for the OA-1K. This estimated dataset includes both flyover and static reference noise data. Engine power settings were translated from the T-6 to the OA-1K following a linear correlation.

The estimated NOISEFILE dataset for the OA-1K described above is a conservative representation of noise levels. In the future, DAF may conduct measurements of OA-1K noise levels that would fully support development of reference noise levels for use in the NoiseMap suite of programs. If so, those reference noise levels could be used for future noise impact analyses involving OA-1K operations.

1.4.2 Training Airspace

When aircraft flight tracks are not well defined but are distributed over a wide area, such as in a MOA, range/Restricted Areas, or MTR with wide corridors, cumulative noise exposure is assessed using the Military Operating Area and Range Noise Model (MR_NMAP), Version 3.0 (Lucas and Calamia, 1994). MR_NMAP allows for entry of airspace information, the horizontal distribution of operations, flight profiles (average power settings, altitude distributions, and speeds), and numbers of sorties. "Horizontal distribution of operations" refers to the modeling of lateral airspace utilization via three general representations:

- Broadly distributed operations throughout three-dimensional volumes of airspace for modeling of MOA and range events
- Operations distributed among parallel tracks for modeling of MTR events
- Operations on specific tracks for modeling of unique MOA, range, MTR, or target area activity

The core program, MR_NMAP, incorporates the number of average daily flight operations during the busiest month by time period, specified horizontal distributions, volume of the airspaces, and profiles of the aircraft to primarily calculate: (a) average L_{dnmr} for entire airspaces or (c) maximum L_{dnmr} under MTRs or specific tracks. Grouping of airspace units used and scheduled together consistently were assessed as one area. This Environmental Impact Statement presents tabulated levels for baseline, no action alternative, and proposed operations.

MR_NMAP does not have the capability to model varying terrain or ground impedance and instead uses a reference ground elevation. It assumes all flight profiles' altitudes are relative to the elevation of the ground. The weather conditions for the airfield modeling were assumed to apply to the modeled flight areas.

As noted in *492nd Special Operations Wing Beddown Draft Environmental Impact Statement* Section 2.2.3, *Airspace Use*, and Section 3.2, *Acoustic Environment*, Air Force Special Operations Command aircrews would occasionally use existing airspaces, including the combat search and rescue low altitude tactical navigation area and various MTRs. Low altitude tactical navigation areas and MTRs near Davis-Monthan AFB are shown in Figure 13. Occasional use of these airspaces would occur within large areas and/or on large numbers of MTRs such that no location on the ground would be expected to be overflown more than once per day on average. These occasional flight operations would not result in appreciable changes in DNL (or L_{dnmr}) at any point on the ground.

When multiple aircraft fly in formation, they are typically either in-trail or displaced laterally from the flight lead such that the resulting maximum overflight noise level for a formation flight (i.e., L_{max}) does not typically exceed that of single-ship sortie. If directly beneath the flight path of an in-trail formation, a person would experience a maximum noise level during overflight of the lead aircraft, followed by some decrease in noise level as that aircraft continues forward, and then followed an increase to a maximum noise level similar to the first maximum during overflight of subsequent aircraft in the formation. For a laterally displaced formation, a person may be directly beneath the flight path of one of the aircraft, in which case the noise level generated by the overhead aircraft is the primary determinant of overall noise levels and the laterally offset aircraft has minimal effect on overall level. For persons roughly equidistant between the flight paths of two laterally displaced aircraft, the distance to both aircraft is greater, and the overall maximum noise level is less loud than for a direct overflight. Cumulative noise metrics, such as L_{dnmr}, account for noise energy generated by all aircraft overflights.

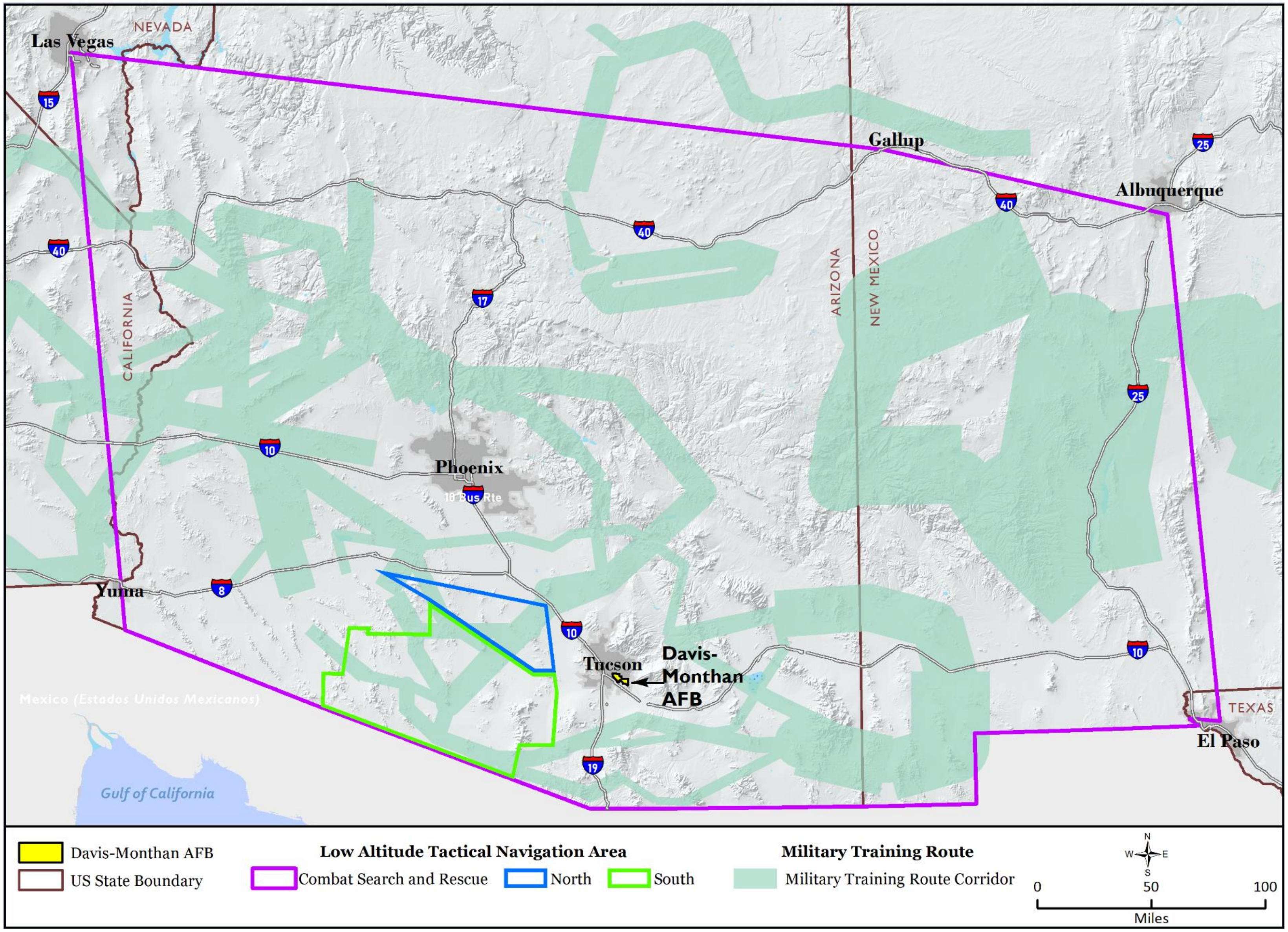


Figure 13. Existing Low Altitude Tactical Navigation Areas and Military Training Routes Near Davis-Monthan AFB

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