Appendix A1
Discussion of Noise and Its Effects on the Environment

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Acknowledgements

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Abbreviations and Acronyms

Acronym	Definition
AGL	Above Ground Level
ANSI	American National Standards Institute
CHABA	Committee on Hearing, Bioacoustics, and Biomechanics
CNEL	Community Noise Equivalent Level
dB	Decibel
dBA or dB(A)	A-Weighted Decibel
DLR	German Aerospace Center (*Deutsches Zentrum für Luft- und Raumfahrt e.V.*)
DNL	Day-Night Average Sound Level
DNWG	Defense Noise Working Group
DoD	Department of Defense
EU	European Union
FAA	(U.S.) Federal Aviation Administration
FICAN	Federal Interagency Committee on Aviation Noise
FICON	Federal Interagency Committee on Noise
HYENA	Hypertension and Exposure to Noise near Airports
Hz	Hertz
IHD	Ischemic heart disease
IRR	Incidence Rate Ratio
ISO	International Organization for Standardization
L	Sound Level
LAX	Los Angeles International Airport
L_{ct}	Community Tolerance Level
L_{dn}	Day-Night Average Sound Level
L_{dnmr}	Onset-Rate Adjusted Monthly Day-Night Average Sound Level
L_{eq}	Equivalent Sound Level
$L_{eq(24)}$	Equivalent Sound Level over 24 hours
$L_{eq(30min)}$	Equivalent Sound Level over 30 minutes
$L_{eq(8)}$	Equivalent Sound Level over 8 hours
$L_{eq(h)}$	Hourly Equivalent Sound Level
L_{max}	Maximum Sound Level
L_{pk}	Peak Sound Pressure Level
mmHg	millimeters of mercury
NA	Number of Events Above
NAL	Number of Events Above a Threshold Level
NDI	Noise Depreciation Index
NIPTS	Noise-induced Permanent Threshold Shift
NORAH	Noise-Related Annoyance, Cognition, and Health
OSHA	United States Occupational Safety and Health Administration
PHL	Potential Hearing Loss
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

Acronym	Definition
U.S.	United States
USEPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
WHO	World Health Organization

A1 Discussion of Noise and its Effects on the Environment

This appendix discusses sound and noise, and the potential effects of noise, particularly aircraft noise, on the human and natural environment. Section A1.1 provides an overview of the basics of sound and noise. Section A1.2 defines and describes the various metrics used to describe noise. Section A1.3 reviews the potential effects of aircraft noise, focusing on effects on humans but also addressing effects on property values, terrain, structures, and animals. Section A1.4 contains the list of references cited.

A1.1 Basics of Sound

Section A1.1 describes sound waves and decibels, and Section A1.2 describes sound levels and types of sounds.

A1.1.1 Sound Waves and Decibels

Sound consists of minute vibrations that travel through the air and are sensed by the human ear. Figure A-1 depicts how sound waves emanate from a tuning fork. As shown, the waves move outward as a series of crests, in which the air is compressed, and troughs, in which the air is expanded. The height of the crests and the depth of the troughs determines the *amplitude* of the wave. The sound *pressure* determines the sound wave's energy, or intensity. The number of crests or troughs that pass a given point each second is called the *frequency* of the sound wave.

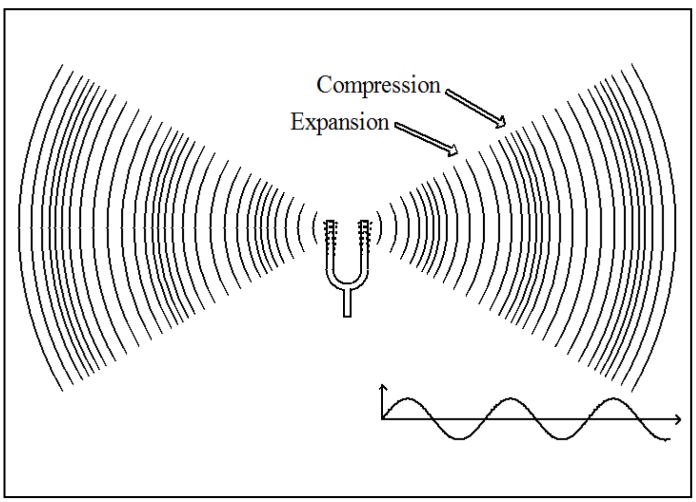


Figure A-1 Sound Waves from a Vibrating Tuning Fork

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 a sound and is related to sound pressure. The greater the sound pressure, the more energy is carried by the sound and the louder the perception of that sound will be.
- *Frequency* determines how the pitch of a sound is perceived. Low-frequency sounds are characterized as rumbles or roars, while high-frequency sounds are often described as sounding like sirens or screeches.

- *Duration* is the length of time a sound can be detected.

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 decibel (dB) is used to represent the intensity of a sound. Such a representation is called a sound level and is abbreviated as L. 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 above 120 dB would be uncomfortable for the average person, and levels of 130 to 140 dB would start to be felt as pain (Berglund and Lindvall, 1995). It is important to realize some people will be more sensitive to sound and some less sensitive; therefore, the level at which sound becomes uncomfortable or painful will vary across the population.

As shown in Figure A-1, the sound from a tuning fork spreads out uniformly as it travels from its source. This spreading causes the sound's intensity to decrease with distance from the source. For a point source of a sound, such as an air conditioning unit, the sound level will decrease by about 6 dB for every doubling of its distance from a receptor. For a busy highway, which creates a linear distribution of noise sources, the sound level will decrease by 3 to 4.5 dB for every doubling of distance.

As sound travels from its source, it is also absorbed by the air. The amount of absorption depends on the frequency composition of the sound and the temperature and humidity of the air. Sound with high-frequency content, such as a human voice, gets absorbed by the air more readily than sound with low-frequency content, such as a military jet. More sound is absorbed in colder and drier air than in hot and wet air. Sound is also affected by wind and temperature gradients, terrain (elevation and ground cover), and structures.

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 understanding 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:

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

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

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

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

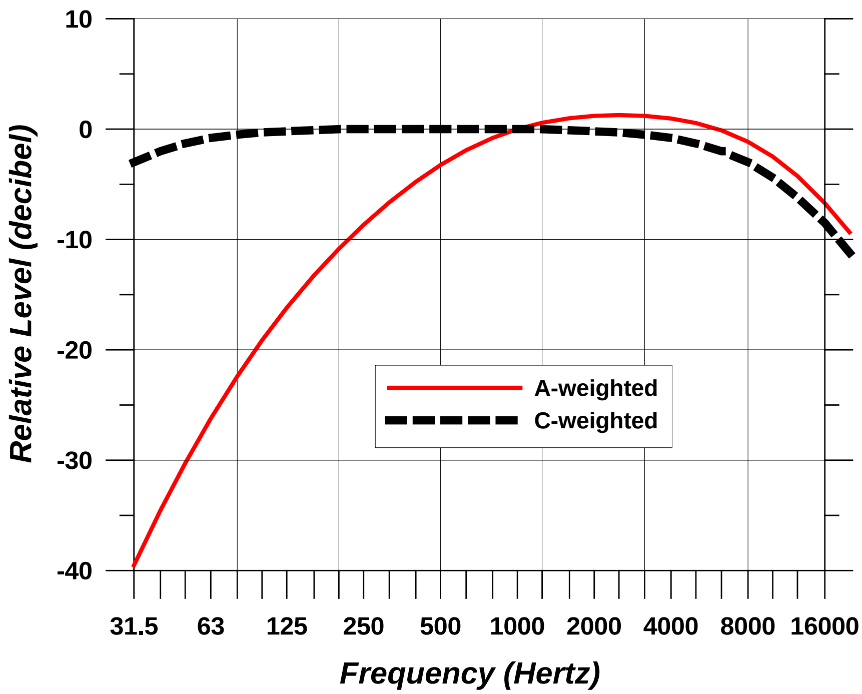
Because the addition of sounds of differing levels is different than that of simply adding numbers, this process is often referred to as "decibel addition."

The minimum change in the sound level of individual events that an average human ear can detect is about 3 dB. On average, a person perceives a change in sound level of about 10 dB as a doubling (or halving) of that sound's loudness. This relation holds true for both 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 to sound linearly. Intensity of a sound is the physical measure of the stimulus, and loudness of a sound is the perceptual measure of a listener's response to it.

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 about 20 Hz to 20,000 Hz. 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, and as we get older, we lose the ability to hear high-frequency sounds. The notes on a piano range in frequency from just over 27 Hz to 4,186 Hz, with middle C equal to 261.6 Hz. Most sounds (including a single note on a piano) are not simply pure tones like those produced by the tuning fork in Figure A-1 but instead contain a mix, or spectrum, of many frequencies.

Sounds with different frequency 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 frequencies of sound. A-weighting and C-weighting are the two most common frequency weightings. These two curves, shown in Figure A-2, are adequate to quantify most environmental sounds. A-weighting puts emphasis on the 1,000 to 4,000 Hz frequency range.

Very loud or impulsive sounds, such as explosions or sonic booms, can sometimes be felt and can cause secondary effects, such as shaking of a structure or rattling of windows. These types of sounds can add to annoyance and are best measured by C-weighted sound levels, denoted dBC. C-weighting is nearly flat throughout the audible frequency range and includes low frequencies that may not be heard but cause shaking or rattling. C-weighting approximates the human ear's sensitivity to higher intensity sounds. For example, using the A-weighted curve, a 125 Hz tone at moderate sound levels (around 50 dB) is perceived to be about 17 dB lower than a 1,000 Hz tone. However, using the C-weighted curve, if the sound level is increased to 100 dB, the two tones are perceived to be the same level.



Source: ANSI S1.4A -1985 "Specification of Sound Level Meters"

Figure A-2 Frequency Characteristics of A- and C-Weighting

A1.1.2 Sound Levels and Types of Sounds

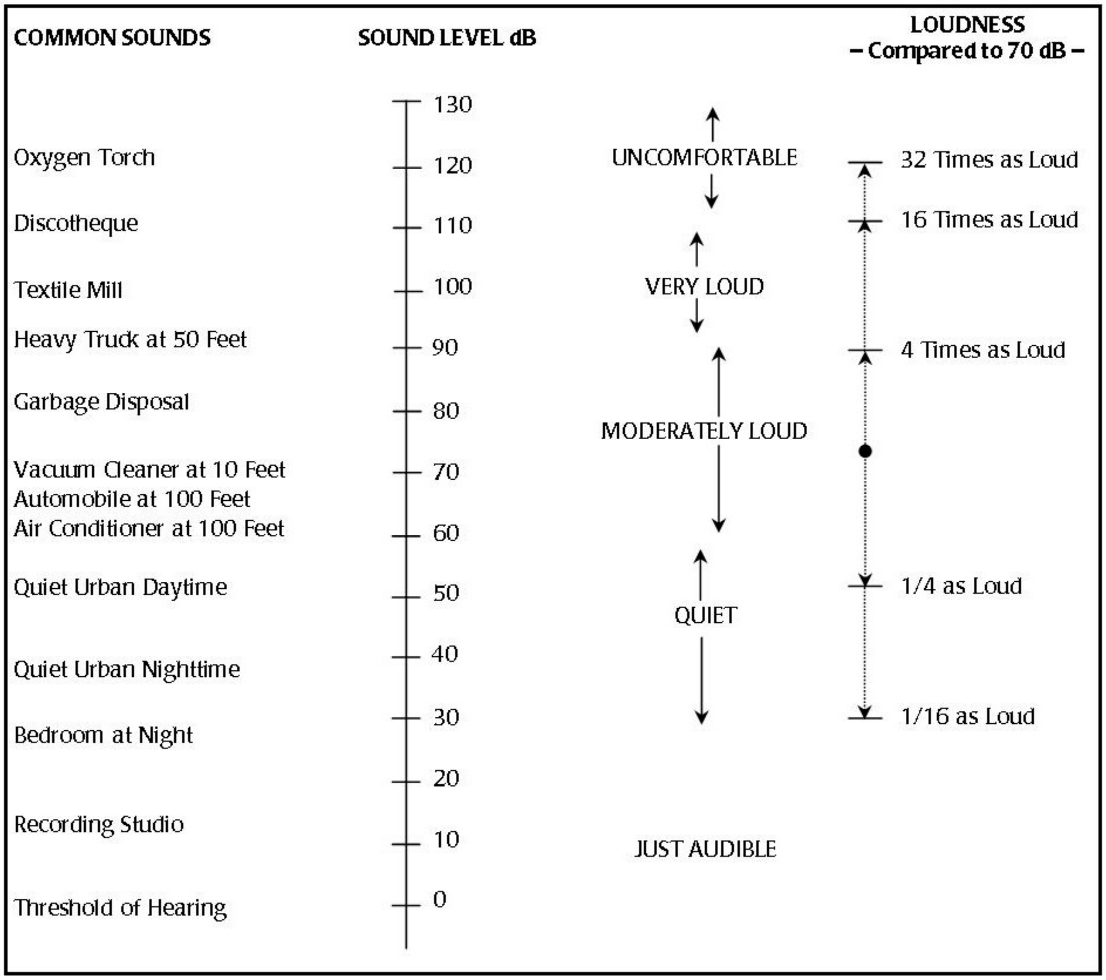
Most environmental sounds are measured and described as A-weighted sound levels, and they may be labeled as dBA or dB(A) rather than dB. When the use of A-weighting is understood, the term “A-weighted” is often omitted, and the unit dB is used. Unless otherwise stated, dB units refer to A-weighted sound levels.

Sound becomes noise when it is unwelcome and interferes with normal activities, such as sleep or conversation. Noise is unwanted sound and can become an issue when its level exceeds the ambient or background sound level. Ambient sound levels in urban areas typically vary 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 sound levels around 45 to 50 dB (USEPA [U.S. Environmental Protection Agency], 1978).

Figure A-3 is a chart of dBA sound levels emitted from common sources. For some sources depicted on the figure, such as the air conditioner and vacuum cleaner, the sound levels shown are continuous sounds, and these sound levels are constant for some time. For other sources depicted on the figure, such as the automobile and heavy truck, the sound levels shown are the maximum sound level emitted during an intermittent event such as a vehicle pass-by. Some sound levels shown, for sources such as “urban daytime” and “urban nighttime,” are average sound levels over extended periods. A variety of noise metrics have been developed to describe noise over different time periods. These are discussed in detail in Section A1.2.

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 are intermittent and the latter primarily continuous. Noise from aircraft overflights typically occurs beneath main approach and departure paths at an airfield, 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, with a single-event duration that is usually less than 1 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 explosions associated with quarrying or mining operations; sonic booms; demolition explosions; and industrial processes that use high explosives; military ordnance use (e.g., armor, artillery, and mortar fire, and bomb detonation); explosive ignition of rockets and missiles; and any other explosive source where the equivalent mass of dynamite exceeds 25 grams (ANSI [American National Standards Institute], 1996).



Source: Harris 1979.

Figure A-3 Typical A-weighted Sound Levels of Common Sounds

A1.1.3 Low-Frequency Noise

Normally, the components of a structure most sensitive to airborne noise are the windows and, infrequently, the plastered walls and ceilings. An evaluation of the sound pressures impinging on the structure may be used to assess the risk for damage. In general, sound pressure levels below 130 dB (unweighted) are unlikely to pose a risk to structures. 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 and at a sound pressure level above 130 dB (unweighted) are potentially damaging to structural components (CHABA [Committee on Hearing, Bioacoustics, and Biomechanics] 1977).

Noise-induced structural vibration may result from aircraft operating at low altitudes, which would occur during takeoff and landing operations. Such vibrations are likely to cause annoyance to dwelling occupants because of induced secondary vibrations or rattling of objects within the dwelling such as hanging pictures, dishes, plaques, and bric-a-brac. Window panes may also vibrate noticeably when exposed to high levels of airborne noise. In general, such noise-induced vibrations occur at sound pressure levels of 110 dB (unweighted) or greater.

Aside from concerns about potential structural damage from low-frequency noise, the perception of low-frequency sound may differ considerably when compared with mid- or high-frequency sound. Laboratory measurements of annoyance from low-frequency noise each use different spectra and levels, making comparisons difficult, but the majority share the same conclusion that annoyance caused by low-frequency sound increases rapidly with level and that dBA sound level alone can underestimate the effects of low-frequency noises (Leventhall, 2004). The most recent update to the International Organization for Standardization (ISO) standard (ISO 1996:1 [2016]) describes the main causes for these differences as:

- a weakening of pitch sensation as the frequency of the sound decreases below 60 Hz;
- a perception of sounds as pulsations and fluctuations;
- a much more rapid increase in loudness and annoyance with increasing sound pressure levels at low frequencies than at middle or high frequencies;
- complaints about feelings of ear pressure;
- an annoyance caused by secondary effects such as rattling of buildings elements, windows, and doors, or the tinkling of bric-a-brac;
- less building sound-transmission loss at low frequencies than at middle or high frequencies.

While the Federal Interagency Committee of Noise (FICON) recommends the use of the dBA Day-Night Average Sound Level (DNL) metric as the primary basis of both commercial and military aircraft noise impacts (FICON, 1992), in a recent update to a research needs statement, the Federal Interagency Committee on Aviation Noise (FICAN) stated the following for low-frequency noise concerns:

> FICAN finds that additional research needs to be conducted before a [low-frequency noise] metric and an associated dose-response relationship can be recommended. For airports with low-frequency noise concerns, supplemental noise analysis--possibly including vibration measurements--should be considered (FICAN, 2018).

A1.2 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 overall dBA sound level, which is appropriate by itself for quantifying constant noise such as that generated by an air conditioner. However, unlike noise from an air conditioning unit, aircraft flyover 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 receptor, and then returns to the background as the aircraft recedes into the distance. An example graph of the resulting sound levels from a flyover is provided in Figure A-4, which also indicates two metrics (Maximum Sound Level [L_{max}] and Sound Exposure Level [SEL]), that are described in Section A1.2.1 below.

A number of metrics can be used to describe a range of situations--from the effect of a particular individual noise event to the cumulative effect of all noise events over a long time. This section describes the metrics relevant to environmental noise analysis of aircraft operations.

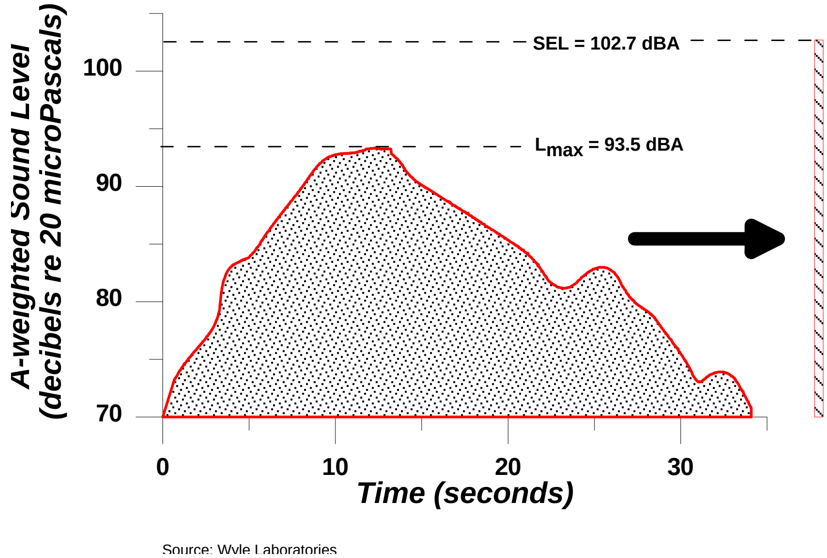


Figure A-4 Sample Time History of Noise Generated by an Aircraft Flyover Event

A1.2.1 Single Events

Maximum Sound Level

The highest dBA sound level measured during a single event in which the sound changes with time, such as a flyover, is called the maximum dBA sound level, or Maximum Sound Level, and is abbreviated L_{max}. The L_{max} is depicted for a sample event in Figure A-4.

L_{max} is the maximum sound level that occurs over a fraction of a second. For aircraft noise, this "fraction of a second" is one-eighth of a second, denoted as "fast" response on a sound-level measurement meter (ANSI, 1988). Slowly varying or steady sounds are generally measured over 1 second and denoted as "slow" response. L_{max} is important in determining whether a noise event will interfere with conversation, television or radio listening, or other common activities. Although L_{max} provides some measure of a given sound event, it does not fully describe the noise because it does not account for how long the sound is heard.

Peak Sound Pressure Level

The Peak Sound Pressure Level (L_{pk}) is the highest instantaneous level measured by a sound-level measurement meter. L_{pk} is typically measured every 20 microseconds, and it is usually based on unweighted or linear response of the meter. L_{pk} is used to describe individual impulsive events, such as blast noise. Because blast noise varies from explosion to explosion and with meteorological (weather) conditions, the United States (U.S.) Department of Defense (DoD) usually characterizes L_{pk} by the metric PK 15(met), which is the L_{pk} that is exceeded 15 percent of the time. The "met" notation refers to the metric accounting for varied meteorological or weather conditions.

Sound Exposure Level

SEL combines both the intensity of a sound and its duration. For an aircraft flyover, SEL includes the maximum and all lower noise levels produced as part of the overflight, together with how long each part lasts. SEL represents the total sound energy in the event. Figure A-4 indicates the SEL for a sample flyover event, representing it as if all the sound energy were contained within 1 second.

Because aircraft noise events last more than a few seconds, the SEL value is larger than L_{max}. SEL does not directly represent the sound level heard at any given time during the event but rather during the entire event. SEL provides a much better measure of aircraft flyover noise exposure than L_{max} alone.

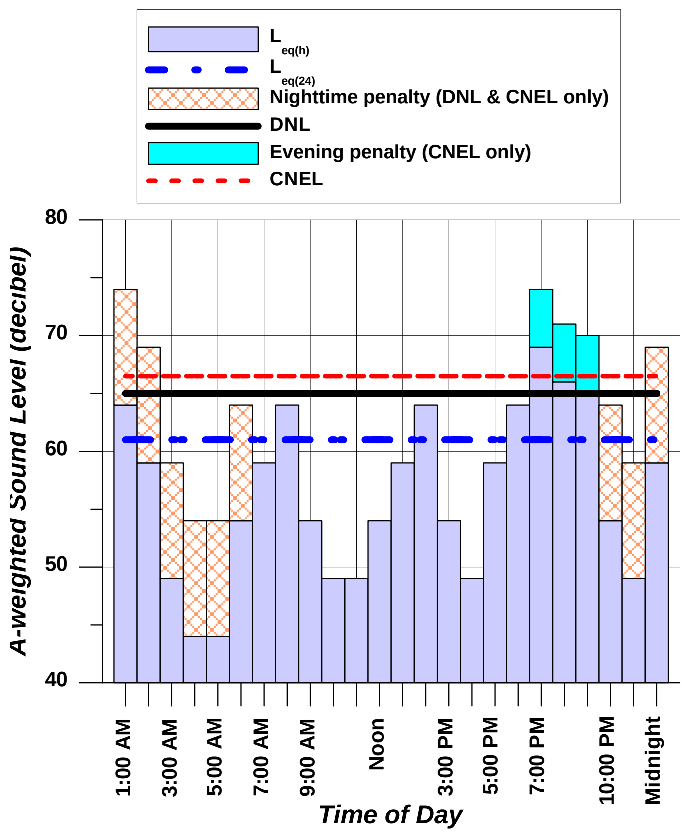
A1.2.2 Cumulative Events

Equivalent Sound Level

Equivalent Sound Level (L_{eq}) is a “cumulative” metric that combines a series of noise events, such as aircraft operations, over a period of time. L_{eq} is the sound level that represents the dB average SEL of all sounds in a specific time period. Just as SEL has proven to be a good measure of a single event, L_{eq} has proven to be a good measure of a 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., $L_{eq(24)}$, or the equivalent sound level for 24 hours). The L_{eq} from 7:00 A.M. to 3:00 P.M. may give exposure of noise for a school day and would be represented as $L_{eq(8)}$, or the equivalent sound level for 8 hours.

Figure A-5 provides an example of $L_{eq(24)}$ using notional hourly equivalent sound levels ($L_{eq(h)}$) for each hour of the day as an example. The $L_{eq(24)}$ for this example is 61 dB.



Source: Wyle Laboratories, Inc.

Figure A-5 Example of $L_{eq(24)}$, DNL, and CNEL Computed from Hourly Equivalent Sound Levels

Day-Night Average Sound Level and Community Noise Equivalent Level

DNL, or L_{dn}, is a cumulative metric that accounts for all noise events, such as aircraft operations, in a 24-hour period. However, unlike $L_{eq(24)}$, DNL contains a nighttime noise adjustment. To account for humans' increased sensitivity to noise at night, DNL applies a 10 dB adjustment to noise events that occur 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 Day-Night Average Sound Level and are equivalent.

Community Noise Equivalent Level (CNEL) is a variation of DNL specified by law in California (California Code of Regulations Title 21, *Public Works*) (Wyle Laboratories, 1970). CNEL has the 10 dB nighttime adjustment for noise events that occur between 10:00 P.M. and 7:00 A.M. but also includes a 4.8 dB adjustment for events occurring during the evening period of 7:00 P.M. to 10:00 P.M. This evening adjustment included in CNEL accounts for the added intrusiveness of sounds occurring during that period.

For airports and military airfields, DNL and CNEL represent the average sound level for an average annual day.

Figure A-5 provides an example of DNL and CNEL using notional $L_{eq(h)}$ for each hour of the day. Note the $L_{eq(h)}$ for the hours between 10:00 P.M. and 7:00 A.M. have a 10 dB adjustment assigned. For CNEL, the hours between 7:00 P.M. and 10:00 P.M. have a 4.8 dB adjustment assigned. The DNL for this example is 65 dB and the CNEL is 66 dB.

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 that day, the ambient sound level is 50 dB. The DNL for this 24-hour period is 65.9 dB. Assume, as a second example, that 10 such 30-second overflights occur during daytime hours during the next 24-hour period and 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. Clearly, 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 a large number of quieter events. For example, a single overflight at 90 dB creates the same DNL as 10 overflights at 80 dB.

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

DNL or CNEL can be used to measure sound levels in a variety of types of communities. Figure A-6 shows the ranges of DNL or CNEL that occur in various types of communities. For example, under a flight path at a major airport, the DNL may exceed 80 dB, while rural areas not near a major airport may experience DNL less than 45 dB. Sound levels in a downtown area of a major metropolis may be equivalent to the sound levels under a flight path of a major airport.

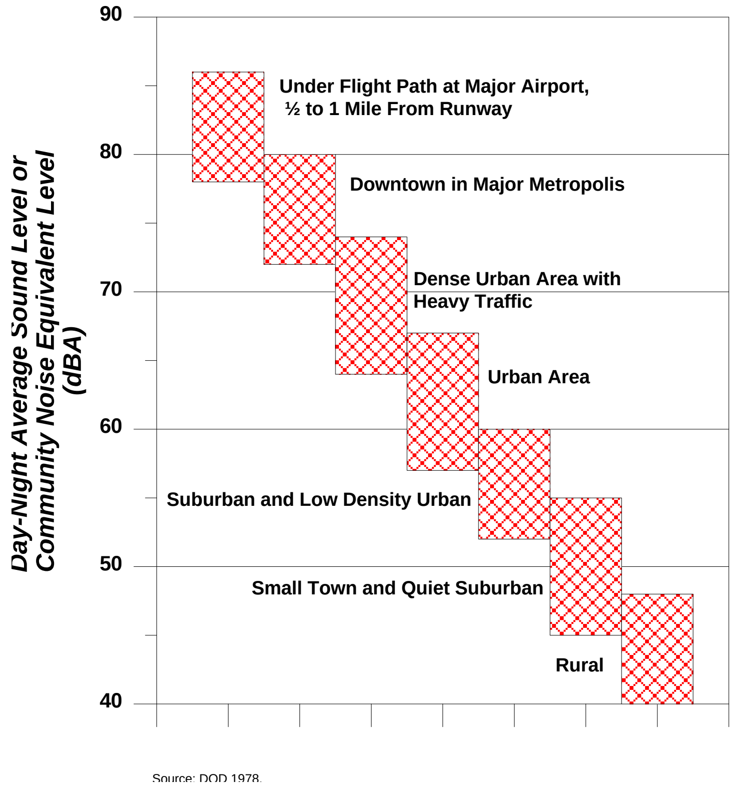


Figure A-6 Typical DNL or CNEL Ranges in Various Types of Communities

Onset-Rate Adjusted Monthly Day-Night Average Sound Level (L_{dnmr}) and Onset-Rate Adjusted Monthly Community Noise Equivalent Level

Military aircraft utilizing Special Use Airspace (SUA), such as Military Training Routes, Military Operations Areas, and Restricted Areas/Ranges, generate a noise environment that is somewhat different from that generated around airfields. Rather than regularly occurring operations such as those conducted at airfields, activity in SUAs is highly sporadic. SUA activity is often seasonal, ranging from 10 operations per hour to less than one 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 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 below 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.”

In California, a variant of L_{dnmr} includes an adjustment for evening operations (7:00 P.M. to 10:00 P.M.) and is referred to as the Onset-Rate Adjusted Monthly CNEL.

A1.2.3 Supplemental Metrics

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 NAL. 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.

NA is a supplemental metric. It is not supported by the amount of science behind DNL or CNEL, but it is valuable in helping to describe the number of noise events the community may hear. 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) flyover events will occur on average at a given location or area at or above a selected threshold noise level.

Time Above a Specified Level

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

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.

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 in order to determine the sound levels and total duration of events that contribute to the DNL. 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.

A1.3 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:

- annoyance
- speech interference
- sleep disturbance

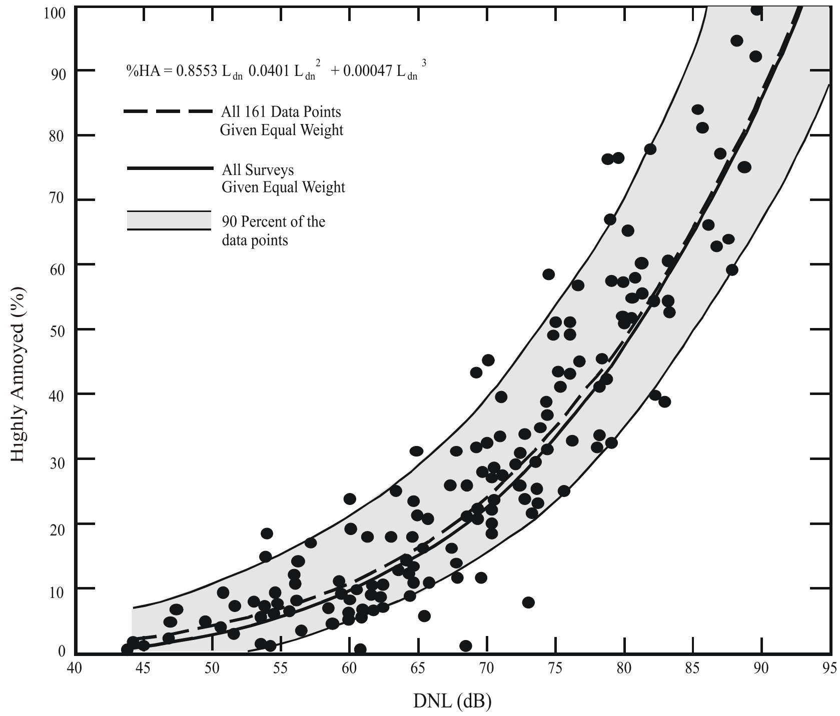
- noise-induced hearing impairment
- non-auditory health effects
- performance effects
- noise effects on children
- property values
- noise-induced vibration effects on structures and humans
- noise effects on terrain
- noise effects on historical and archaeological sites
- noise effects on domestic animals and wildlife

A1.3.1 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 USEPA published its "Levels Document" (USEPA, 1974), which reviewed the noise factors that affected communities. DNL (or L_{dn}) was identified as an appropriate noise metric, and threshold criteria were recommended.

Threshold criteria for annoyance were identified from social surveys, in which people exposed to noise were asked how noise affected 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 they 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, Schultz was able to show a remarkable consistency among the majority of the surveys for which data were available. Figure A-7 shows the result of his study relating DNL to individual annoyance as measured by percent highly annoyed.



Source: Schultz 1978

Figure A-7 Schultz Curve Relating Noise Annoyance to DNL

Schultz's original synthesis included 161 data points. Figure A-8 compares revised fits of the Schultz data set with an expanded set of 400 data points collected through 1989 (Finegold et al., 1994). The new form of the curve is the preferred form in the U.S., endorsed by FICAN (1997). Other forms have been proposed, such as that of Fidell and Silvati (2004), but these have not gained widespread acceptance.

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. However, the correlation between individuals is much lower, at 50 percent or less. This finding is not surprising, given the personal differences between individuals, with some people more sensitive to noise than others. The surveys underlying the Schultz curve include results that show that annoyance from noise is also affected by non-acoustical factors. The influence of non-acoustical factors is a complex interaction influencing an individual's annoyance response to noise (Brisbane Airport Corporation, 2007). Newman and Beattie (1985) divided the non-acoustic factors into the emotional and physical variables shown in Table A-1.

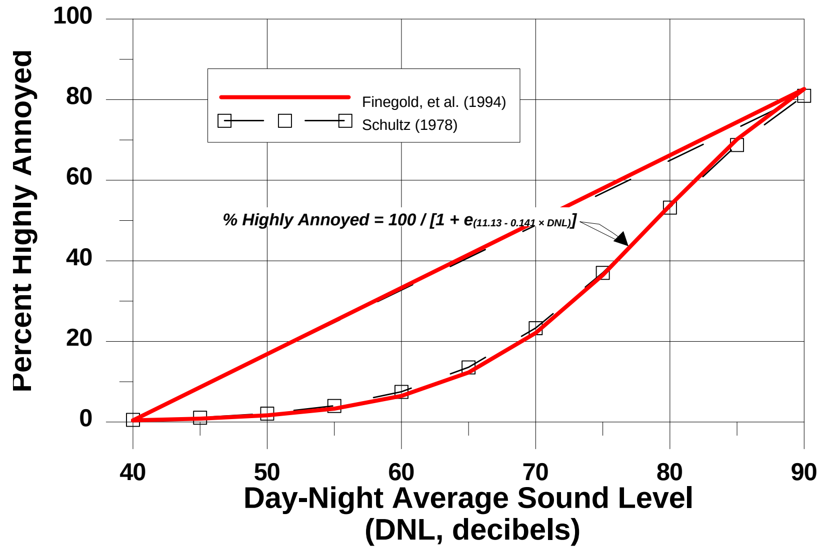


Figure A-8 Response of Communities to Noise: A Comparison of Original Schultz (1978) Curve to Finegold et al (1994) Curve

Table A-1 Non-Acoustic Variables Influencing Aircraft Noise Annoyance

Emotional Variables	***Physical Variables***
Feeling about the necessity or preventability of the noise	Type of neighborhood
Judgement of the importance and value of the activity that is producing the noise	Time of day
Activity at the time an individual hears the noise	Season
Attitude about the environment	Predictability of the noise
General sensitivity to noise	Control over the noise source
Belief about the effect of noise on one's health	Length of time an individual is exposed to a noise
Feeling of fear associated with the noise	

Schreckenberg and Schuemer (2010) and Laszlo et al. (2012) 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, L_{eq} was found to be more important than attitude. Similarly, a series of studies conducted by Marki (2013) at three European airports showed that less than 20 percent of the variance in annoyance can be explained by noise alone (Marki, 2013). Miedema and Voss (1998) found that fear and noise sensitivity have a significant influence on an individual annoyance response. Moreover, in another study, they demonstrated that noise sensitivity is not a function of noise exposure and that noise-sensitive individuals have a steeper annoyance response to increasing noise levels compared to people who are not noise sensitive (Miedema and Vos, 2003).

A study by Plotkin et al. (2011) examined updating DNL to account for these non-acoustic variables. Plotkin et al. (2011) concluded that the data requirements for a general analysis were much greater than are available from most existing studies. It was noted that the most significant issue with DNL is that the metric 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 non-acoustical 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 A-2 summarizes their results. Comparing the updated Schultz curve to these results suggests that the percentage of people highly annoyed by aircraft noise may be higher than previously thought. Authors Miedema and Oudshoorn (2001) supplemented that investigation with further derivation of percentage of population highly annoyed as a function of either DNL or DENL[1], along with the corresponding 95-percent confidence intervals, and obtained similar results.

Table A-2 Percent Highly Annoyed by Different Transportation-Noise Sources

DNL (dB)	*Percent Highly Annoyed (%HA)*			
	Miedema and Vos			*Schultz*
	Air	*Road*	*Rail*	*Combined*
55	12	7	4	3
60	19	12	7	6
65	28	18	11	12
70	37	29	16	22
75	48	40	22	36

Source: Miedema and Vos, 1998.

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

Consistent with the WHO's recommendations, 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).

The ISO update (ISO 1996-1 [2016]) introduced the concept of Community Tolerance Level (L_{ct}) as the DNL at which 50 percent of the people in a particular community are predicted to be highly annoyed by noise exposure. L_{ct} accounts for differences between sources and/or communities when predicting the percentage highly annoyed by noise exposure. ISO also recommended a change to the adjustment range used when comparing aircraft noise to road traffic noise. The previous edition suggested a +3 dB to +6 dB adjustment range for aircraft noise relative to road traffic noise, while the latest edition recommends an adjustment range of +5 dB to +8 dB. This adjustment range allows DNL to be correlated to consistent annoyance rates when originating from different noise sources (i.e. road traffic, aircraft, or railroad). This change to the adjustment range would increase the calculated percent highly annoyed at 65 dB DNL by approximately 2 percent to 5 percent greater than the previous ISO definition. Figure A-9 depicts the estimated percentage of people highly annoyed for a given DNL using both the ISO 1996-1 estimation

[1] DENL is the Day-Evening-Night Average Sound Level, which is similar to CNEL except it has a 5.0 dB adjustment to the evening period. DENL is not used in the U.S.

and the older FICON 1992 method. The results suggest that the percentage of people highly annoyed may be greater for aircraft noise than previously thought.

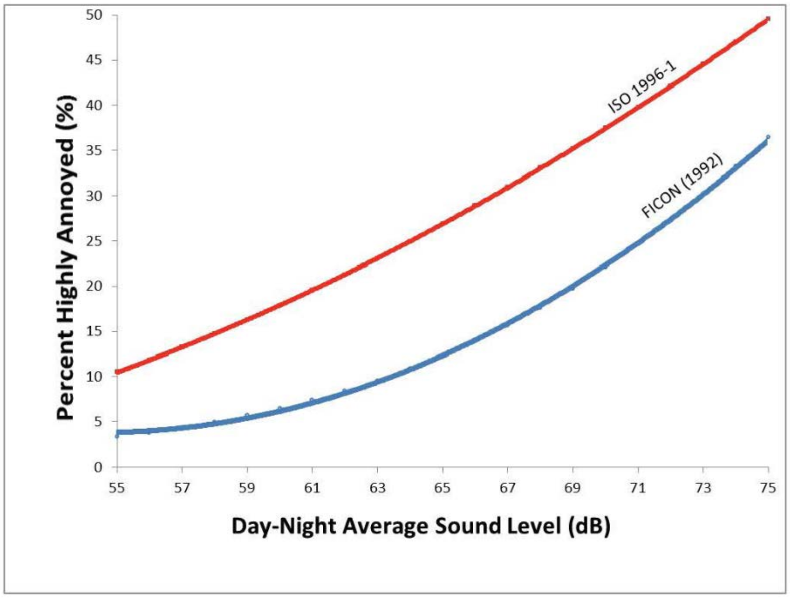


Figure A-9 Percent Highly Annoyed: A Comparison of ISO 1996-1 to FICON 1992

In the 2008 Hypertension and Exposure to Noise near Airports (HYENA) study, annoyance levels due to aircraft noise and road traffic noise were assessed in subjects who lived in the vicinity of six major European airports using the 11-point International Commission on Biological Effects of Noise scale. Exposure-response curves for road noise were congruent with the European Union (EU) standard curves used for predicting the number of highly noise-annoyed subjects, but ratings of annoyance due to aircraft noise were higher than predicted. The study supports findings that people's attitude toward aircraft noise has changed over the years and that the EU standard curve for aircraft noise should be modified (Babisch et al., 2009).

The U.S. Federal Aviation Administration (FAA) is currently conducting a major airport community noise survey at approximately 20 U.S. airports in order to update the relationship between aircraft noise and annoyance (Miller et al., 2014). Results from this study are expected to be released in late 2018.

In a study related to assessing aircraft noise exposure for people in the surrounding community, the Brisbane Airport in Queensland, Australia, assembled a Health Impact Assessment (Volume D7), which discussed, among other noise effects, annoyance and human response to changes in noise exposure versus steady-state response (Section 7.9 of the report) (Brisbane Airport Corporation, 2007). The authors suggest there is a difference between the gradual increase in noise exposure and the additive property of increasing noise levels from a particular event. The latter is called a "step change." The Brisbane Health Impact Assessment references Brown and Kamp (2005), who have reviewed the literature available on human response to such changes. They observe:

> "Most information on the relationship between transport noise exposure and subjective reaction (annoyance/dissatisfaction) comes from steady state surveys at sites where there have not been step changes in noise exposure. Environmental appraisals often need to assess the

effects of such step changes in exposure and there is growing evidence that when noise exposure is changed, annoyance-ratings may change more than would be predicted from steady state relationships.

"Conventional wisdom is that human response to a step change in exposure to transport noise can be predicted from exposure-response curves that have been derived from studies where human response has been assessed over a range of steady-state noise conditions. However, in situations where a step change in transport noise exposure has occurred, various surveys suggest that human response may be different, usually greater, as a result of the increase/decrease in noise, to what would be predicted from exposure-response curves derived under steady-state conditions. Further, there are suggestions that such (over)reaction may be more than a short-term effect. (Brown and Kamp, 2005)."

Guski (2004) describes this change effect in a hypothetical model and also notes that where the noise situation is permanently changed, the annoyance of residents usually changes in a way that cannot be predicted by steady-state dose/response relationships. Most studies show an "over reaction" of the residents: with increasing noise levels, people are much more annoyed than would be predicted by steady-state curves, and, with a decrease of noise levels, people are much less annoyed. Guski also notes that the annoyance may change prematurely before the change of levels, with residents expecting an increase in noise levels reacting more annoyed, and residents expecting a decrease in noise levels less annoyed than would be predicted in the steady-state condition.

Brown and Kamp (2005) conclude:

"Our review of the literature on response to changes in noise leads us to the conclusion that we cannot discount the possibility that overreaction to a step change in transport noise may occur, and that this effect may not attenuate over time. However, evidence is still inconclusive and based on limited studies that tend not to be comparable in terms of method, size, design and context. Further, our view is that most explanations given in the literature for an overreaction are only partly supported, in some cases not at all, and generally there is conflicting evidence for them. There is still also no accepted view on the mechanism by which annoyance changes in response to a change in exposure. In particular, most explanations are usually post-hoc and the noise change studies have not been designed to test them. (Brown and Kamp, 2005)."

The Brisbane Airport Corporation Health Impact Assessment suggests that the potential for "over-reaction" to stepped changes in noise exists and needs to be recognized; people subject to an increase in noise may experience more annoyance than predicted, while people subject to a decrease in noise may experience less annoyance than predicted. Further, any such over-reaction should not necessarily be assumed to be a temporary phenomenon; evidence from existing studies suggests that it could persist for years after the exposure changes (Brisbane Airport Corporation, 2007).

An individual with an increased sensitivity to sounds may have hyperacusis, which results in a lower tolerance of everyday sound (Aazh et al., 2018). A person with hyperacusis reacts differently to sounds due to reactions of increased distress and discomfort from everyday sounds. This condition arises from a problem with the auditory processes within an afflicted individual's brain. The causes and diagnosis are not well understood (Aazh et al., 2018). Physical causes of hyperacusis may range from head injury, ear damage, or viral diseases, to temporomandibular joint disorders (TMJ). Neurologic causes may range from Post-Traumatic Stress Disorder (PTSD), chronic fatigue syndrome, depression, to migraine headaches (American Academy of Otolaryngology--Head and Neck Surgery, 2018). An individual with hyperacusis will also likely have tinnitus, which may lead to further discomfort. Hyperacusis can lead to misophonia, which may cause an individual to react with abnormally strong emotions and behaviors to specific sounds, but hyperacusis does not cause this reaction. Studies of misphonia are very limited at this time.

Another condition that falls under the condition of hyperacusis is noise sensitivity (Aazh et al., 2018). A noise-sensitive individual is characteristically more prone to being annoyed by environmental noise compared to a non-noise-sensitive person regardless of the overall noise exposure (Kishikawa et al., 2006). This result indicates that the annoyance response for noise-sensitive people is not a direct function of noise exposure levels.

A1.3.2 Speech Interference

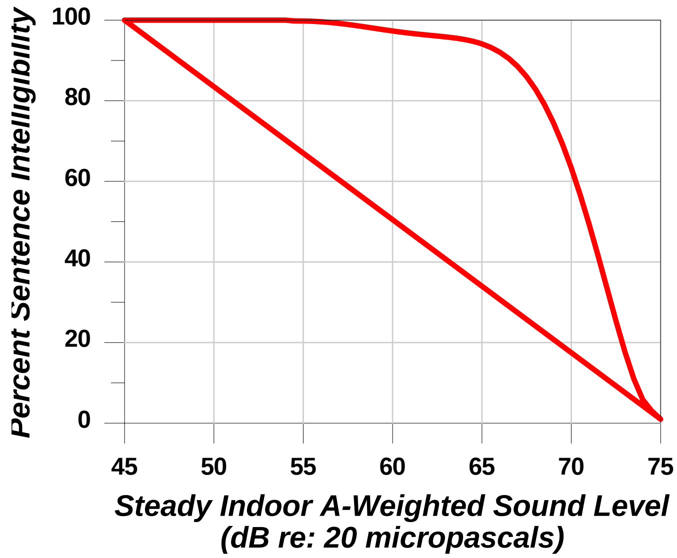
Speech interference from noise is a primary cause of annoyance for communities. Disruption of routine activities such as radio or television listening, telephone use, or conversation leads to frustration and annoyance. The quality of speech communication is also important in classrooms and offices. In the workplace, speech interference from noise can cause fatigue and vocal strain in those who attempt to talk over the noise. In schools it can impair learning.

Speech comprehension is measured in two ways:

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

U.S. Federal Criteria for Interior Noise

In 1974, the USEPA 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 (USEPA, 1974). Figure A-10 shows the effect of steady indoor background sound levels on sentence intelligibility. For an average adult with normal hearing and fluency in the language, steady background indoor sound levels of less than 45 dB L_{eq} are expected to allow 100-percent sentence intelligibility.



Source: USEPA, 1974

Figure A-10 Speech Intelligibility Curve

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

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 noise level, the level of voice communication, and the single-event noise level from 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 initial American National Standards Institute (ANSI) classroom noise standard (ANSI, 2010) and American Speech-Language-Hearing Association (American Speech-Language-Hearing Association, 2005) guidelines concur, recommending at least a 15 dB signal-to-noise ratio in classrooms. 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.

For eligibility for noise insulation funding, the FAA guidelines state that the design objective for a classroom environment is 45 dB L_{eq} during normal school hours (FAA, 1985).

Most aircraft noise is not continuous. Instead, it consists of individual events like the one depicted by the graph in Figure A-4. Since 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 above, single-event criteria that account for those noisy events are also needed.

A 1984 study 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 maximum sound levels 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, a level that would provide 90-percent word intelligibility for the short time periods during aircraft overflights. While SIL is technically the best metric for measuring speech interference, it can be approximated by an L_{max} value. An SIL of 45 dB is equivalent to an L_{max} of 50 dBA for aircraft noise (Wesler, 1986).

Lind et al. (1998) also concluded that an L_{max} criterion of 50 dB would result in 90-percent word intelligibility. 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 a typical single aircraft overflight, this corresponds to an L_{max} of 50 dB. While the WHO (1999) only specifies a background L_{max} criterion, the organization also notes the SIL frequencies and that interference can begin at around 50 dB.

The Airport Cooperative Research Program (ACRP) conducted a study to assess aircraft noise conditions affecting student learning by analyzing the interior and exterior sound levels while observing students and teachers at 11 schools surrounding Los Angeles International Airport (LAX). The five schools located under the LAX flight paths experienced frequent overflight events, while the six schools further south of the airport experienced minimal LAX aircraft noise exposure events. The study found a positive correlation between teacher voice-masking or voice-raising and fluctuations in interior noise events. A majority of teachers reported that they felt aircraft noise interfered with teacher-student communication and caused students to lose concentration. However, the student observations were unable to identify any aircraft-noise-related events that caused a distraction in a child. Other students caused the majority of distractions while playing with various items and daydreaming, and were found to be the significant sources of distractions. The authors, as well as the teachers' opinions gathered in the teacher surveys, concluded that even moderate levels of aircraft noise exposure can impact children's learning due to the correlation between voice-masking events and measured interior sound events (National Academies of Sciences, Engineering, and Medicine, 2017).

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 dB and 55 dB, respectively. $L_{A1,30min}$ represents the dBA sound level 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 (United Kingdom Department for Education and Skills, 2003).

Table A-3 summarizes the criteria discussed. Other than the FAA (1985) 45 dB L_{max} criterion, the criteria 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 the limits listed in Table A-3 were set based on students with normal hearing capability and no special needs. At-risk students may be adversely affected at lower sound levels.

Table A-3 Indoor Noise Level Criteria Based on Speech Intelligibility

Source	*Metric/Level (dB)*	*Effects and Notes*
U.S. FAA (1985)	$L_{eq(during\ school\ hours)}$ = 45 dB	Federal assistance criteria for school sound insulation; supplemental single-event criteria may be used.
Lind et al. (1998), 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.
U.S. ANSI (2010)	L_{eq} = 35 dB, based on Room Volume (e.g., cubic feet)	Acceptable background level for continuous and intermittent noise.
United Kingdom Department for Education and Skills (2003)	$L_{eq(30min)}$ = 30-35 dB L_{max} = 55 dB	Minimum acceptable in classroom and most other learning environs.

A1.3.3 Sleep Disturbance

Sleep disturbance is a major concern for communities exposed to aircraft noise at night. A large amount of research developed in the laboratory during the past 30 years has produced variable results, suggesting a complex interaction of factors including the noise characteristics and individual sensitivity, rather than a clear dose-effect relationship (Muzet, 2007; Kwak et al., 2016). Sleep disorders may cause negative health effects such as cardiovascular problems, neuroendocrine abnormalities, and changes in cognition, mood, and memory. The causal relationships between noise exposure, effects on sleep, and contribution to health disturbances, both behavioral and physical, are not yet firmly established (Zaharna, 2010; Perron et al., 2012). 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:

1. Initial studies, conducted in the 1960s and 1970s, in which the research was focused on sleep observations performed under laboratory conditions.
2. Later studies, conducted from the 1990s up to the present, in which the research was focused on field observations.

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 non-acoustic factors cited for annoyance. The easiest effect to measure is the number of arousals or awakenings caused by noise events. Much of the literature has therefore focused on predicting the percentage of the population that will be awakened at various noise levels.

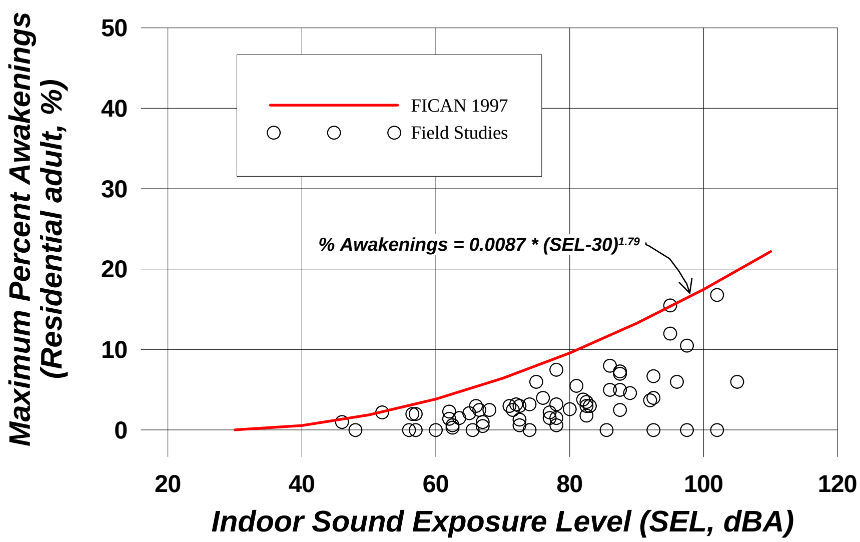
FICON's 1992 review of airport noise issues (FICON, 1992) included an overview of relevant research conducted through the 1970s. Literature reviews and analyses were conducted from 1978 through 1989 using existing data (Griefahn, 1978; Griefahn and Muzet, 1978; Lukas, 1978; Pearsons et. al., 1989). Because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

FICON did, however, recommend an interim dose-response curve, awaiting future research. That curve predicted the percentage of the population expected to be awakened as a function of the exposure to SEL. This curve was based on research conducted for the U.S. Air Force (Finegold et al., 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.

Recent Sleep Disturbance Research: Field and Laboratory Studies

As noted above, early sleep laboratory studies did not account for some important factors, including 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 (e.g., Horne et al., 1994) 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, noise had less of an effect on sleep than had been previously reported from laboratory studies. Laboratory sleep studies tend to show more sleep disturbance than field studies show because people who sleep in their own homes are accustomed to their environment and, therefore, do not wake up as easily (FICAN, 1997).

Based on this new information, FICAN in 1997 recommended a dose-response curve to use instead of the earlier 1992 FICON curve (FICAN, 1997). Figure A-11 shows FICAN's curve, the red line, which is based on the results of three field studies, which are also shown in the figure (Ollerhead et al., 1992; Fidell et al., 1994; Fidell et al., 1995a; Fidell et al., 1995b) along with the data from six previous field studies.



Source: FICAN 1997

Figure A-11 FICAN 1997 Recommended Sleep Disturbance Dose-Response Relationship

Number of Events and Awakenings

It is reasonable to expect that sleep disturbance is affected by the number of events. The German Aerospace Center (DLR) 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, and 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.

Later studies by DLR conducted in the laboratory comparing the probability of awakenings from noise generated by different modes of transportation showed that aircraft noise led to significantly lower awakening probabilities than either road traffic or rail noise (Basner et al., 2011). Furthermore, it was noted that the probability of awakening, per noise event, decreased as the number of noise events increased. The authors concluded that by far the majority of awakenings from noise events merely replaced awakenings that would have occurred spontaneously anyway.

A different approach was taken by an ANSI standards committee (ANSI, 2008), which used the average of the data on field studies shown in Figure A-11 rather than the upper envelope (i.e., the red line), to predict average probability of awakening from one event. Probability theory is then used to project the awakening from multiple noise events.

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 and windows open. 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 and sleeping in bedrooms with their windows closed, and 2 to 3 percent for those sleeping in bedrooms with their windows open. The probability of the exposed population awakening at least once from multiple aircraft events at noise levels of 90 dB SEL is shown in Table A-4.

Table A-4 Probability of Awakening from NA90SEL

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

Source: DoD, 2009b

In December 2008, FICAN recommended the use of this standard. FICAN also recognized that more research is underway by various organizations and that work may result in changes to FICAN's position.

FICAN reaffirmed its recommendation for the use of the ANSI (2008) standard (FICAN, 2008). However, it is noted that this standard has been withdrawn, but it will be used until further recommendations are made by FICAN.

A recent study further examined the relationship between self-reported sleep insufficiency and airport noise using the U.S. Behavioral Risk Factor Surveillance System data and DNL contours generated by the FAA's Integrated Noise Model software for 95 airports (Holt et al., 2015). The survey data comprise the results of a random-digit-dialed telephone survey of non-institutionalized U.S. civilians 18 years or older covering all 50 states. Responses that included sleep insufficiency questions were included in this study totaling more than 700,000 respondents for 2008 and 2009 year datasets. The authors found that, once controlled for individual sociodemographic characteristics and ZIP Code-level socioeconomic status, there were no significant associations between airport noise exposure levels and self-reported sleep insufficiency. These results are consistent with a study that found aircraft-noise-induced awakening are more reasonably predicted from relative rather than absolute SELs (Fidell et al., 2013). However, Kim et al. (2014) found a response relationship between aircraft noise and sleep quality in a community-based cross-sectional study when controlling for a mental health condition (Kim et al., 2014).

The WHO recommends the use of the dBA long-term average sound level L_{night}, measured outside the home, for sleep disturbance and related effects, with an interim target of 55 dB $L_{night, outside}$ and a night noise guideline of 40 dB (WHO, 2009).

The choice of a noise metric for policy-making purposes depends on both the particular type of noise source and the particular effect being studied. Even for sleep disturbance caused by aircraft noise, there is no single noise exposure metric or measurement approach that is generally agreed upon (Finegold, 2010).

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.

A1.3.4 Noise-Induced Hearing Impairment

Residents in communities surrounding airfields 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.

The *Noise-Induced Hearing Impairment* bulletin is one of a series of technical bulletins issued by the DoD Defense Noise Working Group (DNWG) under the initiative to educate and train DoD military, civilian, and contractor personnel, and the public on noise issues. "The ability to convey the effects of military aircraft noise exposure should facilitate both the public discussions and the environmental assessment process," according to DNWG (2013). In its background discussion on the topic of noise-induced hearing impairment, DNWG (2013) states:

> "Considerable data have been collected and analyzed by the scientific/medical community on the effects of noise on workers in industrial settings, and it has been well established that

> continuous exposure to high noise levels from any source will damage human hearing and result in noise induced hearing loss (USEPA, 1974). The scientific community has concluded that there is little likelihood of hearing damage resulting from exposure to aircraft noise at commercial airports. Until recently, the same was thought true for military airbases, but the introduction of new generation fighter aircraft with high thrust to weight ratio and correspondingly high noise levels has required a re-analysis of the risk of hearing damage for those communities close to military airbases. Residents in surrounding communities are expressing concerns regarding the effects of these new aircraft on hearing."

DNWG goes on to define the major components of hearing loss, temporary versus permanent loss, and threshold shift in hearing, and how they can be differentiated:

> "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 or a Permanent Threshold Shift.
>
> "A Temporary Threshold Shift (TTS) can result from exposure to loud noise over a given amount of time, yet the hearing loss is not necessarily permanent. An example of TTS might be a person attending a loud music concert. After the concert is over, the person may experience a threshold shift that may last several hours, depending upon the level and duration of exposure. While experiencing TTS, the person becomes less sensitive to low-level sounds, particularly at certain frequencies in the speech range (typically near 2,000 and 4,000 Hertz). Normal hearing ability eventually returns, as long as the person has enough time to recover in a relatively quiet environment.
>
> "A Permanent Threshold Shift (PTS) usually results from repeated exposure to high noise levels, where the ears are not given adequate time to recover from the strain and fatigue of exposure. A common example of PTS is the result of working in a very noisy environment such as a factory. It is important to note that TTS can eventually become PTS over time. Thus, even if the ear is given time to recover from TTS, repeated occurrence of TTS may eventually lead to permanent hearing loss. The point at which a Temporary Threshold Shift results in a Permanent Threshold Shift is difficult to identify and varies with a person's sensitivity. In general, hearing loss (be it TTS or PTS) is determined by the duration and level of the sound exposure (DNWG, 2013)."

On the topic of noise-induced hearing loss and its specific components, DNWG (2013) provides the following overview:

> "The 1982 EPA Guidelines for Noise Impact Analysis presents the risk of hearing loss from exposure to noise in the workplace in terms of the Noise-Induced Permanent Threshold Shift (NIPTS), a quantity that defines the permanent change in hearing level, or threshold, caused by exposure to noise (USEPA, 1982). It represents the difference in PTS between workers exposed to noise and those who are not exposed. Numerically, the NIPTS is the change in threshold averaged over the frequencies 0.5, 1, 2, and 4 kHz that can be expected from daily exposure to noise over a normal working lifetime of 40 years, with the exposure beginning at an age of 20 years. A grand average of the NIPTS over time (40 years) and hearing sensitivity (10 to 90 percentiles of the exposed population) is termed the Average NIPTS, or Ave. NIPTS for short. The Ave. NIPTS that can be expected for noise exposure as measured by the 24-hour average noise level, Leq24, is given in Table A-5 (USEPA, 1982).

Table A-5 Average (Ave.) NIPTS and 10th Percentile NIPTS as a Function of $L_{eq(24)}$

$L_{eq(24)}$	*Ave. NIPTS (dB)**	*10th Percentile NIPTS (dB)**
75-76	1.0	4.0
76-77	1.0	4.5
77-78	1.6	5.0
78-79	2.0	5.5
79-80	2.5	6.0
80-81	3.0	7.0
81-82	3.5	8.0
82-83	4.0	9.0
83-84	4.5	10.0
84-85	5.5	11.0
85-86	6.0	12.0
86-87	7.0	13.5
87-88	7.5	15.0
88-89	8.5	16.5
89-90	9.5	18.0

Source: DoD, 2012

* rounded to the nearest 0.5 dB

> "Thus, for a noise exposure of 80 Leq24, the expected lifetime average value of NIPTS is 3 dB. The Ave. 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 A-5 in the '10th Percentile NIPTS' column (USEPA, 1982). As in the example above, for individuals exposed to 80 Leq24, the most sensitive of the population would be expected to show a degradation to their hearing of 7 dB over time. 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. Lastly, the variability in audiometric testing is generally assumed to be ±5 dB (USEPA, 1974). (DNWG, 2013)."

According to DNWG, applying these measurement tools for NIPTS to a specific population is the next step in the process of fully understanding noise impacts on a community (DNWG, 2013):

> "In order to quantify the overall impact of noise on a community it is necessary to include the numbers of people who are exposed. This is accomplished by calculating the population average value of Ave. NIPTS, known as the Potential Hearing Loss (PHL), using the following equation:

$$\text{PHL} = \frac{\sum_i NIPTS_i \times P_i}{\sum_i P_i} \quad (1)$$

> where NIPTSi is the Ave. NIPTS for people within the *ith* noise level band (see Table A-5), and Pi is the total population living within the *ith* noise level band. The quantity PHL represents the average change in hearing threshold, or the average hearing loss, for the local community exposed to the noise.
>
> The actual noise exposure is determined by the portion of the time the population is outdoors and the outdoor noise levels to which they are exposed. The EPA Guidelines allows for calculating the exposure taking into account the length of time the population is indoors and exposed to lower levels. If the outdoor exposure exceeds 3 hours per day, the contribution of the indoor levels can usually be neglected. (DNWG, 2013)."

The criteria for measuring permanent hearing loss in the workplace are similar but more complex, according to DNWG (2013):

> "The database from which the risk of hearing loss in Table A-5 was developed is based almost entirely on extensive audiometric measurements of workers in industrial settings. A considerable amount of hearing loss data have been collected and analyzed, including measurements of hearing loss in people with known histories of noise exposure. The available evidence consists of statistical distributions of hearing levels for populations at various exposure levels. Much of the analysis consists of grouping these measurements into populations of the same age with the same history of noise exposure and determining the percentile distribution of hearing loss for populations with the same noise exposure. Thus, the evidence for noise-induced permanent threshold shift can be clearly seen by comparing the distribution of a noise-exposed population with that of a relatively non-noise-exposed population (USEPA, 1974).
>
> "Most of these data are drawn from cross-sectional rather than longitudinal studies. That is, individuals or populations have been tested at only one point in time. Because complete noise exposure histories do not exist, many conclusions are limited by the need to make certain assumptions about the onset and progression of noise-induced hearing loss. (DNWG, 2013)."

The USEPA , National Academy of Sciences, WHO, the Occupational Safety and Health Administration (OSHA), National Institute for Occupational Safety and Health, and DoD have each established their own criteria for measuring hearing loss within the workplace, according to DNWG (2013):

> "Using this database, the EPA established 75 dB for an 8-hour exposure and 70 dB for a 24-hour exposure as the average noise level standard requisite to protect the most sensitive (approximately 1 percent) of the population from greater than a 5 dB permanent threshold shift in hearing. The EPA document explains that the requirement for an adequate margin of safety necessitates a highly conservative approach which dictates the prevention of any effect on hearing, defined here as an essentially insignificant and not measurable NIPTS of less than 5 dB. (USEPA, 1974).
>
> "The National Academy of Sciences Committee on Hearing, Bioacoustics, and Biomechanics (CHABA) identified 75 dB as the minimum level at which hearing loss may occur from continuous, long-term (40 years) exposure (CHABA, 1965).
>
> "The World Health Organization has concluded that environmental and leisure-time noise below a Leq24 value of 70 dB 'will not cause hearing loss in the large majority of the population, even after a lifetime of exposure (WHO, 2000).'

> "The OSHA regulation of 1971 standardizes the limits on workplace noise exposure for protection from hearing loss as an average level of 90 dB over an 8-hour work period, or 85 dB over a 16-hour period (U.S. Department of Labor, 1971). The standard is based on a 5 dB decrease in allowable noise level per doubling of exposure time. Exposure at levels greater than this require a hearing conservation program to be implemented. The maximum level for workplace exposure to continuous noise is 115 dB, and exposure to this level is limited to 15 minutes. A maximum level of 140 dB is specified for impulsive noise.
>
> "The National Institute for Occupational Safety and Health recommends a maximum exposure of 85 dB for a period of 8 hours, with a recommended exchange rate of 3 dB per doubling of exposure time (NIOSH, 1998). The maximum allowable exposure level is 140 dB for both continuous and impulsive noise.
>
> "The Department of Defense requirements for hearing conservation specify that a hearing conservation program should be implemented if the 8-hour average noise level (Leq8) is greater than 85 decibels (DoD, 2004). The recommended exchange rate is a decrease of 3 dB per doubling of exposure time, although an alternative rate of 4 dB is allowed. (DNWG, 2013)."

The DoD has issued guidelines for hearing risk assessment in local communities, according to DNWG (2013):

> "The current DoD policy for assessing hearing loss risk as part of the EIS process is stated in the June 16, 2009 memorandum "Methodology for Assessing Hearing Loss Risk and Impacts in DoD Environmental Impact Analysis" issued by the Under Secretary of Defense (DoD, 2009c). The memorandum defines the conditions under which assessments are required, references the methodology from the 1982 EPA report, and describes how the assessments are to be calculated.
>
> > 'Current and future high performance aircraft create a noise environment in which the current impact analysis based primarily on annoyance may be insufficient to capture the full range of impacts on humans. As part of the noise analysis in all future environmental impact statements, DoD components will use the 80 Day-Night A-Weighted (DNL) noise contour to identify populations at the most risk of potential hearing loss. DoD components will use as part of the analysis, as appropriate, a calculation of the Potential Hearing Loss (PHL) of the at risk population. The PHL (sometimes referred to as Population Hearing Loss) methodology is defined in EPA Report No. 550/9-82-105, *Guidelines for Noise Impact Analysis* (USEPA, 1982).' (DoD, 2009c).
>
> "The 2009 DoD policy directive requires that hearing loss risk be estimated for the population most at risk, defined as the population exposed to a Day-Night Average Noise Level (DNL) greater than or equal to 80 dB, including residents of on-base housing. Limiting the analysis to the 80 DNL contour area does not necessarily imply that populations outside this contour, i.e. at lower exposure levels, are not at some degree of risk of hearing loss, but it is generally considered that this risk is small. The exposure of workers inside the base boundary area should be considered occupational and evaluated using the appropriate DoD component regulations for occupational noise exposure.
>
> "Environmental noise assessments normally estimate the number of people exposed to noise expressed in terms of the DNL noise metric, which contains a 10 dB weighting factor for aircraft

operations occurring between the hours of 2200 and 0700 to account for people's increased sensitivity to noise during the normal sleeping period. However, the mechanism by which high noise levels may cause hearing impairment is physical in nature (by damaging the hair cells in the cochlear) and has no such temporal effects – noise is noise as far as the potential for hearing loss is concerned, regardless of the time of day the exposure occurs. Thus, even though the population most at risk is identified in terms of the 80 DNL contour, it is not appropriate to estimate risk using the DNL metric. The actual assessment of hearing loss risk should be conducted using 24-hour average noise levels (Leq24). (DNWG, 2013)."

Regarding community hearing loss and aircraft noise, DNWG (2013) provides this overview:

"The preponderance of available information on hearing loss risk upon which Table A-5 is based is from the workplace with continuous exposure throughout the day for many years. Community exposure to aircraft noise is not continuous but consists of individual events where the sound level exceeds the background level for a limited time period as the aircraft flies past the observer. The maximum noise levels experienced from military aircraft may be very high, and the exposure could result in a temporary threshold shift (TTS). But unless the flights are continuous, the ear may have adequate time to recover from the strain and fatigue of individual exposures, and normal hearing ability may eventually return.

"There is very limited data on the effect of aircraft noise on hearing. From a civilian airport perspective, the scientific community has concluded that there is little likelihood that the resulting noise exposure from aircraft noise could result in either a temporary or permanent hearing loss (Newman and Beattie, 1985). The EPA criterion (Leq24 = 70 dB) can be exceeded in some areas located near airports, but that is only the case outdoors. Inside a building, where people are more likely to spend most of their time, the average noise level will be much less than 70 dB (Eldred and von Gierke, 1993). Eldred and von Gierke (1993) also report that 'several studies in the U.S., Japan, and the U.K. have confirmed the predictions that the possibility for permanent hearing loss in communities, even under the most intense commercial take-off and landing patterns, is remote.' (DNWG, 2013)."

DNWG (2013) then provides a closer look at military aircraft noise specifically:

"Military aircraft are in general much noisier than their civilian counterparts, but the available data, while sometimes contradictory, appears to indicate a similar lack of significant effects of noise on hearing. A laboratory study (Nixon et al., 1993) measured changes in human hearing from noise representative of low-flying aircraft on Military Training Routes (MTRs). The potential effects of aircraft flying along MTRs are of particular concern as the maximum overflight noise levels can exceed 115 dB, with a rapid increase in noise level exceeding 30 dB/sec. In this study, participants were first subjected to four overflight noise exposures at A-weighted levels of 115 dB to 130 dB. One-half of the subjects showed no change in hearing levels, one-fourth had a temporary 5 dB increase in sensitivity, and one-fourth had a temporary 5 dB decrease in sensitivity. In the next phase, participants were subjected to up to eight successive overflights, separated by 90 second intervals, at a maximum level of 130 dB until a temporary shift in hearing was observed. The temporary hearing threshold shift showed a decrease in sensitivity of up to 10 dB.

"In another study of 115 test subjects between 18 and 50 years old, TTSs were measured after laboratory exposure to military low-altitude flight (MLAF) noise (Ising et al., 1999). The results indicate that repeated exposure to MLAF noise with maximum noise levels greater than 114 dB, may have the potential to cause permanent noise induced hearing loss, especially if the noise level increases rapidly (Ising et al., 1999).

“A report prepared by researchers at the University of Southampton (Lawton and Robinson, 1991) summarized the state of knowledge as of 1991. Their review of the literature indicated that the main body of information with which comparisons can be made of the hearing damage risk from military overflight noise is to be found in standards and regulatory documents published by various organizations. It was concluded that the risk of hearing loss due to a single event of 125 dB maximum level and equivalent duration of the order 0.5 seconds is small, even after repeated daily occurrences over several years. Supplementary experimental evidence, involving TTS, showed that a small amount of TTS might be engendered by military overflight noise at the levels in question, but that this would have no significant long-term effect even on the more susceptible ears. The literature search did uncover a small number of population surveys of hearing loss related to noise, but the quantitative results were rare and only one investigation produced audiometric results linked to noise measurements.

“The report concluded that there is little evidence of hearing loss risk from military overflights, either for adults or children. ‘Whether in the case of TTS or PTS, laboratory or field studies, adults or children, there appear to be no reports of significant hearing damage attributable to the noise of aircraft overflights (Lawton and Robinson, 1991).’

“In Japan, audiological tests were conducted on a sample of residents who had lived near Kadena Air Base for periods ranging from 19 to 43 years (Yamamoto, 1999). The sample had been exposed (not necessarily continuously) to noise levels ranging from DNL 75 to 88 dB. Examinations showed that there was a one in ten chance of a NIPTS of 20 dB at 4 kHz. However, the NIPTS at 2 kHz and lower was much less, so that the value of Ave. NIPTS was on the order of 10 dB or so. These results are consistent with the ‘10th Percentile NIPTS’ figures in Table A-5.

“Ludlow and Sixsmith (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. (DNWG, 2013).”

According to DNWG’s (2013) conclusions, noise levels at commercial and military airfields have important distinguishing characteristics:

“Aviation noise levels near commercial airports are not comparable to the occupational or recreational noise exposures associated with hearing loss, and studies of aircraft noise levels have not definitively correlated permanent hearing impairment with aircraft activity. It is unlikely that airport neighbors will remain outside their homes 24 hours per day, so there is little likelihood of hearing loss below an average sound level of 75 dB.

“Near military airbases, average noise levels above 75 dB may occur, and while new DoD policy dictates that NIPTS should be evaluated, research results to date have not found a definitive relationship between significant permanent hearing impairment (greater than 10 dB) and prolonged exposure to aviation noise. (DNWG, 2013).”

A1.3.5 Nonauditory Health Effects

The general understanding of the possible effects of aircraft noise has been hindered by the publication of overly sensational and misleading articles in the popular press and by similarly sensational statements from reputed scientists, who are calling attention to their work. These statements have proven less than useful in the research and understanding of potential health effects from aircraft noise exposures. Moreover, the sensational statements have disturbing consequences because they provide misleading information, create unfounded worry and negative bias, distort certain facts, and add to a growing mistrust of science. These sensational statements have been firmly criticized by other researchers as lacking in rigor because they do not consider other known factors that cause health problems and because they analyze only a selection of the available data (ANR, 2010). The following discussion attempts to summarize the research into the possible nonauditory effects of aircraft noise based on a review of peer-reviewed research. The research reviewed ranges from general stress-related effects on health to specific individual studies on effects such as heart disease and stroke. In addition to these individual studies, there are summaries of meta-analyses of pooled results from individual studies addressing the same issue. The meta-analyses evaluate the studies for consistent results among the smaller individual studies, and they derive effect estimates from the different studies for a quantitative risk assessment (Babisch, 2013). Meta-analysis is an analytical technique designed to summarize the results of multiple smaller studies in order to increase the sample size and to identify patterns among the several smaller studies. The validity of meta-analysis is highly dependent on the quality of the included smaller studies because it cannot correct the poor design and/or bias of the original studies. Because of these limitations, a meta-analysis of several smaller studies cannot predict the results of a single large study and may result in misleading information for the general public.

A1.3.5.1 Overview

The potential for aircraft noise to impair one’s health deserves special attention and accordingly has been the subject of numerous epidemiological studies and meta-analyses of the gathered data. The basic premise is that noise can cause annoyance, annoyance can cause stress, and prolonged stress is known to be a contributor to a number of health disorders, such as hypertension, myocardial infarction (heart attack), cardiovascular disease, and stroke (Munzel et al., 2014). According to Kryter and Poza (1980), “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 between annoyance and stress and health issues requires careful experimental design because of the large number of confounding issues, such as heredity, medical history, smoking, diet, lack of exercise, and air pollution. Some highly publicized reports on health effects have, in fact, been rooted in poor science. Meecham and Shaw (1979) apparently found a relation between noise levels and mortality rates in neighborhoods located under the approach path to LAX. 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 neighborhoods. But when the Centers for Disease Control performed a more thorough study near Atlanta’s Hartsfield International Airport, no relationships were found for DNL greater than 65 dB (Edmonds et al., 1979).

To put the Odds Ratio (OR) number in context, an OR of 1.5 would be considered a weak relationship between noise and health; 3.5 would be a moderate relationship; 9.0 would be a strong relationship; and 32 a very strong relationship (Cohen, 1988).

An early study by Cantrell (1974) confirmed that noise can provoke stress, but it noted that results on its effect on cardiovascular health were contradictory. Some studies in the 1990s found a connection between aircraft noise and increased blood pressure (Michalak et al., 1990; Ising et al., 1990; Rosenlund et al., 2001), while others did not (Pulles et al., 1990). This inconsistency in results led the WHO in 2000 to conclude that there was only a weak association between long-term noise exposure and hypertension and cardiovascular effects, and that a dose-response relationship could not be established (WHO, 2000). Later, van Kempen concluded that "Whereas noise exposure can contribute to the prevalence of cardiovascular disease, the evidence for a relation between noise exposure and ischemic heart disease is still inconclusive" (van Kempen et al., 2002).

More recently, major studies have been conducted in an attempt to identify an association between noise and health effects, develop a dose-response relationship, and identify a threshold below which the effects are minimal. The most important of these are briefly described below. In these studies, researchers usually present their results in terms of the Odds Ratio, which is the ratio of the odds that health will be impaired by an increase in noise level of 10 dB to the odds that health would be impaired without any noise exposure. An OR of 1.25 means that there is a 25-percent increase in likelihood that noise will impair health. To put the OR number in context, an OR of 1.5 would be considered a weak relationship between noise and health; 3.5 would be a moderate relationship; 9.0 would be a strong relationship; and 32 a very strong relationship (Cohen, 1988). For examples, the OR for the relationship between obesity and hypertension is 3.4 (Pikilidou et al., 2013), and the OR for the relationship between smoking and coronary heart disease is 4.4 (Rosengren et al., 1992). The summary of these studies shows that the relationship between noise and impaired health is a very weak one because none of the statistically significant ORs were greater than 1.5. Most of the ORs were less than 1.2.

A1.3.5.2 Blood Pressure and Hypertension

- The carefully designed HYENA study was conducted around six European airports from 2002 through 2006 (Jarup et al., 2005, 2007, 2008; Babisch et al., 2008). The study covered 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. Noise from aircraft and highways was predicted from models.

  HYENA study results showed an OR less than 1 for the association between daytime aircraft noise and hypertension, which was not statistically significant[2] and indicated no positive association. The OR for the relationship between nighttime aircraft noise and hypertension was 1.14--a result that was marginally significant statistically. For daytime road traffic noise, the OR

[2] In many of the studies reported above, the researchers use the word "significant" to describe a relationship between noise and health, conjuring up the idea that the relationship is strong and that the effect is large. But this is an inappropriate and misleading use of the word in statistical analysis. What the researchers really mean is that the relationship is "statistically significant" in that they are sure that it is real. It does not mean that the effect is large or important, or that it has any decision-making utility. A relationship can be statistically significant, i.e. real, while being weak, or small and insignificant.

was 1.1 and not significant. The measured effects were small and not necessarily distinct from other events. A close review of the data for nighttime aircraft noise raised some questions about the data and the methods employed (ACRP, 2008). Using data from the HYENA study, Haralabidis et al. (2008) reported an increase in systolic blood pressure of 6.2 millimeters of mercury (mmHg) for aircraft noise events (about 6 percent) and an increase of 7.4 mmHg (about 7 percent) for other indoor noises, such as snoring; a snoring partner and road traffic had similar impacts on blood pressure.

- Ancona et al. (2010) reported a study on a randomly selected sample of subjects aged 45 to 70 years who had lived in the study area for at least 5 years. Personal data were collected via interview, and blood pressure measurements were taken for a study population of 578 subjects. No statistically significant association was found between aircraft noise levels and hypertension for noise levels above 75 dB $L_{eq(24)}$ compared to levels below 65 dB. However, there was an increase in nocturnal systolic pressure of 5.4 mmHg (about 5 percent) for subjects in the highest exposure category (greater than or equal to 75 dB).
- Eriksson et al. (2007) found that for subjects exposed to energy-averaged levels above 50 dBA, the adjusted relative risk for hypertension was 1.19 (95-percent CI = 1.03 to 1.37). Maximum aircraft noise levels presented similar results, with a relative risk of 1.20 (1.03 to 1.40) for those exposed above 70 dBA. Stronger associations were suggested among older subjects, those with a normal glucose tolerance, nonsmokers, and subjects not annoyed by noise from other sources. The study comprised a cohort of 2,754 men in four municipalities around Stockholm Arlanda airport who were followed from 1992 to 1994 and 2002 to 2004.
- Matsui et al. (2008) reported higher OR for noise levels greater than L_{den} 70 dB, but not altogether statistically significant, for hypertension from the effects of military aircraft noise at Kadena Air Base in Okinawa, Japan. The study was conducted in 1995 and 1996 but used older noise data that were not necessarily appropriate for the same time period.
- A study of Noise-Related Annoyance, Cognition and Health (NORAH), designed to identify transportation noise effects in communities around German airports, has reported results of self-monitoring of blood pressure of approximately 2,000 residents near Frankfurt Airport exposed to aircraft $L_{eq(24)}$ in the range of 40 to 65 dB during the period 2012 to 2014 after the opening of a new runway (Shreckenberg and Guski, 2015). The results showed small positive effects of noise on blood pressure without statistical significance. No statistically significant effect was determined between aircraft noise and hypertension as defined by the WHO.
- A meta-analysis of Huang el al. (2015) examined four research studies comprising a total of 16,784 residents. The overall OR for hypertension in residents with aircraft noise exposure was 1.36 for men and statistically significant, and 1.31 and not statistically significant for women. No account was taken for any confounding factors. The meta-analysis suggests that aircraft noise could contribute to the prevalence of hypertension, but the evidence for a relationship between aircraft noise exposure and hypertension is still inconclusive because of limitations in study populations, exposure characterization, and adjustment for important confounders.
    - The four studies in Huang's meta-analysis include one by Black et al. (2007) that purports to show relatively high OR values for self-reported hypertension, but these results only applied to a select subset of those surveyed that reported high noise stress. When this data set is excluded, Huang's meta-analysis yields results similar to those obtained in the HYENA and NORAH studies. Furthermore, the longitudinal

study included in the analysis that followed 4,721 people for 8 years (Eriksson et al., 2010) reported an OR of 1.02, which was not statistically significant.

- Rhee et al. (2008) found that subjects exposed to helicopter noise had a significantly higher prevalence of hypertension than the unexposed control group. Although a source-specific difference in the risk of cardiovascular disease by environmental noise exposure is suggested, no other study has evaluated whether or not exposure to noise from helicopters differs from exposure to noise from fighter jets in their influence on the prevalence of hypertension.
- Hwang et al. (2012) conducted a 20-year prospective cohort study of 1,301 aviation workers in Taiwan to follow AGT genotypes (TT, TM, and MM) across four exposure categories according to the levels of noise representing high (>80 dBA), medium (80-65 dBA), and low exposure (64-50 dBA) and the reference level (49-40 dBA). AGT (TT vs MM adjusted incidence rate ratio [IRR] 1.77, 95-percent CI 1.24 to 2.51) and noise exposure (high and medium combined) during 3 to 15 years (adjusted IRR 2.35, 95-percent CI 1.42 to 3.88) were independent determinants of hypertension. Furthermore, the risk of hypertension increased with noise exposure (adjusted IRR 3.73, 95-percent CI 1.84 to 7.56) among TT homozygotes but not among those with at least one M allele (Rothman synergy index = 1.05).
- Haralabidis et al. (2011) studied the association between exposure to transportation noise and blood pressure reduction during nighttime sleep utilizing 24-hour ambulatory blood pressure measurements at 15-minute intervals carried out on 149 persons living near four major European airports. Although road traffic noise exposure was found to decrease blood pressure dipping in diastolic blood pressure, no associated decrease in dipping was found for aircraft noise exposure.

A1.3.5.3 Heart Disease and Stroke

- Huss et al. (2010) examined the risk of mortality from myocardial infarction (heart attack) resulting from exposure to aircraft noise using the Swiss National database of mortality records for the period 2000 to 2005. The analysis was conducted on a total of 4.6 million people, with 15,500 deaths from acute myocardial infarction. The results showed that the risk of death from all circulatory diseases combined was not associated with aircraft noise, and there was not any association between noise and the risk of death from stroke. The overall risk of death from myocardial infarction alone was 1.07 and not statistically significant, but it was higher (OR = 1.3 and not statistically significant) in people exposed to aircraft noise of 60 dB DNL or greater for 15 years or more. The risk of death from myocardial infarction was also higher (OR = 1.10), and statistically significant, for those living near a major road. Cardiovascular risk factors, such as smoking, were not directly taken into account in this study.
- Floud (2013) used the HYENA data to examine the relationship between noise levels and self-reported heart disease and stroke. There was no association for daytime noise and no statistically significant association for nighttime noise. However, for those exposed to nighttime aircraft noise for more than 20 years, the OR was 1.25 per 10 dB increase in noise (L_{night}) and marginally significant.
- Correia et al. (2013) evaluated the risk of hospitalization for cardiovascular diseases in older people (65 years of age and older) residing in areas exposed to a DNL of at least 45 dB around U.S. airports. Health insurance data from 2009 Medicare records were examined for approximately 6 million people living in neighborhoods around 89 airports in the U.S. The

potential confounding effect of socioeconomic status was extracted from several zip-code-level variables from the 2000 U.S. Census. No controls were included for smoking or diet, both of which are strong risk factors for cardiovascular disease. Noise levels were calculated at census block centroids. Taking into account the potential effects of air pollution, they report an OR of 1.035, which was marginally significant statistically. While the overall results show a link between increased noise and increased health risk, some of the individual airport data show a decreased health risk with increased aircraft noise exposure.

- Hansell et al. (2013) investigated the association of aircraft noise with risk of hospital admission for, and mortality from, stroke, coronary heart disease, and cardiovascular disease in neighborhoods around London's Heathrow airport exposed to an equivalent sound level over 16 hours of at least 50 dB. The data were adjusted for age, sex, ethnicity, deprivation, and a smoking proxy (lung cancer mortality) at the census area level but not at the individual level. It was important to consider the effect of ethnicity (in particular, South Asian ethnicity, which is itself strongly associated with risk of coronary heart disease). The reported ORs for stroke, heart disease, and cardiovascular disease were 1.24, 1.21, and 1.14, respectively. Similar results were reported for mortality. The results suggest a higher risk of mortality from coronary heart disease than cardiovascular disease, which seems counter-intuitive given that cardiovascular disease encompasses all the diseases of the heart and circulation, including coronary heart disease and stroke along with heart failure and congenital heart disease (ERCD, 2014).
- Evrard et al. (2015) studied mortality rates for 1.9 million residents living in 161 communes near three major French airports (Paris-Charles de Gaulle, Lyon Saint-Exupéry, and Toulouse-Blagnac) for the period 2007 to 2010. Noise levels in the communes ranged from 42 to 64 dB L_{den}. Lung cancer mortality at the commune level was used as a proxy measure for smoking because data on individual smoking or smoking prevalence were not available. Noise exposure was expressed in terms of a population-weighted level for each commune. After adjustment for concentration of nitrogen dioxide, Risk Ratios (similar to Odds Ratios) per 10 dB increase in noise were found to be 1.18 for mortality from cardiovascular disease, 1.23 for mortality from coronary heart disease, and 1.31 for mortality from myocardial infarction. There was no association between mortality from stroke and aircraft noise. As the author notes, results at the commune level may not be applicable to the individual level.
- Seidler et al. (2016) found a statistically significant linear exposure-risk relationship with heart failure or hypertensive heart disease for aircraft traffic noise (1.6-percent risk increase per 10 dB increase in the 24-hour continuous noise level; 95-percent CI 0.3 to 3.0 percent), road traffic noise (2.4 percent per 10 dB; 95-percent CI 1.6 to 3.2 percent), and railway noise (3.1 percent per 10 dB; 95-percent CI 2.2 to 4.1 percent). For individuals with 24-hour continuous aircraft noise levels less than 40 dB and nightly maximum aircraft noise levels exceeding 50 dB six or more times, a significantly increased risk was observed. In general, risks of hypertensive heart disease were considerably higher than the risks of heart failure.
- The NORAH study also included an examination of the effect of aircraft noise on cardiovascular disease (heart attack and stroke) based on examination of health insurance data between 2006 and 2010 for approximately 1 million people over the age of 40 exposed to aircraft $L_{eq(24)}$ in the range of 40 to 65 dB (Shreckenberg and Guski, 2015). A questionnaire was used to obtain information on confounding factors. The results showed a non-statistically significant increase in risk for heart attack and stroke, and there was no apparent linear relationship between noise

level and either effect. There was, however, a marginally significant but small increase in risk for heart failure (OR of 1.016). The risk of cardiovascular disease was found to be greater for road and rail noise than for aircraft noise.

- Meta-analyses from Babisch and Kamp (2009), Babisch et al. (2013), and Babisch (2013) focused on epidemiological studies or surveys directly related to associations between aircraft noise and cardiovascular disease outcomes. Considering studies at 10 airports covering over 45,000 people, the pooled effect estimate of the relative risk for hypertension was 1.13 per 10 dBA and only marginally significant (WHO, 2011). One of the studies included in the analysis was for military aircraft noise at Okinawa (see Matsui et al., 2008) for which the OR was 1.27 but not statistically significant. The authors conclude that "No single, generalized and empirically supported exposure-response relationship can be established yet for the association between aircraft noise and cardiovascular risk due to methodological differences between studies." The pooled results show different slopes from different studies with different noise level ranges and methods being used.
- A meta-analysis of 11 studies on road and aircraft noise exposure in relation to incident cases of ischemic heart disease (IHD) was transformed into risk estimates per 10 dB increase in exposure by Vienneau et al. (2013). Pooled relative risk for IHD was 1.08 (1.03 to 1.14) per 10 dB increase in noise exposure, with the linear exposure-response starting at 50 dB.
- Passchier-Vermeer and Passchier (2000) reviewed studies on noise exposure and health effects and found sufficient evidence to support observation thresholds for hearing impairment, hypertension, IHD, annoyance, performance, and sleep disturbance due to noise exposure. The intent of the article was not to quantify impacts necessarily but instead to show that noise exposure can have a major effect in industrial societies in general, and it should be up to policy-makers and regulators to address this potential public health problem. In addition, the article recommended prioritizing additional study in two topic areas: 1) cardiovascular effects, and 2) the underlying mechanisms and the study of the effects of noise on children.
- Seidler et al. (2016) studied myocardial infarction risk due to aircraft, rail, and road noise by investigating patients of the Rhine-Main region of Germany who were diagnosed with myocardial infarction in the years 2006 through 2010. The linear model revealed a statistically significant risk increase due to road noise (2.8 percent per 10 dB rise, 95-percent CI [1.2; 4.5]) and railroad noise (2.3 percent per 10 dB rise [0.5; 4.2]) but not airplane noise. Airplane noise levels of 60 dB and above were associated with a higher risk of myocardial infarction (OR 1.42 [0.62; 3.25]). This higher risk is statistically significant if the analysis is restricted to patients who had died of myocardial infarction by 2014/2015 (OR 2.70 [1.08; 6.74]. In this subgroup, the risk estimators for all three types of traffic noise were of comparable magnitude (3.2 percent to 3.9 percent per 10 dB rise in noise level).
- Floud et al. (2011) examined the health effects of aircraft and road traffic noise exposure and the association with medication use. The cross-sectional study measured the use of prescribed antihypertensives, antacids, anxiolytics, hypnotics, antidepressants, and antiasthmatics in 4,861 persons living near seven airports in six European countries. Differences were found between countries in the effect of aircraft noise on antihypertensive use; for nighttime aircraft noise, a 10 dB increase in exposure was associated with ORs of 1.34 (95-percent CI, 1.14 to 1.57) for the UK and 1.19 (1.02 to 1.38) for the Netherlands, but no significant associations were found for other countries. For daytime aircraft noise, excess risks were found for the UK (OR 1.35; CI: 1.13 to

1.60), but a risk deficit was found for Italy (OR 0.82; CI: 0.71 to 0.96). There was an excess risk of taking anxiolytic medication in relation to aircraft noise (OR 1.28; CI: 1.04 to 1.57 for daytime and OR 1.27; CI: 1.01 to 1.59 for nighttime) that held across countries. The authors also found an association between exposure to 24-hour road traffic noise and the use of antacids by men (OR 1.39; CI 1.11 to 1.74).

A1.3.5.4 Mental Health Issues

- The NORAH study found a risk for unipolar depression to increase with exposure to aircraft noise (OR of 1.09), but the relationship was not linear, with the risk decreasing at the higher noise levels, so this result was not considered reliable (Schreckenberg and Guski, 2015).
- A survey study around Frankfurt Airport explored the relationship between aircraft, road traffic, and railway noise with Quality-of-Life (QoL) concerns for both health and environmental views (Schreckenberg et al., 2010). Aircraft noise affected environmental QoL and, to a lesser extent, health QoL. However, one of the study's observations concerned vulnerable groups, such as people with pre-existing illness and/or high noise sensitivities. This group may have limited resources to deal with noise, which can result in increased health problems.
- A study of the effect of aircraft noise around a large international airport, Schiphol Airport, near Amsterdam, found an association between the use of non-prescribed sleep medication or sedatives with aircraft noise during the late evening (10:00 P.M. to 11:00 P.M.). However, the correlation between L_{den} and L_{eq} (10:00 P.M. to 11:00 P.M.) to sleep aids (ORs 1.25 and 1.26, respectively) was not statistically significant (Franssen et al., 2004).
- Beutel et al. (2016) assessed the association of day and night noise annoyance from road traffic, aircraft, railways, industrial, and neighborhood indoor and outdoor noise to anxiety and depression in 15,000 people ages 35 to 74 living in the Rhein-Main Region of Germany. The source and magnitude of noise annoyance was measured by a self-administered questionnaire. Depression and anxiety were also assessed based on established questionnaires. In this study, aircraft noise was the most commonly reported source of annoyance, followed by road noise annoyance. Depression and anxiety increased with the degree of overall noise annoyance. Compared to no annoyance, prevalence ratios for depression and anxiety, respectively, increased from moderate (PR depression 1.20; 95-percent CI 1.00 to 1.45; PR anxiety 1.42; 95-percent CI 1.15 to 1.74) to extreme annoyance (PR depression 1.97; 95-percent CI 1.62 to 2.39; PR anxiety 2.14; 95-percent CI 1.71 to 2.67). Compared to other sources, aircraft noise annoyance was prominent, affecting almost 60 percent of the population. More simply stated, strong noise annoyance was associated with a two-fold higher prevalence of depression and anxiety in the general population. The authors admit that the identified association of annoyance, particularly with aircraft noise, to depression and anxiety is suggestive of a cause but that more study is needed to identify causal relationships. The authors recognized that pre-existing anxiety and depression could contribute to increased susceptibility to noise annoyance. Also, the focus of this paper was on subjective annoyance, which is not related to objective measures of noise exposition.
- Van den Berg et al. (2015) conducted a study that explored the suggested limitation in the Beutel (2016) study: the relationship between pre-existing concern and annoyance. More specifically, they sought insight in the relation between worry about a noise source and annoyance from that source. The motivation for the study was the longstanding important

public concern for noise at a political level in Amsterdam, despite implementation of several measures to reduce noise exposure, and the desire to find other variables such as reducing fear and worry that might also help the situation. Using questionnaires from 1,968 respondents and modeling flight-related noise levels in a greater cosmopolitan area around Amsterdam, the researchers found that respondents with a high risk of anxiety/depression are significantly more likely to be highly worried about living close to the airport or an air route compared to those with a low risk (all $p < 0.05$). Also, respondents who report to have bad/moderate health are significantly more likely to be highly worried about living close to the airport or an air route compared to those with good/excellent health. More generally, the results show there is a strong correlation between annoyance from aircraft or airport noise and worry about the risk for health and/or safety associated with living close to an air route or airport. Also, for aircraft noise, worry increases with both the subjective exposure (annoyance) and the objective exposure (sound level). The authors conclude "that more noise or odor is related to more worry, and this has more effect on persons that have a higher personal risk for being worried and annoyed." When considered within the context of other studies, such as Beutel (2016), it would seem that those who are predisposed to worry are more susceptible to both annoyance and the negative health effects associated with anxiety and depression.

An individual with an increased sensitivity to sounds may have hyperacusis, which results in a lower tolerance of everyday sound (Aazh et al., 2018). A person with hyperacusis reacts differently to sounds due to reactions of increased distress and discomfort from everyday sounds. This condition arises from a problem with the auditory processes within an afflicted individual's brain. The causes and diagnosis are not well understood (Aazh et al., 2018). Physical causes of hyperacusis may range from head injury, ear damage, or viral diseases, to TMJ. Neurologic causes may range from PTSD, chronic fatigue syndrome, depression, to migraine headaches (American Academy of Otolaryngology--Head and Neck Surgery, 2018). An individual with hyperacusis will also likely have tinnitus, which may lead to further discomfort. Hyperacusis can lead to misophonia, which may cause an individual to react with abnormally strong emotions and behaviors to specific sounds, but hyperacusis does not cause this reaction. Studies of misphonia are very limited at this time. Another condition that falls under the condition of hyperacusis is noise sensitivity (Aazh et al., 2018). A noise-sensitive individual is characteristically more prone to being annoyed by environmental noise compared to a non-noise-sensitive person regardless of the overall noise exposure (Kishikawa et al., 2006). This result indicates that the annoyance response for noise-sensitive people is not a direct function of noise exposure levels.

A1.3.5.5 Hospital and Care Facilities

The ACRP (ACRP, 2008) reviewed the literature available at that time to draw the following conclusions regarding noise impacts on patients in hospitals and care facilities:

> "A careful search of recent research regarding aviation noise and hospitals and care facilities identified no studies that addressed this specific issue. It is common for airport noise/land-use compatibility guidelines to list hospitals and care facilities as noise-sensitive uses, although there are no studies that have identified health effects associated with aviation noise. There are numerous studies that identify problems with internal hospital noises such as warning alarms,

> pagers, gurney collisions with doors, talking, etc.; however, none that addressed aviation or roadway noise."

The WHO (2000), in its Guidelines for Community Noise (Section 4.3.3), applies available information on noise to derive the following general guidance. However, the guidance is not informed by research on hospital and care facility effects from aircraft noise.

> "For most spaces in hospitals, the critical effects of noise are on sleep disturbance, annoyance and communication interference, including interference with warning signals. The L_{Amax} of sound events during the night should not exceed 40 dB indoors. For wardrooms in hospitals, the guideline values indoors are 30 dB L_{Aeq}, together with 40 dB L_{Amax} during the night. During the day and evening the guideline value indoors is 30 dB L_{Aeq}. The maximum level should be measured with the instrument set at '*fast*'.
>
> Since patients have less ability to cope with stress, the equivalent sound pressure level should not exceed 35 dB L_{Aeq} in most rooms in which patients are being treated or observed. Particular attention should be given to the sound pressure levels in intensive care units and operating theatres. Sound inside incubators may result in health problems, including sleep disturbance, and may lead to hearing impairment in neonates. Guideline values for sound pressure levels in incubators must await future research."

A1.3.5.6 Summary of Nonauditory Effects

Research studies seem to indicate that aircraft noise may contribute to the risk of health disorders, along with other factors such as heredity, medical history, smoking, alcohol use, diet, lack of exercise, and air pollution, but that the measured effect is small compared to these other factors and often not statistically significant--i.e., not necessarily real. Despite some sensational articles purporting otherwise and the intuitive feeling that noise in some way must impair health, there are no studies that definitively show a causal and significant relationship between aircraft noise and health. Such studies are notoriously difficult to conduct and interpret because of the large number of confounding factors that have to be considered for their effects to be excluded from the analysis. The WHO notes that there is still considerable variation among studies (WHO, 2011). And, almost without exception, research studies conclude that additional research is needed to determine whether such a causal relationship exists. The European Network on Noise and Health (ENNAH, 2013), in its summary report of 2013, concludes that "…..while the literature on non-auditory health effects of environmental noise is extensive, the scientific evidence of the relationship between noise and non-auditory effects is still contradictory."

As a result, it is not possible to state that there is sound scientific evidence that aircraft noise is a significant contributor to health disorders.

A1.3.6 Performance Effects

The effect of noise on the performance of activities or tasks has been the subject of many studies. Some of these studies have found links between continuous high noise levels and performance loss. Noise-induced performance losses are most frequently reported in studies where noise levels are above 85 dB. Moderate noise levels appear to act as a stressor for more sensitive individuals performing a difficult psychomotor task. Little change has typically been found in low-noise cases; however, cognitive learning differences were measured in subjects exposed to noise of passing aircraft with maximum amplitudes of 48 dBA, presented once per minute, while performing text learning compared to a control group exposed to 35 dBA (Trimmel et al., 2012). The findings suggest that background noise below 50 dBA results in impaired and changed structures of learning, as indicated by reproduction scores, because test persons are less able to switch between strategies

While the results of research on the general effect of periodic aircraft noise on performance have yet to yield definitive criteria, several general trends have been noted, including:

- A periodic intermittent noise is more likely to disrupt performance than a steady-state continuous noise of the same level. Flyover noise, due to its intermittent nature, might be more likely to disrupt performance than a steady-state noise of equal level.
- Noise is more inclined to affect the quality than the quantity of work.
- Noise is more likely to impair the performance of tasks that place extreme physical and/or mental demands on workers.

A1.3.7 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 of particular concern for children who are already scholastically challenged.

A1.3.7.1 Effects on Learning and Cognitive Abilities

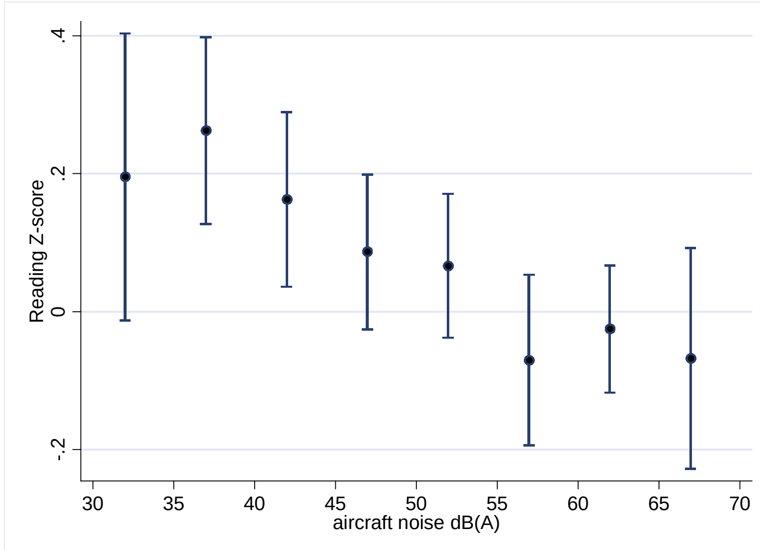
Early studies in several countries (Cohen et al., 1973, 1980, 1981; Bronzaft and McCarthy, 1975; Green et al., 1982; Evans et al., 1998; Haines et al., 2002; Lercher et al., 2003) showed lower reading scores for children living or attending school in noisy areas than for children away from those areas.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

A longitudinal study reported by Evans et al. (1998) conducted prior to relocation of the old Munich Airport in 1992, reported that high noise exposure was associated with deficits in long-term memory and reading comprehension in children with a mean age of 10.8 years. Two years after the closure of the airport, these deficits disappeared, indicating that noise effects on cognition may be reversible if exposure to the noise ceases. Most convincing was the finding that deficits in memory and reading comprehension developed over the two-year follow-up for children who became newly noise exposed near the new airport.

More recently, the Road Traffic and Aircraft Noise Exposure and Children's Cognition and Health (RANCH) study (Stansfeld et al., 2005; Clark et al., 2005) 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., 2005).

Figure A-12 shows RANCH's result relating noise to reading comprehension. It shows that reading falls below average (a z-score of 0) at L_{eq} greater than 55 dB. Because the relationship is linear, reducing exposure at any level should lead to improvements in reading comprehension.



Sources: Stansfeld et al. 2005; Clark et al. 2005

Figure A-12 RANCH Study Reading Scores Varying with L_{eq}

The RANCH study observed that children may be exposed to aircraft noise for many of their childhood years and the consequences of long-term noise exposure were unknown. A follow-up study of the children in the RANCH project is being analyzed to examine the long-term effects on children's reading comprehension (Clark et al., 2009). Preliminary analysis indicated a trend for reading comprehension to be poorer at 15 to 16 years of age for children who attended noise-exposed primary schools. An additional study utilizing the same data set (Clark et al., 2012) investigated the effects of traffic-related air pollution and found little evidence that air pollution moderated the association of noise exposure on children's cognition.

There was also a trend for reading comprehension to be poorer in aircraft-noise-exposed secondary schools. Significant differences in reading scores were found between primary school children in the two different classrooms at the same school (Bronzaft and McCarthy, 1975). One classroom was exposed to high levels of railway noise, while the other classroom was quiet. The mean reading age of the noise-exposed children was 3 to 4 months behind that of the control children. Studies suggest that the evidence of the effects of noise on children's cognition has grown stronger over recent years (Stansfeld and Clark, 2015), but further analysis adjusting for confounding factors is ongoing and is needed to confirm these initial conclusions.

Studies identified a range of linguistic and cognitive factors to be responsible for children´s unique difficulties with speech perception in noise. Children have lower stored phonological knowledge to reconstruct degraded speech, reducing the probability of successfully matching incomplete speech input when compared with adults. Additionally, young children are less able than older children and adults to make use of contextual cues to reconstruct noise-masked words presented in sentential context (Klatte et al., 2013).

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. These were, however, all computed indoor levels, which makes 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, the FICAN study was not expected to obtain final answers, but it provided useful indications (FICAN, 2007).

A recent study of the effect of aircraft noise on student learning (Sharp et al., 2013) examined student test scores at a total of 6,198 U.S. elementary schools, 917 of which were exposed to aircraft noise at 46 airports and with noise exposures exceeding 55 dB DNL. The study found small but statistically significant associations between airport noise and student mathematics and reading test scores, after taking demographic and school factors into account. Associations were also observed for ambient noise and total noise on student mathematics and reading test scores, suggesting that noise levels per se, as well as from aircraft, might play a role in student achievement. Recent evidence suggests that potential negative effects on classroom performance can be due to chronic ambient noise exposure. A study of French 8- and 9-year-old children found a significant association between ambient noise levels in urban environments due primarily to road noise (Pujol et al., 2014). The study estimated noise levels at children's bedrooms (L_{den}) and found a modest effect of lower scores on French tests, and these lower scores were associated with higher L_{den} at children's homes. Once adjusted for classroom $L_{Aeq,day}$, the association between L_{den} and math test scores became borderline significant.

As part of the NORAH study conducted at Frankfurt Airport, reading tests were conducted on 1,209 school children at 29 primary schools. It was found that there was a small decrease in reading performance that corresponded to a 1-month reading delay. However, a recent study observing children at 11 schools surrounding LAX found that the majority of distractions to elementary age students were other students, followed by themselves, which includes playing with various items and daydreaming. Less than 1 percent of distractions were caused by traffic noise (National Academies of Sciences, Engineering, and Medicine, 2017).

While there are many factors that 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 and a North Atlantic Treaty Organization working group to conclude that daycare centers and schools should not be located near major sources of noise, such as highways, airports, and industrial sites (North Atlantic Treaty Organization, 2000; WHO, 1999). The awareness has also led to the classroom noise standard discussed earlier (ANSI, 2010).

A1.3.7.2 Health Effects on Children

A number of studies, including some of the cognitive studies discussed above, have examined the potential for effects on children's health. Health effects include annoyance, psychological health impacts, 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 among 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. The available literature on psychological health impacts of noise exposure reveals inconsistent findings that are perhaps suggestive of highly situational-specific factors. 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 the result for distress. Crombie et al. (2011) found similar hyperactivity results but no significant associations between aircraft noise at school and later mental health issues in children at risk at birth--i.e., those with low birth weight.

Dreger et al. (2015) investigated the influence of different environmental noise sources at children's homes on the incidence of mental health problems in school-aged children. Using a survey of reported level of day and night annoyance by parents as the metric of noise level, the study identified an association between exposure to noise at home and mental health problems such as emotional symptoms, conduct problems, and hyperactivity. Road noise was the most common exposure and was significantly associated with the total difficulties score, emotional symptoms, and conduct problems. Noise by neighbors was associated with conduct problems and hyperactivity. However, aircraft noise (by day) and construction work (by day) were not associated with any of the SDQ categories at a significant level. More generally, and perhaps more importantly, the study found that children who were in the group of constant high exposure, and therefore were continuously exposed for a long time, had higher risk for mental health problems. The authors recognized the lack of quantitative noise measurements as an important study limitation but provide evidence from prior studies indicating reported annoyance as a good proxy.

Hjortebjerg et al. (2016) used noise models to determine average time-weighted road and railroad noise exposure for 46,940 children from birth to age 7 years. Airfield noise was similarly determined but only evaluated as a confounding variable, as was air pollution. A 10 dB increase in average time-weighted road traffic noise exposure from birth to 7 years of age was associated with a 7-percent increase in abnormal versus normal total difficulties scores; 5-percent increases in borderline and abnormal hyperactivity/inattention subscale scores, respectively; and 5-percent and 6-percent increases in abnormal conduct problem and peer relationship problem subscale scores, respectively. Exposure to road traffic noise during pregnancy was not associated with child behavioral problems at 7 years of age. While this study is quantitative, its application to airfield noise is limited due to the different nature of road versus airfield noise.

As with studies of adults, the available 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.

Coronary Risk. The HYENA study discussed earlier 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 this increase was 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 (van Kempen, 2006). In the Munich study (Evans et al., 1998), chronic noise exposure was found to be associated with both baseline systolic blood pressure and lower reactivity of systolic blood pressure to a cognitive task presented under acute noise. After the new airport opened, a significant increase in systolic blood pressure was observed, providing evidence for a causal link between chronic noise exposure and raised blood pressure. No association was found between noise and diastolic blood pressure or reactivity (Stansfeld and Crombie, 2011; Stansfeld, 2015).

However, the relationship between aircraft noise and blood pressure was not fully consistent between surveys in different countries. These findings, taken together with those from previous studies, suggest that no unequivocal conclusions can be drawn about the association between aircraft noise exposure and blood pressure. Overall, the evidence for noise effects on children's blood pressure is mixed and less certain than for noise effects on older adults.

Stress Hormones. Some studies investigated hormonal levels between groups of children exposed to aircraft noise and 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, 2001c). In both instances, there were no differences between the aircraft-noise-exposed children and the control groups.

Sleep Disturbance. A sub-study 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 (Ohrstrom 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. Davies (2012) discusses how a study in France among 10-year-old schoolchildren showed that school noise exposure was associated with higher cortisol levels, indicative of a stress reaction; these finding are supported by a Swedish study that found increased prevalence of reduced diurnal cortisol variability in relation with classroom L_{eq} during school day noise levels of between 59 and 87 dBA.

A1.3.8 Property Values

Noise, along with many other conditions, (i.e. location, number of rooms, crime rate, school district) 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. Studies of the effects of aviation noise on property values are highly complex due to differing community environments, market conditions, and methodological approaches, so study results generally range from some negative impacts to significant negative impacts. However, studies that considered positive aspects of airport accessibility have found net positive impacts on property values, while others found poorly informed buyers often bid higher prices in noise-impacted areas, only to potentially be disappointed after purchase (ACRP, 2008). The value-noise relation is usually presented as the Noise Depreciation Index (NDI), or Noise Sensitivity Depreciation Index, for 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 (1973) reached a similar conclusion. A larger study by Nelson (1980) studying property values near 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. These socioeconomic factors include size of house, number of rooms per house, repair of the house, distance from amenities and business districts, and demographics.

Frankel (1991) conducted surveys of 200 realtors and 70 appraisers in 35 suburban communities near Chicago O'Hare International Airport and found that a significant segment of buyers lacked adequate information about the noise environment and often overbid, only to be disappointed after purchase. Frankel classified noise-affected property owners into two groups: one that moved to the location while the environment was quiet but later became noise-impacted and another that purchased from a previous owner while the property was already noise impacted. Frankel concluded that the former group members bore the true financial burden of airport noise.

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 affected by non-noise factors, especially the wide differences in homes between the two study areas.

Tomkins (1998) conducted a study of the residential areas near Manchester Airport, England, and showed that when using the Noise and Number Index (no longer used but similar to DNL), there was no significant negative relationship between noise and property values. When L_{eq} measure was analyzed, fewer properties are included, but the most noise-blighted are identified. Ultimately, the proximity to the airport had a significant impact and was found to be a more important factor of property values than noise. This could be that potential buyers were more likely to be aware of potentially negative noise impacts when properties were closest to airports and much less aware at further distances.

Lipscomb (2003) analyzed the City of College Park, Georgia, and found that noise did not significantly affect the values of residential properties. Lipscomb concluded that local residents were more accepting of noise because many were employed in airport-related occupations, so the proximity provided offsetting benefits, such as short work commutes.

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 NDI from 0.3 to 1.5 percent per dB, with an average of about 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 2.0 percent per dB, with the average on the order of 0.5 percent per dB. The actual value varies from location to location, and it is very often small compared to non-noise factors such as location, market conditions, neighborhood characteristics, and property age, size, and amenities.

A1.3.9 Noise-Induced Vibration Effects on Structures and Humans

The sound from an aircraft overflight travels from the exterior to the interior of a house in one of two ways: through the solid structural elements or directly through the air. Figure A-13 illustrates the sound transmission through a wall constructed with a brick exterior, stud framing, interior finished wall, and absorbent material in the cavity. 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 finished surface vibrating, with some energy lost in the airspace. This surface then radiates sound into the dwelling interior. As the figure shows, vibrational energy also bypasses the air cavity by traveling through the studs and edge connections.

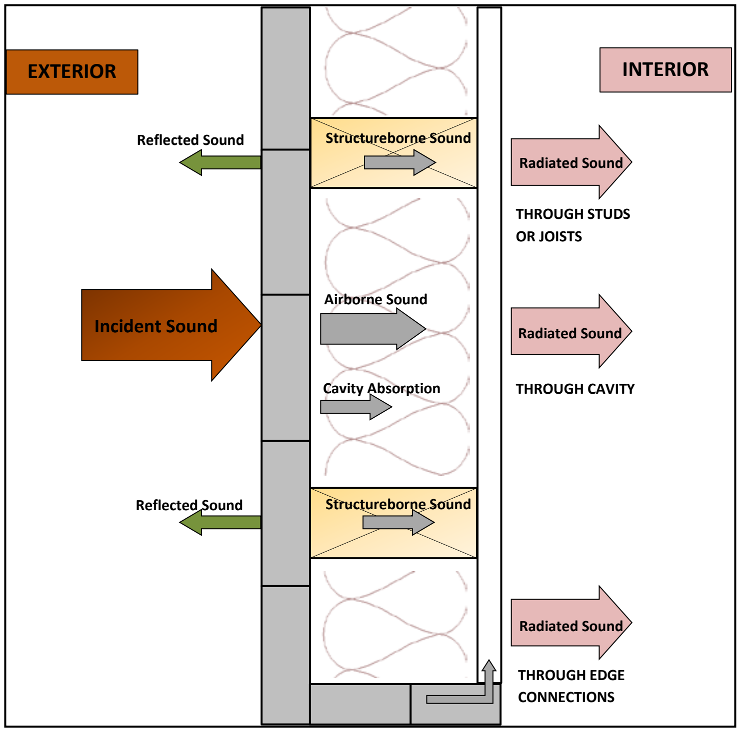


Figure A-13 Depiction of Sound Transmission through Built Construction

High noise levels can cause buildings to vibrate. If noise levels are 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 sound pressures levels and the resonances of the building. While certain frequencies (such as 30 Hz for window breakage) may be of more concern than other frequencies, in general, only sounds lasting more than one second at greater than an unweighted sound level of 130 dB in the 1 Hz to 1,000 Hz frequency range are potentially damaging to structural components (CHABA, 1977; von Gierke and Ward, 1991). Sound levels from normal aircraft operations are typically much less than 130 dB. Even sounds from low-altitude flyovers of heavy aircraft do not reach the potential for damage (Sutherland, 1990).

Noise-induced structural vibration may cause annoyance to dwelling occupants because of induced secondary vibrations, or "rattle," of objects--hanging pictures, dishes, plaques, and bric-a-brac--within the dwelling. Loose window panes may also vibrate noticeably when exposed to high levels of airborne noise, causing homeowners to fear breakage. In general, rattling occurs at unweighted sound levels that last for several seconds at greater than 110 dB.

A field study conducted by Schomer and Neathammer (1985, 1987) examined the role of structural vibration and rattle in human response to helicopter noise. It showed that human response is strongly and negatively influenced when the noise induces noticeable vibration and rattles in the house structure. The A-frequency weighting was adequate to assess community response to helicopter noise when no vibration or rattle was induced. When rattle or vibrations were induced by the helicopter noise, however, A-weighting alone did not assess the community response adequately, such that significant corrections from 12 dB (for little vibration or rattles) to 20 dB (high level of vibration or rattles) needed to be applied for subjects indoors. It was also found that the presence or absence of high-level noise-induced vibration and rattles was strongly dependent on the helicopter's slant distance. It was recommended that no housing or noise-sensitive land uses be located in zones where high levels of vibration or rattle are induced by helicopter noise.

Community reactions to conventional helicopter noise from low numbers of operations for two helicopter types were studied by Fields and Powell (1987). Using resident interviews in combination with controlled helicopter operations, the authors obtained relations between the annoyance score and noise exposure for short-term (9-hour daytime) periods. It was determined that annoyance increased steadily with noise exposure measured in L_{eq} from 45 to 60 dBA for that period. Annoyance response in terms of percentage annoyed was also presented on this scale for various annoyance rating values. The shape of these curves is similar to the well-known dose-response relationship (Schultz curve) for general transportation noise but relates to only the 9-hour daytime period and with no direct comparison with long-term noise exposure.

In a later review of human response to aircraft noise and induced building vibration, Powell and Shepherd (1989) also indicate that in aircraft noise surveys, the annoyance scores are on average greater when vibration is detected than with no vibration detected. Based on the results of the study by Fields and Powell (1987), they conclude, however, that no effect of increased annoyance was found for cases where the helicopter noise level and slant distance were such that appreciable rattle was expected to occur, in contrast to the results of Schomer and Neathammer (1987). Powell and Shepherd (1989) also quote a laboratory study (Cawthorn et al., 1978) in which the sound of rattling glassware added to the aircraft flyover noises but did not increase the level of annoyance.

Community annoyance in the vicinity of airports due to noise-induced vibration and rattle resulting from aircraft ground operations was studied by Fidell et al. (1999) and summarized in the Minneapolis-St. Paul International Airport Low Frequency Noise (LFN) Expert Panel Report (Sutherland et al., 2000). These field surveys of operations in the vicinity of a major international airport indicated that low-frequency aircraft noise can lead to secondary vibration and rattle in residential structures, which may significantly increase annoyance. These studies, however, have been criticized (FICAN, 2002) due to the absence of direct measurements of vibration in support of the findings on the presence of perceptible vibration and rattle. These issues were further addressed by Hodgdon et al. (2007). It was confirmed that the highest levels of noise near the runway during start-of-takeoff-roll and acceleration and during thrust reversal are at frequencies below 200 Hz. It was also found that aircraft noise exposures that contained audible rattling were not the most annoying, likely because the rattle content was audible but not loud compared to the overall noise content. This result is consistent with an earlier study of human response to aircraft noise and induced building vibration (Powell and Shepherd, 1989).

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

1. Type of excitation: steady state, intermittent, or impulsive vibration.
2. Frequency of the excitation. ISO standard 2631-2 (ISO, 1989) recommends a frequency range of 1 to 80 Hz for the assessment of vibration on humans.
3. Orientation of the body with respect to the vibration.

4. The use of the occupied space (i.e., residential, workshop, hospital).
5. Time of day.

Table A-6 lists the whole-body vibration criteria from ISO 2631-2 for one-third octave frequency bands from 1 to 80 Hz.

Table A-6 Vibration Criteria for the Evaluation of Human Exposure to Whole-Body Vibration

Frequency (Hz)	RMS Acceleration (m/s/s)		
	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
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, 1989

A1.3.10 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, thereby 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.

A1.3.11 Noise Effects on Historical and Archaeological Sites

Historic buildings and sites can have elements that are more structurally fragile than conventional buildings. Aircraft noise may affect such sites more severely than newer, modern structures. In older structures, seemingly insignificant surface cracks caused by vibrations from aircraft noise may lead to greater damage from natural forces (Hanson et al., 1991). There are few scientific studies of such effects to provide guidance for their assessment.

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 generating the sound measured was the Concorde. There was special concern for the building's windows because roughly half of the house's 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.

A1.3.12 Effects on Domestic Animals and Wildlife

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

The 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 and sonic booms 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 these 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 temporary, aircraft noise may cause masking of auditory signals within exposed faunal communities. 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 ear drum rupture or temporary and permanent hearing threshold shifts, are not as likely, given the subsonic noise levels produced by aircraft overflights.

Secondary effects may include non-auditory 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 these 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, especially with respect to habituation and ability to adapt to change.

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 a group or an individual is exposed, 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.

A1.3.12.1 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 U.S. Air Force 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 two of 10 cows in late pregnancy aborted after showing rising estrogen and falling progesterone levels. These increased hormonal levels were reported as being linked to 59 aircraft overflights. The remaining eight cows showed no changes in their blood concentrations and calved normally. 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 (U.S. Air Force, 1994a).

A majority of the studies reviewed suggest 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; Casady and Lehmann, 1967; 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 1-year time period, and none were associated with aircraft disturbances (U.S. Air Force, 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, three 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 1 minute (U.S. Air Force, 1994a). Beyer (1983) found that helicopters caused more reaction than other low-aircraft overflights and that helicopters at 30 to 60 feet overhead did not affect milk production and pregnancies of 44 cows in a 1964 study (U.S. Air Force, 1994a).

Additionally, Beyer (1983) reported that five 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 four low-altitude, subsonic jet aircraft flights. 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, unfamiliar persons, or other moving objects (U.S. Air Force, 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 50-100 m), as animals take care not to damage themselves (U.S. Forest Service, 1992). If animals are overflown by aircraft at altitudes of 50-100 m, 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 (U.S. Air Force, 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 (U.S. Air Force, 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, hormone 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 and 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 U.S. Air Force on effects of low-altitude overflights (below 1,000 feet) on domestic fowl, overflight activity has negligible effects (U.S. Air Force, 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 flocks of birds, and birds not previously exposed, are more likely to pile up in response to a noise stimulus (U.S. Air Force, 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 (U.S. Air Force, 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 (U.S. Air Force, 1994b).

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

Low-altitude overflights were shown to cause turkey flocks that were kept inside turkey houses to occasionally pile up and experience high mortality rates due to the aircraft noise and a variety of disturbances unrelated to aircraft (U.S. Air Force, 1994b).

A1.3.12.2 Wildlife

Studies on the effects of overflights and sonic booms on wildlife have been focused mostly on avian species and on ungulates such as caribou (*Rangifer tarandus*) and bighorn sheep (*Ovis canadensis*). 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 (National Park Service, 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).

Mammals

<u>Terrestrial Mammals</u>

Studies of terrestrial mammals have shown that noise levels of 120 dB can damage mammals' ears, and levels at 95 dB 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 bear (*Ursus arctos horribilis*) and polar bear (*Ursus maritimus*) habitat. Wolves (*Canis lupus*) 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).

Wild ungulates (American bison [*Bison 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 past history of disturbances by humans and aircraft. 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. Caribou in Alaska exposed to fixed-wing aircraft and helicopters exhibited running and panic reactions 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 (*Antilocapra Americana*), elk (*Cervus Canadensis*), 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.

Marine Mammals

The physiological composition of the ear in aquatic and marine mammals exhibits adaptation to the aqueous environment. These differences (relative to terrestrial species) manifest themselves in the auricle and middle ear (Manci et al., 1988). Some mammals use echolocation to perceive objects in their surroundings and to determine the directions and locations of sound sources (Simmons, 1983 in Manci et al. 1988).

In 1980, the Acoustical Society of America held a workshop to assess the potential hazard of manmade noise associated with proposed Alaska arctic (North Slope-Outer Continental Shelf) petroleum operations on marine wildlife and to prepare a research plan to secure the knowledge necessary for proper assessment of noise impacts (Acoustical Society of America, 1980). Since 1980, it appears that research on responses of aquatic mammals to aircraft noise and sonic booms has been limited. Research conducted on northern fur seals (*Callorhinus ursinus*), sea lions, and ringed seals (*Pusa hispida*) indicated that there are some differences in how various animal groups receive frequencies of sound. It was observed that these species exhibited varying intensities of a startle response to airborne noise, and this response was habituated over time. The rates of habituation appeared to vary with species, populations, and demographics (age, sex). Time of day of exposure was also a factor (Myrberg, 1978 in Manci et al., 1988).

Studies were conducted near the Channel Islands near the area where the space shuttle launches occur. It was found that there were some response differences between species relative to the loudness of sonic booms. Those booms that were between 80 and 89 dB caused a greater intensity of startle reactions than lower-intensity booms at 72 to 79 dB. However, the duration of the startle responses to louder sonic booms was shorter (Jehl and Cooper, 1980).

Jehl and Cooper (1980) indicated that low-flying helicopters, loud boat noises, and humans were the most disturbing to pinnipeds. According to the research, while the space shuttle launch and associated operational activity noises have not had a measurable effect on the pinniped population, it also suggests that there was a greater "disturbance level" exhibited during launch activities. There was a recommendation to continue observations for behavioral effects and to perform long-term population monitoring (Jehl and Cooper, 1980).

The continued presence of single or multiple noise sources could cause marine mammals to leave a preferred habitat. However, it does not appear likely that overflights could cause migration from suitable habitats because aircraft noise over water is mobile and would not persist over any particular area. Aircraft noise, including supersonic noise, currently occurs in the overwater airspace of Eglin, Tyndall, and Langley Air Force bases from sorties predominantly involving jet aircraft. Survey results reported in Davis et al. (2000) indicate that cetaceans (i.e., dolphins) occur under all of the Eglin and Tyndall marine airspace. The continuing presence of dolphins (family Delphinidae) indicates that aircraft noise does not discourage use of the area and apparently does not harm the locally occurring population.

In a summary by the National Park Service (1994) on the effects of noise on marine mammals, it was determined that gray whales (*Eschrichtius robustus*) and harbor porpoises (*Phocoena phocoena*) showed no outward behavioral response to aircraft noise or overflights. Bottlenose dolphins (*Tursiops truncatus*) showed no obvious reaction in a study involving helicopter overflights at 1,200 to 1,800 feet above the water. Neither did they show any reaction to survey aircraft unless the shadow of the aircraft passed over them, at which point there was some observed tendency to dive (Richardson et al., 1995). Other anthropogenic noises in the marine environment from ships and pleasure craft may have more of an effect on marine mammals than aircraft noise (U.S. Air Force, 2000). The noise effects on cetaceans appear to be somewhat attenuated by the air/water interface. The cetacean fauna along the coast of California have been subjected to sonic booms from military aircraft for many years without apparent adverse effects (Tetra Tech, Inc., 1997).

Manatees (*Trichechus spp.*) appear relatively unresponsive to human-generated noise to the point that they are often suspected of being deaf to oncoming boats (although their hearing is actually similar to that of pinnipeds [Bullock et al., 1980]). Little is known about the importance of acoustic communication to manatees, although they are known to produce at least 10 different types of sounds and are thought to have sensitive hearing (Richardson et al., 1995). Manatees continue to occupy canals near Miami International Airport, which suggests they have become habituated to human disturbance and noise (Metro-Dade County, 1995). Since manatees spend most of their time below the surface and do not startle readily, no effect of aircraft overflights on manatees would be expected (Bowles et al., 1993).

Birds

Auditory research conducted on birds indicates that they fall between reptiles and mammals relative to hearing sensitivity. According to Dooling (1978), within the range of 1,000 to 5,000 Hz, birds show a level of hearing sensitivity similar to that of the more sensitive mammals. In contrast to mammals, bird sensitivity falls off at a greater rate with 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. 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 the Pacific black brant (*Branta bernicla nigricans*) to 85 dB for the crested tern (*Thalasseus bergii*) (Brown, 1990; Ward and Stehn, 1990).

Songbirds were observed to become silent prior to the onset of a sonic boom event (F-111 jets), followed by "raucous discordant cries." There was a return to normal singing within 10 seconds after the boom (Higgins, 1974 in Manci et al., 1988). Ravens (*Corvus corax*) responded by emitting protestation calls, flapping their wings, and soaring.

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 (U.S. Forest Service, 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 (*Leuconotopicus borealis*) 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.

Lynch and Speake (1978) studied the effects of both real and simulated sonic booms on the nesting and brooding eastern wild turkey (*Meleagris gallopavo silvestris*) in Alabama. Hens at four nest sites were subjected to between eight and 11 combined real and simulated sonic booms. All tests elicited similar responses, including quick lifting of the head and apparent alertness for 10 to 20 seconds. No apparent nest failure occurred as a result of the sonic booms. Twenty-one brood groups were also subjected to simulated sonic booms. Reactions varied slightly between groups, but the largest percentage of groups reacted by standing motionless after the initial blast. Upon the sound of the boom, the hens and poults fled until reaching the edge of the woods (approximately 4 to 8 meters). Afterward, the poults resumed feeding activities while the hens remained alert for a short period of time (approximately 15 to 20 seconds). In no instances were poults abandoned, and they did not scatter and become lost. Every observation group returned to normal activities within a maximum of 30 seconds after a blast.

Bald Eagle

A study by Grubb and King (1991) on the reactions of the bald eagle (*Haliaeetus leucocephalus*) 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. Fleischner and Weisberg (1986) stated 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. They also noted that helicopters were four 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 its guidelines for aerial surveys, USFWS (Pagel et al., 2010) summarized past studies by stating that most golden eagles (*Aquila chrysaetos*) 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 considerations (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 data for the larger population of non-manipulated 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, or avoidance reactions were never observed. Non-attending 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, including aviation, activities. Based on the results of this study, the authors recommended reduction of existing buffers around nest sites to 100 meters (325 feet) for helicopter activity.

Richardson and Miller (1997) reviewed buffers as protection for raptors against disturbance from ground-based human activities. No consideration of aircraft activity was included. They stressed a clear line of sight as an important factor in a raptor's response to a particular disturbance, with visual screening allowing a closer approach of humans without disturbing a raptor. A Geographical Information Systems (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 m, 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 (*Pandion haliaetus*) 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 1 to 2 weeks prior to fledging. Helicopters, human presence, float planes, and other ospreys elicited the strongest reactions from nesting ospreys. These responses included flushing, agitation, and aggressive displays. Adult osprey showed high nest occupancy rates during incubation regardless of external influences. The osprey observed occasionally stared in the direction of the flight before the flight 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 helicopters may have been due to the slower flight and therefore longer duration of visual rather than noise-related stimuli.

Red-tailed Hawk

Anderson et al. (1989) conducted a study that investigated the effects of low-level helicopter overflights on 35 red-tailed hawk (*Buteo jamaicensis*) 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 (nine 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.

Upland Game Birds

Greater Sage-grouse

The greater sage-grouse (*Centrocercus urophasianus*) was recently designated as a candidate species for protection under the Endangered Species Act after many years of scrutiny and research (USFWS, 2010). This species is a widespread and characteristic species of the sagebrush ecosystems in the Intermountain West. Greater sage-grouse, like most bird species, rely on auditory signals as part of mating. Sage-grouse are known to select their leks based on acoustic properties and depend on auditory communication for mating behavior (Braun, 2006). Although little specific research has been completed to determine what, if any, effects aircraft overflight and sonic booms would have on the breeding behavior of this species, factors that may be important include season and time of day, altitude, frequency and duration of overflights, and frequency and loudness of sonic booms.

Booth et al. (2009) found, while attempting to count sage-grouse at leks (breeding grounds) using light sport aircraft at 150 meters (492 feet) to 200 meters (650 feet) AGL, that sage-grouse flushed from leks on 12 of 14 approaches when the airplane was within 656 to 984 feet (200 to 300 meters) of the lek. In the other two instances, male grouse stopped exhibiting breeding behavior and crouched but stayed on the lek. The time to resumption of normal behavior after disturbance was not provided in this study. Strutting ceased around the time when observers on the ground heard the aircraft. The light sport aircraft could be safely operated at very low speed (68 kilometers per hour or 37 nautical miles per hour) and was powered by either a two-stroke or a four-stroke engine. It is unclear how the response to the slow-flying light sport aircraft used in the study would compare to overflight by military jets, operating at speeds 10 to 12 times as great as the aircraft used in the study. It is possible that response of the birds was related to the slow speed of the light sport aircraft causing it to resemble an aerial predator.

Other studies have found disturbance from energy operations, and other nearby development have adversely affected breeding behavior of greater sage-grouse (Holloran, 2005; Doherty, 2008; Walker et al., 2007; Harju et al., 2010). These studies do not specifically address overflights, do not isolate noise disturbance from other types of disturbance (e.g., visual, human presence), and do not generally provide noise levels or qualification of the noise source (e.g., continuous or intermittent, frequency, duration).

Because so few studies have been done on greater sage-grouse response to overflights or sonic booms, research on related species may be applicable. Observations on other upland game bird species include those on the behavior of four wild turkey (*Meleagris gallapavo*) hens on their nests during real and simulated sonic booms (Manci et al., 1988). Simulated sonic booms were produced by firing 5-centimeter mortar shells from a location 300 to 500 feet from the nest of each hen. Recordings of pressure for both types of booms measured 0.4 to 1.0 pounds per square foot at the observer's location.

Turkey hens exhibited only a few seconds of head alert behavior at the sound of the sonic boom. No hens were flushed off the nests, and productivity estimates revealed no effect from the booms. Twenty brood groups were also subjected to simulated sonic booms. In no instance did the hens desert any poults (young birds), and the poults did not scatter or desert the rest of the brood group. In every observation, the brood group returned to normal activity within 30 seconds after a simulated sonic boom. Similarly, researchers cited in Manci et al. (1988) observed no difference in hatching success of bobwhite quail (*Colinus virginianus*) exposed to simulated sonic booms of 100 to 250 micronewtons per square meter.

Migratory Waterfowl

Fleming et al. (1996) conducted a study of caged American black ducks (*Anas rubripes*) 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 and 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 because 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 (*Branta bernicla nigricans*) 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. Brant demonstrated a markedly greater reaction to Bell-206-B helicopter flights than fixed wing, single-engine aircraft flights (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 (*Calcarius lapponicus*), 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 than fixed-wing aircraft on the incubating behavior of the black brant, common eider (*Somateria mollissima*), and Arctic tern (*Sterna paradisaea*) (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 (e.g., the bald eagle) caused a number of birds to leave their nests. Non-breeding birds were observed to be more reactive than breeding birds. Waterfowl were affected by helicopter flights, while snow geese (*Chen caerulescens*) were disturbed by Cessna 185 flights. The geese flushed when the planes were less than 1,000 feet AGL 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 (*Branta Canadensis*) and snow geese were thought to be more sensitive to aircraft noise than other animals such as turkey vultures (*Cathartes aura*), coyotes (*Canis latrans*), 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., the great egret [*Ardea alba*], snowy egret [*Egretta thula*] tricolored heron [*Egretta tricolor*], and little blue heron [*Egretta caerulea*]). The training flights involved three or four aircraft and occurred once or twice per day. This study concluded that the reproductive activity--including nest success, nestling survival, and nestling chronology--was independent of F-16 overflights. Dependent variables were more strongly related to ecological factors, including location and physical characteristics of the colony and climatology.

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, non-nesting 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 military training routes. 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 (U.S. Air Force, 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 JFK Airport in New York on herring gulls (*Larus argentatus*) 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 (U.S. Air Force, 2000).

In 1970, sonic booms were potentially linked to a mass hatch failure of sooty terns (*Onychoprion fuscatus*) on the Dry Tortugas (Austin et al., 1970). The cause of the failure was not certain, but it was conjectured that sonic booms from military aircraft or an overgrowth of vegetation were factors. In the previous season, sooty terns were observed to have reacted to sonic booms by rising in a "panic flight," circling over the island, then usually settling down on their eggs again. Hatching that year was normal. Following the 1969 hatch failure, excess vegetation was cleared, and measures were taken to reduce supersonic activity. The 1970 hatch appeared to proceed normally. A colony of noddies (*Anous* spp.) on the same island hatched successfully in 1969, the year of the sooty tern hatch failure.

Subsequent laboratory tests of exposure of eggs to sonic booms and other impulsive noises (Cottereau, 1972; Cogger and Zegarra, 1980; Bowles et al., 1991, 1994) failed to show adverse effects on hatching of eggs. A structural analysis by Ting et al. (2002) showed that, even under extraordinary circumstances, sonic booms would not damage an avian egg.

Burger (1981) observed no effects of subsonic aircraft on herring gulls in the vicinity of JFK 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.

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.

Ellis et al. (1991) performed a study to estimate the effects of low-level military jet aircraft and mid- to high-altitude sonic booms (both actual and simulated) on nesting peregrine falcons (*Falco peregrinus*) and seven other raptors (common black-hawk [*Buteogallus anthracinus*], Harris' hawk [*Parabuteo unicinctus*], zone-tailed hawk [*Buteo albonotatus*], red-tailed hawk, golden eagle, prairie falcon [*Falco mexicanus*], and bald eagle). They observed responses to test stimuli, determined nest success for the year of the testing, and evaluated site occupancy the following year. Both long- and short-term effects were noted in the study. The results reported the successful fledging of young in 34 of 38 nest sites (including all eight species) subjected to low-level flight and/or simulated sonic booms. Twenty-two of the test sites were revisited in the following year, and observations of pairs or lone birds were made at all but one nest. Nesting attempts were underway at 19 of 20 sites that were observed long enough to be certain of breeding activity. Reoccupancy and productivity rates were within or above expected values for self-sustaining populations.

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 re-occupancy. 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 (*Circus hudsonius*) 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/non-disturbance, a study on the Florida snail-kite (*Rostrhamus sociabilis*) stated that the greatest reaction by that species to overflights (approximately 98 dB) was “watching the aircraft fly by.” No detrimental impacts to distribution, breeding success, or behavior were noted.

Fish and Amphibians

The effects of overflight noise on fish and amphibians 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). Although fish do startle in response to noise from low-flying aircraft, and probably to the shadows of aircraft, they have been found to habituate to the sound and overflights. Amphibians that respond to low frequencies and those that respond to ground vibration, such as spadefoot toads, may be affected by noise.

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 because 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 number and frequency of exposures, suggesting no long-term adverse effects. The majority of the literature suggests that domestic animal species (e.g., cows, horses, chickens) and wildlife species exhibit adaptation, acclimation, and habituation after repeated exposure to jet aircraft noise and sonic booms.

Animal responses to aircraft noise appear to be somewhat dependent on, or influenced by, the size, shape, speed, proximity (vertical and horizontal), engine noise, color, and flight profile of the aircraft. 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.

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