APPENDIX A

NOISE

AIRCRAFT NOISE ANALYSIS

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

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

1.0 NOISE DESCRIPTORS AND IMPACT

Aircraft generate two types of sound. One is “subsonic” noise, which is continuous sound generated by the aircraft’s engines and also by air flowing over the aircraft itself. The other is sonic booms, which are transient impulsive sounds generated during supersonic flight. This appendix discusses only subsonic noise because the proposed action involves no supersonic flight.

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

1.1 QUANTIFYING SOUND

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

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

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

60 dB + 60 dB = 63 dB, and

80 dB + 80 dB = 83 dB.

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

60.0 dB + 70.0 dB = 70.4 dB.

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

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

Under laboratory conditions, differences in sound level of 1 dB can be detected by the human ear. In the community, the smallest change in average noise level which can be detected is about 3 dB. A change in sound level of about 10 dB is usually perceived by the average person as a doubling (or halving) of the sound's loudness, and this relation holds true for loud sounds and for quieter sounds. A decrease in sound level of 10 dB actually represents a 90 percent decrease in sound intensity but only a 50 percent decrease in perceived loudness because of the nonlinear response of the human ear (similar to most human senses).

Frequency. The normal human ear can hear frequencies from about 20 Hz to about 20,000 Hz. It is most sensitive to sounds in the 1,000 to 4,000 Hz range. When measuring community response to noise, it is common to adjust the frequency content of the measured sound to correspond to the frequency sensitivity of the human ear. This adjustment is called A-weighting (ANSI 1988). Sound levels that have been so adjusted are referred to as A-weighted sound levels. The amplitude of A-weighted sound levels is measured in dB. It is common for some noise analysts to denote the unit of A-weighted sounds by dBA or dB(A). As long as the use of A-weighting is understood, there is no difference between dB, dBA or dB(A). It is only important that the use of A-weighting be made clear. In this study, sound levels are reported in dB and are A-weighted unless otherwise specified.

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

Time Averaging. Sound pressure of a continuous sound varies greatly with time, so it is customary to deal with sound levels that represent averages over time. Levels presented as instantaneous (i.e., as might be read from the dial of a sound level meter), are based on averages of sound energy over either 1/8 second (fast) or one second (slow). The formal definitions of fast and slow levels are somewhat complex, with details that are important to the makers and users of instrumentation. They may, however, be thought of as levels corresponding to the root-mean-square sound pressure measured over the 1/8-second or 1-second periods.

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

1.2 NOISE METRICS

1.2.1 Maximum Sound Level

The highest A-weighted sound level measured during a single event in which the sound level changes value as time goes on (e.g., an aircraft overflight) is called the maximum A-weighted sound level or maximum sound level, for short. It is usually abbreviated by ALM, L_{max} or L_{Amax}. The maximum sound level is important in judging the interference caused by a noise event with conversation, TV or radio listening, sleep, or other common activities.

1.2.2 Peak Sound Level

For impulsive sounds, the true instantaneous sound pressure is of interest. For sonic booms, this is the peak pressure of the shock wave, as described in Section 3.2 of this Appendix. This pressure is usually presented in physical units of pounds per square foot. Sometimes it is represented on the decibel scale, with symbol L_{pk}. Peak sound levels do not use either A or C weighting.

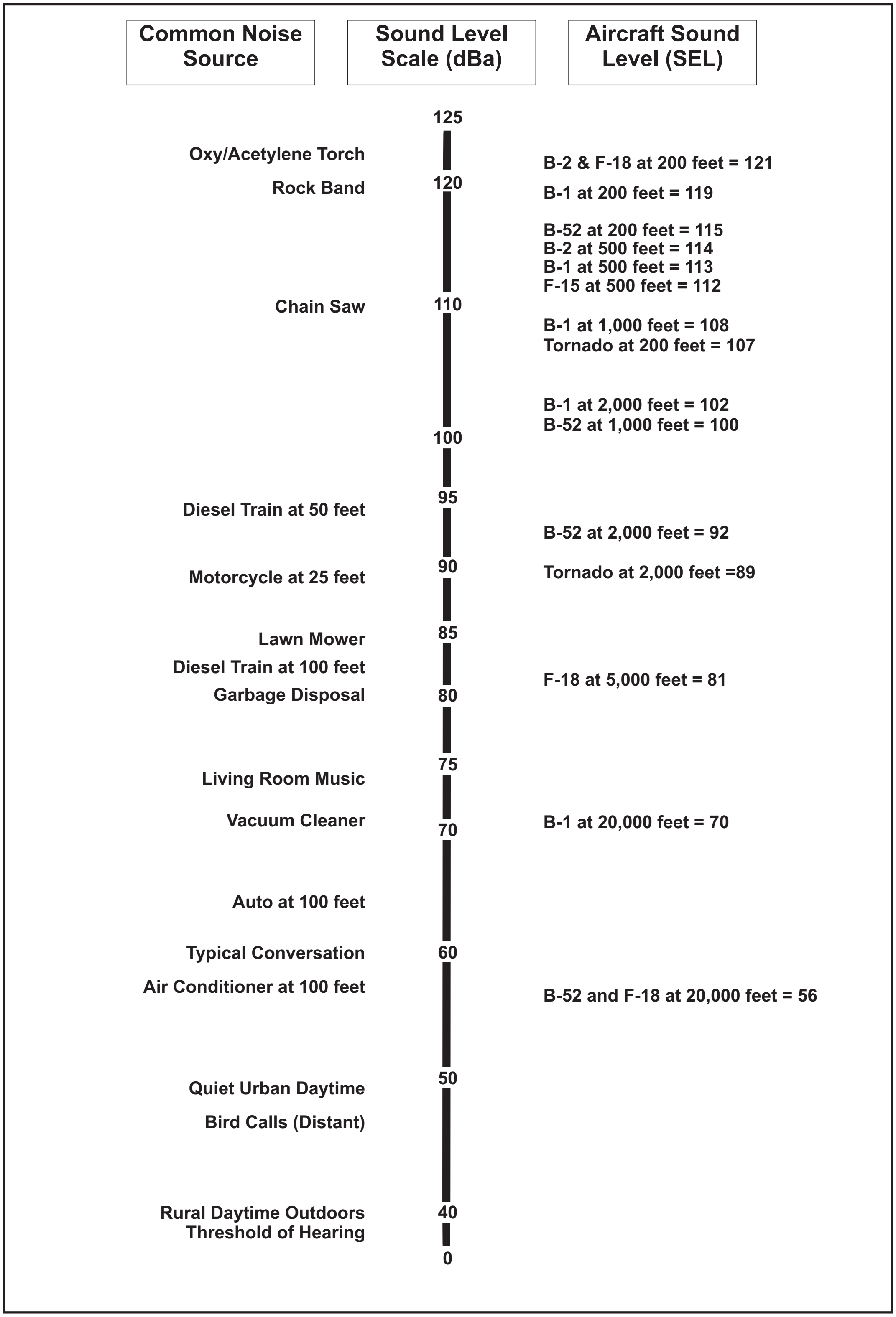


Figure A-1 Typical A-Weighted Sound Levels of Common Sounds

1.2.3 Sound Exposure Level

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

Sound exposure level is a composite metric which represents both the intensity of a sound and its duration. Mathematically, the mean square sound pressure is computed over the duration of the event, then multiplied by the duration in seconds, and the resultant product is turned into a sound level. It does not directly represent the sound level heard at any given time, but rather provides a measure of the net impact of the entire acoustic event. It has been well established in the scientific community that Sound Exposure Level measures this impact much more reliably than just the maximum sound level.

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

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

1.2.4 Equivalent Sound Level

For longer periods of time, total sound is represented by the equivalent continuous sound pressure level (L_{eq}). L_{eq} is the average sound level over some time period (often an hour or a day, but any explicit time span can be specified), with the averaging being done on the same energy basis as used for SEL. SEL and L_{eq} are closely related, differing by (a) whether they are applied over a specific time period or over an event, and (b) whether the duration of the event is included or divided out.

Just as SEL has proven to be a good measure of the noise impact of a single event, Leq has been established to be a good measure of the impact of a series of events during a given time period. Also, while Leq is defined as an average, it is effectively a sum over that time period and is thus a measure of the cumulative impact of noise.

1.2.5 Day-Night Average Sound Level

Noise tends to be more intrusive at night than during the day. This effect is accounted for by applying a 10-dB penalty to events that occur after 10 PM and before 7 AM. If L_{eq} is computed over a 24-hour period with this nighttime penalty applied, the result is the day-night average sound level (DNL or L_{dn}). DNL is the community noise metric recommended by the U.S. Environmental Protection Agency (USEPA 1972) and has been adopted by most federal agencies (FICON 1992). It has been well established that DNL correlates well with community response to noise (Schultz 1978; Finegold *et al.* 1994). This correlation is presented in Section 1.3.

While DNL carries the nomenclature "average," it incorporates all of the noise at a given location. For this reason, DNL is often referred to as a "cumulative" metric. It accounts for the total, or cumulative, noise impact.

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

1.2.6 Onset-Adjusted Monthly Day-Night Average Sound Level

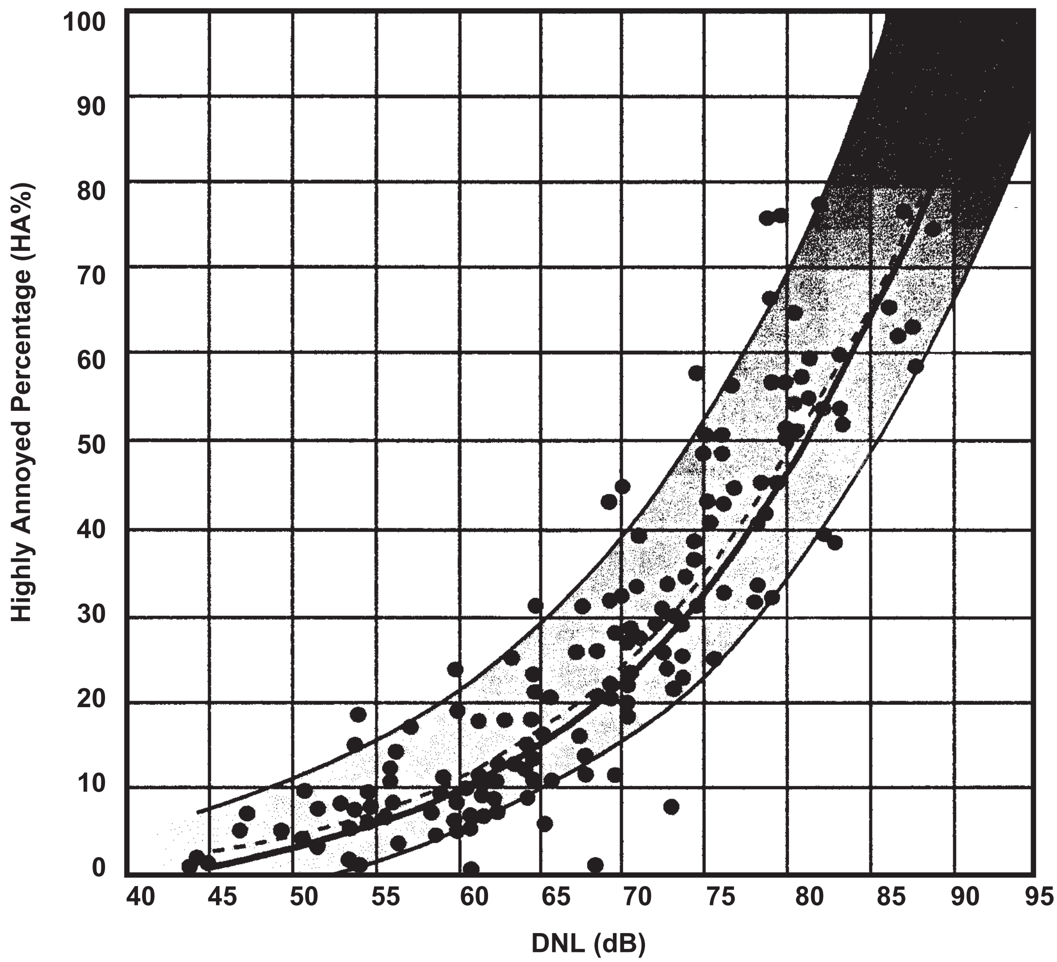
Aircraft operations in military airspaces generate a noise environment somewhat different from other community noise environments. Overflight are sporadic, occurring at random times and varying from day to day and week to week. This situation differs from most community noise environments, in which noise tends to be continuous or patterned. Individual military overflight events also differ from typical community noise events: noise from a low-altitude, high-airspeed flyover can have a rather sudden onset.

To represent these differences, the conventional Day-Night Average Sound Level metric is adjusted to account for the "surprise" effect of the sudden onset of aircraft noise events on humans (Plotkin *et al.* 1987; Stusnick *et al.* 1992; Stusnick *et al.* 1993). For aircraft exhibiting a rate of increase in sound level (called onset rate) of from 15 to 150 dB per second, an adjustment or penalty ranging from 0 to 11 dB is added to the normal Sound Exposure Level. Onset rates above 150 dB per second require a 11 dB penalty, while onset rates below 15 dB per second require no adjustment. The Day-Night Average Sound Level is then determined in the same manner as for conventional aircraft noise events and is designated as Onset-Rate Adjusted Day-Night Average Sound Level (abbreviated L_{dnmr}). Because of the irregular occurrences of aircraft operations, the number of average daily operations is determined by using the calendar month with the highest number of operations. The monthly average is denoted L_{dnmr}.

1.3 NOISE IMPACT

1.3.1 Community Reaction

Studies of community annoyance to numerous types of environmental noise show that DNL correlates well with impact. Schultz (1978) showed a consistent relationship between DNL and annoyance. Figure A-2 shows Shultz's original curve fit. This result shows that there is a remarkable consistency in results of attitudinal surveys which relate the percentages of groups



Source: Schultz, 1978

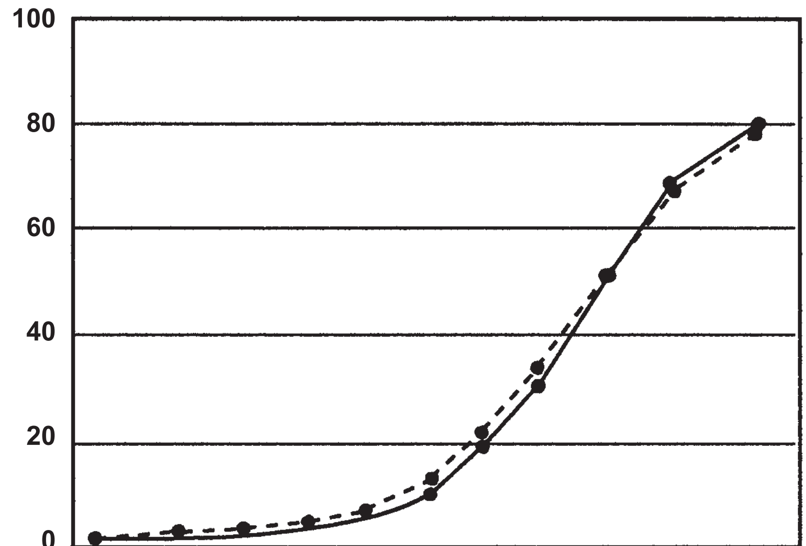
LEGEND

- - - - - $\%HA = 0.8553\,L_{dn} - 0.0401\,L_{dn}^2 + 0.00047\,L_{dn}^3$

—— **All 161 Data Points Given Equal Weight**

▬ **All Surveys Given Equal Weight**

Figure A-2 Community Surveys of Noise Annoyance



		40	45	50	55	60	65	70	75	80	85	90
Day-Night Average Sound Level in dB		40	45	50	55	60	65	70	75	80	85	90
Calculated % HA Points	FINEGOLD	0.41	0.83	1.66	3.31	6.48	12.3	22.1	36.5	53.7	70.2	82.6
	SCHULTZ	0.58	1.11	2.12	4.03	7.52	13.6	23.3	37.1	53.3	68.8	81

LEGEND

Finegold DATA 400 POINTS (Finegold *et al.* 1992)
%HA = 100/[1+EXP (11.13 - 0.141 LDN)]

SCHULTZ DATA 161 POINTS
%HA = 100/[1 + exp (10.43 - 0.132 LDN)]

HA = Highly Annoyed

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

of people who express various degrees of annoyance when exposed to different Day-Night Average Sound Levels.

A more recent study has reaffirmed this relationship (Fidell *et al.* 1991). Figure A-3 (FICON 1992) shows an updated form of the curve fit (Finegold *et al.* 1994) in comparison with the original. The updated fit, which does not differ substantially from the original, is the current preferred form. In general, correlation coefficients of 0.85 to 0.95 are found between the percentages of groups of people highly annoyed and the level of average noise exposure. The correlation coefficients for the annoyance of individuals are relatively low, however, on the order of 0.5 or less. This is not surprising, considering the varying personal factors which influence the manner in which individuals react to noise. Nevertheless, findings substantiate that community annoyance to aircraft noise is represented quite reliably using Day-Night Average Sound Level.

As noted earlier for Sound Exposure Level, Day-Night Average Sound Level does not represent the sound level heard at any particular time, but rather represents the total sound exposure. It accounts for the sound level of individual noise events, the duration of those events, and the number of events. Its use is endorsed by the scientific community (ANSI 1980; ANSI 1988; USEPA 1972; FICUN 1980; FICON 1992).

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

The Schultz curve is generally applied to annual average DNL. In section 1.2.6, L_{dnmr} was described and presented as being appropriate for quantifying noise in military airspaces. In the current study, the Schultz curve is used with L_{dnmr} as the noise metric. L_{dnmr} is always equal to or greater than DNL, so impact is generally higher than would have been predicted if the onset rate and busiest-month adjustments were not accounted for.

There are several points of interest in the noise-annoyance relation (Table A-1). The first is DNL of 65 dB. This is a level most commonly used for noise planning purposes, and represents a compromise between community impact and the need for activities like aviation which do cause noise. Areas exposed to DNL above 65 dB are generally not considered suitable for residential use. The second is DNL of 55 dB, which was identified by EPA as a level below which there is effectively no adverse impact (USEPA 1972). The third is DNL of 75 dB. This is the lowest level at which adverse health effects could be credible (USEPA 1972). The very high annoyance levels make such areas unsuitable for residential land use.

Table A-1. Relation Between Annoyance and DNL

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

1.3.2. Land Use Compatibility

As noted above, the inherent variability between individuals makes it impossible to predict accurately how any individual will react to a given noise event. Nevertheless, when a community is considered as a whole, its overall reaction to noise can be represented with a high degree of confidence. As described above, the best noise exposure metric for this correlation is the Day-Night Average Sound Level or Onset-Rate Adjusted Day-Night Average Sound Level for military overflights.

In June 1980, an ad hoc Federal Interagency Committee on Urban Noise published guidelines (FICUN 1980) relating Day-Night Average Sound Levels to compatible land uses. This committee was composed of representatives from the United States Departments of Defense, Transportation, and Housing and Urban Development; the Environmental Protection Agency; and the Veterans Administration. Since the issuance of these guidelines, federal agencies have generally adopted these guidelines for their noise analyses.

Following the lead of the committee, the Department of Defense and the Federal Aviation Administration (FAA) adopted the concept of land-use compatibility as the accepted measure of aircraft noise effect. The FAA included the committee's guidelines in the Federal Aviation Regulations (USDOT 1984). These guidelines are reprinted in Table A-2, along with the explanatory notes included in the regulation. Although these guidelines are not mandatory (note the footnote "*" in the table), they provide the best means for determining noise impact in airport communities. In general, residential land uses normally are not compatible with outdoor Day-Night Average Sound Levels (DNL values) above 65 dB, and the extent of land areas and populations exposed to DNL of 65 dB and higher provides the best means for assessing the noise impacts of alternative aircraft actions. In some cases, where noise change exceeds 3 dB, the 1992 FICON indicates the 60 dB DNL may be a more appropriate incompatibility level for densely populated areas.

2.0 NOISE EFFECTS

The discussion in section 1.3 presents the global effect of noise on communities. The following sections describe particular noise effects.

2.1 HEARING LOSS

Noise-induced hearing loss is probably the best defined of the potential effects of human exposure to excessive noise. Federal workplace standards for protection from hearing loss allow a time-average level of 90 dB over an 8-hour work period, or 85 dB averaged over a 16-hour period. Even the most protective criterion (no measurable hearing loss for the most sensitive portion of the population at the ear's most sensitive frequency, 4,000 Hz, after a 40-year exposure) suggests a time-average sound level of 70 dB over a 24-hour period (USEPA 1972). Since it is unlikely that airport neighbors will remain outside their homes 24 hours per day for extended periods of time, there is little possibility of hearing loss below a Day-Night Average Sound Level of 75 dB, and this level is extremely conservative.

2.2 NONAUDITORY HEALTH EFFECTS

Nonauditory health effects of long-term noise exposure, where noise may act as a risk factor, have not been found to occur at levels below those protective against noise-induced hearing loss, described above. Most studies attempting to clarify such health effects have found that noise exposure levels established for hearing protection will also protect against any potential nonauditory health effects, at least in workplace conditions. The best scientific summary of these findings is contained in the lead paper at the National Institutes of Health Conference on Noise and Hearing Loss, held on 22–24 January 1990 in Washington, D.C., which states the following: "The nonauditory effects of chronic noise exposure, when noise is suspected to act as one of the risk factors in the development of hypertension, cardiovascular disease, and other nervous disorders, have never been proven to occur as chronic manifestations at levels below these criteria (an average of 75 dBA for complete protection against hearing loss for an eight-hour day). At the International Congress (1988) on Noise as a Public Health Problem, most studies attempting to clarify such health effects did not find them at levels below the criteria protective of noise-induced hearing loss, and even above these criteria, results regarding such

Table A-2. Land-Use Compatibility With Yearly Day-Night Average Sound Levels

Land Use	Yearly Day-Night Average Sound Level (DNL) in Decibels					
	Below 65	**65–70**	**70–75**	**75–80**	**80–85**	**Over 85**
Residential						
Residential, other than mobile homes and transient lodgings	Y	N(1)	N(1)	N	N	N
Mobile home parks	Y	N	N	N	N	N
Transient lodgings	Y	N(1)	N(1)	N(1)	N	N
Public Use						
Schools	Y	N(1)	N(1)	N	**N**	**N**
Hospitals and nursing homes	Y	25	30	N	N	N
Churches, auditoria, and concert halls	Y	25	30	N	N	N
Government services	Y	Y	25	30	N	N
Transportation	Y	Y	Y(2)	Y(3)	Y(4)	Y(4)
Parking	Y	Y	Y(2)	Y(3)	Y(4)	N
Commercial Use						
Offices, business and professional	Y	Y	25	30	N	N
Wholesale and retail—building materials, hardware, and farm equipment	Y	Y	Y(2)	Y(3)	Y(4)	N
Retail trade—general	Y	Y	25	30	N	N
Utilities	Y	Y	Y(2)	Y(3)	Y(4)	N
Communication	Y	Y	25	30	N	N
Manufacturing and Production						
Manufacturing, general	Y	Y	Y(2)	Y(3)	Y(4)	N
Photographic and optical	Y	Y	25	30	N	N
Agriculture (except livestock) and forestry	Y	Y(6)	Y(7)	Y(8)	Y(8)	Y(8)
Livestock farming and breeding	Y	Y(6)	Y(7)	N	N	N
Mining and fishing, resource production and extraction	Y	Y	Y	Y	Y	Y
Recreational						
Outdoor sports arenas and spectator sports	Y	Y(5)	Y(5)	N	N	N
Outdoor music shells, amphitheaters	Y	N	N	N	N	N
Nature exhibits and zoos	Y	Y	N	N	N	N
Amusements, parks, resorts, and camps	Y	Y	Y	N	N	N
Golf courses, riding stables, and water recreation	Y	Y	25	30	N	N

Numbers in parentheses refer to notes.

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

KEY TO TABLE A-2

SLUCM = Standard Land-Use Coding Manual.
Y (YES) = Land Use and related structures compatible without restrictions.
N (No) = Land Use and related structures are not compatible and should be prohibited.
NLR = Noise Level Reduction (outdoor to indoor) to be achieved through incorporation of noise attenuation into the design and construction of the structure.
25, 30, or 35 = Land Use and related structures generally compatible; measures to achieve NLR of 25, 30, or 35 dB must be incorporated into design and construction of structures.

NOTES FOR TABLE A-2

(1) Where the community determines that residential or school uses must be allowed, measures to achieve outdoor-to-indoor Noise Level Reduction (NLR) of at least 25 dB and 30 dB should be incorporated into building codes and be considered in individual approvals. Normal residential construction can be expected to provide an NLR of 20 dB; thus the reduction requirements are often stated as 5, 10, or 15 dB over standard construction and normally assume mechanical ventilation and closed windows year-round. However, the use of NLR criteria will not eliminate outdoor noise problems.
(2) Measures to achieve NLR 25 dB must be incorporated into the design and construction of portions of these buildings where the public is received, office areas, noise-sensitive areas, or where the normal noise level is low.
(3) Measures to achieve NLR 30 dB must be incorporated into the design and construction of portions of these buildings where the public is received, office areas, noise-sensitive areas, or where the normal noise level is low.
(4) Measures to achieve NLR 35 dB must be incorporated into the design and construction of portions of these buildings where the public is received, office areas, noise-sensitive areas, or where the normal noise level is low.
(5) Land-use compatible provided special sound reinforcement systems are installed.
(6) Residential buildings require an NLR of 25.
(7) Residential buildings require an NLR of 30.
(8) Residential buildings not permitted.

health effects were ambiguous. Consequently, it can be concluded that establishing and enforcing exposure levels protecting against noise-induced hearing loss would not only solve the noise-induced hearing loss problem but also any potential nonauditory health effects in the work place (von Gierke 1990; parenthetical wording added for clarification).

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

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

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

A recent review of health effects, prepared by a Committee of the Health Council of The Netherlands (CHCN 1996) reviewed currently available published information on this topic. They concluded that the threshold for possible long-term health effects was a 16-hour (0600 to 2200) L_{eq} of 70 dB. Projecting this to 24 hours and applying the 10 dB nighttime penalty used with DNL, this corresponds to DNL of about 75 dB. The study also affirmed the risk threshold for hearing loss, as discussed earlier.

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

2.3 ANNOYANCE

The primary effect of aircraft noise on exposed communities is one of annoyance. Noise annoyance is defined by the U.S. Environmental Protection Agency as any negative subjective reaction on the part of an individual or group (USEPA 1972). As noted in the discussion of Day-Night Average Sound Level above, community annoyance is best measured by that metric.

Because the EPA Levels Document (USEPA 1972) identified DNL of 55 dB as "...requisite to protect public health and welfare with an adequate margin of safety," it is commonly assumed that 55 dB should be adopted as a criterion for community noise analysis. From a noise exposure perspective, that would be an ideal selection. However, financial and technical resources are generally not available to achieve that goal. Most agencies have identified DNL of 65 dB as a criterion which protects those most impacted by noise, and which can often be achieved on a practical basis (FICON 1992). This corresponds to about 13 percent of the exposed population being highly annoyed.

Although DNL of 65 dB is widely used as a benchmark for significant noise impact, and is often an acceptable compromise, it is not a statutory limit and it is appropriate to consider other thresholds in particular cases.

2.4 SPEECH INTERFERENCE

Speech interference associated with aircraft noise is a primary cause of annoyance to individuals on the ground. The disruption of routine activities such as radio or television listening, telephone use, or family conversation gives rise to frustration and irritation. The quality of speech communication is also important in classrooms, offices, and industrial settings and can cause fatigue and vocal strain in those who attempt to communicate over the noise. Research has shown that the use of the Sound Exposure Level metric will measure speech interference successfully, and that a Sound Exposure Level exceeding 65 dB will begin to interfere with speech communication.

2.5 SLEEP INTERFERENCE

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

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

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

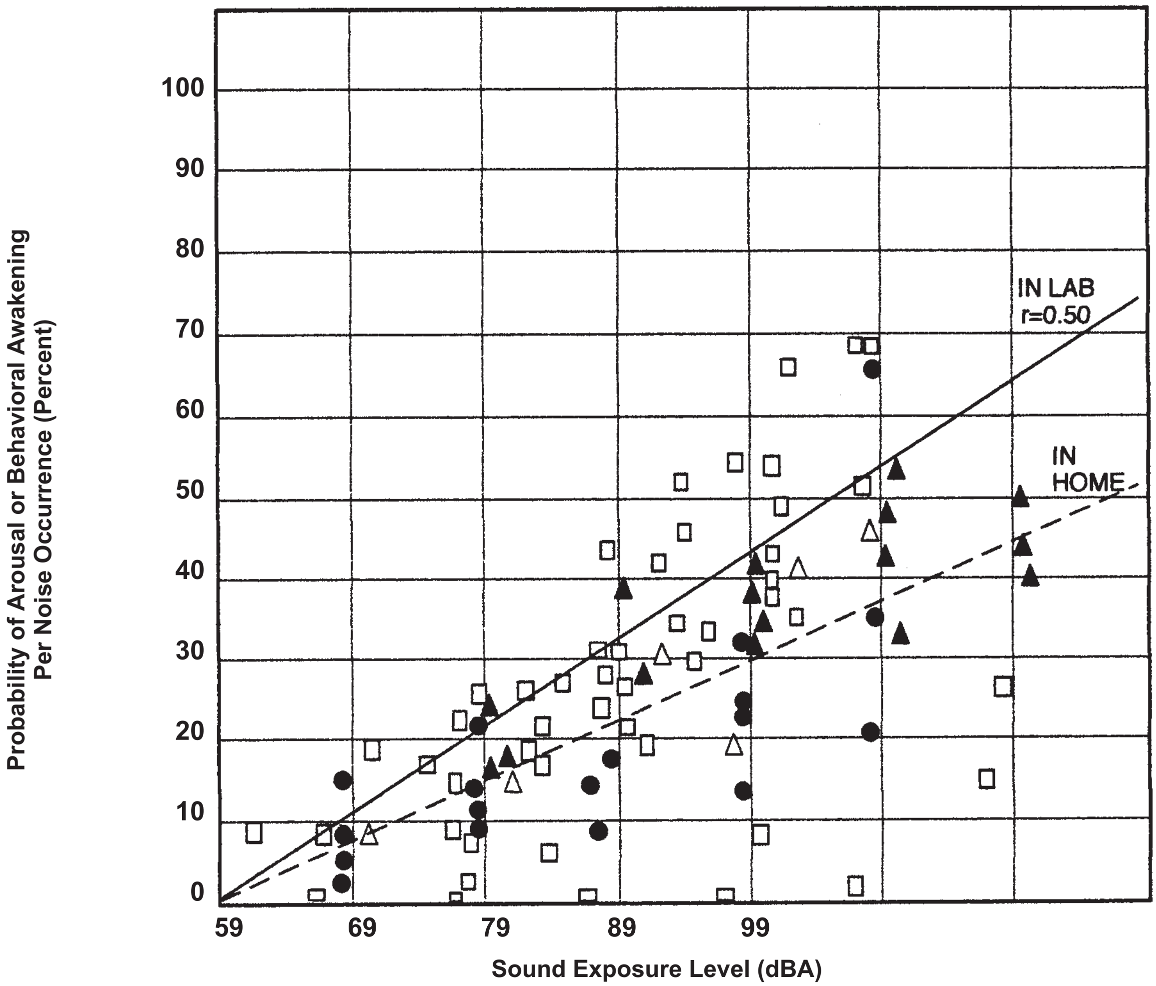
There is some controversy associated with the recent studies, so a conservative approach should be taken in judging sleep interference. Based on older data, the U.S. Environmental Protection Agency identified an indoor Day-Night Average Sound Level of 45 dB as necessary to protect against sleep interference (USEPA 1972). Assuming a very conservative structural noise insulation of 20 dB for typical dwelling units, this corresponds to an outdoor Day-Night Average Sound Level of 65 dB as minimizing sleep interference.

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

2.6 NOISE EFFECTS ON DOMESTIC ANIMALS AND WILDLIFE

Animal species differ greatly in their responses to noise. Each species has adapted, physically and behaviorally, to fill its ecological role in nature, and its hearing ability usually reflects that role. Animals rely on their 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. Secondary effects may include nonauditory effects similar to those exhibited by humans: stress, hypertension, and other nervous disorders. Tertiary effects may include interference with mating and resultant population declines.

There are available many scientific studies regarding the effects of noise on wildlife and some anecdotal reports of wildlife "flight" due to noise. Few of these studies or reports include any reliable measures of the actual noise levels involved. However, in the absence of definitive data on the effect of noise on animals, the Committee on Hearing, Bioacoustics, and Biomechanics of the National Research Council has proposed that protective noise criteria for animals be taken to be the same as for humans (NRC NAS 1977).



LEGEND

- □ Laboratory Studies, Variety of Noises, Lukas
- ● Steady State (In Home)
- ▲ Transient (In Home)
- △ Truck Noise, Laboratory Study, Thiesen
  Transformer, Transmission Line, Window Air Conditioner, and Distant Traffic Noise, Horonjeff

Figure A-4 Probability of Arousal or Behavioral Awakening in Terms of Sound Exposure Level

2.7 NOISE EFFECTS ON STRUCTURES

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

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

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

2.8 NOISE EFFECTS ON TERRAIN

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

2.9 NOISE EFFECTS ON HISTORICAL AND ARCHAEOLOGICAL SITES

Because of the potential for increased fragility of structural components of historical buildings and other historical sites, aircraft noise may affect such sites more severely than newer, modern structures. Again, there are few scientific studies of such effects to provide guidance for their assessment.

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

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

3.0 NOISE MODELING

An aircraft in subsonic flight generally emits noise from two sources: the engines and flow noise around the airframe. Noise generation mechanisms are complex, and in practical models the noise sources must be based on measured data. The Air Force has developed a series of computer models and aircraft noise data bases for this purpose. The models include NOISEMAP (Moulton 1992) for noise around airbases, ROUTEMAP (Lucas and Plotkin 1988) for noise associated with low-level training routes, and MR_NMAP (Lucas and Calamia 1996) for use in MOAs and ranges. These models use the NOISEFILE database developed by the Air Force. NOISEFILE data includes SEL and L_{Amax} as a function of speed and power setting for aircraft in straight flight.

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

MR_NMAP was used to compute noise levels in this analysis. The primary noise metric computed by MR_NMAP was L_{dnmr} averaged over each airspace. The program was also used to compute the number of times per day that SEL of 65 dB would be exceeded at any given location in the range complex. Supporting routines from NOISEMAP were used to calculate SEL and L_{Amax} for various flight altitudes and lateral offsets from a ground receiver position.

4.0 AICUZ OVERVIEW

4.1 INTRODUCTION

The Air Installation Compatible Use Zone (AICUZ) Program is a Department of Defense (DoD) planning program which was developed in response to growing incompatible urban development (encroachment) around military airfields. The Air Force AICUZ program policy is to promote land use compatibility through participation in local, regional, state, and federal land use planning control and coordination processes.

Most Air Force installations were built in the 1940s and early 1950s and in relatively remote areas. Since then, urban growth has extended toward the boundaries of many of these installations. Problems result when complaints over the effects of aircraft operations (e.g., noise, low overflight, etc.) lead to operational changes which negatively impact the flying mission. Incompatible encroachment has been a contributor to the cessation of flying mission and base closures at installations such as Lowery AFB in Colorado, Chanute AFB in Illinois, and Laredo AFB in Texas. As communities grow and expand, it is only natural that they become more interested in orderly development. This should include adequate provisions to protect the Air Force facilities which are an integral part of the communities physical and economic structure.

The Air Force has been successful in encouraging the adoption of enabling legislation for planning compatible development around airfields in Arizona, Texas, and Alabama. Other states such as California have adopted legislation after recognizing the need to protect all airfields from encroachment. The Air Force encourages the adoption of state-enabling legislation for this purpose, and will cooperate with the appropriate authorities regarding its implementation.

4.2 PROGRAM OBJECTIVES

The AICUZ program has two objectives:

- assist local, regional, state, and federal officials in protecting and promoting the public health, safety, and welfare by promoting compatible development within the AICUZ area of influence and

- protect Air Force operational capability from the effects of land use which are incompatible with aircraft operations.

The AICUZ study must be consistent with current land use planning principles and procedures as well as current techniques in noise assessment methodology. Also, it must adequately describe current air operations and procedures and provide recommendations for compatible land use development based on nationally recognized standards. In some cases, projections for future air operations are included in the AICUZ study if the community requests it. The inclusion of future projections in the AICUZ must avoid releasing new information scheduled to be released through the Environmental Impact Analysis Process (EIAP). If future projections are planned to be included, approval from the MAJCOM/CE is required. The AICUZ should relate to state laws, enabling legislation, and local economic and political conditions. The AICUZ is not an end in itself but rather one of many land use determinants used by local planners and decisionmakers. The AICUZ study must have a factual and rational basis.

4.3 REGULATORY BASIS

Several documents provide the regulatory basis for the AICUZ program:

- DoD Instruction (DoDI) 4165.57 established and requires the military departments to develop, implement, and maintain an AICUZ program for installations with flying operations. This DoDI:

  1. sets forth DoD policy on achieving compatible use of public and private lands in the vicinity of military airfields;
  2. defines (a) required restrictions on the uses and heights of obstructions in the vicinity of air installations to provide for safety of flight and to assure that people and facilities are not concentrated in areas susceptible to aircraft accidents and (b) desirable restrictions on land use to assure its compatibility with the characteristics, including noise, of air installations operations;
  3. describes the procedures by which AICUZ may be defined; and
  4. provides policy on the extent of government interest in real property within those zones which may be retained or acquired to protect the operational capability of active military airfields (subject in each case to the availability of required authorizations and appropriations).

- The General Services Administration (GSA), Federal Management Circular (FMC) 75-2 entitled "Compatible Land Uses at Federal Airfields" requires federal agencies, that operate airfields to work with local, regional, state, and other federal officials on compatible land use planning. It requires other federal agencies to ensure their programs serve and foster compatible land use according to plans (such as AICUZ) developed by the federal agency operating on airfield. It requires HUD, VA, FHA and other Federal agencies to implement the AICUZ program as they are able under their mandate.

- AFI 32-7063, "Air Installation Compatible Use Zone (AICUZ) Program" sets forth the policy, responsibilities, and requirements of the program. Topics covered include program objectives, responsibilities, land use compatibility guidelines, and AICUZ studies and updating.

- AFJM 32-8008 (formerly AFM 86-14), "Airfield and Heliport Planning Criteria" provides standardized criteria for all DoD service components for planning and developing the layout of runways, taxiways aprons, and related facilities for airfields and heliports. It provides criteria for establishing planes and surfaces of navigational airspace surrounding the airfields and heliports for the purpose of controlling potential obstructions to aircraft operations.

- AFMAN 32-7067 (formerly AFM 19-10), "Planning in the Noise Environment" is a Tri-Service manual which discusses noise characteristics, noise sources, effects of noise, noise monitoring, tools for noise analysis and reducing noise conflicts.
- AFI 13-201, "Air Force Airspace Management" establishes practices to decrease disturbances from flight operations that might cause adverse public reaction, and provides flying unit commanders with general guidance for dealing with local problems. This instruction sets forth the AICUZ responsibilities of the flying operation organizations at Air Force installations.

4.4 EVOLUTION OF THE AICUZ PROGRAM

The military services, particularly the Air Force, have been advocates of noise planning for a long time. Many aspects of the noise program presently used for civilian airports have their roots in the Air Force's experiences. As early as 1957, the Air Force began establishing procedures for estimating noise exposure and gauging community reaction to aircraft operations. By 1964, the Air Force was working on the relationship between land use planning and aircraft noise. Even at that early time, the Air Force recognized the need to address noise from a land use planning perspective. The Air Force's major concern is the threat posed to the flying mission at an installation as a result of incompatible development.

The late 1960s and early 1970s marked the beginning of the environmental movement. Emphasis on incorporating environmental concerns into the planning process was of major concern to the U.S. Government. Notable events included Air Force research on sonic boom exposure in the 1960s, FAA civilian aircraft certification in 1969, the National Environmental Policy Act in 1969, and the Noise Control Act in 1972. These efforts only increased the awareness of the military on noise planning issues and provided the basis for institutionalizing its programs.

In 1971, the Greenbelt concept was initiated by the Air Force to address the growing problem of incompatible development around airfields (encroachment). The idea behind "Greenbelt" was to establish a buffer zone around the installation through the purchase of property. For obvious budgetary considerations, this concept proved to be economically infeasible.

4.4.1 Noise Description

The AICUZ study was first implemented by the Air Force in 1973. The Air Force adopted the NOISEMAP computer program to describe noise impacts created by aircraft operations. NOISEMAP is one of two EPA-approved programs, the other being the Integrated Noise Model (INM), used by the FAA for civilian airports. The Air Force continues to improve the NOISEMAP program.

The next significant event in the development of the military noise program was the 1974 EPA designation of the noise descriptor "DNL," or Day-Night Average Sound Level. In that year, the EPA Administrator, under authority in the Noise Control Act of 1972, recommended federal agencies adopt the DNL noise descriptor system. The Air Force and EPA agreed upon an implementation procedure by which all future AICUZ studies would be prepared in DNL.

The development of DNL was an important milestone in the AICUZ program. It provides a single descriptor for the noise level. This reduced confusion, increased credibility, and allowed for comparative research efforts on the effects of noise.

4.4.2 Height Restrictions

Another aspect of the AICUZ program, which is paralleled in the civilian community, is the height obstruction criteria. U.S. standard instrument approach and departure procedures (Joint Air Force, Navy, Army, and FAA Criteria Handbook – AFM 55-9) prescribes flight path area and vertical clearances from terrain and manmade obstructions. The restrictions limit the height of buildings and other structures in the vicinity of the airfield to ensure the safety of pilots, aircraft and individuals and structures on the ground. AFJM 32-8008 provides more details on the height restriction criteria.

4.4.3 Accident Potential Zones

Accident Potential Zones (APZs) are one aspect of the AICUZ program where military application differs from civilian airfields. An analysis of aircraft accidents within 10 nautical miles of an airfield for the period of 1968-1972 led to defining areas of high accident potential known as the Clear Zone (CZ), Accident Potential Zone I (APZ I), and Accident Potential Zone II (APZ II). The majority of these accidents (62%) occurred either on or adjacent to the airfield or within the CZ, while only about 8% occurred in APZ I and 5% in APZ II. It was concluded that the CZ warranted special attention due to the high incident of accident potential that severely limited acceptable land uses. The Air Force has spent approximately $65 million to acquire real property interests within the clear zones. The percentages of accidents within the two APZs are such that while purchase is not necessary, some type of land use control is essential. The Air Force recommendation is to limit the number of people exposed through selective land use planning.

4.4.4 Land Use Guidelines

Most complaints are related to noise generated by aircraft operations. Noise around an airport is a fact of life, however, as aircraft operations increase the noise exposure increases and complaints increase with demands for noise reductions. In most cases, noise reduction is accomplished by restricting airfield or aircraft operations.

The Federal Interagency Committee on Noise (FICON), published “Guidelines for Considering Noise in Land Use Planning and Control” in June 1980. The committee, now called FICAN (Federal Interagency Committee on Aircraft Noise) is made up of representatives from federal departments that include Transportation, Defense, Environmental Protection Agency, Veterans

Administration, and Housing and Urban Development. The purpose of these guidelines is to encourage the best land use, consistent with community planning objectives, while minimizing exposure to excessive noise levels.

4.4.5 Noise Reduction Efforts

Military and civilian noise planning efforts have benefited from mutual interest and efforts. One area is research and development. Developing quieter engines for the KC-135, for example, came about through commercial efforts to reduce fuel costs and noise impacts of the Boeing 707. Other efforts have gone into developing engine test facilities, or hush houses, where engines can run at full power with dramatically reduced noise effects to the surrounding environment. Noise abatement procedures are also practiced in Air Force flight scheduling and aircraft operating procedures. Modification to flight tracks, imposition of quiet hours, and use of preferential runways are all techniques used by both the military and civilian airfields to reduce noise. At most installations, Air Force noise reduction efforts have been used to their maximum degree, and land use planning and controls are the answer for further protection of the community.

4.4.6 Conclusion

In summary, the difference between noise concerns for the military and the civilian sector continue to become less. The exchange of technical noise information and assistance is needed to address and solve similar problems. Requests from the civilian side to jointly use military airfields are increasing. The Air Force presently has several joint use airfields. Air National Guard and Air Force Reserve units operate from several major airports in the country. There are also large scale joint service operations that include activities at civilian airports. Therefore, both civilian and military airfield operators need to understand each other's mission requirements and their implication with regard to noise and land use planning.

The overall goal of the Air Force AICUZ program is to reduce people's exposure to high levels of aircraft noise and accident potential through compatible land use controls adopted by the local communities. To this end, the Air Force initiated a program to assist local communities in implementing AICUZ recommendations. This program is called the Joint Land Use Study (JLUS) program. Meanwhile, the Air Force must continue to provide the public with current information which will assist them in making prudent land use decisions and mutually work together to resolve the problems of growth and encroachment.

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