Noise Background

General

Noise, often defined as unwanted sound, is one of the most common environmental issues associated with aircraft operations. Of course, aircraft are not the only sources of noise in a rural surrounding. Noise from interstate and local roadway traffic, rail, industrial, and neighborhood sources also intrude on the everyday quality of life in these areas. Nevertheless, aircraft are readily identifiable to those affected by their noise and are typically singled out for special attention and criticism. Consequently, aircraft noise issues often dominate analyses of environmental impacts.

Sound is a physical phenomenon consisting of small vibrations, which travel through a medium (i.e., intervening substance) such as air, and are sensed by the human ear. Whether that sound is interpreted as pleasant (e.g., music) or unpleasant (e.g., transportation-related noise) depends largely on the listener's current activity, past experience, and attitude toward the source of that sound. It is often true that one person's music is another person's noise.

The measurement and human perception of sound involves two basic physical characteristics – intensity and frequency. Intensity is a measure of the acoustic energy of the sound vibrations and is expressed in terms of sound pressure. The higher the sound's pressure, the more energy carried by the sound and the louder the perception of that sound. The second important physical characteristic is frequency, which is the number of times per second the air vibrates or oscillates. Low-frequency sounds are characterized as rumbles or roars, while high-frequency sounds are typified by sirens or screeches.

The loudest sounds which can be detected comfortably by the human ear, have intensities that are 1 trillion times higher than those of sound that cannot be detected by humans. Because of this vast range, any attempt to represent the intensity of sound using a linear scale becomes very unmanageable. As a result, a logarithmic unit known as the decibel (dB) is used to represent the intensity of a sound. Such a representation is known as a sound level.

A sound level of 0 dB is approximately the threshold of human hearing and is barely audible under extremely quiet listening conditions. Normal speech has a sound level of approximately 60 dB. Sound levels above about 120 dB begin to be felt inside the human ear as discomfort and eventually pain at still higher levels.

Because of the logarithmic nature of the dB unit, sound levels cannot be added or subtracted 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 an addition is often referred to as "dB addition" or "energy addition." The latter term arises from the fact that what we are really doing when we add dB values is first converting each dB 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 dB equivalent.

An important facet of dB addition arises later when the concept of time-average sound levels is introduced to explain Day-Night Average A-Weighted Sound Level (DNL) (see the Noise Metrics discussion below). Because of the logarithmic units, the time-average sound levels are dominated by the louder levels, which occur during the averaging period. As a simple example, consider a sound level of 100 dB that lasts for 30-seconds, followed by a sound level of 50 dB which also lasts for 30-seconds. The time-average sound level over the total 60-second period is 97 dB, not 75 dB.

Sound frequency is measured in terms of cycles per second (cps), or hertz (Hz), which is the preferred scientific unit for cps. The normal human ear can detect sounds over a wide range of frequencies. However, not all frequencies in this range are heard equally well by the human ear which is most sensitive to frequencies in the 1,000 to 4,000 Hz range. In measuring community noise, this frequency dependence is taken into account by adjusting the very high and low frequencies to approximate the human ear's lower sensitivity to those frequencies. This is called "A-weighting" and is commonly used in measurements of community environmental noise.

Sound levels measured using A-weighting are referred to as A-weighted sound levels. However, since most environmental impact analysis documents deal only with A-weighted sound levels, the adjective "A-weighted" is often omitted, and A-weighted sound levels are referred to simply as sound levels. In some instances the author will indicate that the levels have been A-weighted by using the abbreviation dBA for decibel. As long as the use of A-weighting is understood to be used, there is no difference implied by the terms "sound level" and "A-weighted sound level" or by the units dB and

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dBA. In this document all sound levels are A-weighted sound levels and the adjective "A-weighted" has been omitted.

Sound levels do not represent instantaneous measurements but rather averages over short periods of time. Two measurement time periods are most common – one second and one-eighth of a second. A measured sound level averaged over one second is called a slow response sound level; one averaged over one-eighth of a second is called a fast response sound level. Most environmental noise studies use slow response measurements, and the adjective "slow response" is usually omitted. It is easy to understand why the proper descriptor "slow response A-weighted sound level" is usually shortened to "sound level" in environmental impact analysis documents.

Noise Metrics

A "metric" is defined as something "of, involving, or used in measurement." As used in environmental noise analyses, a metric refers to the unit or quantity, which quantitatively measures the effect of noise on the environment. Noise studies have typically involved a confusing proliferation of noise metrics as individual researchers have attempted to understand and represent the effects of noise. As a result, past literature describing environmental noise abatement has included many different metrics.

More recently, however, various federal agencies involved in environmental noise mitigation have agreed on common metrics for environmental impact analysis documents, and both the Department of Defense (DoD) and the Federal Aviation Administration (FAA) have specified those which should be used for federal aviation noise assessments. These metrics are as follows:

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 (ALM) or maximum sound level, for short.

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 (SEL) combines both of these characteristics into a single metric.

SEL is a logarithmic measure of the total acoustic energy transmitted to the listener during the event. Mathematically, it represents the sound level of the constant sound that would, in one second, generate the same acoustic energy, as did the actual time-varying noise event. Since aircraft overflights usually last longer than one second, the SEL of an overflight is usually greater than the ALM of the overflight.

Note that SEL is a composite metric (i.e., made up of distinct parts), which represents both the intensity of a sound level and its duration. It does not directly represent the sound level heard at any given time, but rather provides a measure of the net impact of the entire acoustic event. It has been well established in the scientific community that SEL measures this impact much more reliably than just the A-weighted sound level.

Because the SEL and the ALM are both A-weighted sound levels expressed in dBs, there is sometimes confusion between the two, so the specific metric used should be clearly stated.

Day-Night Average A-Weighted Sound Level

Time-averaged sound levels are measurements of sound levels, which are averaged over a specified length of time. These levels provide a measure of the average sound energy during the measurement period.

For the evaluation of community noise effects, and particularly aircraft noise effects, DNL is used. DNL averages aircraft sound levels at a location over a complete 24-hour period, with a 10 dB adjustment added to those noise events which take place between 10:00 p.m. and 7:00 a.m. (local time). This 10 dB "penalty" represents the added intrusiveness of sounds which occur during normal sleeping hours, both because of the increased sensitivity to noise during those hours and because ambient sound levels during nighttime are typically about 10 dB lower than during daytime hours.

DNL provides a single measure of overall noise impact, but does not provide specific information on the number of noise events or the individual sound levels, which occur during the day. For example, a DNL of 65 could result from a few very noisy events, or many quieter events during the 24-hour period.

As noted earlier for SEL, DNL does not represent the sound level heard at any particular time, but rather represents the total sound exposure. Scientific studies and social surveys, which have been conducted to determine community annoyance to all types of environmental noise, have found DNL to be the best measure of that annoyance. Its use is endorsed by the following scientific communities: American National Standards Institute (1980, 1988); United States Environmental Protection Agency [USEPA] (1974); and Federal Interagency Committee on Noise [FICON] (1980, 1992).

Opinion surveys about aircraft noise have been conducted in different countries to find the percentages of groups of people who express various degrees of annoyance when exposed to different levels of DNL. The results of these surveys are remarkably consistent. Synthesis of Social Surveys of Noise Annoyance (Schultz 1978) was published in 1978. A more recent study has reaffirmed the results found in the 1978 study (Fidell et al. 1991). In general, correlation coefficients of 0.85 to 0.95 are found between the percentages of groups of people highly annoyed and the level of average noise exposure. The correlation coefficients for the annoyance of individuals are relatively low, however, on the order of 0.5 or less. This is not surprising, considering the varying personal factors that influence the manner in which individuals react to noise. Nevertheless, the findings of these and other studies substantiate that community annoyance to aircraft noise is represented quite reliably using DNL.

This relation between community annoyance and time-average sound level also has been confirmed for infrequent aircraft noise events. Community Reactions to Helicopter Noise (Schmoer et al. 1991) reported the reactions of individuals in a community to daily helicopter overflights correlated quite well with the daily time-average sound levels over this range of numbers of daily noise events.

The use of DNL has been criticized recently as not accurately representing community annoyance and land-use compatibility with aircraft noise. Much of that criticism stems from a lack of understanding of the basis for the measurement or calculation of DNL. One frequent criticism is based on the inherent feeling that people react more to single noise events and not as much to "meaningless" time-average sound levels.

In fact, a time-average noise metric, such as DNL, takes into account both the noise levels of all individual events which occur during a 24-hour period and the number of times those events occur. As described briefly above, the logarithmic nature of the dB unit causes the noise levels of the loudest events to control the 24-hour average.

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As a simple example of this characteristic, consider a case in which only one aircraft overflight occurs in daytime during a 24-hour period, creating a sound level of 100 dB for 30 seconds. During the remaining 23-hours, 59-minutes, and 30 seconds of the day, the ambient sound level is 50 dB. The DNL for this 24-hour period is 65.5. Assume, as a second example that ten such 30-second overflights occur in daytime hours during the next 24-hour period, with the same ambient sound level of 50 dB during the remaining 23-hours and 55-minutes of the day. The DNL for this 24-hour period is 75.4. 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. This is the basic concept of a time-averaged sound metric such as DNL.

Onset Rate-Adjusted Day-Night Average

Onset rate-adjusted day-night average, a-weighted sound level (Ldnmr) is an additional noise metric which has been developed specifically for aircraft operations at low altitudes along Military Training Routes (MTRs) by the USAF under direction of the Armstrong Aerospace Medical Research Laboratory. Individual low-altitude events on MTRs are different from typical noise sources because the rapid onset of aircraft noise can create a "startle" effect. The Ldnmr is similar to the DNL in that it is an average metric with a 10 dB penalty for events occurring between 10:00 p.m. and 7:00 a.m. However, Ldnmr represents an average for an entire month utilizing the highest monthly sortie activity, and includes an additional 0 to 11 dB penalty to compensate for the "startle" effect of a low-altitude overflight. Because of this penalty, Ldnmr always equals or exceeds DNL. Ldnmr is currently the approved MTR noise metric for the armed services, and the USAF recommends calculation of Ldnmr values for noise assessments along MTRs. Because it is a conservative measure of average noise exposure over time with built-in penalties for rapid onset of noise, Ldnmr closely correlates with the probability of "highly annoying" a noise receptor, and is appropriate to use in areas where receptors would be highly sensitized to potential noise impacts.

Noise Effects

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 (Equivalent Continuous Sound Pressure Level (LEQ) 90 dB over an 8-hour period, or LEQ 85 dB averaged over a 16-hour period. Even the most protective criterion suggests a time-averaged sound level of DNL 70 over a 24-hour period. Since it is unlikely that airport neighbors will remain outside

their homes 24-hours per day for extended periods of time, and there is little possibility of hearing loss below a DNL of 75, this protection level is extremely conservative.

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 which protect against noise-induced hearing loss (described in Section C.3.1). 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 Institute of Health Conference on Noise and Hearing Loss, held on 22-24 January 1990 in Washington, D.C. (Von Gierke 1990).

> *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 dB for complete protection against hearing loss for an eight-hour day]. At the recent (1988) International Congress on Noise as a Public Health Problem, most studies attempting to clarify such health effects did not find them at levels below the criteria protective of noise-induced hearing loss, and even above these criteria, results regarding such health effects were ambiguous. Consequently, one comes to the conclusion that establishing and enforcing exposure levels protecting against noise-induced hearing loss would not only solve the noise-induced hearing loss problem but also any potential nonauditory health effects in the work place.*

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. In addition, even those studies which purport to find such health effects use time-averaged noise levels of 75 dB and higher for their research.

For example, in an often-quoted paper, two University of California at Los Angeles (UCLA) researchers apparently found a relationship 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 (Meacham et al. 1979). Nevertheless, three other UCLA professors analyzed those same data and found no relation between noise exposure and mortality rates (Frericks et al. 1980).

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

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

Annoyance

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

It is often suggested that a lower DNL, such as 60 or 55, be adopted as the threshold of community noise annoyance for airport environmental analysis documents. While there is no technical reason why a lower level cannot be measured or calculated for comparison purposes, a DNL of 65:

1. Provides a valid basis for comparing and assessing community noise effects;
2. Represents a noise exposure level which is normally dominated by aircraft noise and not other community or nearby highway noise sources; and
3. Reflects the FAA's threshold for grant-in-aid funding of airport noise mitigation projects.

The United States Department of Housing and Urban Development (HUD) also established a DNL standard of 65 for eligibility for federally guaranteed home loans. Although the FAA , HUD, and DoD consider 65 DNL as the threshold of significance for assessing noise impacts, this threshold does not distinguish between urban, suburban, or rural settings. Along with several other federal agencies, the USEPA takes a more conservative approach to noise assessment including a more restrictive 55 DNL threshold for noise in rural areas or "places in which quiet is a basis for use" (USEPA 1974).

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 "whenever intrusive noise exceeds approximately 60 dB indoors, there will be interference with speech communication" (FICON 1992). A steady A-weighted background sound level of 60 dB will produce 93 percent intelligibility; that of 70 dB will produce 66 percent intelligibility; and that of 75 dB will produce 2 percent intelligibility (Figure C-1 in USEPA 1974).

Sleep Interference

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 louder noise level than does a change in sleep stage.

An analysis sponsored by the United States Air Force (USAF) summarized 21 published studies concerning the effects of noise on sleep (Pearsons et al. 1989). The analysis concluded that a lack of reliable studies in homes, combined with large differences among the results from the various laboratory studies and the limited in-home studies, did not permit development of an acceptable 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 in the home. 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.

Nevertheless, some guidance is available in judging sleep interference. The USEPA identified an indoor DNL of 45 as necessary to protect against sleep interference (USEPA 1974). Since typical dwelling units provide a sound level reduction of 20 dB, an outdoor noise level of DNL 65 would cause minimal interference with sleep.

The FICON (FICON 1992) reviewed the sleep disturbance issue and presented an USAF-developed sleep disturbance dose-response prediction curve, based on data from Analyses of the Predictability of Noise-Induced Sleep Disturbance (Pearsons et al. 1989), as an interim tool for analysis of potential sleep disturbance. This interim curve shows that for an indoor SEL of 65 dB, approximately 15 percent or less of those exposed would be awakened.

Noise Background

Noise Effects on Domestic Animals and Wildlife

Wildlife 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 many scientific studies available 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.

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 (National Academy of Sciences 1977).

Effects of Noise-Induced Vibration on Structures and Humans

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

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 pressure impinging on (i.e., affecting) the structure is normally sufficient to determine the possibility of damage. In general, sound levels above 130 dB (peak sound pressure 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 (Von Gierke et al 1991).

In terms of average acceleration of wall or ceiling vibration, the thresholds for structural damage (International Organization for Standardization [ISO] 1989) are:

- 0.5 m/s/s – threshold of risk of damage to sensitive structures (i.e. ancient monuments); and

- 1.0 m/s/s/ - threshold of risk of damage to normal dwellings (i.e. houses with plaster ceilings and walls).

Noise-induced structural vibration may also cause annoyance to dwelling occupants because of induced secondary vibrations, or "rattle", of objects within the dwelling – hanging pictures, dishes, plaques, etc. Loose windowpanes may also vibrate noticeably when exposed to high levels of noise, causing homeowners to fear breakage. In general, such noise-induced vibrations occur at sound levels above those considered normally compatible with residential land use. Thus, noise levels compatible for residential land use (i.e., below DNL 65) would not cause significant secondary noise-induced vibrations.

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

- Type of excitation: steady state, intermittent, or impulsive vibration;

- Frequency of the excitation. ISO 2631-2 recommends a frequency range of 1 to 80 Hz be used for assessing the effect of vibration on humans;

- Orientation of the body with respect to the vibration;

- The use of the occupied space; and

- Time of day.

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 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.

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.

Noise Background

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. These measurements were made in connection with the proposed scheduled operation of the supersonic Concorde aircraft at Dulles (Wesler 1977). There was a special concern for the building's windows, since roughly half of the 324 windowpanes 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.

As noted above for the noise effects of noise-induced vibrations on normal structures, assessments of noise exposure levels for normally compatible land uses should also assist in protecting historic and archaeological sites from structural damage caused by aircraft noise.

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