APPENDIX F Noise Descriptors and Noise Effects on Humans

F-1. THE PHYSICS AND MEASUREMENT OF NOISE

In the FAA's 1985 report "Aviation Noise Effects," noise is defined as an unwanted sound. "Sound is a complex vibration transmitted through the air which, upon reaching our ears, may be perceived as beautiful, desirable, or unwanted. It is this unwanted sound which people normally refer to as noise." "Aircraft noise" is unwanted sound caused by aircraft overflights and aircraft engines running on the ground.[1/]

Noise and sound are thus physically the same, the difference being in the subjective opinion of the receiver. A sound is produced by a source that induces vibrations in the air. The vibration produces alternating bands of relatively dense and sparse particles of air, spreading outward from the source like ripples do on water after a stone is thrown into it. The result of the air movement is sound waves radiating in all directions that can be reflected and scattered. When the source stops vibrating, the sound waves disappear almost instantaneously and the sound ceases. The human ear is extremely sensitive to sound pressure fluctuations.

Sound can be defined in terms of three components:

- Loudness (amplitude)
- Pitch (frequency)
- Duration (time pattern)

The **loudness** of sound is defined as the sound pressure or measurement of the difference between atmospheric pressure (with no sound present) and the total pressure (with sound present). Amplitude of sound is like the relative height of the ripples caused by the stone thrown into the water. The unit of sound pressure is the decibel (dB). Because the "ripples" of sound typically heard by the human ear may vary in height from ***1 to 100 trillion units***, a logarithmic scale is used to compress the scale to make the number more manageable. The decibel scale allows people to describe loudness using numbers ranging ***zero to about 140***. The exhibit depicts various examples of noise sources at different sound levels. The human ear has an extremely wide range of response to sound amplitude. Sharply painful sound is ***100 trillion (10^{14}) times greater*** in sound pressure than the least audible sound. In decibels, this 100 trillion to 1 ratio in sound pressure is simplified logarithmically to ***140 dB***.

[1/] Steven J. Newman and Kristy R. Beattie, *Aviation Noise Effects* (Washington D.C.: Department of Transportation, Federal Aviation Administration, Office of Environmental and Energy, 1985), 1, FAA-EE-85-2.

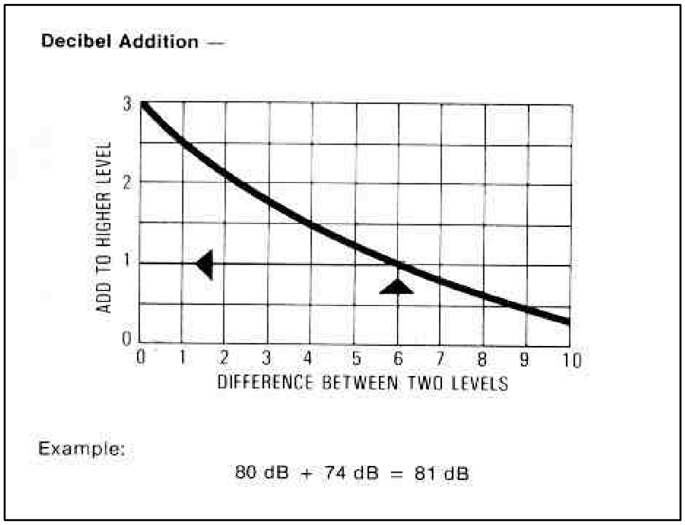

EXHIBIT F-1: **EXAMPLE OF ADDITION OF TWO DECIBEL LEVELS**

In terms of human perception of loudness, the decibel is a useful measurement. By definition, a sound which has ten times the mean square sound pressure of the reference sound is 10 dB greater than the reference sound. A sound which has 100 times the mean square sound pressure of the reference sound is 20 dB greater. The usefulness comes from the fact that mean square sound pressure of interest (human perception) extends over a range of ***100 trillion to 1***. Such a large number is much more conveniently represented on the logarithmic scale as ***140 dB (10 x 14 Bel)***.

The use of the logarithmic decibel scale requires different arithmetic than used with linear scales. The sound pressures of two separate sounds are not directly arithmetically additive. For example in **Exhibit F-1**, if a sound of 80 dB is added to another sound of 74 dB, the total is a one decibel increase to 81 dB, not an addition to 154 dB. If two equally loud noise events occur simultaneously, the sound pressure level from the combined events is only 3 dB higher than the level produced by either event alone. The interesting result of logarithmic addition is the greater weight it gives to the higher noise levels compared to quieter levels.

Logarithmic math also returns interesting results when averaging sound levels. As the example in Exhibit F-2 shows, the loudest sound levels are the dominant influence in the averaging process. In the example, two sound levels of equal duration are averaged. One is 100 dB, the other 50 dB. Using linear arithmetic, the result would be 75 dB. The logarithmic result is 97 dB because 100 dB contains 100,000 times the sound energy as 50 dB.

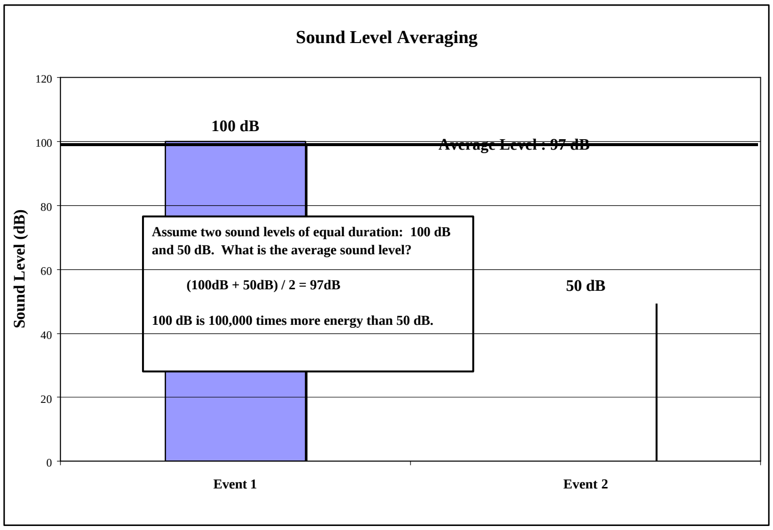

EXHIBIT F-2: EXAMPLE OF SOUND LEVEL AVERAGING

In terms of human perception, a 10 dB increase in sound energy over a given frequency is perceived as a doubling of loudness, while a 10 dB decrease seems only half as loud. Recalling the logarithmic nature of the decibel scale, this means that most people perceive a ten-fold increase in sound energy as a two-fold increase in loudness. A three dB increase which is equivalent to a doubling of sound energy is detected by the ear as a perceptible increase in loudness.

The pitch (or frequency) of sound can be compared to the distance between ripples caused by a stone being thrown into the water. Closely spaced ripples are analogous to high-pitched sounds such as a soprano's voice. Widely spread ripples are analogous to a bass' voice. The rate at which a sound source makes air vibrate determines frequency. The term "Hertz" is a measure of the rate of vibration – the number of cycles, or waves, per second. One's ability to hear a sound depends greatly on the frequency composition. Humans hear sounds best at frequencies between 1000 and 6000 Hertz. Sound at frequencies above 10,000 Hertz (high-pitched hissing) and below 100 Hertz (low rumble) are much more difficult to hear.

To measure sound on a scale approximated to the way people hear, more weight must be given to the frequencies that people hear more easily and less weight to low/high frequencies not easily detected by humans. In "Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety" (Levels Document), prepared by the Environmental Protection Agency (EPA), Office of Noise Abatement and Control, A-weighting is recommended to describe environmental noise.2/ A-weighting is found to correlate well with people's subjective judgment of the loudness of sounds. All metrics used in this EIS are A-weighted scales. The A-weighted metric is shown in **Exhibit F-3** along with other types of weighted levels. As shown on the exhibit, the B- and C-weighted scales both give more weight to low frequency sound

2/ U.S. Environmental Protection Agency, Office of Noise Abatement and Control, *Information on Levels of Environmental Noise Requisite to Protect Health and Welfare with an Adequate Margin of Safety*, (Washington D.C.: Government Printing Office, 1974).

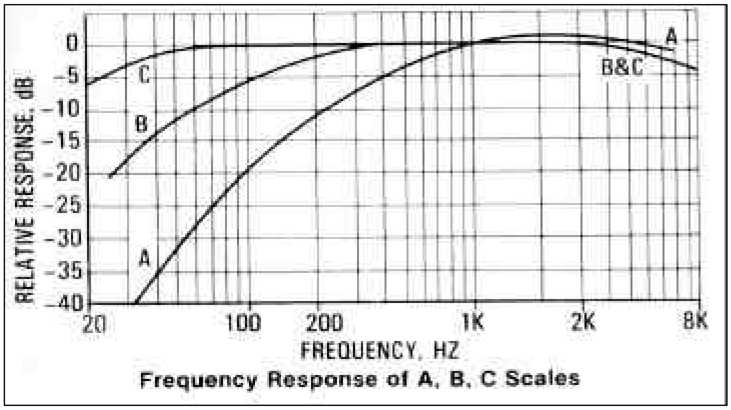

EXHIBIT F-3: **DECIBEL WEIGHTING SCALES**

than the A-weighted scale. In quantifying the effects of noise on humans, the metric used should be comparable to what the human ear senses, which is the A-weighted decibel.

The duration of sounds – their pattern of loudness and pitch over time – can vary greatly. Sounds can be classified as continuous like a waterfall, impulsive like a firecracker, or intermittent like an aircraft overflight. Aircraft takeoffs and landings are intermittent sounds that are produced for short periods, with the loudness taking a shape similar to a Bell-curve. The duration of an aircraft event is defined by the time when the sound energy begins to rise above the background noise level to the point when the sound level falls below the background level.

Sound Metrics "Rules of Thumb"

The physics and measurement of noise are best understood with the following rules of thumb:

- An increase of 3 dB is noticeable to most people.
- An increase of 10 dB is perceived by people as twice as loud.
- Doubling or halving the distance between a sound source and receiver results in a change of 6 dB.
- Adding two identical sounds produces a total sound level 3 dB higher.
- When two different sound levels are averaged, the result is nearly the same as the higher sound level.

F-2. STANDARD NOISE DESCRIPTORS

From the noise components (loudness, frequency, and duration), five common noise descriptors have been developed:

- 24-Hour Time Above Threshold (**TA**)
- Equivalent Sound Level (**Leq**)
- Maximum Level (**Lmax**)
- Sound Exposure Level (**SEL**)
- Day/Night Average Sound Level (**DNL**)

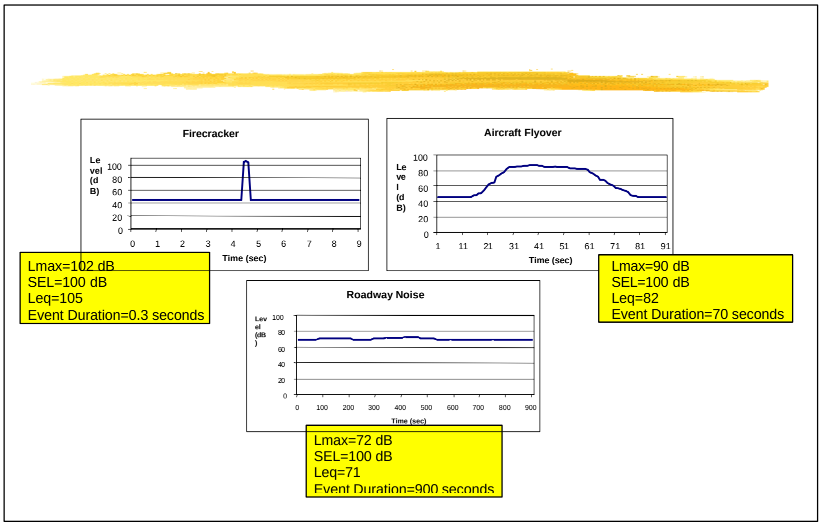

EXHIBIT F-**4: COMPARISON OF DIFFERENT SOUNDS**

DNL is the primary noise descriptor for this EIS. FAA Order 1050.1E, “Environmental Impacts: Policies and Procedures,” and 5050.4A, “Airport Environmental Handbook,” require the use of the DNL noise metric in evaluating aircraft noise exposure. In addition to **DNL**, which is used for the general assessment of noise impacts, the other descriptors (**Lmax**, **SEL**, **Leq** and **TA**) may be used to provide additional information about aircraft noise characteristics.

F-2.1 Supplemental Noise Metrics

The **TA**, or time above, metric indicates the amount of time per average day that a location is exposed to noise in excess of a given decibel threshold, say 85 dB. The measure is helpful in determining the exposure of certain noise-sensitive uses (schools, sleeping quarters, etc.) to extended periods of noise at various levels that may be disruptive to the activity occurring there.

The **SEL** metric, or sound exposure level, is used to describe the total sound of a single noise event. “Exposure” means the dosage of sound energy that is transmitted to the human ear. Noise levels from a single event change with time, rising and falling as the noise source comes and goes. **Exhibit F-4** shows graphs of different sound events. One simple way to compare the three events is to measure the maximum level (**Lmax**) of each source. The maximum, however, identifies only one dimension of each event. By excluding the duration of the noise events, it does not identify the total noise exposure created during each event. The SEL considers not only the loudness (Lmax), but also the duration. As shown in **Exhibit F-4**, the firecracker is quick, less than one second, and loud. The roadway noise has a low Lmax, but the duration lasts about fifteen minutes. The aircraft event has a lower Lmax than the firecracker, but its duration is more than one minute longer. All three events are defined by distinct Lmax levels and durations, yet the SELs are the same because all three events transmit an equal dosage of sound energy to the human ear. As shown by **Exhibit F-5**, the SEL allows for an “apple-to-apple” comparison of multiple single-noise events.

As depicted in **Exhibit F-5**, SEL compiles all of the noise energy associated with a single event and integrates the energy to a single reference second. Consequently, the SEL will always be greater than the peak decibel level (Lmax) of the event. Aircraft SEL levels are normally between 6 and 10 decibels higher than the Lmax for an event.

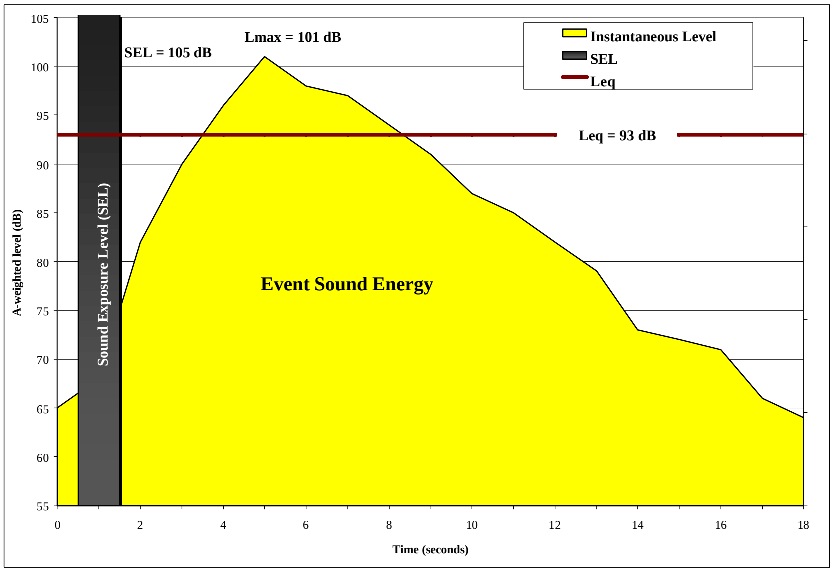

EXHIBIT F-5: RELATIONSHIP AMONG NOISE METRICS

The **Leq** (equivalent sound level) metric is used to define cumulative noise exposure. Leq is a single value of sound level for any desired duration, which includes all of the time-varying sound energy within the measured period. Typical measurement periods are one hour, eight hours, and 24-hours. For example, an 8-hour Leq of 67 dBA indicates that the amount of sound energy in all the peaks and valleys that occur in the 8-hour period is equivalent to the energy in a continuous sound level of 67 dBA. Leq is a useful metric because of a phenomenon known as the "equal energy rule." Scientists have found that a very loud noise with a short duration will have the same effect on humans as a quieter noise lasting a longer time when the total energy of both sound events is the same.

F-2.2 Day/Night Average Sound Level

The **DNL** (day-night average sound level) metric is similar to Leq, but it is always computed for a 24-hour period. To represent the greater annoyance caused by a noise event at night, the DNL metric adds an extra weight for nighttime noise. The DNL metric requires that the sound levels occurring between 10:00 P.M. and 7:00 A.M. (nighttime) be augmented by 10 dB, to account for the annoyance of noise during time periods when people are trying to sleep and ambient noise levels are lower. The weighting, in essence, equates one night flight to ten day flights.

DNL's emergence as the standard metric for aviation noise analysis is primarily due to the EPA's effort to comply with the Noise Control Act of 1972. The EPA designated a task group to "consider the characterization of the impact of airport community noise and develop a community noise exposure measure."[3/] The task group recommended DNL as the metric for aircraft noise studies.

In the EPA's "Information of Levels" document published in 1974, the EPA researched the validity behind use of DNL in quantifying noise exposure. They began by analyzing the daily variation of aircraft noise by comparing the difference between Ld (daytime noise level) and

[3/] U.S. Environmental Protection Agency, Office of Noise Abatement and Control. *Information on Levels* , A-10.

Ln (nighttime noise level). The EPA plotted 63 sets of measurements that spanned noise environments ranging from the quiet of a wilderness area to the noisiest of airport and highway environments. The results showed that at the lowest levels (DNL around 40-55 dB), Ln is not the primary control in determining DNL because the nighttime ambient noise level is so much lower than in the daytime. At higher DNL levels (65-90 dB), the values of Ln are not much lower than those for Ld. Because of the 10 dB nighttime weighting, Ln will control the DNL value. In the report, the EPA concluded, "The choice of the 10 dB nighttime weighting in the computation of DNL has the following effect: In low noise level environments below DNL of approximately 55 dB, the natural drop in Ln values is approximately 10 dB, so that Ld and Ln contribute about equally to DNL. However, in high noise environments, the night noise levels drop relatively little from their daytime values."[4/] The EPA had concluded that DNL provides an accurate metric for quantifying "noise," or unwanted annoying sounds.

In 1974, the EPA endorsed the use of DNL recommended in the Levels Document, based on the following considerations:

- The measure is applicable to the evaluation of pervasive long-term noise in various defined areas and under various conditions over long periods of time.
- The measure correlates well with known effects of the noise environment on individuals and the public.
- The measure is simple, practical and accurate. In principle, it is useful for planning.
- Measurement equipment is commercially available.
- DNL is closely related to methods currently in use.
- The metric at a given location is predictable, within an acceptable tolerance, from knowledge of the physical events producing the noise.[5/]

In 1980, the Federal Interagency Committee on Urban Noise (FICUN) met to consolidate Federal guidance on incorporating noise considerations in local land use planning. The Committee selected DNL as the best metric for measuring noise for land use planning, thus endorsing the EPA's earlier work and making it applicable to all Federal agencies. Land use compatibility guidelines were established based on DNL levels.[6/]

In response to the requirements of the Aviation Safety and Noise Abatement Act of 1979 and the recommendations of FICUN and EPA, the FAA established DNL as the single system for measuring and evaluating aircraft noise for land use planning and noise impact assessment. The agency also identified land uses, which are compatible with various exposures. The FAA found DNL to be a workable tool for use in relating aircraft noise to community reaction. The FAA has designated specific applications

[4/] Ibid., A-15.

[5/] Ibid. , A-1 – A-23.

[6/] Federal Interagency Committee on Urban Noise (FICUN). *Guidelines for Considering Noise in Land Use Planning and Control.* (1980)

for DNL – airport noise compatibility studies (under FAR Part 150 guidelines) and environmental studies under FAA Orders 1050.1E and 5050.4A.

In August 1992, the Federal Interagency Committee on Noise (FICON) published a document entitled "Federal Agency Review of Selected Airport Noise Analysis Issues." The Committee was comprised of representatives from the U.S. Environmental Protection Agency (EPA), the Department of Transportation (DOT), the FAA, the U.S. Air Force, the U.S. Navy, the Department of Housing and Urban Development (HUD), the Department of Veterans Affairs (VA), and others. FICON focused on the manner in which airport noise impacts are determined and described, the extent to which impacts outside recognized criteria should be reviewed in National Environmental Policy Act (NEPA) documents, and the range of FAA controlled mitigation measures that are analyzed. In regards to DNL, the Committee found no new sound descriptors or metrics of sufficient scientific standing to substitute for DNL. Other metrics could be used only to supplement, not replace DNL.[7/]

In 1993, the FAA issued its *Report to Congress on Effects of Airport Noise*, which studied the social, economic, and health effects of airport noise, and determined the actual level at which noise creates an adverse effect on people. Regarding DNL, the FAA stated, "Overall, the best measure of the social, economic, and health effects of airport noise on communities is the Day-Night Average Sound Level (DNL)."[8/]

Most aviation noise studies, including this EA, utilize computer-generated estimates of average annual day/night noise exposure. DNL values are calculated by adding the predicted SELs of individual aircraft operations that fly over a location during a 24-hour period and weighting nighttime overflights by 10 dB. Numerous studies have confirmed reasonableness of the predicted values with noise monitoring data.

F-3. EFFECTS OF NOISE EXPOSURE ON PEOPLE

Making a sweeping generalization about the impacts of noise on people is difficult because of the wide variations in individual reactions. Much has been learned, but some physical and psychological responses to noise are not yet fully understood and continue to be debated by researchers.

F-3.1 Effects on Hearing

Hearing loss is the major health danger posed by noise. The EPA's *Information on Levels* document (1974) concluded that exposure to noise of greater than 70 Leq (used to take in account the actual non-weighted energy entering the ear) on a continuous basis, over a long duration (40 consecutive years) at the human ear's most damage-sensitive frequency, may result in a very small but permanent loss of hearing. A 70 Leq noise level is considered the

[7/] Federal Interagency Committee on Noise (FICON). *Federal Agency Review of Selected Airport Noise Analysis Issues*. (1992)

[8/] U.S. Department of Transportation, Federal Aviation Administration. *Report to Congress on Effects of Airport Noise* (Washington D.C.: Government Printing Office, 1993), 1.

margin of safety for 24-hour noise exposure throughout the year.[9/]

In *Aviation Noise Effects*, three studies are cited which examined hearing loss among people living near airports. They found that individuals in the community near an airport are at no risk of suffering hearing damage from aircraft noise under normal circumstances.[10/]

The Occupational Safety and Health Administration (OSHA) has established standards for permissible noise exposure in the workplace to guard against the risk of hearing loss. When legal limits are exceeded, hearing protection is required. The standards, shown in **Table F-1**, establish a sliding scale of permissible noise levels by duration of exposure. OSHA permits noise levels of up to 90 dBA for eight hours per day, without requiring hearing protection. The regulations require employers to establish hearing conservation programs where noise levels exceed 85 Leq during the 8-hour workday. This involves the monitoring of work place noise, the testing of employees' hearing, the provision of hearing protectors to employees at risk of hearing loss, and the establishment of a training program to inform employees about the effects of work place noise on hearing and the effectiveness of hearing protection devices.

Table F-1
Permissible Noise Exposures
OSHA Standards

DURATION PER DAY, HOURS	SOUND LEVEL (DBA) SLOW RESPONSE
8	90
6	92
4	95
3	97
2	100
1 ½	102
1	105
½	110
¼ or less	115

Source: 29 CFR Ch. XVII, Section 1910.95 (b)

Experience at airports has shown that even at sites with cumulative noise exposure near 75 DNL, the total time that noise levels exceed 80 dBA typically ranges from 10 to 15 minutes, far below the critical hearing damage thresholds. This supports the conclusion that airport noise in areas off the airport property is too low to be considered potentially damaging to hearing.[11/]

With respect to the risk of hearing loss, Taylor and Wilkins' research (1987) concluded, "Those most at risk [of hearing loss] are personnel in the transportation industry, especially airport ground staff. Beyond this group, it is unlikely that the general public will be exposed to sustained high levels of transportation noise sufficient to result in hearing loss. Transportation noise control in

9 U.S. Environmental Agency, Office of Noise Abatement and Control. *Information on Levels*, C-17.

10/ Newman. *Aviation Noise Effects*, 39.

11/ U.S. Department of Transportation, Federal Aviation Administration. *Environmental Impact Statement for Proposed Master Plan Update Developmental Options of Seattle-Tacoma International* (Seattle, prepared by Landrum & Brown, Inc. 1996), C-75 – C-149.

the community can therefore not be justified on the grounds of hearing protection."[12]

F-3.2 Non-Auditory Health Effects

Beliefs exist that aviation noise can harm the general physical and mental health of airport neighbors. Effects on the cardiovascular system, mortality rates, birth weights, achievement scores, and psychiatric admissions have been examined in research literature. The question of pathological effects remains unsettled because of conflicting findings based on differing methodologies and uneven study quality. While research is continuing, there is insufficient scientific evidence to support these concerns.[13]

In Taylor and Wilkins' article "Health Effects" published in *Transportation Noise Reference Book*, they conclude the following in their review of the research:

The evidence of non-auditory effects of transportation noise is more ambiguous, leading to differences of opinion regarding the burden of prudence for noise control. There is no strong evidence that noise has a direct causal effect on such health outcomes as cardiovascular disease, reproductive abnormality, or psychiatric disorder. At the same time, the evidence is not strong enough to reject the hypothesis that noise is in some way involved in the multi-causal process leading to these disorders...But even with necessary improvements in study design, the inherent difficulty of isolating the effect of a low dose agent such as transportation noise within a complex etiological system will remain. It seems unlikely, therefore, that research in the near future will yield findings which are definitive in either a positive or negative direction. Consequently, arguments for transportation noise control will probably continue to be based primarily on welfare criteria such as annoyance and activity disturbance.[14]

Case studies on mental illness and hypertension in the 1990s indicate that the above conclusion remains valid. Yoshida and Nakamura found that long-term exposure to sound pressure levels above 65 DNL may contribute to reported ill effects on mental well-being. This case study, however, concluded that more research is needed because the results also contained some contrary effects, indicating that in some circumstances ill effects were negatively correlated with increasing noise.[15]

Griefahn (1992) studied the impact of noise exposure, ranging from 62 dBA to 80 dBA, on people with hypertension. She found that there is a tendency for vasoconstriction to increase among untreated hypertensive people as noise level increases. However, she also found that beta blocking medication prevented any increase in vasoconstriction attributable to noise. She concluded that while noise may be related to the onset of hypertension, especially in the presence of other risk factors, hypertensive people do not run a higher risk of ill health effects if they are properly treated.[16]

[12] S.M. Taylor and P.A. Wilkins. "Health Effects." *Transportation Noise Reference Book*. Ed. P.M. Nelson. (Butterworths, 1987).

[13] Newman. *Aviation Noise Effects*. 59-62.

[14] Taylor. "Health Effects", *Transportation Noise*.

[15] T. Yoshida and S. Nakamura. *Community and Health of Inhabitants*. Vol. 2, International Conference on Noise Control Engineering (1990), 1125-1128.

[16] B. Griefhn. *Hypertension – A particular Risk For Noise Exposure*. Vol. 2, International Conference On Noise Control Engineering. (1992), 1123 – 1126.

F-3.3 Sleep Disturbance

Sleep disturbance is a highly recognized factor contributing to aircraft annoyance. The effect of noise on sleep interference is well documented, although the long term effects are unclear. Physical and emotional well-being requires sleep, and noise can interfere with sleep even when an individual is not consciously awakened. Even though long term effects of sleep deprivation on mental and physical function is not known, it can be assumed to be harmful. It is also known that sleepers do not fully adjust to noise disruption over time, although they may awaken less often and have fewer conscious memories of the disruption.

Historically, studies of sleep disturbance have been conducted mainly in laboratories using various indicators of response (i.e., verbal response, button push, and electroencephalographic recordings). However, laboratory studies do not allow generalizations about the potential for sleep disturbance in an actual airport setting, and the impact of these disturbances on the residents.

In recent years, field studies have been done where individuals were exposed to noise in their own homes during the nighttime hours. J.M. Fields reviewed eight studies conducted in homes, four of which examined aircraft noise.[17/] Sleep disturbance was correlated with cumulative noise exposure metrics, such as Leq, in the studies. The studies showed a distinct tendency for increased sleep disturbance as cumulative noise exposure increased. Fields notes, however, that sleep disturbance was common regardless of the noise level and was contributed to by numerous factors. Fields states, "The prevalence of sleep disturbance in the absence of noise means that considerable caution must be exercised in interpreting any reports of sleep disturbance in noisy areas."

A large discrepancy between field study and laboratory results exists as cited by Pearsons in his literature review for the U.S. Air Force.[18/] He found that noise-induced awakenings in the home were much less prevalent than in the laboratory. He also concluded that much higher noise levels were required to induce awakenings in the home than in the laboratory. Some experts theorize that the significant number of awakenings in a laboratory environment versus a field environment is caused by a lack of habituation.[19/] People are fully habituated to their home environment, including the noise levels. Based on his review, Pearsons found no specific adverse health effects associated with sleep disturbance. However, sleep disturbance itself can be deemed an annoyance, thereby making it an impact caused by noise.

In "Community Annoyance and Sleep Disturbance: Updated Criteria for Assessing the Impacts of General Transportation Noise on People," Finegold reviewed the data in Pearsons' report of 1990 and developed a regression analysis. As shown in **Exhibit F-6**, an exponential curve, labeled as "FICON 1992," was found to fit the categorized data reasonably well. Finegold recommended that this curve be used as a provisional means of predicting potential sleep disturbance from aircraft noise.

[17/] Fields, J.M. *Cumulative Airport Noise Exposure Metrics: An Assessment of Evidence for Time-of-Day Weighting*. (Washington D.C.: Government Printing Office, 1986) Report No. DOT/FAA/EE-86/10.

[18/] K.S. Pearsons, "Predicting noise-induced sleep disturbance," *Journal of the Acoustical Society of America*. (1990), 331-338.

[19/] L.S. Finegold. "Current status of sleep disturbance research and development of a criterion for aircraft noise exposure," *Journal of the Acoustical Society of America*. (1994), 1807.

He cautioned that because the curve was derived using laboratory and field data, the predictions of sleep disruption in an actual community setting derived from this curve would likely be high. In 1992, the Federal Interagency Committee on Noise (FICON) recommended Finegold's curve as an interim dose-response curve to predict the percent of the exposed population expected to be awakened as a function of the exposure to single event noise levels expressed in terms of sound exposure level (SEL).

Three more studies were conducted in the United Kingdom in 1992, Los Angeles in 1992, and Denver in 1995. The Federal Interagency Committee on Aviation Noise (FICAN) reviewed the three studies along with previous studies to recommend a revised sleep disturbance relationship with aviation noise.[20/] The FICAN 1997 curve shown in **Exhibit F-6** predicts a "conservative dose-response relationship for the combined field data."[21/] The exhibit also shows the FICON curve as a comparison. Based on the current studies, the occurrence of aircraft noise-related awakenings for a particular SEL level is significantly overestimated by the FICON curve. The FICAN 1997 curve represents the upper limit of the observed in-home data. Therefore, the FICAN 1997 curve is interpreted as predicting the maximum percentage of the exposed population expected to be "behaviorally" awakened for a given community. "Behavioral awakenings" are defined as awakening by the subject enough to initiate a physical acknowledgment, such as a verbal response. FICAN emphasizes that the recent studies do not establish relationships between aircraft noise and other potential sleep disturbance or related health effects. Currently, FICAN recommends the use of the FICAN 1997 dose-response curve when predicting the percent of the exposed population expected to be awakened by aircraft noise. The equation used to provide predicted numbers is:

$$\textit{Awakenings} = 0.0087\ x\ (SEL\text{-}30)^{1.79}$$

[20/] Federal Interagency Committee on Aircraft Noise (FICAN). *Effects of Aviation Noise on Awakenings from Sleep*. (June 1997), 1.

[21/] FICAN. *Effects of Aviation Noise*. 9.

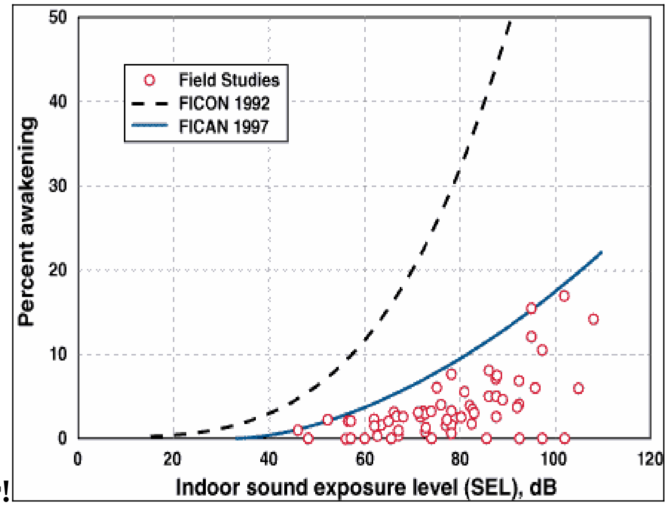

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Exhibit F-6**: FICON 1992 vs. FICAN 1997 Sleep Disturbance Curves**

F-3.4 Speech Interference

Another impact of noise on human activities is interference with speech communication. This can affect a number of common activities, including conversations in the home and outdoors, classroom teaching, listening to radio and television, and telephone conversations. In addition to disrupting recreational and social activities, the masking of speech by airport noise can reduce education time and the performance of work involving speech communication. The degree to which noise interferes with indoor speech depends not only on physical factors, such as noise levels, distance between the speaker and listener, and room acoustics, but also non-physical factors such as the speaker's enunciation and the listener's interest in and familiarity with the topic.

Speech interference caused by aircraft noise is a primary source of annoyance to individuals on the ground. **Exhibit F-7** shows the impact of noise on speech communications.

In general, people begin to experience difficulty with speech communication when background noise levels exceed 55 dBA.[22/] Once the A-weighted sound pressure level of a noise event increases above 70 dBA, telephone communication becomes difficult and people talking at distances greater than three feet apart may have to shout. The highest noise that allows conversation with 100 percent intelligibility at normal voice levels throughout an average room is 45 dB, but 99 percent intelligibility is possible at 55 dB and 95 percent is possible at 65 dB.

The second graph within **Exhibit F-7** depicts the level of communication required within a given distance to have a satisfactory face-to-face conversation. Using the graph, once the A-

[22/] *Airport Noise Report*, 1041-83818 (July 9, 1990).

weighted sound pressure level of a noise event increases above 70 dBA, people talking at distances greater than three feet apart may have to raise their voice level near to a shout. As the noise event level increases, the voice level necessary to maintain a satisfactory conversation increases, especially for longer distances between the listener and the speaker. Once the noise event level increases beyond 90 dBA, unaided face-to-face communication becomes inadequate no matter the distance between the listener and speaker.

In addition to interrupting speech, noise can cause significant frustration and irritation by disrupting leisure activities such as listening to the radio, television, and music. A 1963 study sponsored by the British government found that aircraft noise of 75 dB annoyed the highest percentage of the population when it interfered with television sound.[23/]

F-3.5 Vibration

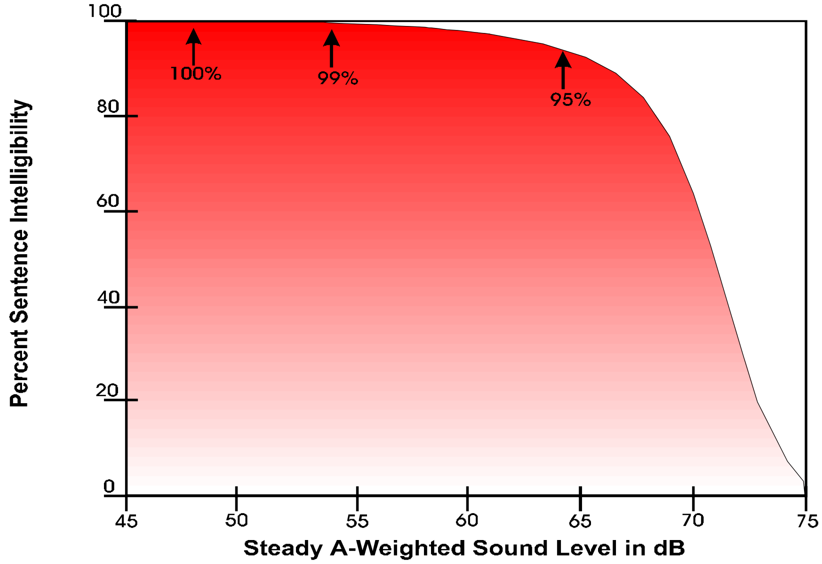
Structural vibration from aircraft noise in the low frequency band is a common concern for airport neighbors. While vibration contributes to annoyance reported by residents near airports, especially when accompanied by high audible sound levels, it rarely carries enough energy to damage safely constructed structures. High-impulse sounds such as blasting, thunder, or sonic booms are more likely to cause damage than continuous sounds such as aircraft noise.

Risk of structural damage from aircraft noise was studied as part of the environmental assessment of the Concorde supersonic jet transport. Probability of damage from Concorde overflights was found to be extremely low. Actual overflight noise measurements of a Concorde overflight at Sully Plantation near Dulles International Airport in Fairfax County, Virginia, was recorded at 115 dBA. No damage to the historic structures was found. Because the Concorde causes significantly more vibration than conventional commercial jet aircraft, the risk of structural damage caused by aircraft noise near airports is considered to be negligible.[24/,25/]

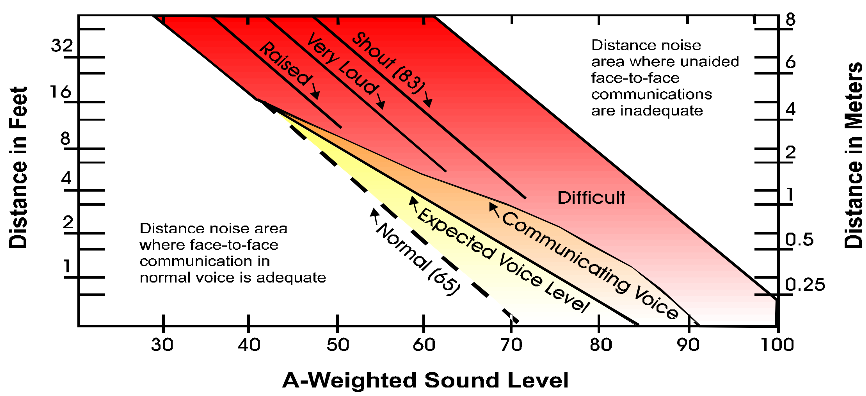
23/ *Great Britain Committee on the Problem of Noise.* Final Report. Presented to Parliament by the Lord Minister for Science by Command of Her Majesty. London, H.M. Stationery Office, July 1963.

24/ R.L. Hershey, et al. *Analysis of the Effect of Concorde Aircraft Noise on Historic Structures*. (Washington D.C.: Government Printing Office, 1975), FAA-RD-75-118.

25/ J.H. Wiggins. *The Influence of Concorde Noise on Structural Vibrations*. (Washington D.C.: Government Printing Office, 1975), FA-75-1241-1.



Intelligibility of Speech with Varying Background Sound Levels.



Voice Levels Needed to Rise Above Ambient Noise for Satisfactory Communication Between Talker and Listener at Varying Distances.

Source: Federal Aviation Administration, 1992.

***Exhibit F-7**: Impacts on Speech Intelligibility*

F-3.5 Fear of Accidents

In some cases, noise is only an indirect indicator of the real concern of airport neighbors: safety. The sound of an approaching aircraft may cause apprehension in some people about the possibility of an aircraft accident occurring over their area. This fear is a factor motivating some complaints of annoyance in neighborhoods near airports around the country.[26/] This effect tends to be most pronounced in areas directly beneath frequently used flight tracks.[27/] There is no known research on the mental effects on airport neighbors that might result from perceived threats to personal safety. However, comments routinely received from the public in forums conducted for airport noise studies around the nation confirms the concern.

F-3.6 Residential Property Values

This section addresses the issue of aircraft noise effects, if any, on residential real estate values. Isolating the influence of a single environmental factor, such as aircraft noise, on housing values is difficult, since those values are established through a market process involving many different factors. Among these are the location, as well as the quality, condition and features of the home. The location of the property is generally the most important factor, encompassing the average income level of the community in which the real estate is located and the proximity of the property to employment centers, commuter links, schools, parks, and neighborhood shopping and services. Other aspects of perceived neighborhood quality are also important in setting housing prices, such as the quality of community services, the condition of neighboring homes, neighborhood safety and property tax rates.

Numerous studies have attempted to quantify the impact of aircraft noise on property values. The typical methodology has been to compare two or more neighborhoods to determine where the aircraft noise has affected property values. In a typical study, housing prices in a neighborhood or community that is located further away from the airport. This other community, which is selected to be as similar as possible to the community near the airport from a real estate valuation perspective, serves as the "control" community in the comparative analysis.

Some older studies suggested that residential real estate values in communities near airports may have been unaffected or reduced. However, other studies, including those conducted fro airports such as Atlanta, Pittsburgh, and Denver, have concluded that airports are substantial economic generators, creating thousands of jobs both on-site and off-site28. These studies found that the direct and indirect economic activity and employment opportunities created by airports made nearby communities attractive locations for both business and residential use, thereby increasing market demand for housing, and consequently increasing housing values in those communities. The study conducted for

[26/] K.D. Kryter. *Physiological, Psychological, and Social Effects of Noise*. (NASA Reference Publication 1115, 1984), 533.

[27/] T. Gjestland. *Aircraft Noise Annoyance*, Vol. 2 1989 International Conference On Noise Control Engineering. (1989) 903 – 908.

[28] *Hartsfield Atlanta International Airport Economic Impact Reports*, 1987; *Economic Impacts of the Dallas/Ft. Worth Airport on Real Estate Values*, KPMC Peat Marwick, Jul 1989; *The Regional Economic Impact of Stapleton International Airport and Future Development: Summary Report*, City of Denver, 1985; *Denver Aviation Development Agenda; 2005*, Herman Kontich Strand, August 1991; *The Local and Regional Economic Impacts of Washington Dulles International and National Airports*, Marrin O'Connell Associates, 1988; *Airport Area Economic Development; Recommendations for the Pittsburgh Region*, Carnegie Mellon University, 1989.

Pittsburgh concluded that of the nine airports reviewed, all had a positive impact on the economy of their regions and showed greater job growth than other areas of the Pittsburgh region. The Atlanta study demonstrated that airports served to increase the property tax base in area surrounding an airport. Such an increase in the tax base enables local governments to provide a greater level of services to local residents, which may positively affect residential property values.

Another large-scale study of airport impacts on nearby property values, conducted for the Dallas/Ft. Worth International Airport in 1990, found that real estate values in the area surrounding the airport had increased at a faster rate than real estate in a comparable area not located near the airport29. Moreover, a study conducted for the Nashville International Airport in 1993, analyzing home values for the previous decade, found that aircraft noise levels had no effect on the actual sales prices of homes in the area around the airport and concluded that "the hypothesis that high noise levels in an area have a negative impact on the value of homes must be rejected for the study area"30.

In 1996, Dr. Sanford Fidell of BNN conducted a comprehensive analysis on the effects of military aircraft on property values. Using historical data collected since 1975, Dr. Fidell concluded that the findings strongly suggest a lack of casual relationship between aircraft noise and residential property sales values. He emphasized that major factors that determine difference in sale prices are not based on noise effects. Dr. Fidell states: "Thus, depending on when, where, and how your home was built, what other types of homes have been built within several miles of yours, and regional and national economic trends, it is possible that aircraft noise might have a minor effect on the sale prices of your property. However, such an effect (if any) is likely to be so much smaller than the effect of many other factors on the sale price of your property that it might be very difficult to verify31. Thus, particularly in the more recent studies relating to this issue, it appears that airports have no effect of even a positive effect on property values.

Finally, a real estate survey of Chicago areas suburbs conducted by Chicago Magazine in October 2000 indicates that the average sales prices of homes in communities in the vicinity of the Airport have appreciated dramatically since 1994 and have continued to increase between 1999 and 2000. In fact, in contrast to home prices in some other communities located away from the Airport, there was not one community near the airport that experience a decline in average home prices during the period surveyed. The average increase in sale price between 1999 and 2000 for communities that are either entirely or partially within the 1997 65 DNL was 9.7 percent, compared to 7.9 percent for communities outside the 65 DNL.32

F-3.7 Work Performance

The EPA found that continuous exposure to high noise levels could affect work performance, especially in high stress occupations.[33/] Based on the FAA's land use compatibility guidelines

[29] *Dallas/Fort Worth International Airport Impact Study.* Ernst & Young January 1990.

[30] *A Statistical Analysis of the Possible Effect of Airport-Generated Noise on Home Prices and Marekting Times in the Donelson Area of Nashville, Tennesse from 1983 to Present.* H. Stan Banton, Ph.D. M.A.I. Banton, Roach & Beasley, circa 1993.

[31] *Effects of Military Aircraft Noise on Residential Property Values.* BBN Systems and Technologies. October 16, 1996

[32] *2000 Real Estate Survey.* Chicago Magazine, October 2000.

[33/]Environmental Protection Agency, *Levels Document.*

under FAR 150, these adverse effects are most likely to occur within the 75 DNL contour.

F-4. AVERAGE COMMUNITY RESPONSE TO NOISE

Individual human response to noise is highly variable and influenced by emotional and physical factors. Emotional factors include: feelings about the necessity or preventability of the noise; judgements about the value of the activity creating the noise; an individual's activity at the time the noise is heard; general sensitivity to noise; beliefs about the impact of noise on health; and sense of fear associated with the source of the noise. Physical factors influencing reaction to noise include the background noise in the community, the time of day, the season of the year, the predictability of the noise, and the individual's control over the noise source.

Although individual responses to noise can vary greatly, the average response among a group of people is much less variable. This allows for a general analysis about the effect of the average noise exposure levels caused by aircraft on a community, despite the wide variations in individual response.

Several experts in the field have examined average residential community response to noise, focusing on the relationship between annoyance and noise exposure. The studies have produced similar findings that annoyance is most directly related to cumulative noise exposure rather than single event exposure.

As depicted in **Exhibit F-8**, annoyance has been found to increase along an S-shaped or logistic curve as cumulative noise exposure increases. The curve was developed by Finegold et al. (1992 and 1994)[34/]. It is based on data derived from a number of transportation noise studies. The curve shows the relationship between DNL levels and the percentage of population highly annoyed. The curve is known as the "Updated Schultz Curve" after the original concept developed by Schultz in 1978.[35/] In 1992, FICON recognized this curve to be the best available source of data for the noise dosage-response.[36/]

[34/] L.S. Finegold. Et al. "Community Annoyance and Sleep Disturbance: Updated Criteria for Assessing the Impacts of General Transportation Noise on People," *Noise Control Engineering Journal.* Vol. 42, No. 1 (Jan.-Feb. 1994).
[35/] T.J. Schultz. "Synthesis of Social Surveys on Noise Annoyance," *Journal of Acoustical Society of America*. Vol. 64, No. 2 (1978), 377– 405.
[36/] FICON, *Federal Agency Review.* 3-5.

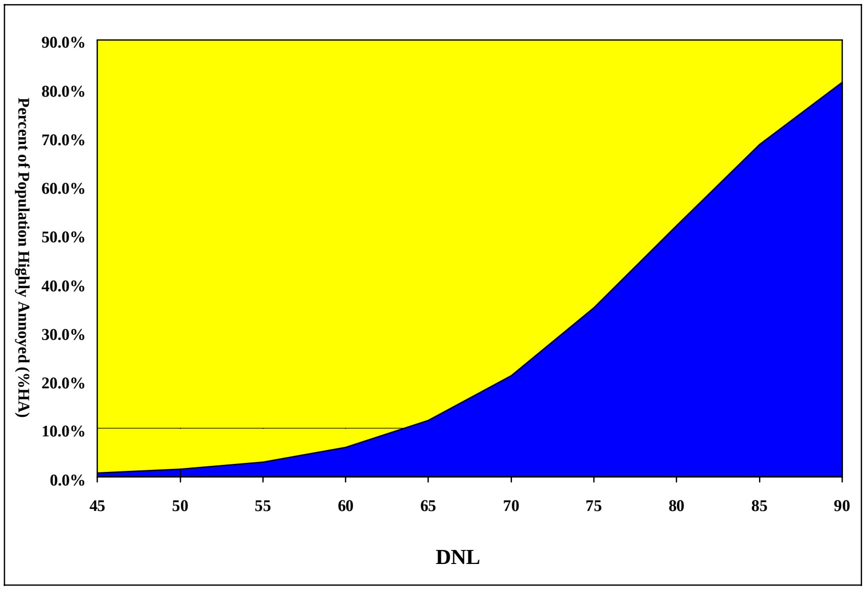


Exhibit F-8*: Percentage of Population Highly Annoyed by General Transportation Noise*

The "Updated Schultz Curve" shows that annoyance is measurable beginning at 45 DNL, where 0.8 percent of people are highly annoyed. The ratio increases gradually to 6.1 percent at 60 DNL. Starting at 65 DNL, the percent of people highly annoyed increases steeply from 11.6 percent up to 68.4 percent at 85 DNL.

F-5. NOISE IMPACT CRITERIA

The FAA has considered the matter of threshold levels above which aircraft noise causes an adverse impact on people. The agency has established 65 DNL as the threshold above which aircraft noise is considered to be not compatible in residential areas. In addition, the FAA has determined that a significant impact occurs if a proposed action would result in an increase of 1.5 DNL or more on any noise-sensitive area within the 65 DNL exposure level.[37/]

In 1992, the Federal Interagency Committee on Noise (FICON) recommended that noise increases of 3 dB or more between DNL 60 and 65 dB be evaluated in environmental studies when increases of 1.5 DNL or more occur at noise-sensitive locations at or above 65 DNL. Increases of this magnitude below 65 DNL are not to be considered as "significant impacts," but they are to receive consideration. The FAA

[37] FAA Order 1050.1E; FAR Part 150 Section 150.21(a)(2)(d); FICON 1992, Pp. 3-5.

adopted FICON's recommendation into FAA Order 1050.1E.

In 1990, the FAA issued a noise screening procedure for determining whether certain airspace actions above 3,000 feet above ground level (AGL) might increase DNL levels by five decibels or more.[38/] The procedure served as a response to FAA experience that increases in noise of 5 dB or more at cumulative levels well below 65 DNL could be disturbing to people and become a source of public concern. In the Environmental Impact Statement for the Expanded East Coast Plan (EECP), the FAA evaluated noise levels down to the 45 DNL level for potential increases in DNL noise exposure of 5 dB or more. In the EECP study, the FAA determined that the 45 DNL level is the minimum level at which noise needed to be considered because "even distant ambient noise sources and natural sounds such as wind in trees can easily exceed this [45 DNL] value."[39/] This threshold of change was subsequently used in the Chicago Terminal Airspace Project (CTAP) EIS and the Potomac Consolidated TRACON Airspace Redesign EIS. The FAA formalized the use of this threshold of change in the recent release of FAA Order 1050.1E.

For the purpose of this EA, increases of 3 DNL between 60 and 65 DNL are considered "slight to moderate impacts" as are increases of 5 DNL or greater at levels between 45 DNL to 60 DNL. The increase in noise at these levels is enough to be noticeable and potentially disturbing to some people, but the cumulative noise level is not high enough to constitute a "significant impact." **Table F-2** summarizes the criteria utilized to assess the level of change in noise exposure attributable to the MAP alternatives. Appendix E includes a more detailed discussion relating to determination of aircraft noise impact levels.

[38] FAA Notice 7210.360. September 14, 1990.
[39] Expanded East Coast Plan – Changes in Aircraft Flight Patterns Over the State of New Jersey. Federal Aviation Administration. 1995, Pp. 5-9.

TABLE F-2
Criteria for Determining Impact of Increases in Aircraft Noise

DNL Noise Exposure With Proposed Action	Minimum Increase in DNL With Proposed Action	Level of Impact	Reference
65 dB or higher	1.5 dB	Significant	FAA Order 1050.1E, Apdx. A, 14.3 Part 150, Sec. 150.21(2)(d) FICON 1992
60 to 65 dB	3.0 dB	Slight to Moderate	FAA Order 1050.1E, Apdx A, 14.4c FICON 1992
45 to 60 dB	5.0 dB	Slight to Moderate	FAA Order 1050.1E, Apdx A, 14.5e FAA Notice 7210.360

F-6. SUMMARY

Sound travels through air like a ripple through water caused by a stone. The sound's characteristics vary by the height of the ripple (loudness), the frequency rate of the ripples (pitch) and how long the ripples last (duration). The decibel scale allows people to describe loudness. In terms of human perception of loudness, the decibel is a useful measurement. Due to the logarithmic nature of the decibel scale and the sensitivity of the human ear, most people perceive a ten-fold increase in sound energy as a two-fold increase in loudness. To measure sound on a scale approximated to the way people hear, more weight must be given to the frequencies that people hear more easily and less weight to low/high frequencies not easily detected by humans. The A-weighted sound level is used due to its good correlation to human hearing.

Sound levels with two different peak levels (Lmax) and different duration can produce equal sound exposure levels (SEL) when the duration of each event is mathematically compressed to one-second. Scientists have found that individual human responses to noise (unwanted sound) do not correlate well with single events due to varied perceptions of noise. Cumulative (average) sound exposure metrics, on the other hand, do correlate well. Leq is a cumulative metric that takes into account the average sound energy level during any specified period of time, whereas DNL (day/night average sound level) is a 24-hour average with a 10 dB penalty for each event occurring at night (10:00 P.M. to 07:00 A.M.). DNL is intended to account for the increased annoyance attributable to noise during the night when ambient levels are lower. Use of the DNL metric to describe aircraft noise is required for all airport noise studies developed under regulations of FAR Part 150 and in all aviation-related environmental assessments and impact statements.

The effects of noise on people include hearing loss, non-auditory health effects, and annoyance. While harm to physical health from aircraft noise is generally not a problem in neighborhoods near airports, annoyance is the most common problem. Annoyance can be caused by sleep disturbance, speech interference, vibration, safety concerns, and other emotional or physical factors.

Individual responses to noise are highly variable, making prediction of annoyance to environmental noise very difficult. The average response among a large group of people, however, is less variable and correlates well with cumulative noise dosage metrics such as

Leq and DNL. The relationship between average community response and cumulative noise exposure serves as the basis for the development of aircraft noise impact analysis. When significant impacts are found at specific locations, other metrics such as Lmax, SEL, and Time-Above provide additional detail for interpreting the character of the impact.