

# INTRODUCTION TO NOISE

This document provides the background reference material on the principles of noise, noise analysis, and modeling, as well as the preparation of airport noise exposure contours and how the estimates of noise impacts inside a 65 Day-Night Average Sound Level (DNL) noise contour are determined. The data is derived from a variety of sources including, but not limited to, records maintained by airport management and the Federal Aviation Administration (FAA), and mapping available from the airport, and local planning agencies.

## 1 SOUND AND NOISE

Sound is created by a vibrating source that induces vibrations in the air. The vibration produces relatively dense and sparse alternating bands of particles of air, spreading outward from the source like ripples on a pond. Sound waves dissipate with increasing distance from the source. Sound waves can also be reflected, diffracted, refracted, or scattered. When the source stops vibrating, the sound waves disappear almost instantly and the sound ceases.

Sound conveys information to listeners. It can be instructional, alarming, pleasant and relaxing, or annoying. Identical sounds can be characterized by different people or even by the same person at different times, as desirable or unwanted. Unwanted sound is commonly referred to as "noise."

Sound can be defined in terms of three components:

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

### 1.1 SOUND LEVEL

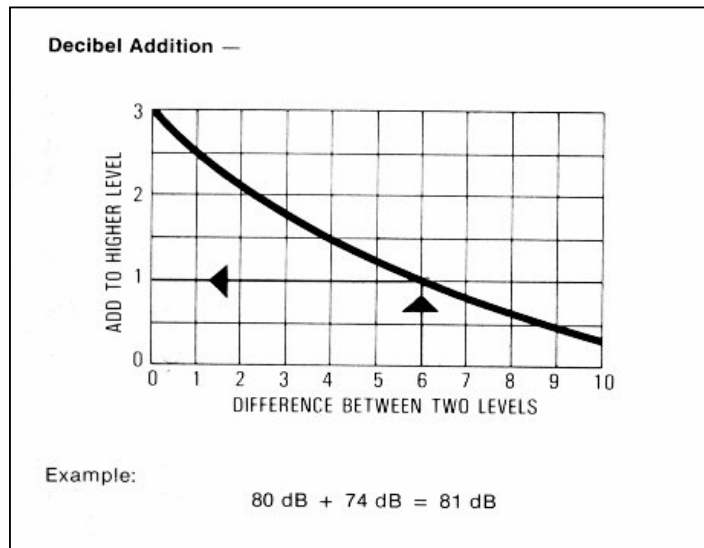
The level of sound is measured by the difference between atmospheric pressure (without the sound) and the total pressure (with the sound). Amplitude of sound is like the relative height of the ripples caused by the stone thrown into the water. Although physicists typically measure pressure using the linear Pascal scale, sound is measured using the logarithmic decibel (dB) scale. This is because the range of sound pressures detectable by the human ear can range from *1 to 100 trillion units*. A logarithmic scale allows us to discuss and analyze noise using numbers that are more manageable. Audible sound to the human ear ranges from approximately 1 to 140 dB, although everyday sounds rarely rise above about 120 dB. The human ear is extremely sensitive to sound pressure fluctuations. A sound of 140 dB, which is sharply painful to humans, contains *100 trillion ( $10^{14}$ ) times more* sound pressure than the least audible sound.

By definition, a 10 dB increase in sound is equal to a tenfold ( $10^1$ ) increase in the mean square sound pressure of the reference sound. A 20 dB increase is a 100-fold ( $10^2$ ) increase in the mean square sound pressure of the reference sound. A 30 dB increase is a 1,000-fold ( $10^3$ ) increase in mean square sound pressure.

A logarithmic scale requires different mathematics than are used with linear scales. The sound pressures of two separate sounds, expressed in dB, are not added arithmetically. For example, if a sound of 80 dB is added to another sound of 74 dB, the total is a 1 dB increase in the louder sound (81 dB), not the arithmetic sum of 154 dB (See **Figure D-1, Example of Addition of Two Decibel Levels**). If two equally loud noise events occur simultaneously, the sound pressure level from the combined events is 3 dB higher than the level produced by either event alone.

Logarithmic averaging also yields results that are quite different from simple arithmetic. Consider the example shown in **Figure D-2, Example of Sound Level Averaging**. Two sound levels of equal duration are averaged. One has a level of 100 dB, the other 50 dB. Using conventional arithmetic, the average would be 75 dB. The true result, using logarithmic math, is 97 dB. This is because 100 dB has far more energy than 50 dB (100,000 times as much) and is overwhelmingly dominant in computing the average of the two sounds.

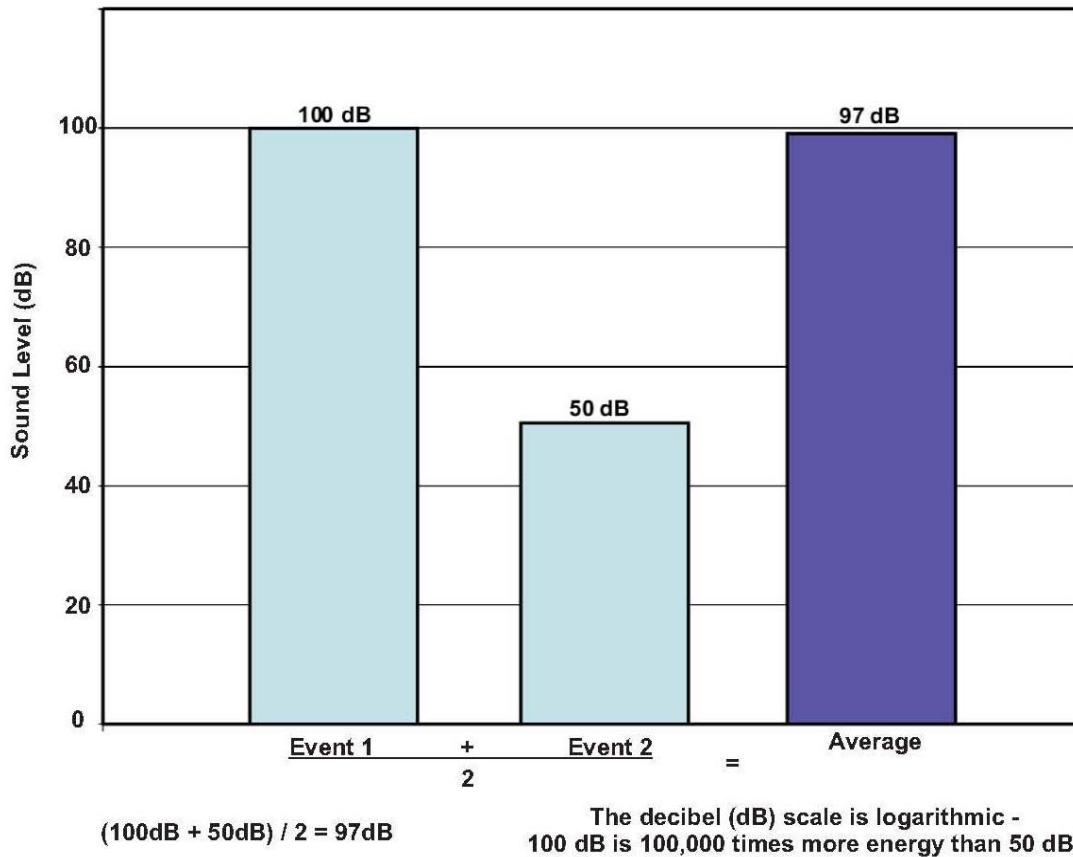
**Figure D-1:  
EXAMPLE OF ADDITION OF TWO DECIBEL LEVELS**



Source: *Information on Levels*. USEPA. March 1974.

Human perceptions of changes in sound pressure are less sensitive than a sound level meter. People typically *perceive* a tenfold increase in sound pressure, a 10 dB increase, as a doubling of loudness. Conversely, a 10 dB decrease in sound pressure is normally *perceived* as half as loud. In community settings, most people perceive a 3 dB increase in sound pressure (a doubling of the sound pressure or energy) as just noticeable. (In laboratory settings, people with good hearing are able to detect changes in sounds of as little as 1 dB.)

**Figure D-2:  
Example of Sound Level Averaging**



## 1.2 SOUND FREQUENCY

The pitch (or frequency) of sound can vary greatly from a low-pitched rumble to a shrill whistle. Consider the analogy of ripples in a pond; high frequency sounds are vibrations with tightly spaced ripples, while low rumbles are vibrations with widely spaced ripples. The rate at which a source vibrates determines the frequency. The rate of vibration is measured in units called "Hertz" – the number of cycles, or waves, per second. The ability to hear a sound depends greatly on the frequency composition. Humans hear sounds best at frequencies between 1,000 and 6,000 Hertz. Sounds at frequencies above 10,000 Hertz (high-pitched hissing) and below 100 Hertz (low rumble) are much more difficult to hear.

To measure sound in a way that approximates what the human ear hears, then more weight must be given to sounds at the frequencies that humans hear well and less weight to sounds at frequencies humans do not hear well. Acousticians have developed several weighting scales for measuring sound. The A-weighted scale was developed to correlate with the judgments people make about the loudness of sounds. The A-weighted decibel scale (dBA) is used in studies where audible sound is the focus of inquiry. The U.S. Environmental Protection Agency (USEPA) has

recommended the use of the A-weighted decibel scale in studies of environmental noise.<sup>1</sup> Its use is required by the FAA in airport noise studies.<sup>2</sup> For the purposes of this analysis, dBA was used as the noise metric and dB and dBA are used interchangeably.

### **1.3 DURATION OF SOUNDS**

The duration of sounds – the patterns 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 aircraft overflights. Intermittent sounds are produced for relatively short periods, with the instantaneous sound level during the event roughly appearing as a bell-shaped curve. An aircraft event is characterized by the period during which it rises above the background sound level, reaches its peak, and then recedes below the background level.

## **2 STANDARD NOISE DESCRIPTORS**

Given the multiple dimensions of sound, a variety of descriptors, or metrics, have been developed for describing sound and noise. Some of the most commonly used metrics are discussed in this section. They include:

- Maximum Level (**L<sub>max</sub>**)
- Time Above Level (**TA**)
- Sound Exposure Level (**SEL**)
- Number of Events Above (**NEA**)
- Equivalent Sound Level (**Leq**)
- Day/Night Average Sound Level (**DNL**)

### **2.1 MAXIMUM LEVEL (L<sub>max</sub>)**

L<sub>max</sub> is simply the highest sound level recorded during an event or over a given period of time. It provides a simple and understandable way to describe a sound event and compare it with other events. In addition to describing the peak sound level, L<sub>max</sub> can be reported on an appropriately weighted decibel scale (A-weighted, for example) so that it can disclose information about the frequency range of the sound event in addition to the loudness.

L<sub>max</sub>, however, fails to provide any information about the duration of the sound event. This can be a critical shortcoming when comparing different sounds. Even if they have identical L<sub>max</sub> values, events of greater duration contain more sound energy than those of shorter duration. Further, in a real world situation, the loudest event may be infrequent, while slightly less loud events may occur often. Research has demonstrated that for many kinds of sound effects, the total sound energy, not just the peak sound level, is a critical consideration.

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<sup>1</sup> *Information on Levels of Environmental Noise Requisite to Protect Health and Welfare with an Adequate Margin of Safety*. U.S. Environmental Protection Agency, Office of Noise Abatement and Control. 1974, Page A-10.

<sup>2</sup> "Airport Noise Compatibility Planning." 14 CFR Part 150, Sec. A150.3.

## **2.2 TIME ABOVE LEVEL (TA)**

The “time above,” or TA, metric indicates the amount of time that sound at a particular location exceeds a given sound level threshold. TA is often expressed in terms of the total time per day (or part of the day) that the threshold is exceeded. The TA metric explicitly provides information about the duration of sound events, although it conveys no information about the peak levels during the period of observation.

## **2.3 SOUND EXPOSURE LEVEL (SEL)**

The sound exposure level, or SEL metric, provides a way of describing the total sound energy of a single event. In computing the SEL value, all sound energy occurring during the event that is within 10 dB of the peak level (L<sub>max</sub>) is mathematically integrated over one second. (Very little information is lost by discarding the sound below the 10 dB cut-off, since the highest sound levels completely dominate the integration calculation.) Consequently, the SEL is always greater than the L<sub>max</sub> for events with a duration greater than one second. SELs for aircraft overflights typically range from 5 dB to 10 dB higher than the L<sub>max</sub> for the event.

## **2.4 NUMBER OF EVENTS ABOVE (NEA)**

The “number of events above,” or NEA, metric indicates the number of occurrences of sound events at a particular location that exceed a given sound level threshold during a prescribed period of time. NEA is often expressed in terms of the number of events per day for which the threshold is exceeded. The NEA metric provides information about the number of sound events that reach a certain level, although it conveys no information about the ultimate peak levels of those exceeding events.

## **2.5 EQUIVALENT SOUND LEVEL (LEQ)**

The equivalent sound level (Leq) metric may be used to define cumulative noise dosage, or noise exposure, over a period of time. In computing Leq, the logarithmically calculated total noise energy over a given period of time, during which numerous events may have occurred, is averaged over the time period. The Leq represents the steady sound level that is equivalent to the varying sound levels actually occurring during the period of observation. For example, an 8-hour Leq of 67 dB indicates that the amount of sound energy in all the peaks and valleys that occurred in the 8-hour period is equivalent to the energy in a continuous sound level of 67 dB. Leq is typically computed for measurement periods of one hour, eight hours, or 24 hours, although any time period can be specified. It is also frequently computed for a single noise event.

Leq is a critical noise metric for many kinds of analysis where total noise dosage, or noise exposure, is under investigation. As already noted, noise dosage is important in understanding the effects of noise on both animals and people. Indeed, research has led to the formulation of the “equal energy rule.” This rule states that it is the total acoustical energy to which people are exposed that explains the effects the noise will have on them. That is, a very loud noise with a short duration will have

the same effect as a lesser noise with a longer duration if they have the same total sound energy.

## **2.6 DAY-NIGHT AVERAGE SOUND LEVEL (DNL)**

The DNL metric is a special variation of the 24-hour Leq metric. Like Leq, the DNL metric describes the total noise exposure during a given period. Unlike Leq, however, DNL, by definition, can only be applied to a 24-hour period. In computing DNL, an extra weighting of 10 dB is assigned to any sound levels occurring between the hours of 10:00:00 p.m. and 6:59:59 a.m. This penalty is intended to account for the greater annoyance that nighttime noise is presumed to cause for most people. Recalling the logarithmic nature of the dB scale, this extra weight treats one nighttime noise event as equivalent to ten daytime events of the same magnitude.

As with Leq, DNL values are strongly influenced by the loud events. For example, 30 seconds of sound of 100 dB, followed by 23 hours, 59 minutes, and 30 seconds of silence would compute to a DNL value of 65 dB. If the 30 seconds occurred at night, it would yield a DNL of 75 dB.

This example can be roughly equated to an airport noise environment. Recall that an SEL is the mathematical compression of a noise event into one second. Thus, 30 SELs of 100 dB during a 24-hour period would equal DNL 65 dB or DNL 75 dB if they all occurred at night. This situation could actually occur in places around a real airport. If the area experienced 30 overflights during the day, each of which produced an SEL of 100 dB, it would be exposed to DNL 65 dB. Recalling the relationship of SEL to the peak noise level (L<sub>max</sub>) of an aircraft overflight, the L<sub>max</sub> recorded for each of those overflights (the peak level a person would actually hear) would typically range from 90 dB to 95 dB.

### **2.6.1 Federal Requirements to Use DNL in Environmental Noise Studies**

DNL is the standard metric used for environmental noise analysis in the U.S. This practice originated with the USEPA's effort to comply with the Noise Control Act of 1972. The USEPA designated a task group to "consider the characterization of the impact of airport community noise and develop a community noise exposure measure."<sup>3</sup> The task group recommended using the DNL metric. The USEPA accepted the recommendation in 1974, based on the following considerations:

1. 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.
2. The measure correlates well with known effects of the noise environment on individuals and the public.
3. The measure is simple, practical, and accurate.
4. Measurement equipment is commercially available.

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<sup>3</sup> *Information on Levels of Environmental Noise Requisite to Protect Health and Welfare with an Adequate Margin of Safety.* U.S. Environmental Protection Agency, Office of Noise Abatement and Control. 1974, P. A-10.

5. The metric at a given location is predictable, within an acceptable tolerance, from knowledge of the physical events producing the noise.<sup>4</sup>

Soon thereafter, the Department of Housing and Urban Development (HUD), Department of Defense, and the Veterans Administration adopted the use of DNL.

At about the same time, the Acoustical Society of America developed a standard (ANSI S3.23-1980) which established DNL as the preferred metric for outdoor environments. This standard was reevaluated in 1990 the same conclusions were reached regarding the use of DNL (ANSI S12.40-1990).

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 noise metric for this purpose, thus endorsing the earlier work of the USEPA and making it applicable to all Federal agencies.<sup>5</sup>

In response to the requirements of the Aviation Safety and Noise Abatement (ASNA) Act of 1979 and the recommendations of FICUN and USEPA, the FAA established DNL in 1981 as the single metric for use in airport noise and land use compatibility planning. This decision was incorporated into the final rule implementing ASNA, Title 14 of the Code of Federal Regulations (14 CFR) Part 150, in 1985.

In the early 1990s, Congress authorized the creation of a new interagency committee to study airport noise issues. The Federal Interagency Committee on Noise (FICON) was formed with membership from the USEPA, 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 concluded in its 1992 report that Federal agencies should "continue the use of the DNL metric as the principal means for describing long term noise exposure of civil and military aircraft operations."<sup>6</sup> FICON further concluded that there were no new sound descriptors of sufficient scientific standing to substitute for the DNL cumulative noise exposure metric.<sup>7</sup>

In 1993, the FAA issued its *Report to Congress on Effects of Airport Noise*. 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)."<sup>8</sup>

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<sup>4</sup> *Information on Levels of Environmental Noise Requisite to Protect Health and Welfare with an Adequate Margin of Safety*. U.S. Environmental Protection Agency, Office of Noise Abatement and Control. 1974, Pp. A-1-A-23.

<sup>5</sup> *Guidelines for Considering Noise in Land Use Planning and Control*. Federal Interagency Committee on Urban Noise (FICUN). 1980.

<sup>6</sup> *Federal Agency Review of Selected Airport Noise Analysis Issues*. Federal Interagency Committee on Noise (FICON). August 1992, Pp. 3-1.

<sup>7</sup> *Federal Agency Review of Selected Airport Noise Analysis Issues*, Technical Report, Volume 2. Federal Interagency Committee on Noise (Technical). August 1992, Pp. 2-3.

<sup>8</sup> *Report to Congress on Effects of Airport Noise*. Federal Aviation Administration. 1993, P. 1.

### **3 GENERAL NOISE MODELING INFORMATION**

The same noise metrics and noise model are used to compute all noise exposure contours and other evaluations prepared for National Environmental Policy Act (NEPA) documents and Part 150 Studies.

#### **3.1 NOISE MODEL**

The Integrated Noise Model (INM) is a computer model that evaluates aircraft noise impacts in the vicinity of airports. It is developed based on the algorithm and framework from SAE AIR 1845 standard, which used Noise-Power-Distance (NPD) data to estimate noise accounting for specific operation mode, thrust setting, and source-receiver geometry, acoustic directivity and other environmental factors. The INM can output either noise contours for an area or noise levels at specific locations. The noise output can be either exposure-based, maximum-level-based, or time-based.<sup>9</sup>

##### **3.1.1 What is INM Designed to Do?**

In the United States, INM is the preferred model typically used for FAR Part 150 noise compatibility planning and for FAA Order 1050 Environmental Assessments (EAs) and Environmental Impact Statements (EISs). The INM has many analytical uses, such as:

1. Assessing current aircraft noise impacts around a given airport or heliport
2. Assessing changes in noise impact resulting from new or extended runways or runway configurations
3. Assessing changes in noise impact resulting from new traffic demand and fleet mix
4. Evaluating noise impacts from new operational procedures
5. Evaluating noise impacts from aircraft operations in and around National Parks

The INM was developed under the guidance of the FAA and is the only model generally approved by the FAA for use in Part 150 studies, EAs and EISs. The noise pattern calculated by the INM for an airport is a function of several factors, including the number of aircraft operations during the period evaluated, the types of aircraft flown, the time of day when they are flown, the way they are flown, how frequently each runway is used for landing and takeoff, and the routes of flight used to and from the runways. Substantial variations in any one of these factors, when extended over a long period of time, may cause marked changes to the noise pattern.

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<sup>9</sup> *Integrated Noise Model, Background:*  
[http://www.faa.gov/about/office\\_org/headquarters\\_offices/apl/research/models/inm\\_model/](http://www.faa.gov/about/office_org/headquarters_offices/apl/research/models/inm_model/).