AVIATION NOISE

Noise is one of the most important environmental concerns for people that reside or work near an airport. Although the greatest noise impact is in the airport vicinity, disturbances due to aviation noise can occur due to arriving and departing flights as well as overflights. The benefits of new technologies that have significantly reduced the individual aircraft noise profile have been offset by the cumulative effect of the growth in the number of flights over residential areas.

This section is organized as follows:

1. Physics of Sound and Noise
    a. Sound is Waves of Compressed Air
    b. Sound, Noise & Information
    c. Properties of Noise
        i. Frequency
        ii. Sound Pressure
        iii. Sound Power
        iv. Duration
2. Hearing
    a. Audible Range of Human Ear
    b. How the Ear Works
3. Health Effects of Noise
    a. Noise Induced Hearing Loss (NIHL)
4. Noise Measurements and Metrics
    a. Measures
        i. Decibels
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        iii. Effective Perceived Noise Level (EPNL)
    b. Single Event Metrics
        i. Maximum Sound Level (L_{Max})
        ii. Sound Exposure Level (SEL)
    c. Multiple Events Metrics
        i. Equivalent Noise level (Leq)
        ii. Day-night Average Sound Level (DNL or LDN)
        iii. Noise Contours
5. Noise Design and Operation Standards
6. Noise Mitigation Strategies

Noise and the Future of Society: CBS Video
http://www.cbsnews.com/video/watch/?id=5578396n

1. <u>Physics of Sound and Noise</u>

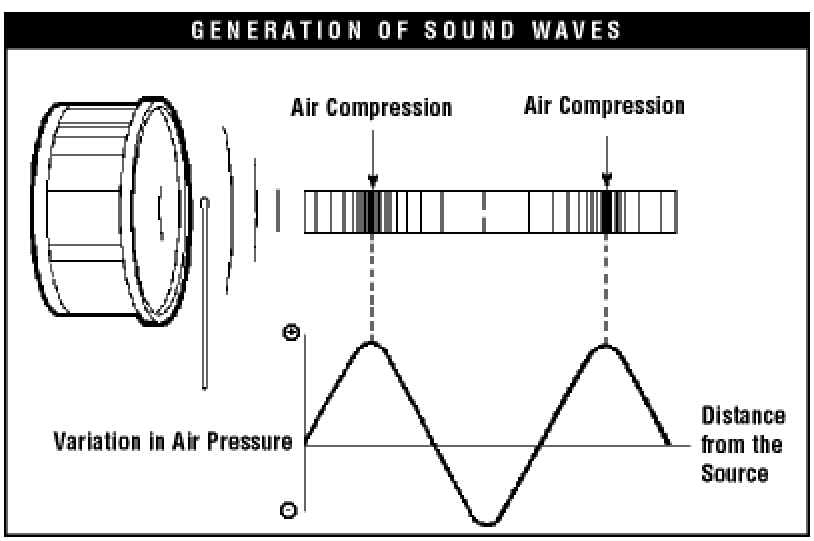
This section provides an overview of the physics of sound as follows:

a. Physics of Sound
b. Sound, Noise and Information
c. Four Properties of Sound
    i. Frequency
    ii. Sound Pressure
    iii. Sound Power
    iv. Duration

Physics of Sound

When the surface of a drum is hit, the surface vibrates back and forth. As it moves forward, it pushes the air in contact with the surface. This creates a positive (higher) pressure by compressing the air. When the surface moves in the opposite direction, it creates a negative (lower) pressure by decompressing the air. The air pressure changes travel as waves through the air (Figure 1).

Highly sensitive mechanisms in the ear convert the changes in air pressure to electrical impulses to the brain, creating what we call sound. The perceived sound is transformed by the structure of the human hearing mechanism, which translates perceptual oscillations into complex perceptual phenomena related to the frequency and intensity of the sound waves.



Note: The medium in which the vibration takes place has significant roles in determining sound. A sound transported in gas has higher the velocity than a sound transported in a solid. The higher the velocity of sound, the higher the pitch (e.g. inhaling helium from a balloon).

Sound, Noise & Information

Sound is what we hear. Noise is unwanted sound. The difference between sound and noise depends upon the listener and the circumstances. The roar of a jet engine can be of no use to those that live in the vicinity of an airport, but useful to someone alerted to the presence of an aircraft while in the flightpath of the vehicle.

In either case, it can be hazardous to a person's hearing if the sound is loud and they are exposed long and often enough.

Properties of Sound

The properties of sound which are important in the workplace are:

- Frequency (or pitch)
- Sound Pressure (or loudness, amplitude)
- Sound Power
- Time Duration

Frequency (or Pitch)

Frequency is the rate at which the source produces complete cycles of high and low pressure regions known as sound waves.

The term frequency refers to the number of times per second that a vibrating body completes one cycle of motion. The unit for frequency is the hertz (Hz). One Hz is equivalent to 1 cycle per second:

Low frequencies are associated with low pitched or bass sounds. High frequencies result in high-pitched or treble sounds.

A healthy, young person can hear sounds with frequencies from roughly 20 to 20,000 Hz. The sound of human speech is mainly in the range 300 to 3,000 Hz.

Frequency is also known as Pitch

Sound Pressure (Loudness or Amplitude)

Sound pressure is the amount of air pressure fluctuation a noise source creates. We "hear" or perceive sound pressure as loudness. If the drum in the example above is struck lightly, the surface moves only a very short distance from it’s position of rest and produces weak pressure fluctuations and a faint sound. If the drum is hit harder, its surface moves farther from its rest position. As a result, the pressure increase is greater. To the listener, the sound is louder.

Sound pressure also depends on the environment in which the source is located and the listener's distance from the source. The sound produced by the drum is louder closer to the drum than farther away. Also if there are hard surfaces that can reflect the sound (e.g. walls in a room), the sound will feel louder than if you heard the same sound, from the same distance, in a wide-open field.

Sound pressure is usually expressed in units called pascals (Pa).

Thus the common sounds we hear have sound pressure over a wide range (0.00002 Pa - 20 Pa). A healthy, young person can hear sound pressures as low as 0.00002 Pa. A normal conversation produces a sound pressure of 0.02 Pa. A gasoline-powered lawn mower produces about 1 Pa. The sound is painfully loud at levels around 20 Pa.

Sound Power

Sound power is the sound energy transferred per second from the noise source to the air. A noise source, such as a compressor or drum, has a given, constant sound power that does not change if the source is placed in a different environment.

Power is expressed in units called watts (W). An average whisper generates a sound power of 0.0000001 watts (0.1 microwatt (µW)), a truck horn 0.1 W, and a turbo jet engine 100,000 W.

Like sound pressure, sound power (in W) is usually expressed as sound power levels in dB.

What is the relation between sound pressure and sound power?

Because the sound power of a noise source is constant and specific, it can be used to calculate the expected sound pressure. The calculation requires detailed information about the noise source's environment. Usually a noise source with a lower sound power generates less sound pressure.

A manufacturer can often provide the sound power of equipment. A number of international standards are available for labeling machines and equipment with their noise emission levels. From the sound power of a compressor, one can calculate the expected sound pressure and sound pressure level at a certain location and distance. This information can be helpful in determining possible noise exposures and how they compare to the noise guidelines.

Time Duration

Length of time sound is present. Generally measured in units of seconds.

TEST YOURSELF

1. List the four properties of sound, their units and range (where applicable)

Properties of Sound	Units	Range (where applicable)

2. A healthy young person can hear can hear sounds in the FREQUENCY range:
    a. 0 to 20,000 Hz
    b. 20 to 20,000 Hz
    c. 300 to 3,000 Hz
    d. 300 to 20,000 Hz

3. The sound of human speech is mainly in the range FREQUENCY range
    a. 0 to 20,000 Hz
    b. 20 to 20,000 Hz
    c. 300 to 3,000 Hz
    d. 300 to 20,000 Hz

4. Sound PRESSURE is usually expressed in units
    a. Pascals (Pa)
    b. Hertz (Hz)
    c. Non-dimensional
    d. Watts (W)
    e. Volts
    f. Seconds (s)

5. A healthy young person can hear can hear sounds in the PRESSURE range:
    a. 0 Pa – 20 Pa
    b. 0.00002 Pa - 20 Pa
    c. 0.02 Pa – 20 Pa
    d. 20 Pa – 20,000 Pa

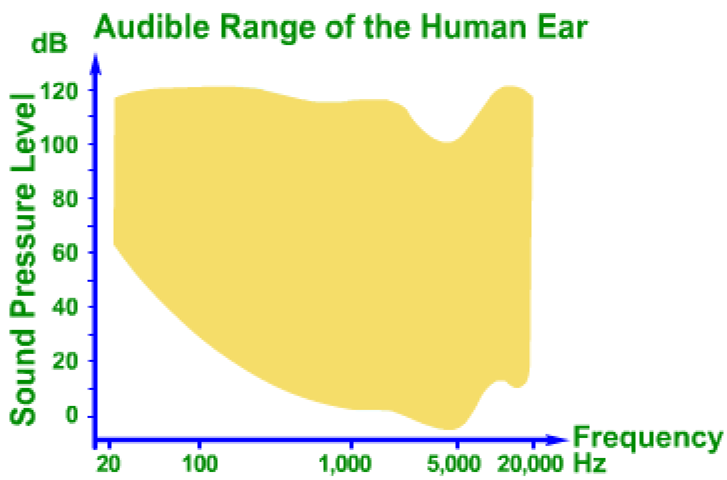
6. Sound POWER is usually expressed in units
    a. Pascals (Pa)

b. Hertz (Hz)
c. Non-dimensional
d. Watts (W)
e. Volts
f. Seconds (s)

7. Hearing

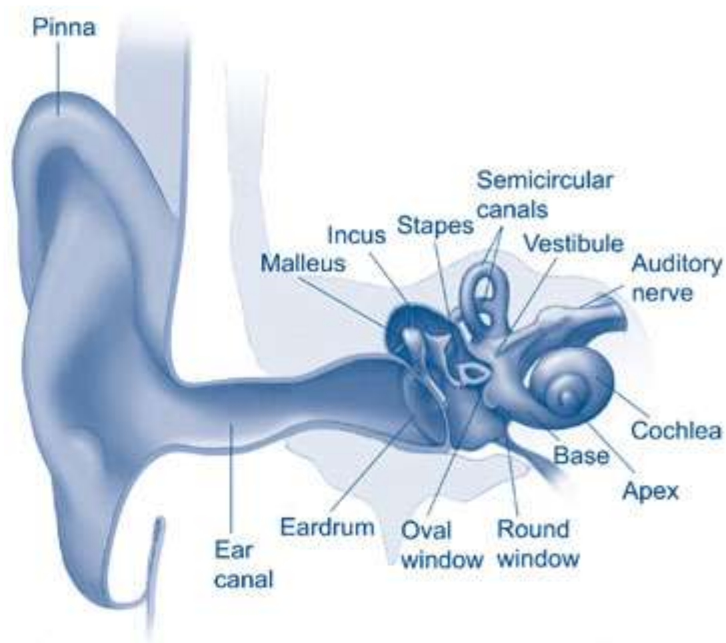
The hearing mechanism of the ear senses the sound waves and converts them into information which it relays to the brain. The brain interprets the information as sound. Even very loud sounds produce pressure fluctuations which are extremely small (1 in 10,000) compared to ambient air pressure (i.e., atmospheric pressure). The hearing mechanism in the ear is sensitive enough to detect even small pressure waves. It is also very delicate: this is why loud sound may damage hearing.

The response of the human ear to sound is dependent on the frequency of the sound. The audible frequency range for the human ear is 20Hz to 20,000 Hz. The human ear has peak response around 2,500 to 3,000 Hz and has a relatively low response at low frequencies.



Hearing depends on a series of events that change sound waves in the air into electrical signals. Our auditory nerve then carries these signals to the brain through a complex series of steps.

Video of ear mechanisms: http://www.youtube.com/watch?v=skXQ6PuIc4s&feature=related



1. Sound waves enter the outer ear and travel through a narrow passageway called the ear canal, which leads to the eardrum.

2. The eardrum vibrates from the incoming sound waves and sends these vibrations to three tiny bones in the middle ear. These bones are called the malleus, incus, and stapes.

3. The bones in the middle ear amplify, or increase, the sound vibrations and send them to the inner ear—also called the cochlea—which is shaped like a snail and is filled with fluid. An elastic membrane runs from the beginning to the end of the cochlea, splitting it into an upper and lower part. This membrane is called the "basilar" membrane because it serves as the base, or ground floor, on which key hearing structures sit.

4. The sound vibrations cause the fluid inside the cochlea to ripple, and a traveling wave forms along the basilar membrane. Hair cells—sensory cells sitting on top of the membrane—"ride the wave."

5. As the hair cells move up and down, their bristly structures bump up against an overlying membrane and tilt to one side. This tilting action causes pore-like channels, which are on the surface of the bristles, to open up. When that happens, certain chemicals rush in, creating an electrical signal.

6. The auditory nerve carries this electrical signal to the brain, which translates it into a "sound" that we recognize and understand.

7. Hair cells near the base of the cochlea detect higher-pitched sounds, such as a cell phone ringing. Those nearer the apex, or centermost point, detect lower-pitched sounds, such as a large dog barking.

TEST YOURSELF

1. The audible range of the human ear usually expressed by the properties of:
    a. Frequency and Pressure
    b. Frequency and Power
    c. Power and Frequency
    d. Frequency, Pressure and Power

2. The human ear is better at hearing:
    a. High frequencies than Low frequencies
    b. Low frequencies than High frequencies
    c. (a) and (b)
    d. Neither (a) nor (b)

3. Describe the roles of the Outer, Middle and Inner ear. Explain the transfortmations and the mechanisms involved in each section

4. Health Effects of Excessive Noise

Problems related to noise include hearing loss, stress, high blood pressure, sleep loss, distraction and lost productivity, and a general reduction in the quality of life and opportunities for tranquillity. The basic effect of excessive noise is Noise Induced Hearing Loss (NIHL).

Noise-induced Hearing Loss (NIHL)

Humans are continuously experiencing sounds in our environment such as iPods, cellphones, household appliances, and traffic. Normally, we hear these sounds at safe levels that do not affect our hearing. However, when we are exposed to harmful noise—sounds that are too loud or loud sounds that last a long time—sensitive structures in our inner ear can be damaged, causing noise-induced hearing loss (NIHL). These sensitive structures (hair cells) are small sensory cells that convert sound energy into electrical signals that travel to the brain. Once damaged, our hair cells cannot grow back.

NIHL can be caused by a one-time exposure to an intense “impulse” sound, such as an explosion, or by continuous exposure to loud sounds over an extended period of time, such as noise generated in a woodworking shop.

- Sources of noise that can cause NIHL include motorcycles, firecrackers, and small firearms, all emitting sounds from 120 to 150 decibels.
- Long or repeated exposure to sounds at or above 85 decibels can cause hearing loss. The louder the sound, the shorter the time period before NIHL can occur. Sounds of less than 75 decibels, even after long exposure, are unlikely to cause hearing loss.

Although being aware of decibel levels is an important factor in protecting one’s hearing, distance from the source of the sound and duration of exposure to the sound are equally important. A good rule of thumb is to avoid noises that are “too loud” and “too close” or that last “too long.”

Exposure to harmful sounds causes damage to the hair cells as well as the auditory, or hearing, nerve (see figure). Impulse sound can result in immediate hearing loss that may be permanent. This kind of hearing loss may be accompanied by tinnitus—a ringing, buzzing, or roaring in the ears or head—which may subside over time. Hearing loss and tinnitus may be experienced in one or both ears, and tinnitus may continue constantly or occasionally throughout a lifetime.

Continuous exposure to loud noise also can damage the structure of hair cells, resulting in hearing loss and tinnitus, although the process occurs more gradually than for impulse noise.

Exposure to impulse and continuous noise may cause only a temporary hearing loss. If a person regains hearing, the temporary hearing loss is called a temporary threshold shift. The temporary threshold shift largely disappears 16 to 48 hours after exposure to loud noise. You can prevent NIHL from both impulse and continuous noise by regularly using hearing protectors such as earplugs or earmuffs.

Scientists believe that, depending on the type of noise, the pure force of vibrations from the noise can cause hearing loss. Recent studies also show that exposure to harmful noise levels triggers the formation of molecules inside the ear that damage hair cells and result in NIHL. These destructive molecules play an important role in hearing loss in children and adults who listen to loud noise for too long.

Symptoms of NIHL

When a person is exposed to loud noise over a long period of time, symptoms of NIHL will increase gradually. Over time, the sounds a person hears may become distorted or muffled, and it may be difficult for the person to understand speech. Someone with NIHL may not even be aware of the loss, but it can be detected with a hearing test.

Who is affected by NIHL?

People of all ages, including children, teens, young adults, and older people, can develop NIHL. Approximately 15 percent of Americans between the ages of 20 and 69—or 26 million Americans—have high frequency hearing loss that may have been caused by exposure to loud sounds or noise at work or in leisure activities. Recreational activities that can put someone at risk for NIHL include target shooting and hunting, snowmobile riding, woodworking and other hobbies, playing in a band, and attending rock concerts. Harmful noises at home may come from lawnmowers, leaf blowers, and shop tools.

NIHL is 100 percent preventable. All individuals should understand the hazards of noise and how to practice good hearing health in everyday life. To protect hearing, know and avoid which noises can cause damage (those at or above 85 decibels).

5. Noise Measurements and Metrics

This section describes the measures and metrics used to quantify noise.

Measures:

1. Decibel (dB)
2. A-weighted Decibel (dBA)
3. Effective Perceived Noise Level (EPNL)

Metrics for Single Noise Events:

4. L_{Max}
5. Sound Exposure Level (SEL)

Metrics for Cumulative Noise Events

6. Equivalent Noise Level (Leq)
7. Day-night Average Sound Level (DNL)
8. DNL Noise Contours

Decibels

Sound has properties of sound pressure, frequency, power and time duration. Sound pressure is expressed in units called pascals (Pa). The audible range of sound pressure level for human is 0.00002Pa to 20Pa.

It is difficult to work with such a broad range of sound pressures. To overcome the wide range of sound pressure measured in pascals the unit of sound level has been converted to a logarithmic scale know as the decibel (dB, or tenth (deci) of a Bel)). The decibel or dB scale compresses the scale of numbers into a manageable range.

Review of Logarithms

The "log" or logarithm of a number is a mathematical manipulation of the number, based on multiples of 10. It is the exponent that indicates the power to which the number 10 is raised to produce a given number. For example, the logarithm of 10 is 1 since 10 is multiplied by itself only once to get 10. Similarly, the logarithm of 100 is 2 since 10 times 10 is 100. The logarithm of 1000 is 3 since 10 times 10 times 10 is 1000.

log(1) = 0 Since 10 to the exponent 0 = 1,
log(10) = 1 since 10 to the exponent 1 = 10,
log(100) = 2 since 10 to the exponent 2 = 100,
log(1000) = 3 since 10 to the exponent 3 = 1000

The logarithm scale simply compresses the large span of numbers into a manageable range. In other words, the scale from 10 to 1000 is compressed, by using the logarithms, to a scale of 1 to 3.

Sound Pressure in Decibels

Sound pressure level in decibels is defined as:

dB = 20 log (Sound Pressure/Reference Pressure)

The decibel scale for sound pressures uses as the reference pressure the lowest noise that the healthy young person can hear (0.00002 Pa). It divides all other sound pressures by this amount when calculating the decibel value. Sound pressures converted to the decibel scale are called sound pressure levels, abbreviated Lp.

The sound pressure level (Lp) of the quietest noise the healthy young person can hear is calculated in this way:

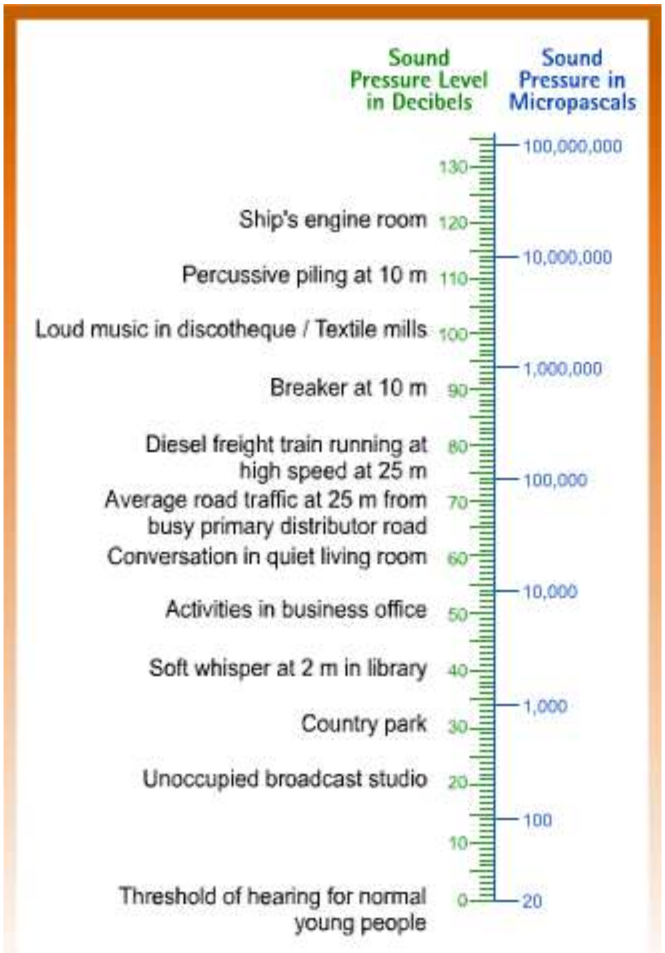
Lp = 20 log (0.00002/ 0.00002) = 20 log (1) = 20 X 0 = 0 dB

The sound pressure level (Lp) in a very quiet room, where the sound pressure is 0.002 Pa, is calculated:

Lp = 20 log (0.002/ 0.00002) = 20 log (100) = 20 X 2 = 40 dB

The sound pressure level of a typical gasoline-powered lawn mower, which has a sound pressure of 1 Pa, is calculated

Lp = 20 log (1/0.00002) = 20 log (50 000) = 20 X 4.7 = 94 dB



Relation between sound pressure in micropascals and sound pressure level in decibels re 20 μPa.

Decibel Math

The table below summarizes the addition, subtraction, multiplication and division of logarithmic measures used in the Decibel scale.

Change in sound energy	**Change in dB**
Sound energy doubled	3 dB increase
Sound energy halved	3 dB decrease
Sound energy increased by factor of 10	10 dB increase
Sound energy decreased by factor of 10	10 dB decrease
Sound energy increased by factor of 100	20 dB increase
Sound energy decreased by factor of 100	20 dB decrease

Adding and Subtracting Noise levels

What is the impact of two sound sources? Are the sound pressures superimposed? Can they be added or subtracted in the usual arithmetical way.

If one engine emits a sound level of 90 dB, and a second identical engine is placed beside the first, the combined sound level is 93 dB, not 180 dB.

The process for establishing the sound level from two independent sources is as follows;

Step 1: Determine the difference between the two levels and find the corresponding row in the left hand column.

Step 2: Find the number [dB or dB(A)] corresponding to this difference in the right hand column of the table.

Addition of Decibels	
Numerical difference between two noise levels [dB(A)]	Amount to be added to the higher of the two noise levels [dB or dB(A)]
0	3.0
0.1 - 0.9	2.5
1.0 - 2.4	2.0
2.4 - 4.0	1.5
4.1 - 6.0	1.0
6.1 - 10	0.5
10	0.0

Step 3: Add this number to the higher of the two decibel levels.

Example: Two engines each emitting a noise level of 90 dB:

- Step 1: The numerical difference between the two levels is 0 dB (90-90= 0), using the first row.
- Step 2: The number corresponding to this difference of 0, taken from the right hand column, is 3.
- Step 3: Add 3 to the highest level, in this case 90. Therefore, the resulting noise level is 93 dB.

When the difference between two noise levels is 10 dB(A) or more, the amount to be added to the higher noise level is zero. In such cases, no adjustment factor is needed because adding in the contribution of the lower in the total noise level makes no perceptible difference in what people can hear or measure. For example if your workplace noise level is 95 dB(A) and you add another machine that produces 80 dB(A) noise, the workplace noise level will still be 95dB(A).

Since sound pressure is inversely proportional to the square of the distance from the source, a formula can be developed to determine the dB values at any specific distance from the sound source. These estimations are not totally accurate, but can approximate sound levels in lieu of actual measurements.

12 Log10 (D2 / D1)

D2 = Distance from the source for the 2nd sound source
D1 = Distance from the source for the 1st sound source

Example:

D1 = 1 meter from the noise source
D2 = 7 meters from the noise source

12 log10(7) = 10 dBA reduction from 1 to 7 meters from the sound source

A-weighted Decibels

The sensitivity of the human ear to sound depends on the loudness as well as the frequency (or pitch of the sound). People hear some frequencies better than others. If a person hears two sounds of the same sound pressure but different frequencies, one sound may appear louder than the other. This occurs because people hear high frequency noise much better than low frequency noise. For example, the human ear is significantly more sensitive to noise in the region of 6 kHz than to tones of equivalent level.

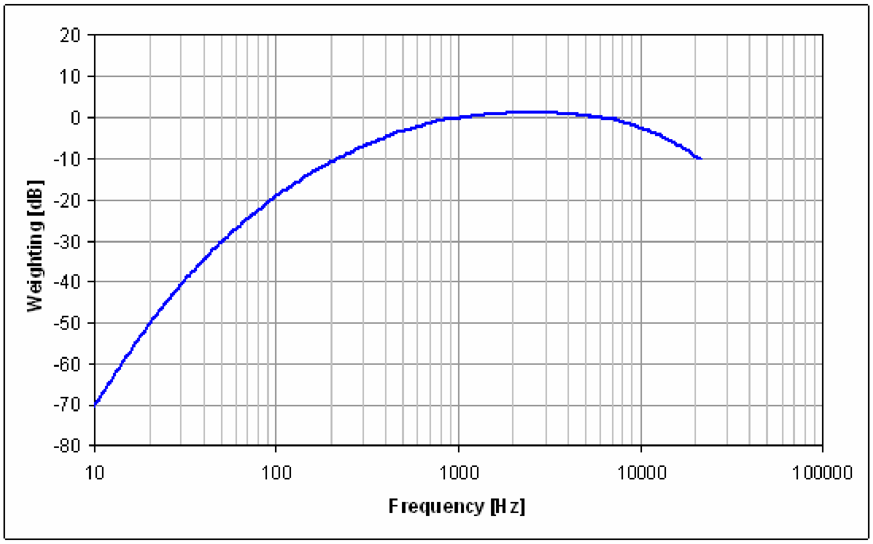
Noise measurement readings can be adjusted to correspond to this peculiarity of human hearing. The units of measure are known as A-weighted decibels (dBA).A-weighting serves two important purposes: 1. gives a single number measure of noise level by integrating sound levels at all frequencies, 2. gives a scale for noise level as experienced or perceived by the human ear.

The A-weighting value in decibels as a funcion of frequency is given by:

$$W_A = 10Log\left[\frac{1.562339 f^4}{\left(f^2 + 107.65265^2\right)\left(f^2 + 737.86223^2\right)}\right] + 10Log\left[\frac{2.242881 x 10^{16} f^4}{\left(f^2 + 20.598997^2\right)^2\left(f^2 + 12194.22^2\right)^2}\right]$$

where

W_A = weighting to be applied, dB
f = frequency, Hz



Typical Noise Levels dBA	
Noise Source	**dB(A)**
pneumatic chipper at 1 metre	115
hand-held circular saw at 1 metre	115
textile room	103
newspaper press	95
power lawn mower at 1 metre	92
diesel truck 50 km per hour at 20 metres	85
passenger car 60 km per hour at 20 metres	65
conversation at 1 metre	55
quiet room	40

Effective Perceived Noise Level (EPNL)

Jet engines are perceived to be noisier than propeller aircraft because of differences in the spectrum of the noise they produce.

EPNL measurements consist of a frequency weighting scheme that incorporates a penalty for the presence of *pure tones* to account for people's increased annoyance with single frequencies, such as the tones emanating from the compressor of turbofan engines.

$$EPNL = PNL_{max} + 10 \log (t_{10}/20) + F \text{ (dB)}$$

Where:

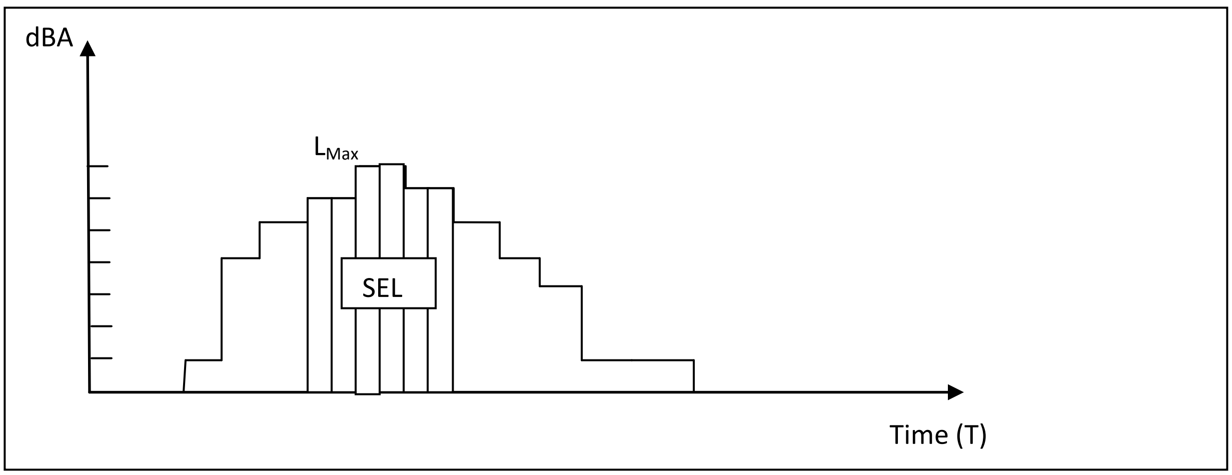
- PNL_{max} is the maximum perceived noise level during flyover in PNdB
- t_{10} is the duration (in seconds) of the noise level within 10 dB of the peak PNL,
- *F* is a correction for pure tones (which are generally found to be more annoying than broad band noise without perceived tones). In practice, *F* is about +3 dB.

Measures of a Single Noise Event

There are two most commonly used measures of a Noise event:

1. Maximum Sound Level (LMax)
2. Sound Exposure Level (SEL).

Audible noise event (e.g. generated by an aircraft movement) lasts for a period of time T, and can be defined by the A-weighted measure of noise loudness dBA. Readings taken for each time instant Δt represent the sound level at time $i\Delta t$ where is an integer $1 \le i \le N$.



L_{Max} is a measure of the maximum sound level reached during T. L_{Max} is the highest dBA recorded. If L_i denotes the sound level recorded at each instant Δt for $1 \le i \le N$, then

$$LMax = \max_{1 \le i \le N} L_i$$

SEL is a single measure of all the sound level readings recorded during period T. SEL is the “total noise impact” of a noise event on listener. SEL is a measure of the area under the L(t) curve adjusted for the logarithmic scale.

$$SEL = 10 \log \left(\sum_{i=1 \text{ to } N} 10^{Li/10} \Delta t\right) \quad \text{where } \Delta t = 1 \text{ sec}$$

In practice, SEL is computed using only the readings within 10 dbA of L_{Max}. Due to the logarithmic scale, the contribution to SEL is dominated by the readings within 10dBA of Lmax.

Note: SEL will, by definition have a higher value than LMax.

Example:

Compute LMax and SEL for the following noise event.

a) Compute LMax
b) Identify noise readings for computation of SEL
c) Compute SEL

Instant of Time	**dBA**
1	81.6
2	91.3
3	98.2
4	94.7
5	94.2
6	93.3
7	92.9
8	85.8
9	83.7
10	73.1
11	72.9
12	71.1
13	62.3
14	51.7
15	42.8

Measures of Noise - Cumulative Events

Cumulative measures of noise estimate the impact of the noise for series of noise events. These measures are based noise readings at a particular location (e.g. housing development near an airport) over a period of time (e.g. 24 hours). The cumulative measures combine the loudness of the event with the frequency of events by adding logarithmically the SEL values associated with each noise event.

Two cumulative noise measures are used:

(1) Equaivalent Noise level (Leq)
(2) Day-night Average Sound Level (DNL or LDN).

Leq is the average SEL of noise per unit time (1 second) during the specified time period. For example, the Leq for a day is the sum of the SEL events during that day divided by 86,400 seconds (i.e. 60 secs/min * 60 mins/hr * 24 hours/day = 86,400 seconds in a day).

$$L_{eq} = 10 \log (1/T \sum 10^{SELj/10})$$

L_{DN} is Leq adjusted for nighttime noise with a penalty of 10dBA for each SEL nighttime movement. Nightime is defined as 10pm to 6am.

$$L_{DN} = 10 \log [1/ 86{,}400 (\sum_{i=1 \text{ to } J} 10^{SELj/10} + (\sum_{i=1 \text{ to } K} 10^{SELk +10/10}))$$

Where there are J day-time events, and K night-time events.

The L_{DN} equation counts one night time SEL event as equivalent to ten day-time SEL events.

L_{DN} Noise Contours

Day-Night Levels (L_{DN}) are used to generate noise contours in the vicinity of an airport. The noise contours define the locations that experience L_{DN} within range of DNL (e.g. > 75 DNL, 65 to 75 DNL).

Collecting noise data is prohibitively expensive and can be complicated by ambient noise of noises from other sources. As a result, noise contours are typically generated by simulations of air traffic in the vicinity of airports. For example, the FAA's Integrated Noise Model (INM) take as inputs the aircraft-type in the fleet mix at the airport, proportion of each type in the schedule, and information on runway configurations. The INM generates flight arrival/departure trajectories and estimates the SEL at locations in the vicinity of the airport. The SEL values are used to compute the L_{DN} values that are in turn used to create noise contours.

Calculating Average Annual DNL for an Airport through Simulation

There are four generic steps:

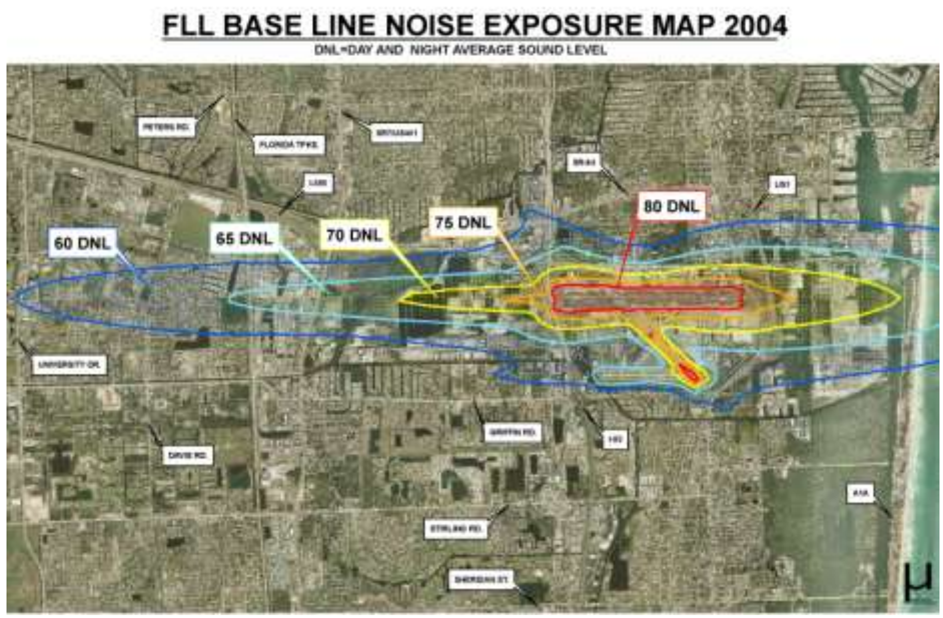
1. Sample 30-60 days of arrival and departure radar tracks throughout the year to generate an "annualized" average 24-hour set of flights and trajectories.
2. For each segment of each trajectory (e.g. takeoff, initial climb out) compute the Thrust generated. The thrust is then used to compute noise. The slant range distance from each segment to a grid of observers on the ground is calculated. The equations of state of the aircraft are defined in SAE AIR 1845 Equations
3. SEL is computed for each observer for each flight segment as a function of engine power setting and distance (slant range) from aircraft to observer
4. The Total Noise Impact DNL for each observer is calcumated for all the flights for all the days

$DNLj = 10 \log10 (1/T) \{ \Sigma day\_flights\ \Sigma segments\ 10SEL(ij)/10 + \Sigma night\_flights\ \Sigma segments\ 10[SEL(ij)+10]/10 \}$

Where:

T = dosage period (e.g., 24 hours)

Broward County airport noise contours. Areas in the red contour is > 80 DNL. These areas include the long east/west runway and the departure end of the north-west/south-east runway.



Example FAR part 150 Noise Contour Analysis for Seattle-Tacoma Airport. This table details the number of people and type of activities impacted by each level of DNL.

Table 1
EXISTING LAND USE WITHIN FUTURE NOISE EXPOSURE MAP CONTOURS, 2006
King County International Airport FAR Part 150 Study

Land Use	DNL 55 Contour		DNL 60 Contour		DNL 65** Contour		DNL 70** Contour		DNL 75** Contour	
Residential*	NA	Ac	NA	Ac	459	Ac	66	Ac	0	Ac
People	50,807		15,594		4,255		672		0	
House. Units	20,490		6,484		1,882		328		0	
Schools	NA		NA		1		0		0	
Historical Sites	NA		NA		2		2		0	
Fire Stations	NA		NA		2		2		1	
Com/Retail	NA	Ac	NA	Ac	186	Ac	83	Ac	2	Ac
Manufacture	NA	Ac	NA	Ac	863	Ac	322	Ac	79	Ac
Other	NA	Ac	NA	Ac	1,357	Ac	689	Ac	418	Ac
Total	**17,100**	**Ac**	**6,833**	**Ac**	**2,865**	**Ac**	**1,160**	**Ac**	**499**	**Ac**

*Based on FAA Part 150 Land Use Compatibility Guidelines, residential land uses and schools are considered compatible with sound attenuation. Cleveland School is within the Future KCIA 65 DNL noise contour.

**It should also be noted that only those non-compatible land uses within the 65 and greater DNL contours are eligible for FAA funding participation.

TEST YOURSELF

1. Logarithms are used for measuring sound pressure because they
    a. Convert small numbers into large numbers
    b. Compress a scale with a wide range of numbers into a manageable range
    c. Expand a scale with a narrow range of numbers into a manageable range
    d. Adjust for outliers to make for a manageable range

2. The equation for Decibels is shown below

    dB = 20 log (a/b).

    The variables **a** and **b** represent:

    a. a = Actual Sound Pressure, b = Reference Sound Pressure
    b. a = Reference Sound Pressure, b = Actual Sound Pressure
    c. a = Actual Sound Pressure, b = Speed of Sound

3. The Sound Pressure in Decibels of a lawn mower with Sound Pressure of 1 Pa is

   Lp = 20 log (______ / _______) = _________ dB

4. The Sound Pressure in Decibels of the quietest sound audible by the human ear with Pressure of 0.00002Pa is

   Lp = 20 log (______ / _______) = _________ dB

5. Match the left hand column Change in Sound with the right column Change in dB

Change in Sound		**Change in dB**
Sound energy doubled		20 dB decrease
Sound energy halved		3 dB increase
Sound energy increased by factor of 10		3 dB decrease
Sound energy decreased by factor of 10		10 dB increase
Sound energy increased by factor of 100		10 dB decrease
Sound energy decreased by factor of 100		20 dB increase

6. Describe the process for calculating the sound level from two independent sources

7. If the sound level from two independent sources at the same location is greater than 10dB difference, the total sound is
   a. Sum of the two independent sound levels
   b. The difference between the two independent sound levels

c. The maximum of the two independent sound levels
d. The maximum of the two independent sound levels

8. Calculate the sound from two engines side-by-side emitting a noise level of 90 dB and 92 dB

9. The symbol for A-Weighted noise levels is

   a. dBA
   b. A-dB
   c. dB_A

10. The A-Weighted noise levels accounts for peculiarities of the way the human ear perceives noise by weighting:
    a. Pressure and Temperature
    b. Frequency and Duration
    c. Pressure and Frequency
    d. Frequency and Power

11. Effective Perceived Noise Levels (EPNL) accounts for: CIRCLE ALL THAT APPLY

    a. Noise level
    b. Frequency
    c. (pure) Tones (i.e. single frequencies)
    d. Duration
    e. Nigh-time noise events

12. Match each term of calculation with its definition

    A. L_{max} ______ takes into account all the noise readings during a given time period
    B. SEL ______ a generic metric for cumulative noise events
    C. L_{eq} ______ standard metric of the FAA for cumulative noise events adjusted for night-time noise
    D. L_{dn} ______ measures the highest sound level reached during a given time period

13. Match each term of calculation with its correct formula

    A. L_{dn} ______ $10 \cdot \log\left(\frac{1}{T}\sum_{j=1}^{M} 10^{SEL_j/10}\right)$

    B. L_{max} ______ $10 \cdot \log\left(\int_{O}^{T} 10^{L(t)/10}\, dt\right)$

C. SEL _____ $10 \cdot \log\left[\frac{1}{86{,}400}\left(\sum_{j=1}^{J} 10^{SEL_j/10} + \sum_{k=1}^{K} 10^{(SEL_k+10)/10}\right)\right]$

D. L_{eq} _____ $\max_{0 \le t \le T} L(t)$

11. The readings of a noise sensor near .an airport during the 15 “loudest” seconds of a noise event are given below. Readings are in dBA taken a 1-s intervals

1	2	3	4	5	6	7	8	9	10	11	12
81.6	91.3	73.4	94.7	94.2	93.3	72.9	85.8	73.1	83.7	72.9	71.1

13	14	15
79.3	95.4	73.1

First, identify L_{max}, then find the SEL.

Solution

L_{max} = 95.4 dBA

$$SEL = 10 \cdot \log[(10^{81.6/10} + 10^{91.3/10} + 10^{73.4/10} + 10^{94.7/10} + 10^{94.2/10} + 10^{93.3/10} + 10^{72.9/10} + 10^{85.8/10} + 10^{73.1/10} + 10^{83.7/10} + 10^{72.9/10} + 10^{71.1/10} + 10^{79.3/10} + 10^{95.4/10} + 10^{73.1/10})(1)] =$$

$$10 \cdot \log(1349463257) \approx 101.3\text{dBA}$$

14. A noise sensor located near an airport captures noise events. During the first 10 minutes of monitoring, one aircraft arrives producing an A-weighted SEL of 92dB. During the next 10 minutes, another aircraft produces an A-weighted SEL of 97dB
    a. What is the A-weighted equivalent continuous noise level over the first ten minutes
    b. What is the A-weighted equivalent continuous level over the full 20 minutes?

Solution

Leq = 10log[(1/(10*60))* ($10^{92/10}$ *1)] = 64.2dB

Leq = 10 log { [($10^{92/10}$ * 1) + ($10^{97/10}$ *1)] / [20 * 60]} = 67.4dB

12. Consider the situation in which 10 noise events generated by landing and departing aircraft occurred at a particular location, 8 during daytime and 2 during nighttime. The associated SEL values are 73.2, 71.9, 71.5, 82.7, 86.6, 84.9, 75.1, and 77.2 dBA for the daytime events and 78.4, and 87.8 dBA for the nighttime events. Assume that the first three daytime events took place between 10 and 11 AM. First, find the equivalent sound level (L_{eq}) and then find the day-night average sound level (L_{dn}).

$$L_{eq} = 10 \cdot \log\left[\frac{1}{3600}\left(10^{73.2/10} + 10^{71.9/10} + 10^{71.5/10}\right)\right] = 41.5\,\text{dBA}$$

$$L_{dn} = 10 \cdot \log\left(10^{73.2/10} + 10^{71.9/10} + 10^{71.5/10} + 10^{82.7/10} + 10^{86.6/10} + 10^{84.9/10} + 10^{75.1/10} + 10^{77.2/10} + \right.$$

$$\left. + 10^{88.4/10} + 10^{97.8/10}\right) - 49.4 = 49.5\,\text{dBA}$$

13. Describe the four steps for generating DNL Noise contours for an airport.
14. With reference to the Noise contour for Broward County Airport (above), which runway (east or west) is generally used for takeoffs? Which runway (east or west) is generally used for departures? Explain.

15. Design and Operations Standards

The "noise climate" is a function of the noise levels made by each aircraft and the number of aircraft.

World Health Organization (WHO) recommends that L_{DN} of 50 dBA in exterior sound levels is necessary to ensure that noise will not have an adverse health effect.

Airport Standards

NOISE CONTROL ACT of 1972: "The Congress declares that it is the policy of the United States to promote an environment for all Americans free from noise that jeopardizes their health or welfare."

Aviation Safety and Noise Abatement Act of 1979 (ASNA)

FAA Part 150 Study

Federal Aviation Regulations (FAR) Part 150, *Airport Noise Compatibility Planning,* sets standards for noise compatibility planning.

Prescribes the procedures, standards, and methodology governing the development, submission, and review of airport noise exposure maps and airport noise compatibility programs, including the process for evaluating and approving or disapproving those programs.

Part 150 prescribes single systems for—(a) measuring noise at airports and surrounding areas that generally provides a highly reliable relationship between projected noise exposure and surveyed reaction of people to noise; and (b) determining exposure of individuals to noise that results from the operations of an airport.

Part 150 also identifies those land uses which are normally compatible with various levels of exposure to noise by individuals. It provides technical assistance to airport operators, in conjunction with other local, State, and Federal authorities, to prepare and execute appropriate noise compatibility planning and implementation programs.

A Part 150 submission to the FAA includes two elements:

- Noise Exposure Maps (NEMs) – Existing (e.g. 2005) and future (e.g. 2012) noise exposure
- Noise Compatibility Program (NCP) – Measures to abate and mitigate noise impacts above 65 DNL

DNL contour (limits of FAA policy)

Why do a Part 150 Study?
A Part 150 Study is entirely voluntary, typically prepared to:

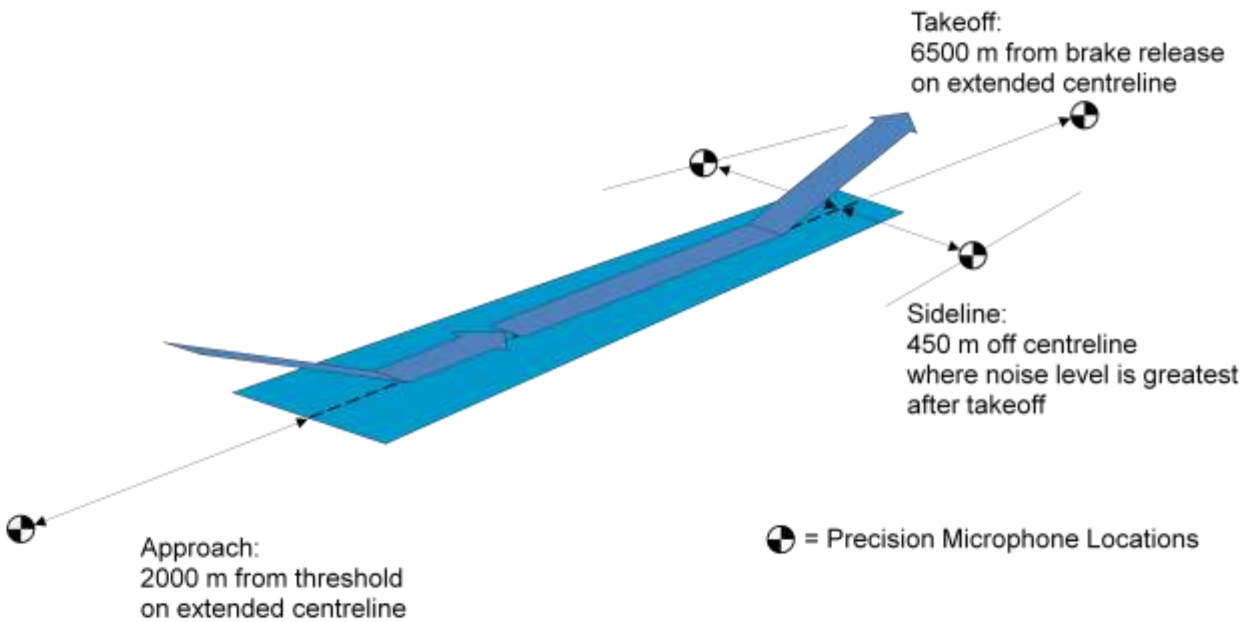
- Qualify the airport sponsor for federal funds for noise mitigation
- Obtain FAA approval and implementation of noise abatement measures

Aircraft Standards

Noise levels from individual aircraft are regulated by the noise certification requirements in the Federal Aviation Regulations (FAR) Part 36 and by the Convention on International Civil Aviation (ICAO) Annex 16.

EPNL (Effective Perceived Noise Level), measured in EPNdB, are used to assess aircraft noise. This measure of noise accounts for loudness as well as the tonal content of the spectrum and the time which the aircraft noise remains within 10dB of the peak noise.

The EPNL measurements are taken at three locations in a landing-takeoff cycle: approach measuring point under the glideslope, takeoff measuring point under the takeoff flightpath, and sideline measuring point abeam takeoff path at rotate end of runway.



The noise standards vary by aircraft type and increase linearly as function of aircraft takeoff weight (i.e. bigger aircraft can generate more noise). The certification standards are grouped into categories of aircraft known as Stage 1, 2,3, 4.

Stage 1
A Stage 1 noise level means a take-off, flyover, or approach noise level greater than the Stage 2 noise limits. Stage 1 aircraft were eliminated or retrofit meet Stage 2 standards by 1980.

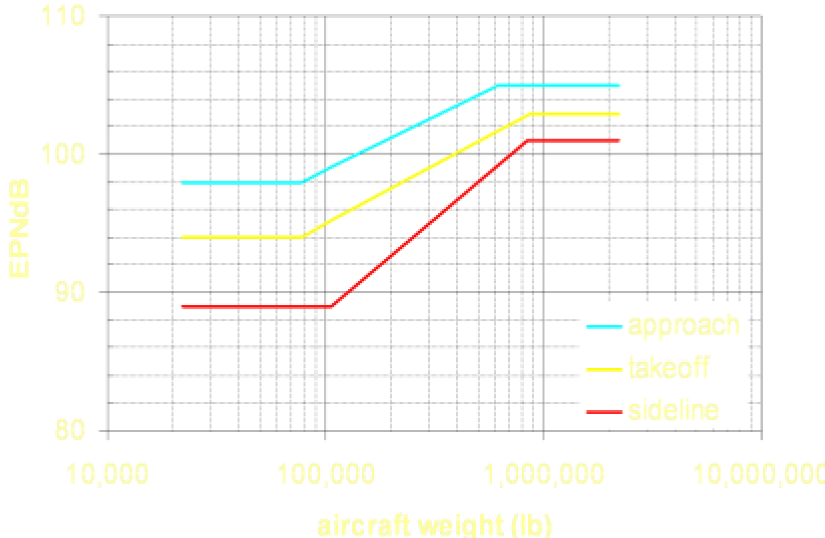
Stage 2
Stage 2 noise limits for airplanes regardless of the number of engines are as follows:

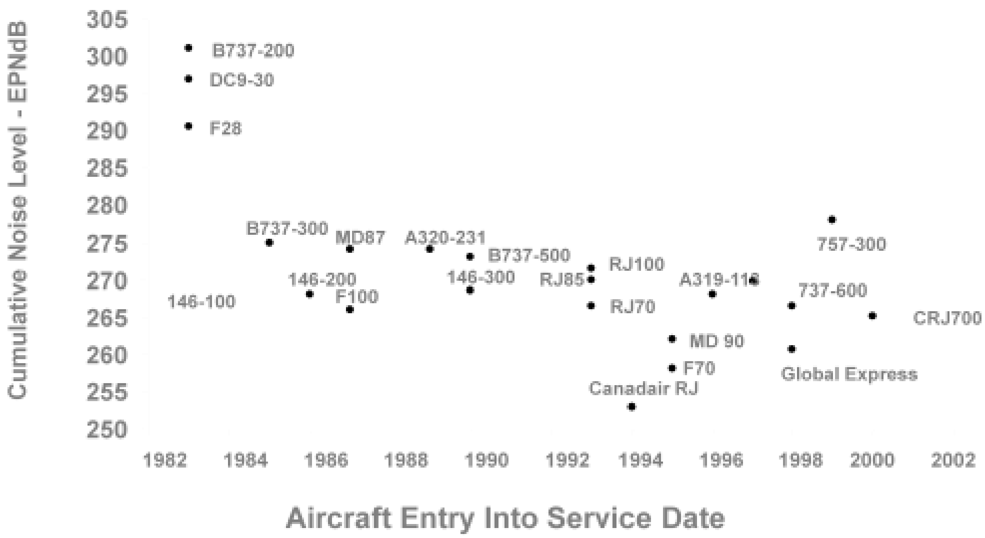
- **For Take-off:** 108 EPNdB for maximum weights of 600,000 pounds or more, reduced by 5 EPNdB per halving of the 600,000 pounds maximum weight down to 93 EPNdB for maximum weights of 75,000 pounds and less.
- **For Sideline and Approach:** 108 EPNdB for maximum weights of 600,000 pounds or more, reduced by 2 EPNdB per halving of the 600,000 pounds maximum weight down to 102 EPNdB for maximum weights of 75,000 pounds or less.

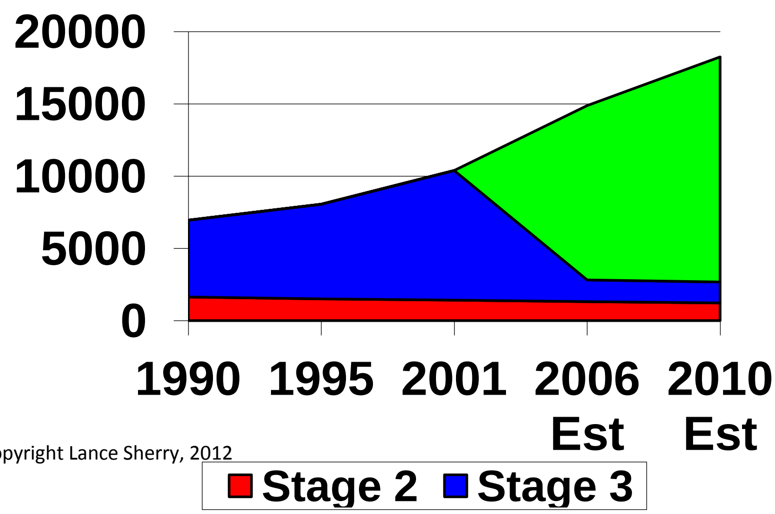
Stage 2 aircraft were retrofit or eliminated from service in 2003.

Stage 3
Stage 3 noise limits are as follows:

- **For Take-off:** airplanes with more than 3 engines 106 EPNdB for maximum weights of 850,000 pounds or more, reduced by 4 EPNdB per halving of the 850,000 pounds maximum weight down to 89 EPNdB for maximum weights of 44,673 pounds or less.
- **For Take-off:** airplanes with 3 engines 104 EPNdB for maximum weights of 850,000 pounds or more, reduced by 4 EPNdB per halving of the 850,000 pounds maximum weight down to 89 EPNdB for maximum weights of 63,177 pounds or less.
- **For Take-off:** airplanes with fewer than 3 engines 101 EPNdB for maximum weights of 850,000 pounds or more, reduced by 4 EPNdB per halving of the 850,000 pounds maximum weight down to 89 EPNdB for maximum weights of 106,250 pounds or less.
- **For Sideline:** regardless of the number of engines 103 EPNdB for maximum weights of 882,000 pounds or more, reduced by 2.56 EPNdB per halving of the 882,000 pounds maximum weight down to 94 EPNdB for maximum weights of 77,200 pounds or less.
- **For Approach:** regardless of the number of engines 105 EPNdB for maximum weights of 617,300 pounds or more, reduced by 2.33 EPNdB per halving of the 617,300 pounds maximum weight down to 98 EPNdB for maximum weights of 77,200 pounds or less.


110
100
90
80
EPNdB
approach
takeoff
sideline
10,000
100,000
1,000,000
10,000,000
aircraft weight (lb)


Cumulative Noise Level - EPNdB
305
300
295
290
285
280
275
270
265
260
255
250
B737-200
DC9-30
F28
B737-300
MD87
A320-231
B737-500
146-200
146-300
RJ100
RJ85
A319-114
757-300
737-600
146-100
F100
RJ70
CRJ700
MD 90
F70
Global Express
Canadair RJ
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
Aircraft Entry Into Service Date


20000
15000
10000
5000
0
1990
1995
2001
2006 Est
2010 Est
Stage 2
Stage 3

16. <u>Noise Mitigation Strategies</u>

The problem of pollution is a phenomenon known as the Tragedy of the Commons. By putting something in (i.e. sewage, or chemical, radioactive, and heat wastes into water; noxious and dangerous fumes into the air), the rational agent finds that their share of the cost of the pollution discharged into the commons is less than the cost of mitigation or purifying the pollution. Since this is true for all parties sharing the common, they are locked into a system of "fouling our own nest," so long as we behave only as independent, rational, free enterprisers.

<u>Tragedy of the Commons</u>

Picture a pasture open to all farmers for grazing their cattle.

To maximize their return on their investment, each farmer will try to keep as many cattle as possible on the commons.

Such an arrangement may work reasonably satisfactorily for centuries because tribal wars, poaching, and disease keep the numbers of both man and beast well below the carrying capacity of the land.

Finally, however, comes the day of reckoning, that is, the day when the long-desired goal of social stability becomes a reality. At this point, the inherent logic of the commons remorselessly generates tragedy.

As a rational being, each farmer seeks to maximize his gain. Explicitly or implicitly, more or less consciously, he asks, "What is the utility *to me* of adding one more animal to my herd?" This utility has one negative and one positive component.

1. The positive component is a function of the increment of one animal. Since the farmer receives all the proceeds from the sale of the additional animal, the positive utility is nearly + 1.

2. The negative component is a function of the additional overgrazing created by one more animal. Since, however, the effects of overgrazing are shared by all the herdsmen, the negative utility for any particular decisionmaking herdsman is only a fraction of - 1.

Adding together the component partial utilities, the rational farmer concludes that the only sensible course is to add another animal to his herd. And another....

But this is the conclusion reached by each and every rational herdsman sharing a commons. Therein is the tragedy. Each man is locked into a system that compels him to increase his herd without limit — in a world that is limited.

Ruin is the destination toward which all men rush, each pursuing his own best interest in a society that believes in the freedom of the commons. Freedom in a commons brings ruin to all.

Operational Mitigation Strategies

Thrust reduction following takeoff. To ensure safe margins for flight, aircraft use maximum thrust ofr the takeoff, then cut-back thrust to a maximum climb thrust at 1500'. Although this thrust-cutback reduces noise, it also reduces the rate of climb, dispersing less noise for a longer period of time.

Preferred Noise Routes – departure and arrival procedures are designed with flightpaths that do not overfly residential areas.

Constant Descent Arrival – allow flights to descend with close to idle thrust from the Cruise flightlevel. CDA's also eliminate level segments, known as" dive and drive," by directly lining up on the glideslope.

Monitoring and Penalties

Curfews and Restrictions

TEST YOURSELF

1. Describe the "tragedy of the commons." Explain why the tragedy of the commons cannot be averted.

2. Match the Noise mitigation approaches with their descriptions:

A. Noise monitoring systems	_____ influencing airports to operate within stated noise ranges by giving them money for following these ranges and penalizing them when they don't
B. Community relations and public participation programs	_____ soundproofing surrounding buildings and acquiring surrounding property through the real estate market or by applying eminent domain
C. Land-use policies	_____ demonstrating to the public at large an airport's concern about its negative environmental impacts and its commitment to alleviating problems in concert with the affected communities

D. Airport design interventions	_____Allowing noise at airports to be reported and recorded to a central computer for noise analysis and reporting
E. Surface operations and flight operations	_____inhibiting the way an airport operates by placing limitations on the aircraft types at an airport and the times of day an airport can operate
F. Interventions outside airport property	_____reducing noise impacts on airport neighbors by a number of possible modifications, adjustments, or additions to the physical layout and structures on the airport property.
G. Access restrictions	_____applying proactive action that attempts to anticipate future problems and attempt to forestall them though judicious planning in the form of zoning restrictions and building codes
H. Economic incentives	_____ placing restrictions on both noise and engine emissions