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about SOUND

U.S. ENVIRONMENTAL PROTECTION AGENCY

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U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF NOISE ABATEMENT AND CONTROL
WASHINGTON, D.C. 20460
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ABOUT SOUND

This booklet is intended for anyone requiring a knowledge of the fundamentals of acoustics and noise. It provides enough detail to allow the reader to become familiar with the physical phenomenon of sound and how it is propagated, described, and, to a certain degree, perceived. A bibliography is provided for those requiring more detailed technical information on specific aspects of this expansive subject.

Basic Properties of Sound Waves

Sound waves occur in a medium having the properties of mass and elasticity. For our purposes, this medium is considered to be air.

Air consists of gas molecules that are distributed fairly evenly and that move around in a random fashion. Air exerts a pressure (atmospheric) of about 14.7 $lb/in.^2$, which is roughly equivalent to 10^6 $dynes/cm^2$. This atmospheric pressure is directly related to the density (mass per unit volume) of the air.

Because air possesses both inertia and elasticity, sound waves can be propagated in it. The inertia of air is due to its weight, 0.075 pound per cubic foot. Elasticity is the characteristic that tends to pull a displaced particle (the molecule) back to its original resting position. The transfer of momentum, through molecular displacement, from the displaced molecule to an adjacent one is the mechanism of sound wave propagation.

When a vibrating object moves outward it compresses a layer of air surrounding it. This compression travels outward, dissipating in relation to the energy that created it. As the vibrating object moves inward, the surrounding air is rarefied. This rarefaction travels outward in a manner similar to the compression. The result is therefore a series of alternating compressions and rarefactions, in sympathy with the vibrations. This is illustrated in figure 1.

The number of times per second that the wave passes from a period of compression, through a period of rarefaction, and starts another compression period is referred to as the frequency of the wave. Frequency

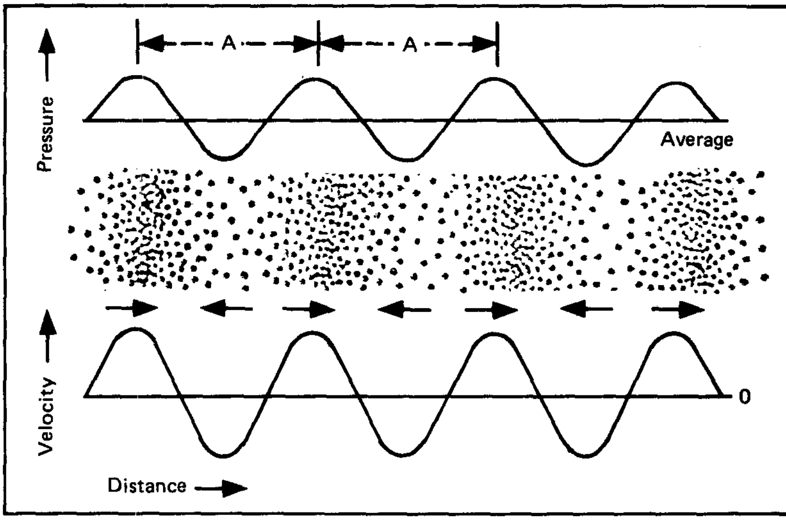

Figure 1

The upper curve in the figure shows how pressure varies above and below average with distance at a given time. The lower curve shows how velocity varies, above zero (that is, molecules moving to the right) and below zero (that is, molecules moving to the left). The distance (A) between crests of both curves is the wavelength of the sound.

is expressed in cycles per second, or hertz (Hz). The distance traveled by the wave through one complete cycle is referred to as the wavelength (Figure 2).

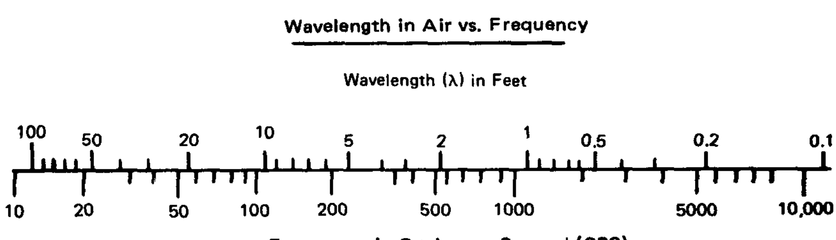

Figure 2

The rate at which the molecular displacement occurs is termed the particle velocity of the wave, or displacement per unit of time. This is illustrated in Figure 3. Under normal conditions of temperature and pressure, the velocity of sound in air is 1100 feet per second.

> Note: Wavelength vs. Frequency. The higher the frequency, the shorter the wavelength and vice versa. A tone of 20 Hz has a wavelength of 55 feet. (Wavelength x frequency = 1100 ft/sec in air).

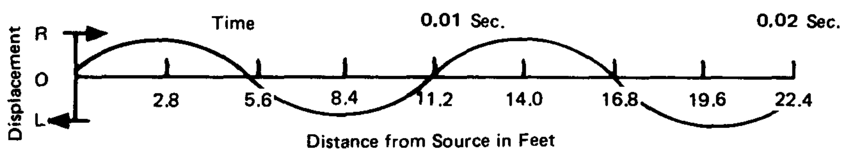

Figure 3

Intensity and Loudness

Sound propagated from a simple source radiates more or less equally in all directions from that source, forming what might be called a sphere of acoustic power. The power is expressed as watts/m^2. Since the power sphere increases proportionally with the increase in distance from the source, the power per unit of area, or intensity, decreases because the constant power quantity is being distributed over an expanding area. Figure 4 provides an illustration of this principle.

The acoustic power radiated from a source cannot be conveniently measured in watts by instruments. However, the changes in atmospheric pressure caused by the sound wave can be determined so as to provide a meaningful measure. The fluctuation above and below the normal atmospheric pressure is called the sound pressure and is the most common measure of strength of a sound or noise. Sound pressure measurements and the units of specifying intensity are the bases for:

1. Human hearing levels, since the ear is most sensitive to sound propagated in air.

2. Noise levels of various noise producing sources.

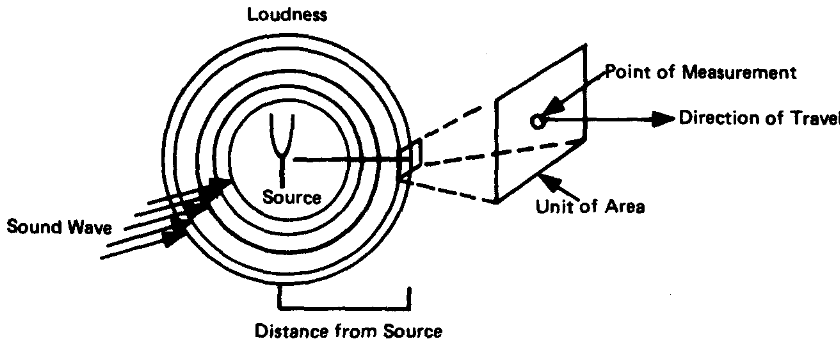

Figure 4

3. Reference and calibration levels (pressures) for audiometers and other such equipment.

4. Computation of power wattage levels.

The Decibel

The intensity of the faintest sound that the normal person can hear is about 0.0000000000001 watts/m^2; the intensity of sound produced by a Saturn rocket at liftoff is greater than 100,000,000 watts/m^2, a range of 100,000,000,000,000,000,000. There is a simpler way to represent these numbers, however: scientific notation. In scientific notation, numbers are represented as numbers between 1 and 10, multiplied by 10 raised to some power. For example, the number 10 can be represented as one times 10 (1.0 x 10), the number 100 as 10 squared (1.0 x 10^2), the number 1000 as one times 10 cubed (1.0 x 10^3), and so on. In the same manner, 0.001 can be represented as 1.0 x 10^{-3} $\frac{1}{(1000)}$, 0.01 as 1.0 x 10^{-2} $\frac{1}{(100)}$, etc. The following list gives examples of numbers represented in scientific notation:

Number	Scientific Notation
0.0025	2.5 x 10^{-3}
2.5	2.5 x 10^0 (10^0 = 1.0)
250	2.5 x 10^2
2,500,000	2.5 x 10^6

Using scientific notation, we can represent the intensity of the faintest audible sound as 1.0×10^{-12} watts/ m^2 and the sound intensity produced by the Saturn rocket as 1.0×10^8 watts/m^2. Now, suppose we divide all of the numbers in our range of values by the lowest one (1.0×10^{-12}). Our range now extends from 1.0 to 1.0×10^{20}. Most of us would find it difficult to use a measurement scale with such a large range. Fortunately, we can use another mathematical notation to compress the scale of numbers into one that is more comprehensible: the logarithmic scale. The logarithm (log) of a number is the power to which 10 must be raised to produce the number in question. For example:

$10^3 = 1000$ and $\log 1000 = 3.0$

$10^{2.5} = 316$ and $\log 316 = 2.5$

$10^0 = 1.0$ and $\log 1 = 0$

$10^{0.3} = 2$ and $\log 2 = 0.3$

By using the logarithms of our ratios, we can form a new measurement scale in which an increase of 1.0 represents a tenfold increase in the ratio. All of our ratios can now be represented between the numbers 0.0 and 20.0; i.e., $\log 1.0 = 0.0$ and $\log (1.0 \times 10^{20}) = 20.0$. The unit for these types of measurement scales is the bel, named after Alexander G. Bell, inventor of the telephone. Each 1-bel increase in the measure represents a tenfold increase over the last measure. A bel turns out to be a rather large unit, so for convenience, the bel is divided into 10 subunits called decibels, abbreviated dB. Using a decibel scale our range is now between 0.0 and 200.0 rather than between 0.0 and 20.0. These kinds of scales are standard in the electronics and acoustical industries for measuring ratios of powers or quantities proportional to power such as voltage or sound pressure. These types of measurements are called levels. By definition,

$$\text{A level in bels} = \log\left(\frac{\text{Measured Quantity}}{\text{Reference Quantity}}\right).$$

To express the level in decibels we multiply by ten. Thus,

$$\text{A level in decibels} = 10 \log\left(\frac{\text{Measured Quantity}}{\text{Reference Quantity}}\right).$$

As previously mentioned, sound pressure (SP) can be measured more conveniently and accurately than sound power. It can be shown mathematically that sound intensity, or sound power, varies proportionally to the square of the sound pressure.

Mathematically,

$$\text{Intensity Level} = 10 \log\left(\frac{\text{Sound Intensity}}{\text{Reference Intensity}}\right)\text{dB.}$$

$$\text{Sound Pressure Level (SPL)} = 10 \log\left(\frac{SP}{SP_{ref}}\right)^2 \text{dB.}$$

The log of a quantity squared is equal to twice the log of the quantity; therefore,

$$\text{SPL} = 20 \log\left(\frac{SP}{SP_{ref}}\right)\text{db.}$$

The reference sound pressure (SP_{ref}) used in acoustics is 20 micropascals, which ideally in air is the pressure equivalent of 10^{-12} watts/m^2 (the threshold of human hearing). Power levels or intensities can be computed from sound pressure measurements. A 20-dB increase in the sound pressure level (SPL) represents a tenfold increase in the sound pressure (SP). For example, compare a measurement of 120 dB overall SPL to 60 dB overall SPL. Although 120 dB is only twice the numerical value of 60 dB, the sound pressure required to produce 120 dB is 1000 times the sound pressure required to produce 60 dB.

There are a few rules to remember when using the decibel.

1. The decibel is used to express ratios. The reference quantity must be specified.

2. In acoustics, the reference sound pressure is 20 micropascals.

3. Power levels are not easily measured but are usually computed from measured SPLs.

Combining Noise Levels

Because they are logarithmic, decibels are not additive. If two similar noise sources produce the same amount of noise (say 100 dB each), the total noise level will be 103 dB, not 200 dB. Figure 5 provides a guide to the addition of decibels. The following example using Figure 5 as a basis, provides an illustration of the way in which the noise levels of multiple sources would be added.

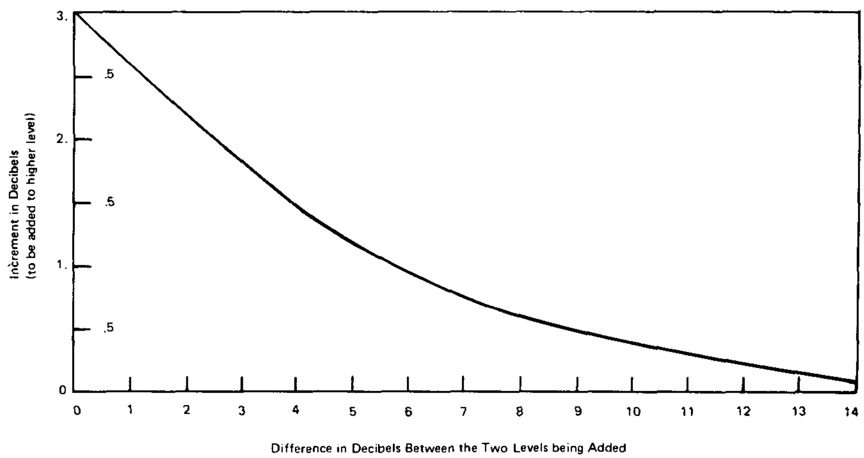

Figure 5

Source by itself		Difference	Amount to be added		New Total
100 dB +101 dB	......	1 dB	2.7 dB	....	103.7 dB
+100 dB	......	3.7 dB ...	1.6 dB	....	105.3 dB
+ 96 dB	......	9.3 dB ...	0.4 dB	....	105.7 dB

Attenuation With Distance

Sound attenuates according to the inverse square law: sound intensity decreases inversely with the square of the distance from the source. In other words, each time the distance from the noise source doubles, the sound pressure is halved. This phenomenon produces a decrease of about 6 dB each time the distance from the source is doubled. When frequency is taken into account along with attenuation with distance, it is seen that higher frequency sound dissipates at a greater rate than does low frequency sound (Figure 6). Figure 6 does not take into account attenuation resulting from wind gradients, temperature gradients, ground cover, etc.

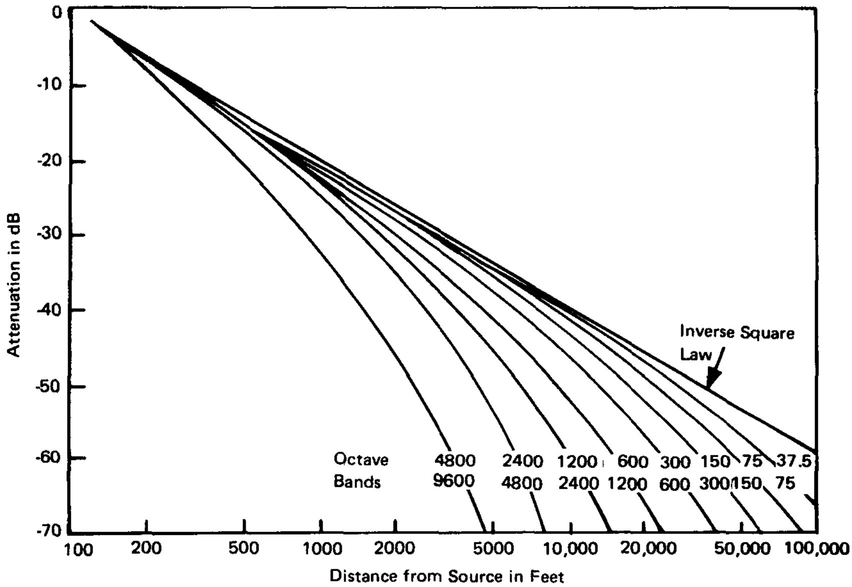

Figure 6

Human Hearing and Acoustics

In laboratory experiments, it was found that the "absolute" threshold of hearing in young adults corresponded to a pressure of about 0.0002 dyne/cm^2. This reference level was determined in a quiet ambient noise atmosphere and at the most acute frequency range of human hearing, between 1000 and 4000 Hz. The general range of human hearing is usually defined as being between 20 and 20,000 Hz. Frequencies below 20 Hz are callled infrasonic, with frequencies between 20 and 20,000 Hz called sonic or referred to as the audible frequency area. Frequencies above 20,000 Hz (some texts refer to above 15,000) are called ultrasonic.

The loudness of sound (sensation) depends upon the intensity, but it also depends upon the frequency of the sound and the characteristics of the human ear. The intensity of sound is a purely physical quantity, whereas, the loudness depends also upon the characteristics of the ear. Thus, the intensity of a given sound striking the ear of a normal hearing person and of a hard-of-hearing person might be the same, but the loudness sensation would be quite different. Again, a 100-Hz tone that is barely audible has about 5000 times the intensity of a 1000-Hz tone that is equally loud, i.e., barely audible, whereas 100-Hz and 1000-Hz tones would sound equally loud at a 100-dB level. The relationship between frequency intensity and loudness is quite involved. We do have, however, a sense of relative loudness so that there is a fair measure of agreement among trained observers in their judgments as to when one sound is one-half, one-third, and so on as loud as another. The question is often asked, "Suppose we reduce the intensity level of a noise by 10 decibels, what percentage reduction in loudness have we obtained?" The answer is that it depends on what the initial level was. Figure 7 can be used to give an approximate answer for different values of the original level.

When human ear response to frequency and intensity is plotted, we find that the response is *not* linear and that it varies with sensation level. Figure 8, an equal loudness chart, demonstrates this response characteristic. The equal *loudness levels* in Figure 8 were defined as the intensity required to make a given test tone seem equally as loud as the reference tone, which was the 1000 Hz reference. The unit of loudness level that is used to plot the data is called the *phon*. Thus, the loudness level in phons of any sound of that frequency is equal to its intensity level in decibels. Generally, the following is noted from the equal loudness curves:

1. At low intensity levels, high frequency tones sound louder than low frequency tones of the same intensity.

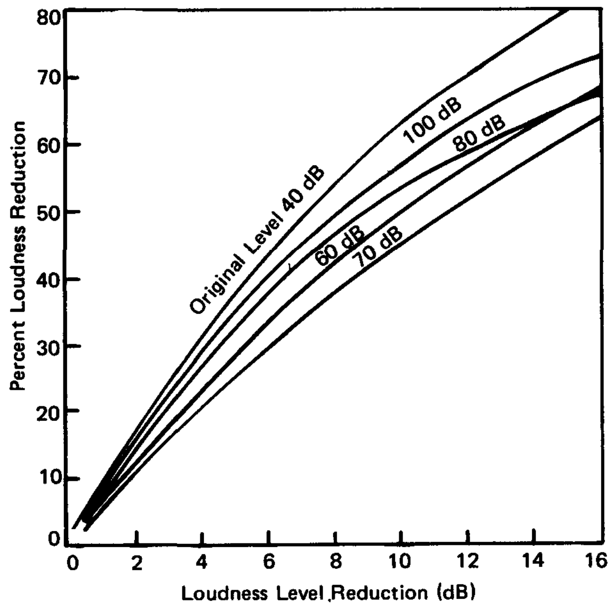

Figure 7

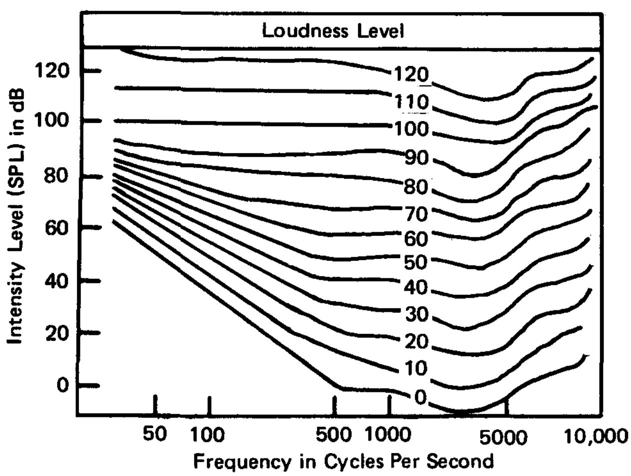

Figure 8

2. At high intensity levels, all tones of the same intensity sound almost equally loud, regardless of their frequency.

3. At low intensity levels, a given change in intensity level produces a larger change in loudness at low frequencies than at high frequencies.

4. At high intensity levels, a given change in intensity level produces practically the same change in loudness regardless of frequency.

Audiometry

The "Absolute Zero" level of hearing determined in the laboratory was found to be 16 to 20 dB too low for a "Normal Population" Audiometric Zero. Thus, the American Audiometric Zero is about 20 dB above the zero based on the 0.0002 dyne/cm^2 reference.

The intensity (loudness) scale on most audiometers has a range of from -10 dB through 0 dB and up to 100 dB, with the maximum intensity range dependent on the particular test frequency. Frequencies below 1000 Hz and above 4000 Hz usually do not have a full 100 dB (on audiometer intensity scale). These maximum intensity limits should always be noted whenever testing the hearing of a person having a severe loss of hearing. The maximum intensity limits, if they exist, are usually marked below the frequency indicator scale on the audiometer.

The majority of audiometer intensity scales are calibrated in 5-dB steps: 5, 10, 15, 20, 25, etc. And, even if the audiometer has a variable intensity control, usually the 5-dB steps are still recorded.

The speech reception threshold was also found to be approximately 16 to 20 dB above the 0.0002 dyne/cm^2 reference. Thus, the audiometric zero for speech material is about the same as the audiometric reference for 1000-Hz test frequency area.

Human Response To Noise

Generally, any unwanted sound is referred to as noise. Thus, noise does not necessarily imply that the sound field is loud. It is the attributes making up a noise that determine whether it is annoying. Some of the main attributes are:

1. The frequency spectrum, broadband or narrowband
2. Intensity levels

3. Modulation characteristics
4. Time and place of the occurrence of the noise
5. Duration of the noise (short or continuous)
6. Individual background.

The frequency spectrum of sound refers to the breakdown of acoustic energy from 20 through 10,000 Hz. This breakdown is usually accomplished by measuring acoustic energy, or sound pressure levels, in eight octave bands, the most common of which are (in Hz):

Band Number 1	20 through 75
Band Number 2	75 through 150
Band Number 3	150 through 300
Band Number 4	300 through 600
Band Number 5	600 through 1200
Band Number 6	1200 through 2400
Band Number 7	2400 through 4800
Band Number 8	4800 through 9600 (10,000)

The most significant bands regarding possible hazardous effects on man are bands 4, 5, 6, and 7 (300 through 4800 Hz).

Obviously, intensity is a factor in determining deleterious effects on humans, as indicated in the table below. But frequency, too, must be considered, especially where one is trying to gauge characteristics of annoyance. Generally, higher frequency noise is more annoying at equal intensities, than lower intensity noise.

Intensity Levels and Human Speech-Hearing

dB	
140	Threshold of pain
130	Feeling of tickle
120	Average threshold of discomfort for pure tones
110	Loud shout at 1 ft distance
100	Discomfort for speech begins around this level
90	
80	Loud speech
70	
60	Average speech conversational level
50	
40	Faint speech at 3 ft distance
30	Whisper (average)

20	Very quiet speech (faint)
10	
0	Threshold of hearing (young adult)

Speech Interference Level (SIL)

The numerical average of the sound pressure level (SPL) readings in the 600-1200, 1200-2400, and 2400-4800 octave bands has been empirically shown to correlate with the subjective level of speech interference. Figure 9 indicates the communication interference caused by various SILs.

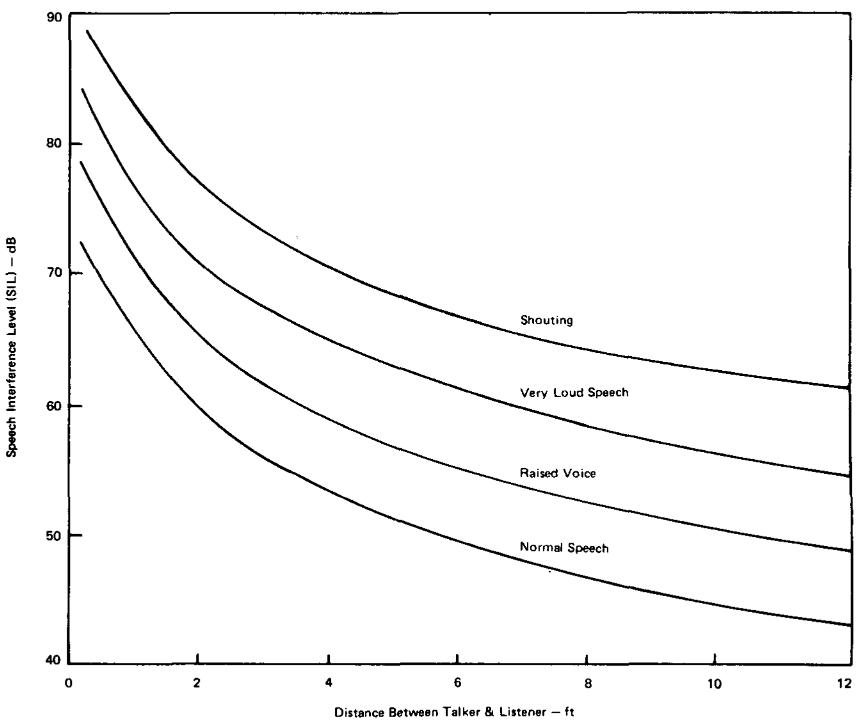

Figure 9

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GLOSSARY

A-WEIGHTED SOUND LEVEL–The ear does not respond equally to frequencies, but is less efficient at low and high frequencies than it is at medium or speech range frequencies. Thus, to obtain a single number representing the sound level of a noise containing a wide range of frequencies in a manner representative of the ear's response, it is necessary to reduce the effects of the low and high frequencies with respect to the medium frequencies. The resultant sound level is said to be A-weighted, and the units are dB. A popular method of indicating the A-weighted units is dBA. The A-weighted sound level level is also called the noise level. Sound level meters have an A-weighting network for measuring A-weighted sound level.

ABSORPTION–Absorption is a property of materials that reduces the amount of sound energy reflected. Thus, the introduction of an "absorbent" into the surfaces of a room will reduce the sound pressure level in that room by virtue of the fact that sound energy striking the room surfaces will not be totally reflected. It should be mentioned that this is an entirely different process from that of transmission loss through a material, which determines how much sound gets into the room via the walls, ceiling, and floor. The effect of absorption merely reduces the resultant sound level in the room produced by energy that has already entered the room.

ABSORPTION COEFFICIENT–A measure of sound-absorbing ability of a surface. This coefficient is defined as the fraction of incident sound energy absorbed or otherwise not reflected by the surface. Unless otherwise specified, a diffuse sound field is assumed. The values of sound-absorption coefficient usually range from about 0.01 for marble slate to almost 1.0 for long absorbing wedges such as are used in anechoic chambers.

ACCELEROMETER (ACCELERATION PICKUP)–An electroacoustic transducer that responds to the acceleration of the surface to which the transducer is attached, and delivers essentially equivalent electric waves.

ACOUSTICAL POWER–See sound power.

ACOUSTICS–(1) The science of sound, including the generation, transmission, and effects of sound waves, both audible and inaudible. (2) The physical qualities of a room or other enclosure (such as size, shape, amount of noise) that determine the audibility and perception of speech and music.

AIRBORNE SOUND–Sound that reaches the point of interest by propagation through air.

AIR FLOW RESISTANCE–See flow resistance.

AMBIENT NOISE LEVEL–The ambient noise level follows the usage of the word "ambient" throughout the environmental sciences (except acoustics). That is, the ambient noise level is that level that exists at any instant, regardless of source.

ANALYSIS–The analysis of a noise generally refers to the examination of the composition of noise in its various frequency bands, such as octaves or third-octave bands.

ANECHOIC ROOM–An anechoic room is one whose boundaries have been designed (with acoustically absorbent materials) to absorb nearly all the sound incident on its boundaries, thereby affording a test room essentially free from reflected sound.

ANTINODE (LOOP)–A point, line, or surface in a standing wave where the vibration or sound pressure has maximum amplitude.

ARTICULATION INDEX (AI)–A numerically calculated measure of the intelligibility of transmitted or processed speech. It takes into account the limitations of the transmission path and the background noise. The articulation index can range in magnitude between 0 and 1.0. If the AI is less than 0.1, speech intelligibility is generally low. If it is above 0.6, speech intelligibility is generally high.

AUDIOFREQUENCY–The frequency of oscillation of an audible sinewave of sound; any frequency between 20 and 20,000 Hz. See also frequency.

AURAL–Of or pertaining to the ear or hearing.

AUDIOGRAM—A graph showing hearing loss as a function of frequency.

AUDIOMETER—An instrument for measuring hearing sensitivity of hearing loss.

BACKGROUND NOISE—The total of all noise in a system or situation, independent of the presence of the desired signal. In acoustical measurements, strictly speaking, the term "background noise" means electrical noise in the measurement system. However, in popular usage the term "background noise" is also used with the same meaning as "residual noise."

BAFFLE—A baffle is a shielding structure or series of partitions used to increase the effective length of the external transmission path between two points in an acoustic system. For example, baffles may be used in sound traps (as in air conditioning ducts) or in automotive mufflers to decrease the sound transmitted while affording a path for air flow.

BAND—A segment of the frequency spectrum.

BAND CENTER FREQUENCY—The designated (geometric) mean frequency of a band of noise or other signal. For example, 1000 Hz is the band center frequency for the octave band that extends from 707 Hz to 1414 Hz, or for the third-octave band that extends from 891 Hz to 1123 Hz.

BAND PRESSURE (OR POWER) LEVEL—The pressure (or power) level for the sound contained within a specified frequency band. The band may be specified either by its lower and upper cutoff frequencies, or by its geometric center frequency. The width of the band is often indicated by a prefatory modifier; e.g., octave band, third-octave band, 10-Hz band.

BOOM CARPET—The area on the ground underneath an aircraft flying at supersonic speeds that is hit by a sonic boom of specified magnitude.

BROADBAND NOISE—Noise with components over a wide range of frequencies.

C-WEIGHTED SOUND LEVEL (dBC)—A quantity, in decibels, read from a standard sound-level meter that is switched to the weighting network labeled "C". The C-weighting network weighs the frequencies between 70 Hz and 4000 Hz uniformly, but below and above these limits, frequencies are slightly discriminated against. Generally, C-weighted measurements are essentially the same as overall sound-pressure levels, which require no discrimination at any frequency.

COINCIDENCE EFFECT—The coincidence effect occurs when the wavelength of the bending wave in a panel coincides with the length of an incident sound wave at the angle at which it strikes the panel. At any particular frequency, this effect can occur only if the wave in air is traveling at a particular angle with respect to the surface of the panel. Under this condition, a high degree of coupling is achieved between the bending wave in the panel and the sound in the air. When the coincidence effect occurs, the transmission loss for the panel is greatly reduced. See also critical frequency.

COMMUNITY NOISE EQUIVALENT LEVEL—Community Noise Equivalent Level (CNEL) is a scale that takes account of all the A-weighted acoustic energy received at a point, from all noise events causing noise levels above some prescribed value. Weighting factors are included that place greater importance upon noise events occurring during the evening hours (7:00 p.m. to 10:00 p.m.) and even greater importance upon noise events at night (10:00 p.m. to 6:00 a.m.).

COMPOSITE NOISE RATING—Composite noise rating (CNR) is a scale that takes account of the totality of all aircraft operations at an airport in quantifying the total aircraft noise environment. It was the earliest method for evaluating compatible land use around airports and is still in wide use by the Department of Defense in predicting noise environments around military airfields. Basically, to calculate a CNR value, one begins with a measure of the maximum noise magnitude from each aircraft flyby and adds weighting factors that sum the cumulative effect of all flights. The scale used to describe individual noise events is perceived noise level (in PNdB); the term accounting for number of flights is $10 \log_{10} N$ (where N is the number of flight operations), and each night operation counts as much as 10 daytime operations. Very approximately, the noise exposure level at a point expressed in the CNR scale will be numerically 35-37 dB *higher* than if expressed in the CNEL scale.

CONTINUOUS SOUND SPECTRUM—A continuous sound spectrum is composed of components that are continuously distributed over a frequency region.

CRITERION—A criterion, in Federal environmental usage, is a statement of the cause and effect relationship between a given level of pollutant and specific effects on human life.

CRITICAL FREQUENCY—The critical frequency is the lowest frequency at which the coincidence effect can occur. At this frequency, the coincidence angle is 90°, that is, the sound wave is traveling parallel to the surface of the panel. Below this frequency, the wavelength in air is greater than the bending wavelength in the panel.

CUTOFF FREQUENCIES—The frequencies that mark the ends of a band, or at which the characteristics of a filter change from pass to no-pass.

CYLINDRICAL DIVERGENCE—Cylindrical divergence is the condition of propagation of cylindrical waves that accounts for the regular decrease in intensity of a cylindrical wave at progressively greater distances from the source. Under this condition, the sound-pressure level decreases 3 decibels with each doubling of distance from the source. See also spherical divergence.

CYLINDRICAL WAVE—A cylindrical wave is a wave in which the surfaces of constant phase are coaxial cylinders. A line of closely-spaced sound sources radiating into an open space produces a free sound field of cylindrical waves. See also cylindrical divergence.

CYCLES PER SECOND—A measure of frequency numerically equivalent to Hertz.

DAMAGE RISK CRITERION—A statement of noise levels (including frequency, duration, intermittancy, and other factors) above which permanent hearing loss of at least a specified amount is likely to be sustained by a person (to a given degree of probability). See also hearing loss, criterion.

DAMPING—The dissipation of energy with time or distance. The term is generally applied to the attenuation of sound in a structure owing to the internal sound-dissipative properties of the structure or owing to the addition of sound-dissipative materials.

DECIBEL—The decibel (abbreviated "dB") is a measure, on a logarithmic scale, of the magnitude of a particular quantity (such as sound pressure, sound power, intensity) with respect to a standard reference value (0.0002 microbars for sound pressure and 10-12 watt for sound power).

DIFFUSE SOUND FIELD—The presence of many reflected waves (echoes) in a room (or auditorium) having a very small amount of sound absorption, arising from repeated reflections of sound in various directions. In a diffuse field, the sound pressure level, averaged over time, is everywhere the same and the flow of sound energy is equally probable in all directions.

DIRECTIVITY INDEX—In a given direction from a sound source, the difference in decibels between (a) the sound-pressure level produced by the source in that direction, and (b) the space-average sound-pressure level of that source, measured at the same distance.

DIRECTIVITY PATTERN—The directivity pattern of a source of sound is the hypothetical surface in space over which the sound pressure levels produced by the source are constant. See also directivity index.

DOPPLER EFFECT (DOPPLER SHIFT)—The apparent upward shift in frequency of a sound as a noise source approaches the listener (or vice versa), and the apparent downward shift when the noise source recedes. The classic example is the change in pitch of a railroad whistle as the locomotive approaches and passes by.

DUCT LINING OR WRAPPING—Usually a sheet of porous material placed on the inner or outer wall(s) of a duct to introduce sound attenuation and heat insulation. It is often used in air conditioning systems. Linings are more effective in attenuating sound that travels inside along the length of a duct, while wrappings are more effective in preventing sound from being radiated from the duct sidewalls into surrounding spaces.

EFFECTIVE PERCEIVED NOISE LEVEL (EPNL)—A physical measure designed to estimate the effective "noisiness" of a single noise event usually an aircraft fly-over; it is derived from instantaneous Perceived Noise Level (PNL) values by applying corrections for pure tones and for the duration of the noise.

ELECTROACOUSTICS—The science and technology of transforming sound waves into currents in electrical circuits (and vice versa), by means of microphones, loudspeakers, and electronic amplifiers and filters.

FAR FIELD—Consider any sound source in free space. At a sufficient distance from the source, the sound pressure level obeys the inverse-square law (the sound pressure decreases 6 dB with each doubling of distance from the source). Also, the sound particle velocity is in phase with the sound pressure. This region is called the far field of the sound source. Regions closer to the source, where these two conditions do not hold, constitute the near field. In an enclosure, as opposed to free space, there can also sometimes be a far field region if there is not so much reflected sound that the near field and the reverberant field merge. See also reverberant field.

FILTER—A device that transmits certain frequency components of the signal (sound or electrical) incident upon it, and rejects other frequency components of the incident signal.

FLOW RESISTANCE—The flow resistance of a porous material is one of the most important quantities determining the sound absorbing characteristics of the material. Flow resistance is a ratio of the pressure differential across a sample of the porous material to the air velocity through it.

FOOTPRINT (NOISE)—The shape and size of the geographical pattern of of noise impact that an aircraft makes on the areas near an airport while landing or taking off.

FREE SOUND FIELD (FREE FIELD)—A sound field in which the effects of obstacles or boundaries on sound propagated in that field are negligible.

FREQUENCY—The number of times per second that the sine-wave of sound repeats itself, or that the sine-wave of a vibrating object repeats itself. Now expressed in Hertz (Hz), formerly in cycles per second (cps).

FUNCTION—A quantity that varies as a result of variations of another quantity.

FUNDAMENTAL FREQUENCY—The frequency with which a periodic function reproduces itself, sometimes called the first harmonic (see also harmonic).

GAUSSIAN DISTRIBUTION (or NORMAL DISTRIBUTION)—A term used in statistics to describe the extent and frequency of deviations or errors. The outstanding characteristics are a tendency to a maximum number of occurrences at or near the center or mean point, the progressive decrease of frequency of occurrence with distance from the center, and the symmetry of distribution on either side of the center. In respect of random noise, each fluctuation of amplitude is an occurrence, whether above or below the mean level; the peak value of each fluctuation is the error and the distribution of errors with time is Gaussian.

GRADIENT—A variation of the local speed of sound with height above ground or other measure of distance causing refraction of sound. It is most commonly caused by rising or falling temperature with altitude or by differences in wind speed.

HARMONIC—A sinusoidal (pure-tone) component whose frequency is a whole-number multiple of the fundamental frequency of the wave. If a component has a frequency twice that of the fundamental it is called the second harmonic.

HEARING DISABILITY—An actual or presumed inability, due to hearing impairment, to remain employed at full wages.

HEARING HANDICAP—The disadvantage imposed by a hearing impairment sufficient to affect one's efficiency in the situation of everyday living.

HEARING IMPAIRMENT—A deviation or change for the worse in either hearing structure or function, usually outside the normal range; see hearing loss.

HEARING LOSS—At a specified frequency, an amount, in decibels, by which the threshold of audibility for that ear exceeds a certain specified audiometric threshold, that is to say, the amount by which a person's hearing is worse than some selected norm. The norm may be the threshold established at some earlier time for that ear, or the average threshold for some large population, or the threshold selected by some standards body for audiometric measurements.

HEARING LOSS FOR SPEECH—The difference in decibels between the speech levels at which the "average normal" ear and a defective ear, respectively, reach the same intelligibility, often arbitrarily set at 50 percent.

HERTZ—Unit of measurement of frequency, numerically equal to cycles per second.

IMPACT—(1) An impact is a single collision of one mass in motion with a second mass that may be either in motion or at rest. (2) Impact is a word used to express the extent or severity of an environmental problem; e.g., the number of persons exposed to a given noise environment.

IMPACT INSULATION CLASS (IIC)—A single-figure rating that is intended to permit the comparison of the impact sound insulating merits of floor-ceiling assemblies in terms of a reference contour.

IMPACT SOUND—The sound arising from the impact of a solid object on an interior surface (wall, floor, or ceiling) of a building. Typical sources are footsteps, dropped objects, etc.

INFRASONIC—Of a frequency below the audiofrequency range.

INVERSE-SQUARE LAW—The inverse-square law describes that acoustic situation where the mean-square pressure changes in inverse proportion to the square of the distance from the source. Under this condition, the sound-pressure level decreases 6 decibels with each doubling of distance from the source. See also spherical divergence.

ISOLATION—See vibration isolator.

JET NOISE—Noise produced by the exhaust of a jet into its surrounding atmosphere. It is generally associated with the turbulence generated along the interface between the jet stream and the atmosphere.

L_{10} LEVEL—The sound level exceeded 10 percent of the time. Corresponds to peaks of noise in the time history of environmental noise in a particular setting.

L_{50} LEVEL—The sound level exceeded 50 percent of the time. Corresponds to the average level of noise in a particular setting, over time.

L_{90} LEVEL—The sound level exceeded 90 percent of the time. Corresponds to the residual noise level.

LEVEL—The value of a quantity in decibels. The level of an acoustical quantity (sound pressure or sound power), in decibels, is 10 times the logarithm (base 10) of the ratio of the quantity to a reference quantity of the same physical kind.

LINE SPECTRUM—The spectrum of a sound whose components occur at a number of discrete frequencies.

LIVE ROOM—One characterized by an unusually small amount of sound absorption. See reverberation room.

LOUDNESS—The judgment of intensity of a sound by a human being. Loudness depends primarily upon the sound pressure of the stimulus. Over much of the loudness range it takes about a threefold increase in sound pressure (approximately 10 dB) to produce a doubling of loudness.

LOUDNESS LEVEL—The loudness level of a sound, in phons, is numerically equal to the median sound pressure level, in decibels, relative to 0.0002 microbar, of a free progressive wave of frequency 1000 Hz presented to listeners facing the source, which in a number of trials is judged by the listeners to be equally loud.

MACH NUMBER—The ratio of a speed of a moving element to the speed of sound in the surrounding medium.

MASKING—The action of bringing one sound (audible when heard alone) to inaudibility or to unintelligibility by the introduction of another sound. It is most marked when the masked sound is of higher frequency than the masking sound.

MASKING NOISE—A noise that is intense enough to render inaudible or unintelligible another sound that is simultaneously present.

MEAN FREE PATH—The average distance sound travels between successive reflections in a room.

MEDIUM—A substance carrying a sound wave.

MICROBAR—A microbar is a unit of pressure, equal to 1 dyne per square centimeter.

MICROPHONE—An electroacoustic transducer that responds to sound waves and delivers essentially equivalent electric waves.

NEAR FIELD—See far field.

NODE—A point, line, or surface where a wave has zero amplitude.

NOISE—Any sound that is undesirable because it interferes with speech and hearing, or is intense enough to damage hearing, or is otherwise annoying.

NOISE CRITERION (NC) CURVES—Any of several versions (SC, NC, NCA, PNC) of criteria used for rating the acceptability of continuous indoor noise levels, such as produced by air-handling systems.

NOISE EXPOSURE FORECAST—Noise exposure forecast (NEF) is a scale (analogous to CNEL and CNR) that has been used by the federal government in land use planning guides for use in connection with airports.

In the NEF scale, the basic measure of magnitude for individual noise events is the effective perceived noise level (EPNL), in units of EPNdB. This magnitude measure includes the effect of duration per event. The terms accounting for number of flights and for weighting by time period are the same as in the CNR scale. Very approximately, the noise exposure level at a point expressed in the NEF scale will be numerically about 33 dB *lower* than if expressed in the CNEL scale.

NOISE INSULATION—See sound insulation.

NOISE ISOLATION CLASS (NIC)—A single number rating derived in a prescribed manner from the measured values of noise reduction. It provides an evaluation of the sound isolation between two enclosed spaces that are acoustically connected by one or more paths.

NOISE LEVEL—See sound level.

NOISE AND NUMBER INDEX (NNI)—A measure based on Perceived Noise Level, and with weighting factors added to account for the number of noise events, and used (in some European countries) for rating the noise environment near airports.

NOISE POLLUTION LEVEL (L_{NP} or NPL)—A measure of the total community noise, postulated to be applicable to both traffic noise and aircraft noise. It is computed from the "energy average" of the noise level and the standard deviation of the time-varying noise level.

NOISE REDUCTION (NR)—The noise reduction between two areas or rooms is the numerical difference, in decibels, of the average sound pressure levels in those areas or rooms. A measurement of "noise reduction" combines the effect of the transmission loss performance of structures separating the two areas or rooms, plus the effect of acoustic absorption present in the receiving room.

NOISE REDUCTION COEFFICIENT (NRC)—A measure of the acoustical absorption performance of a material, calculated by averaging its sound absorption coefficients at 250, 500, 1000, and 2000 Hz, expressed to the nearest integral multiple of 0.05.

NORMAL DISTRIBUTION—See Gaussian distribution.

NOYS—A unit used in the calculation of Perceived Noise Level.

OCTAVE—An octave is the interval between two sounds having a basic frequency ratio of two. For example, there are 8 octaves on the keyboard of a standard piano.

OCTAVE BAND—All of the components, in a sound spectrum, whose frequencies are between two sine wave components separated by an octave.

OCTAVE-BAND SOUND PRESSURE LEVEL—The integrated sound pressure level of only those sine-wave components in a specified octave band, for a noise or sound having a wide spectrum.

OSCILLATION—The variation with time, alternately increasing and decreasing, (a) of some feature of an audible sound, such as the sound pressure, or (b) of some feature of a vibrating solid object, such as the displacement of its surface.

PARTIAL NODE—A partial node is the point, line, or surface in a standing wave system where there is a minimum amplitude differing from zero.

PEAK SOUND PRESSURE—The maximum instantaneous sound pressure (a) for a transient or impulsive sound of short duration, or (b) in a specified time interval for a sound of long duration.

PERCEIVED NOISE LEVEL (PNL)—A quantity expressed in decibels that provides a subjective assessment of the perceived "noisiness" of aircraft noise. The units of Perceived Noise Level are Perceived Noise Decibels, PNdB.

PERIOD—The duration of time it takes for a periodic wave form (like a sine wave) to repeat itself.

PERMANENT THRESHOLD SHIFT (PTS)—See temporary threshold shift.

PHASE—For a particular value of the independent variable, the fractional part of a period through which the independent variable has advanced, measured from an arbitrary reference.

PHON—The unit of measurement for loudness *level.*

$\text{Phons} = 40 + \log_2 \text{sone}$.

PINK NOISE—Noise where level decreases with increasing frequency to yield constant energy per octave of band width.

PITCH—A listener's perception of the frequency of a pure tone; the higher the frequency, the higher the pitch.

PLANE WAVE—A wave whose wave fronts are parallel and perpendicular to the direction in which the wave is travelling.

PNdB—See perceived noise level.

PRESBYCUSIS—The decline in hearing acuity that normally occurs as a person grows older.

PURE TONE—A sound wave whose waveform is that of a sine-wave.

RANDOM INCIDENCE—If an object is in a diffuse sound field, the sound waves that comprise the sound field are said to strike the object from all angles of incidence at random. See also Gaussian distribution.

RANDOM NOISE—An oscillation whose instantaneous magnitude is not specified for any given instant of time. It can be described in a statistical sense by probability distribution functions giving the fraction of the total time that the magnitude of the noise lies within a specified range.

RATE OF DECAY—Rate of decay is the time rate at which the sound-pressure level (or other stated characteristic, such as a vibration level) decreases at a given point and at a given time after the source is turned off. The commonly used unit is decibels per second.

REFRACTION—The bending of a sound wave from its original path, either because it is passing from one medium to another or because (in air) of a temperature or wind gradient in the medium.

RESIDUAL NOISE LEVEL—The term "residual noise" has been adopted to mean the noise that exists at a point as a result of the combination of many distant sources, individually indistinguishable. In statistical terms, it is the level that exists 90 percent of the time. (Acousticians should note it means the same level to which they have customarily applied that term "ambient.") See also background noise.

RESONANCE—The relatively large amplitude of vibration produced when the frequency of some source of sound or vibration "matches" or synchronizes with the natural frequency of vibration of some object, component, or system.

RESONATOR—A resonator is a device that resounds or vibrates in sympathy with some source of sound or vibration.

RETROFIT—The retroactive modification of an existing building or machine. In current usage, the most common application of the word "retrofit" is to the question of modification of existing jet aircraft engines for noise abatement purposes.

REVERBERANT FIELD—The region in a room where the reflected sound dominates, as opposed to the region close to the noise source where the direct sound dominates.

REVERBERATION—The persistence of sound in an enclosed space, as a result of multiple reflections, after the sound source has stopped.

REVERBERATION ROOM—A room having a long reverberation time, especially designed to make the sound field inside it as diffuse (homogeneous) as possible. Also called a live room.

REVERBERATION TIME (RT)—The reverberation time of a room is the time taken for the sound pressure level (or sound intensity) to decrease to one-millionth (60 dB) of its steady-state value when the source of sound energy is suddenly interrupted. It is a measure of the persistence of an impulsive sound in a room and of the amount of acoustical absorption present inside the room.

ROOM CONSTANT—The room constant is equal to (a) the product of the average absorption coefficient of the room and the total internal area of the room, divided by (b) the quantity one minus the average absorption coefficient.

ROOT-MEAN-SQUARE (RMS)—The root-mean square value of a quantity that is varying as a function of time is obtained by squaring the function at each instant, obtaining the average of the squared values over the interval of interest, and taking the square root of this average. For a sine wave, multiply the RMS value by $\sqrt{2}$, or about 1.43, to get the peak value of the wave. The RMS value, also called the effective value of the sound pressure, is the best measure of ordinary continuous sound, but the peak value is necessary for assessment of impulse noises.

SHIELDING—The attenuation of a sound by placing walls, buildings, or other barriers between a sound source and the receiver.

SINE-WAVE—A sound wave, audible as a pure tone, in which the sound pressure is a sinusoidal function of time.

SONE–The unit of measurement for loudness. One sone is the loudness of a sound whose level is 40 phons.

SONIC BOOM–The pressure transient produced at an observing point by a vehicle that is moving past (or over) it faster than the speed of sound.

SOUND–See acoustics (1).

SOUND ABSORPTION COEFFICIENT–See absorption coefficient.

SOUND ANALYZER–A sound analyzer is a device for measuring the band-pressure level or pressure-spectrum level of a sound as a function of frequency.

SOUND INSULATION–(1) The use of structures and materials designed to reduce the transmission of sound from one room or area to another or from the exterior to the interior of a building. (2) The degree by which sound transmission is reduced by means of sound insulating structures and materials.

SOUND LEVEL (NOISE LEVEL)–The weighted sound pressure level obtained by use of a sound level meter having a standard frequency-filter for attenuating part of the sound spectrum.

SOUND LEVEL METER–An instrument, comprising a microphone, an amplifier, an output meter, and frequency-weighting networks, that is used for the measurement of noise and sound levels in a specified manner.

SOUND POWER–The total amount of energy radiated into the atmospheric air per unit time by a source of sound.

SOUND POWER LEVEL–The level of sound power, averaged over a period of time, the reference being 10^{-12} watts.

SOUND PRESSURE–(1) The minute fluctuations in atmospheric pressure that accompany the passage of a sound wave; the pressure fluctuations on the tympanic membrane are transmitted to the inner ear and give rise to the sensation of audible sound. (2) For a steady sound, the value of the sound pressure averaged over a period of time.

(3) Sound pressure is usually measured (a) in dynes per square centimeter (dyn/cm^2), or (b) in newtons per square meter (N/m^2). 1 N/m^2 = 10 dyn/cm^2 10^{-5} times the atmospheric pressure.

SOUND PRESSURE LEVEL–The root-mean-square value of the pressure fluctuations above and below atmospheric pressure due to a sound wave; expressed in decibels re a reference pressure of 0.0002 microbars (2×10^{-5} newtons per square meter).

SOUND SHADOW–The acoustical equivalent of a light shadow. A sound shadow is often partial because of diffraction effects.

SOUND TRANSMISSION CLASS (STC)–The preferred single figure rating system designed to give an estimate of the sound insulation properties of a partition or a rank ordering of a series of partitions. It is intended for use primarily when speech and office noise constitute the principal noise problem.

SOUND TRANSMISSION COEFFICIENT–The fraction of incident sound energy transmitted through a structural configuration.

SOUND TRANSMISSION LOSS (TRANSMISSION LOSS (TL))–A measure of sound insulation provided by a structural configuration. Expressed in decibels, it is 10 times the logarithm to the base 10 of the reciprocal of the sound transmission coefficient of the configuration.

SPACE-AVERAGE SOUND-PRESSURE LEVEL–The space-average sound pressure level is the sound-pressure level averaged over all directions at a constant distance from the source.

SPECTRUM–The description a sound wave's resolution into components, each of different frequency and (usually) different amplitude and phase.

SPEECH-INTERFERENCE LEVEL (SIL)–A calculated quantity providing a guide to the interfering effect of a noise on reception of speech communication. The speech-interference level is the arithmetic average of the octave-band sound-pressure levels of the interfering noise in the most important part of the speech frequency range. The levels in the three octave-frequency bands centered at 500, 1000, and 2000 Hz are commonly averaged to determine the speech-interference level. Numerically, the magnitudes of aircraft sounds in the speech-interference level scale are approximately 18 to 22 dB less than the same sound in the perceived noise level scale in PNdB,

SPEED (VELOCITY) OF SOUND IN AIR–The speed of sound in air is 344 m/sec or 1128 ft/sec at 78°F.

SPHERICAL DIVERGENCE–Spherical divergence is the condition of propagation of spherical waves that relates to the regular decrease in intensity of a spherical sound wave at progressively greater distances from the source. Under this condition the sound-pressure level decreases 6 decibels with each doubling of distance from the source. See also cylindrical divergence.

SPHERICAL WAVE–A sound wave in which the surfaces of constant phase are concentric spheres. A small (point) source radiating into an open space produces a free sound field of spherical waves.

SPL–See sound pressure level.

STANDARD–(1) A prescribed method of measuring acoustical quantities. Standards in this sense are promulgated by professional and scientific societies like ANSI, SAE, ISO, etc., as well as by other groups. (2) In the sense used in Federal environmental statutes, a standard is a specific statement of permitted environmental conditions.

STANDING WAVE–A periodic sound wave having a fixed distribution in space, the result of interference of traveling sound waves of the same frequency and kind. Such sound waves are characterized by the existence of nodes, or partial nodes, and antinodes that are fixed in space.

STEADY-STATE SOUNDS–Sounds whose average characteristics remain constant in time. An example of a steady-state sound is an air conditioning unit.

STRUCTUREBORNE SOUND–Sound that reaches the point of interest, over at least part of its path, by vibration of a solid structure.

SUBHARMONIC—A sound component of frequency a whole number of times less than the fundamental frequency of the sounds' complex wave.

TAPPING MACHINE—A device that produces a standard impulsive noise by letting weights drop a fixed distance onto the floor. Used in tests measuring the isolation from impact noise provided by various floor-ceiling constructions.

TEMPORARY THRESHOLD SHIFT (TTS)—A temporary impairment of hearing capability as indicated by an increase in the threshold of audibility. By definition, the ear recovers after a given period of time. Sufficient exposures to noise of sufficient intensity, from which the ear never completely recovers, will lead to a permanent threshold shift (PTS), which constitutes hearing loss. See hearing loss, threshold shift, threshold of audibility.

THIRD-OCTAVE BAND—A frequency band whose cutoff frequencies have a ratio of 2 to the one-third power, which is approximately 1.26. The cutoff frequencies of 891 Hz and 1112 Hz define a third-octave band in common use. See also band center frequency.

THRESHOLD OF AUDIBILITY (THRESHOLD OF DETECTABILITY)—The minimum sound-pressure level at which a person can hear a specified sound for a specified fraction of trials.

THRESHOLD SHIFT—An increase in a hearing threshold level that results from exposure to noise.

TONE—A sound of definite pitch. A pure tone has a sinusoidal wave form.

TRAFFIC NOISE INDEX (TNI)—A measure of the noise environment created by vehicular traffic on highways; it is computed from measured values of the noise levels exceeded 10 percent and 90 percent of the time.

TRANSMISSION LOSS—See sound transmission loss.

TRANSDUCER—A device capable of being actuated by waves from one or more transmission systems or media and supplying related waves to one or more other transmission systems or media. Examples are microphones, accelerometers, and loudspeakers.

TTS—See temporary threshold shift.

ULTRASONIC—Pertaining to sound frequencies above the audible sound spectrum (in general, higher than 20,000 Hz).

VIBRATION ISOLATOR—A resilient support for machinery and other equipment that might be a source of vibration, designed to reduce the amount of vibration transmitted to the building structure.

WAVEFORM—A presentation of some feature of a sound wave, e.g., the sound pressure, as a graph showing the moment-by-moment variation of sound pressure with time.

WAVEFRONT—An imaginary surface of a sound wave on its way through the atmosphere. At all points on the wavefront, the wave is of equal amplitude and phase.

WAVELENGTH—For a periodic wave (such as sound in air), the perpendicular distance between analogous points on any two successive waves. The wavelength of sound in air or in water is inversely proportional to the frequency of the sound. Thus, the lower the frequency, the longer the wavelength.

WHITE NOISE—Noise whose energy is uniform over a wide range of frequencies, being analogous in spectrum characteristics to white light. White noise has a "hissing" sound. See also broadband noise.

WRAPPING—See duct lining or wrapping.

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