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# HANDBOOK OF AIRCRFT NOISE METRICS

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# Handbook of Aircraft Noise Metrics

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**16. Abstract**

The HANDBOOK OF AIRCRAFT NOISE METRICS contains detailed information on 22 noise metrics that are associated with the measurement and prediction of the effects of aircraft noise. Some of the instantaneous frequency weighted sound level measures, such as A-weighted sound level, are used to provide an immediate assessment of the aircraft noise level. Other multiple event metrics, such as day-night average sound level, were designed to relate sound levels measured over a period of time to subjective responses in an effort to determine compatible land uses and aid in community planning. The various measures are divided into four chapters: (I) Instantaneous sound level metrics; (II) Duration corrected single event metrics; (III) Multiple event metrics; and (IV) Speech communication metrics. The scope of each measure is then examined in terms of its: Definition, Purpose, Background, Relationship to Other Measures, Calculation Method, Example, Equipment, References and Standards.

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## INTRODUCTION

This Handbook provides a summary of the many different noise ratings which are currently employed to describe the sounds from aircraft and environmental sounds in general. However, in order to make full use of the Handbook, it is important to understand some of the basic characteristics of sounds including the quantification and the manner in which they are normally presented.

The sound we hear is the result of a sound source inducing vibration in the air. The vibration produces alternating bands of relatively dense and sparse particles of air, spreading outward from the source in the same way as ripples do on water after a stone is thrown into it. The result of the movement of the particles is a fluctuation in the normal atmospheric pressure, or sound waves. These waves radiate in all directions from the source and may be reflected and scattered or, like other wave actions, may turn corners. When the source stops vibrating, the sound waves disappear almost instantaneously, and the sound ceases.

Sound may be described in terms of three variables:

1) Frequency (perceived as pitch)
2) Amplitude (perceived as loudness)
3) Time pattern

### Frequency

The rate at which a sound source vibrates, or makes the air vibrate, determines frequency. The unit of time is usually one second and the term "Hertz" (after an early investigator of the physics of sound) is used to designate the number of cycles per second.

The human ear and that of most animals has a wide range of response. Humans can identify sounds with frequencies from about 16 Hz (Hertz) to 20,000 Hz. Because pure tones are relatively rare in real-life situations, most sounds consist instead of a complex mixture of many frequencies. The frequency content of these sounds is characterized by a band of frequencies, usually an octave or 1/3 octave in width. An octave band of frequency is one whose upper frequency is twice its lower frequency limit (similar to the octave on a piano). A 1/3 octave band is similar, but it takes 3 to be equivalent to an octave.

## Amplitude

Sound pressure is the amplitude or measure of the difference between atmospheric pressure (with no sound present) and the total pressure (with sound present). Although there are other measures of sound amplitude, sound pressure is the fundamental measure and is the basic ingredient of the various measurement descriptors in this Handbook.

The unit of sound pressure is the decibel (dB); thus it is said that a sound pressure level is a certain number of decibels. The decibel scale is a logarithmic scale, not a linear one such as the scale of length. A logarithmic scale is used because the range of sound intensities is so great that it is convenient to compress the scale to encompass all the sounds that need to be measured. The human ear has an extremely wide range of response to sound amplitude. Sharply painful sound is 10 million times greater in sound pressure than the least audible sound. In decibels, this 10 million to 1 ratio is simplified logarithmically to 140 dB.

Another unusual property of the decibel scale is that the sound pressure levels of two separate sounds are not directly (that is, arithmetically) additive. For example, if a sound of 70 dB is added to another sound of 70 dB, the total is only a 3-decibel increase (to 73 dB), not a doubling to 140 dB. Furthermore, if two sounds are of different levels, the lower level adds less to the higher as this difference increases. If the difference is as much as 10 dB, the lower level adds almost nothing to the higher level. In other words, adding a 60 decibel sound to a 70 decibel sound only increases the total sound pressure level less than one-half decibel.

## Time Pattern

The temporal nature of sound may be described in terms of its pattern of time and level: continuity, fluctuation, impulsiveness, intermittency. Continuous sounds are those produced for relatively long periods at a constant level, such as the noise of a waterfall. Intermittent sounds are those which are produced for short periods, such as the ringing of a telephone or aircraft take-offs and landings. Impulse noises are sounds which are produced in an extremely short span of time, such as a pistol shot or a hand clap. Fluctuating sounds vary in level over time, such as the loudness of traffic sounds at a busy intersection.

## Illustrations of Sound Attributes

The three attributes of sound were described above. However, it is important to see how acoustical data with these attributes are typically presented since these data form the inputs for the ratings discussed in this Handbook. Different types of sound samples are used to illustrate the various attributes. In illustrating the various attributes for the different types of sound samples, four types of graphs will be employed.

Figure 1 shows a plot of sound pressure versus time for a steady tone of constant frequency. Note that the pressure fluctuations for the tone vary above and below atmospheric pressure. Figure 2 shows the same information in terms of sound level. This plot is merely a horizontal line at a given level since the sound level of the tone does not change with time. Figure 3 shows a plot of frequency versus time, which again is a horizontal line since the frequency of the tone does not change with time. Figure 4 shows a plot of sound level versus frequency. The level is represented by a vertical line at the specified frequency.

These four graphs will be utilized to show other attributes in describing other types of sounds. Notice that each of the graphs is missing one of the sound attributes. For example, the sound level versus time shows no information about frequency. This is not a problem for this particular example since the frequency is always the same. For more complex sounds with frequencies and levels changing with the times, it is sometimes

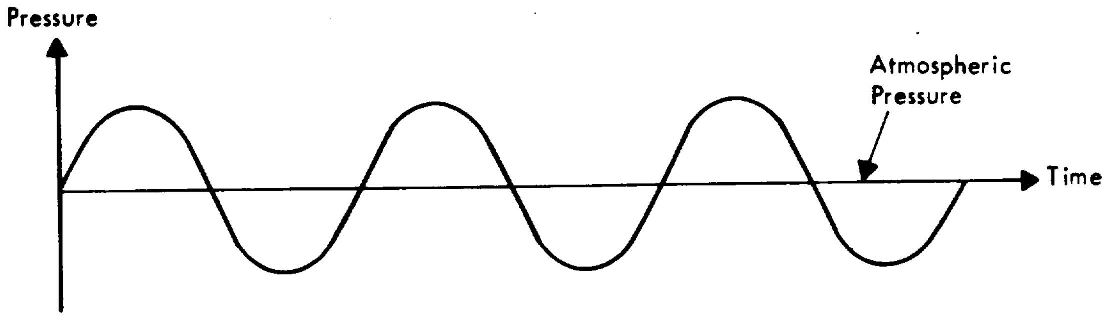


FIGURE 1. SOUND PRESSURE OF TONE

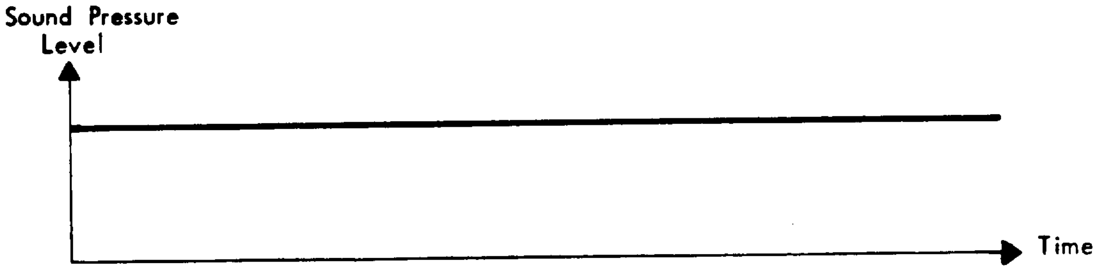


FIGURE 2. SOUND PRESSURE LEVEL OF TONE

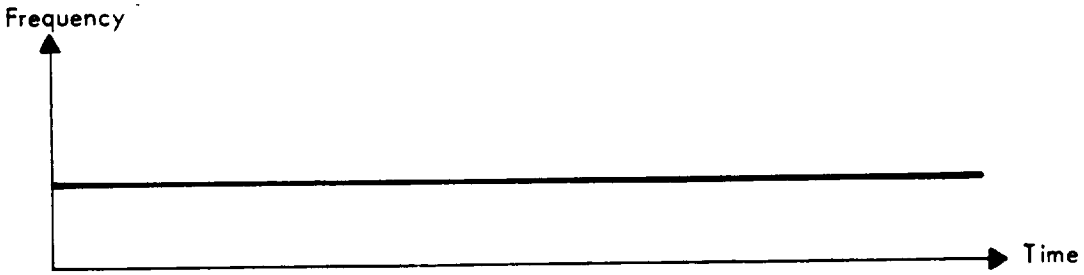


FIGURE 3. FREQUENCY OF TONE

FIGURE 4. SPECTRUM OF TONE

necessary to show several graphs or a more encompassing three-dimensional graph which can display all three aspects of the sound in one figure such as found in Figure 5.

Figure 6 shows an example of two tones occurring sequentially with an off period between the tones. The upper part (a) of the graph shows the pressure fluctuations about atmospheric pressure. The first tone is a high frequency, high amplitude tone, followed by an off period, and finally a low frequency, low magnitude tone. The (b) portion of the figure represents the same two tones changing in magnitude as a function of time. Since the level of the tone is a logarithmic quantity, the changes in amplitude do not appear as great as the pressure changes themselves represented in part (a) of the figure. The frequency versus time portion of the figure in part (c) indicates that the frequency decreases for the second tone. Part (d) of the figure shows the frequency spectrum. The frequency scale is normally a logarithmic scale also which allows the broad range of frequency present in the audible range to be presented on a single scale. Notice again that there is no information in the level versus frequency plot to indicate the order in which the two tones were presented.

Several other examples could be given for various types of tones changing with frequencies or intermittent with time. However, since most noises which occur are broadband in nature, that is, they contain many different frequencies, the remaining examples will deal with noise instead of tones.

Figure 7 shows a steady narrowband of noise. The pressure of fluctuations of the noise are indicated in part 7(a). Part 7(b)

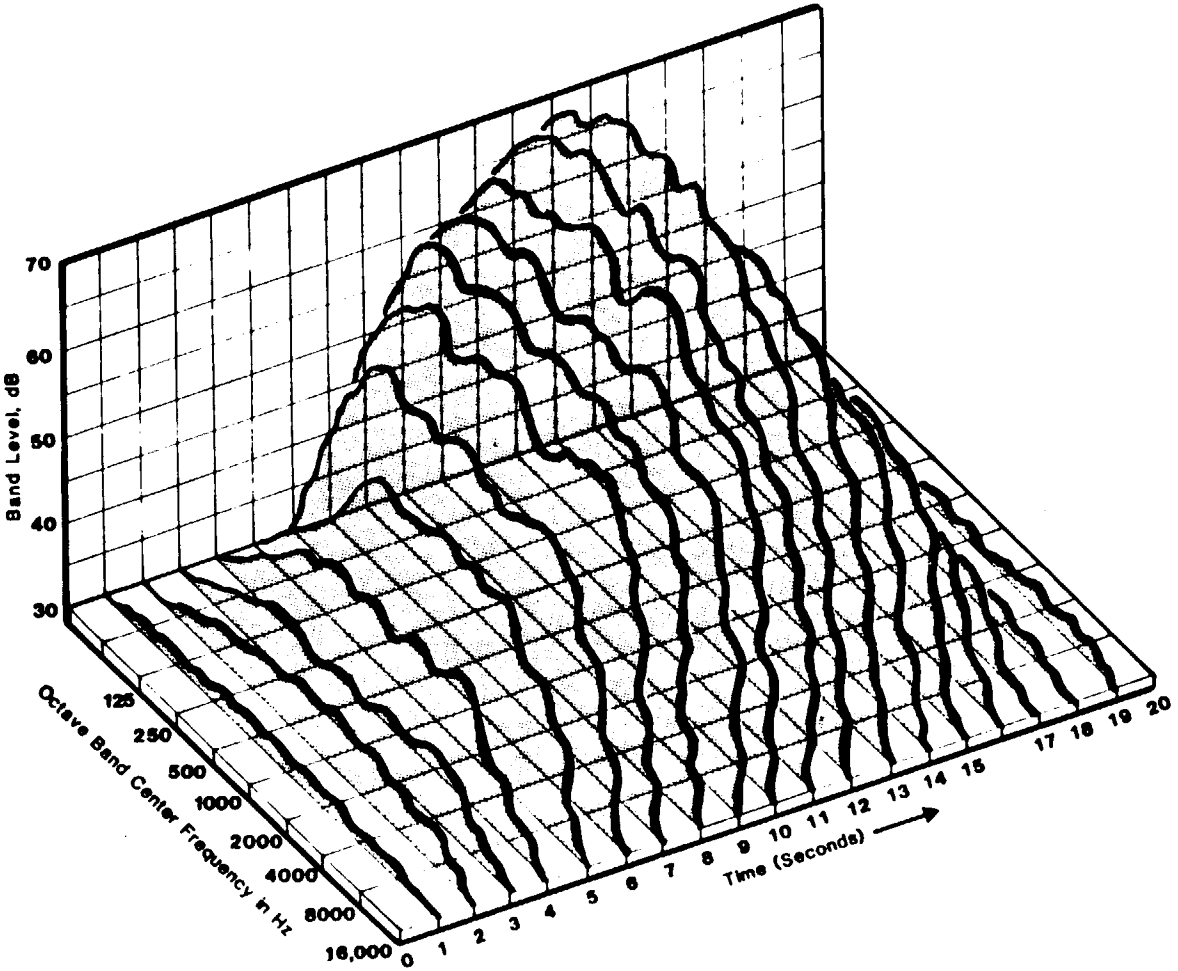
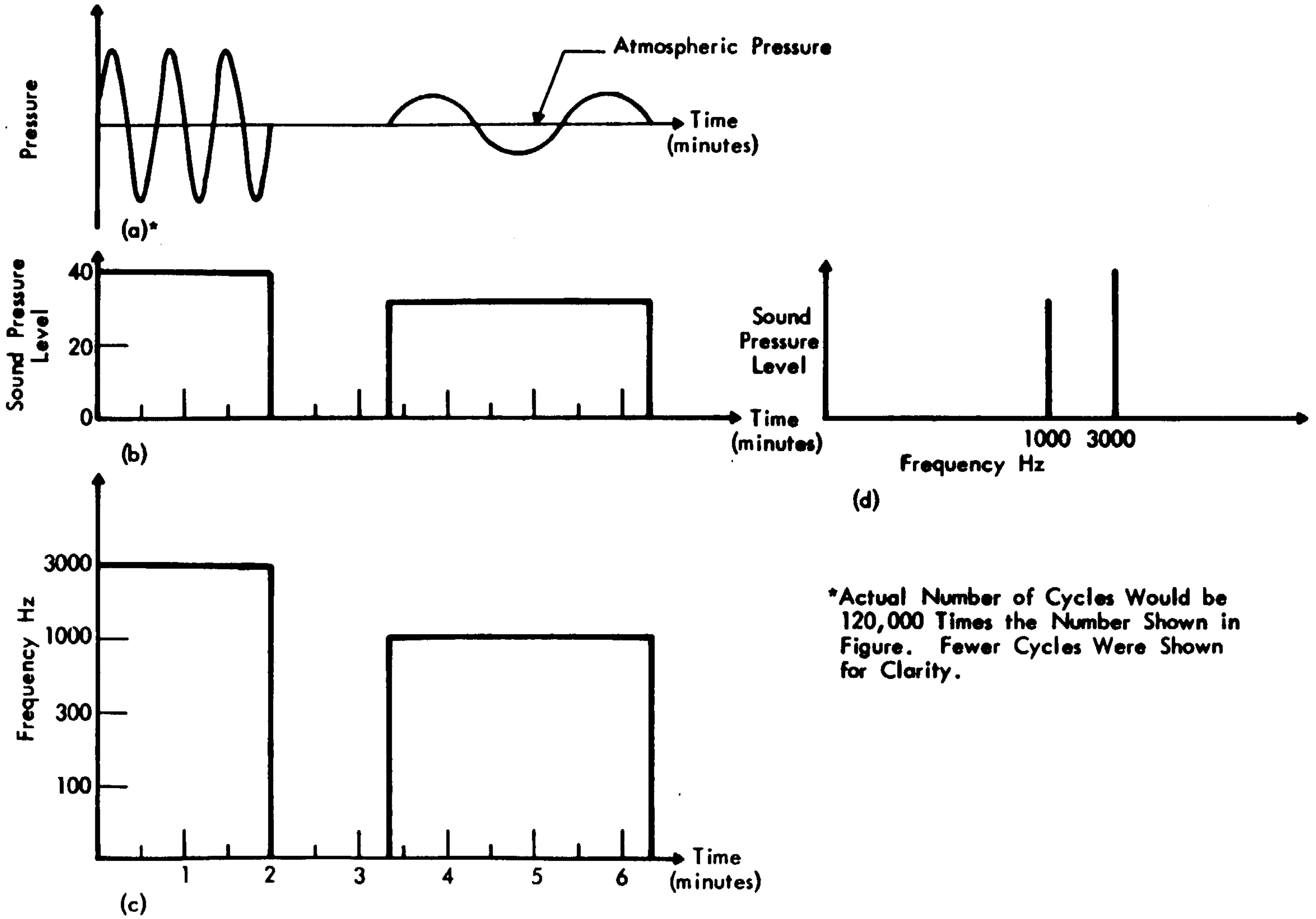
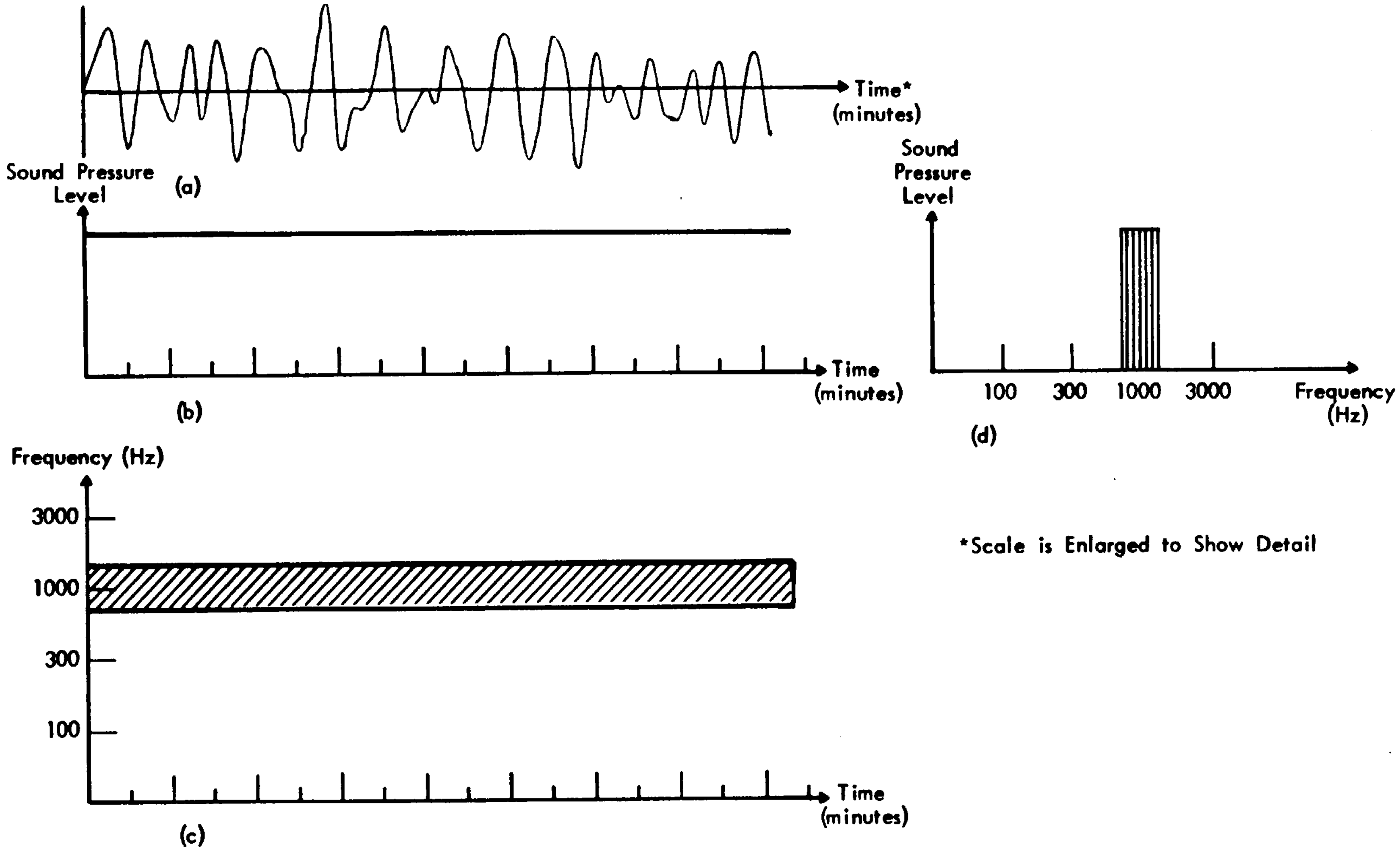


FIGURE 5. TIME VARYING AIRCRAFT SPECTRA



*Actual Number of Cycles Would be 120,000 Times the Number Shown in Figure. Fewer Cycles Were Shown for Clarity.

FIGURE 6. TWO TONES OF DIFFERENT FREQUENCY OCCURRING AT DIFFERENT TIMES



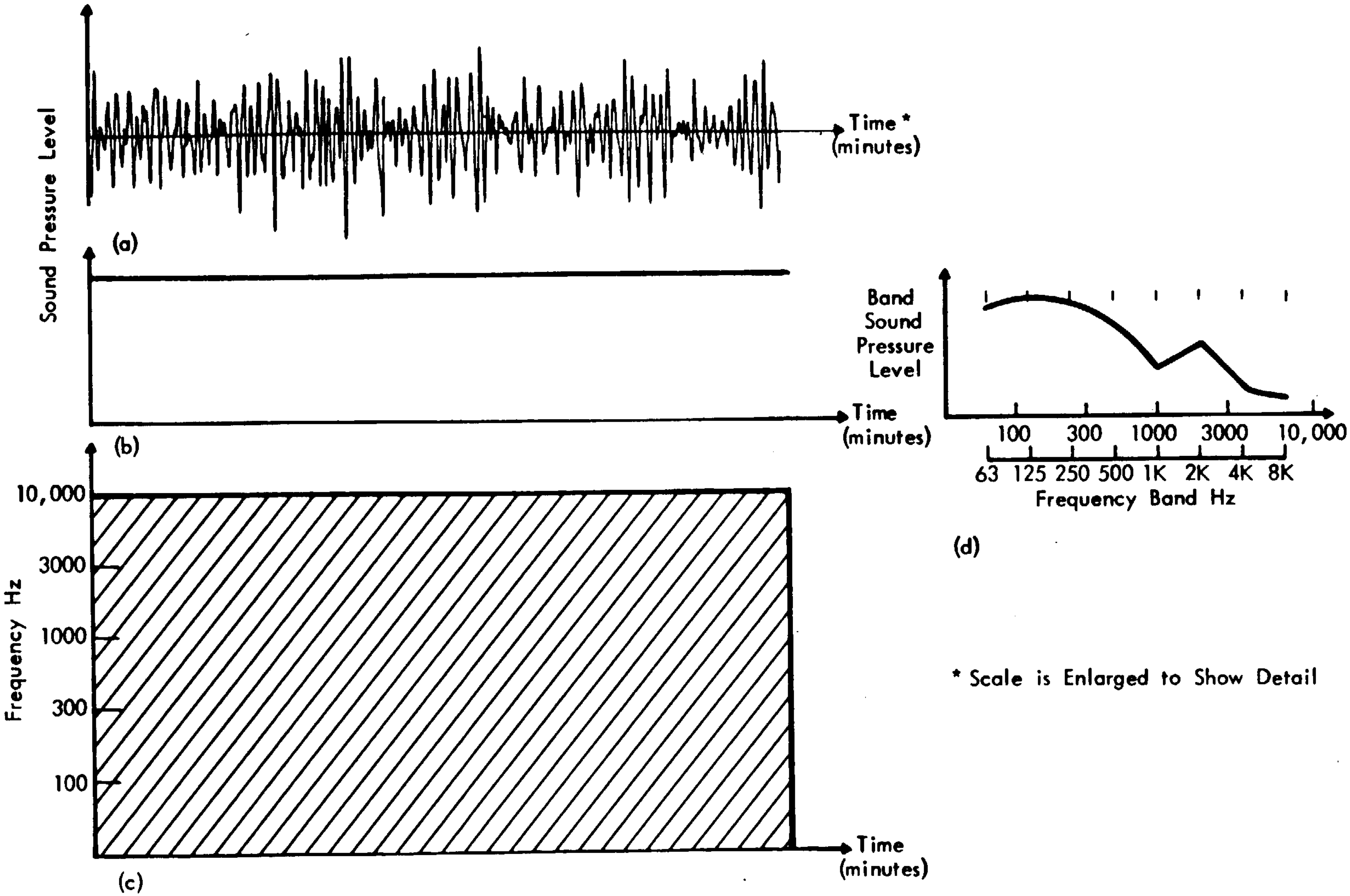
*Scale is Enlarged to Show Detail

FIGURE 7. OCTAVE BAND OF NOISE AT 1000 Hz

shows the sound level of the noise which, since it is steady, is represented by a horizontal line. Part 7(c) shows the frequency band as a function of time which is also horizontal since the sample is constant in frequency. The band of frequency is also represented in part 7(d) which indicates the spectrum of the noise.

Figure 8 shows also a steady noise, but this one is broadband in nature. It is difficult to note any difference in the pressure fluctuations of the broadband noise in Figure 8(a) compared to the narrowband of noise in Figure 7(a). Also, the plot of sound level for the two cases is the same (part 7(b) and 8(b)). However, the plot of frequency versus time covers a much broader bandwidth in Figure 8(c), compared to Figure 7(c). It is difficult to indicate the amplitude of the various parts of the spectrum as a function of time. Therefore, they are merely suggested by a shaded area which encompasses the entire bandwidth of the sound. Amplitude of the various frequency portions of the noise are shown by the spectrum part of Figure 8( Here it is shown that there is more low frequency energy than high frequency energy in this particular example. The spectrum for most noises is usually represented by octave or third octave band levels and although represented by a continuous line, is actually a series of finite measurements for particular octave or third octave band levels.

Moving from a steady state type of noise to a single event type of noise, we mainly see a change in the plots of pressure or level versus time. In these cases, the level starts at the normal background level already present in a given acoustical environment and rises to a maximum level indicated by the greatest pressure fluctuations in Figure 8(a) or the highest



* Scale is Enlarged to Show Detail

FIGURE 8. BROAD BAND OF NOISE

level shown in Figure 8(b). Since it is assumed that the frequencies do not change with time, neither part (c) nor (d) differ from their counterparts in Figure 7 for a steady narrowband noise.

## Working With Sound Levels

### Combining Sound Levels

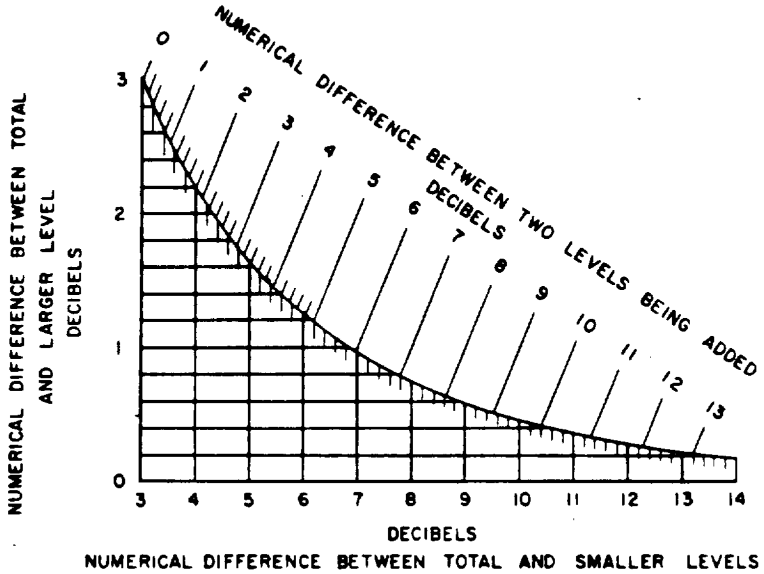
As stated earlier, sound levels are quantified on a logarithmic scale and, as such, cannot be combined using simple addition. For example, two sounds of the same level when added together increase the total sound level by 3 dB. In order to combine sounds of other levels, Figure 9 provides a convenient method of doing so. If more than two sounds are to be combined, then Figure 9 may be used repeatedly until all sounds have been combined.

### Sound Propagation

As one moves farther and farther away from a sound source, the sound level experienced becomes less and less. If the size of the source is small compared to the distance from the source, the source may be treated as a "point source" and the decrease in sound pressure level represented by the formula:

$$\Delta = 20 \log \frac{d}{d_{ref}}$$

where d is the distance from the source to the observer and $d_{ref}$ is the distance at which the sound level measure was taken. Using this formula, one can determine that there is a 6 dB



* Ref. Peterson A.P.G. and E.E. Gross,
"Handbook of Noise Measurement",
Seventh ed. General Radio Company, 1972

FIGURE 9. CHART FOR COMBINING SOUNDS OF DIFFERENT LEVELS

reduction in level every time the distance from a source to the observer doubles. When the distance from the source to the observer becomes very large (greater than 305 meters (1000 ft)) additional effects occur which further diminish the sound level and characteristics. Such losses are associated with atmospheric effects and are more apparent at high frequencies than at low frequencies. For further information, the reader is referred to atmospheric absorption tables which provide sound attenuation for different frequencies as a function of temperature and humidity.

Other elements can affect the sound level. Such elements include the effects of wind, barriers, reflections from other obstacles, and the effects of enclosures either about the source or the receiver. These aspects are beyond the scope of this Handbook, and the reader is referred to other literature on noise control and reduction which are more suitable for details of this nature.

# CHAPTER I

## INSTANTANEOUS SOUND LEVEL METRICS

Part A. Frequency Weighted Metrics

Part B. Computed Metrics

# Part A. Frequency Weighted Metrics

| | |
|---|---|
| TITLE | A-WEIGHTED SOUND LEVEL |
| ABBREVIATION | SLA |
| SYMBOL | $L_A$ |
| UNIT | Decibel (dB)* |
| GEOGRAPHICAL USAGE | International |

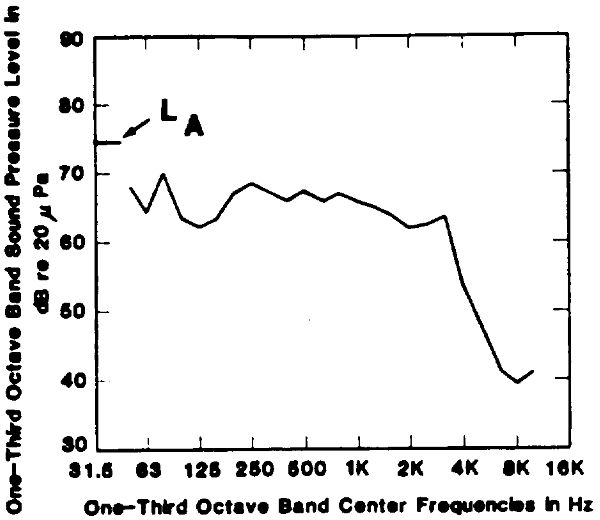


FIGURE SLA-1. AIRCRAFT FLYOVER SPECTRUM

| | |
|---|---|
| DEFINITION | A-weighted sound level is sound pressure level modified to de-emphasize the low frequency portion of sounds. The weighting employed is depicted in Figure SLA-2. It is one of several such weightings (A, B, C, D) found on a sound level meter which attempts to approximate the human ear's response to sound. |
| PURPOSE | A-weighted sound level is used to approximate the relative "noisiness" or "annoyance" of many commonly occurring steady state or intermittent |

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*It is often seen in the literature as dBA or dB(A). However, according to ANSI Y10.11-1979, the correct unit is decibels without a modifier.

sounds. It is often employed in measuring outdoor community noise such as aircraft flyovers and vehicular traffic. However, for short impulsive sounds, or sounds with very intense low frequency characteristics or with discrete tonal components, A-weighted sound level does not do an adequate job of accounting for people's subjective response and other more precise measures should be used.

**BACKGROUND**

A-weighted sound level was initially intended to be a convenient way to approximate subjectively judged loudness for measured sound levels between 24 and 55 dB. However, in practical usage it was found that A-weighted sound level correlated extremely well with human responses to many different sounds regardless of the levels.

This simple rating is a valid and reliable measure of many types of noise signals and is comparable to many of the more complex noise rating methods. A-weighted sound level is also used as the basic frequency weighting for other measures such as the statistical measure $L_X$ or for equivalent continuous level, (QL). In fact, sound level is understood to mean A-weighted sound level if no frequency weighting is specified.

An electrical network designed to provide the A-weighting has been conveniently incorporated into most sound level meters since approximately the late 1930's. This affords a simple direct method of measuring the A-level of a given noise signal. The resulting weighted spectrum is summed to obtain a single rating number. Figure SLA-1 shows a typical airplane flyover spectrum and the resulting A-level.

A-weighted sound level is widely accepted in both industrial and community noise control programs. It has been incorporated in many ordinances and regulations at both the state and federal level. And, it is often used in the rules and regulations published by several federal agencies including the Department of Labor (DOL), the Environmental Protection Agency (EPA), the Department of Transportation (DOT), and the Department of Housing and Urban Development (HUD).

*Relation to Other Ratings*

A-weighted sound level can be estimated from another sound measure as follows:

Perceived Noise Level (PNL) ($L_{PN}$)

$$L_A \cong L_{PN} - 13 \ (\pm 3 \text{ dB})$$

**CALCULATION METHOD**

A-weighted sound level for a given noise can either be calculated using the values in Table SLA-1, or Figure SLA-2, or can be measured using a sound level meter with an A-weighted network. The

A-weighted value of a sound can be calculated for octave or one-third octave frequency band measures, and then energy averaged to obtain a single number.

The formulas for computing A-weighted sound level from 10 Hz to 20,000 Hz for octave and one-third octave bands is as follows:

Octave Band

$$L_A = 10 \log_{10} \left[ \sum_{i=1}^{n} 10^{\frac{L_{A(i)}}{10}} \right]$$

where: $L_{A(i)}$ is A-weighted corrected sound level of $i^{th}$ octave band.

$n$ is the highest octave band used.

One-Third Octave Band

$$L_A = 10 \log_{10} \left[ \sum_{i=1}^{n} 10^{\frac{L_{A(i)}}{10}} \right]$$

where: $L_{A(i)}$ is A-weighted corrected sound level of $i^{th}$ one-third octave band.

$n$ is the highest one-third octave band.

**EXAMPLE**

The example of an A-weighted sound level calculation for a turbo-fan jet aircraft flyover is outlined in Table SLA-2. Figure SLA-3 shows the effect of applying the A-weighted correction spectrum to the aircraft flyover spectrum.

This example (Table SLA-2) is for a one-third octave band analysis of the aircraft flyover noise. The A-weighted corrections for one-third octave bands (Table SLA-1) are first added to the aircraft noise one-third octave band and then the individual bands are summed on an energy basis. In order to sum the levels of the bands, the corrected levels are converted to relative pressure squared by dividing by ten and taking the antilog of the result.

$$\text{Relative Pressure Squared} = 10^{\frac{L_{A(i)}}{10}} \qquad [3]$$

The relative pressure squared is then summed and converted back to corresponding decibels.

*Equation 2*

$$L_A = 10 \log_{10} \left[ \sum_{i=1}^{n} 10^{\frac{L_{A(i)}}{10}} \right]$$

$$L_A = 10 \log_{10} (6803.48 \times 10^6)$$

The result for this example is:

$$L_A = 98.3 \text{ dB.}$$

EQUIPMENT

1) Sound level meter (ANSI S1.4-1971)
2) Tape recorder and octave or one-third octave band analyzer.

TABLE SLA-1

A-WEIGHTING CORRECTION FUNCTIONS

| Frequency Hz | A-Weighting Relative Response dB |
|---|---|
| 10 | -70.4 |
| 12.5 | -63.4 |
| *16 | -56.7 |
| 20 | -50.5 |
| 25 | -44.7 |
| *31.5 | -39.4 |
| 40 | -34.6 |
| 50 | -30.2 |
| *63 | -26.2 |
| 80 | -22.5 |
| 100 | -19.1 |
| *125 | -16.1 |
| 160 | -13.4 |
| 200 | -10.9 |
| *250 | - 8.6 |
| 315 | - 6.6 |
| 400 | - 4.8 |
| *500 | - 3.2 |
| 630 | - 1.9 |
| 800 | - 0.8 |
| *1000 | 0 |
| 1250 | + 0.6 |
| 1600 | + 1.0 |
| *2000 | + 1.2 |
| 2500 | + 1.3 |
| 3150 | + 1.2 |
| *4000 | + 1.0 |
| 5000 | + 0.5 |
| 6300 | - 0.1 |
| *8000 | - 1.1 |
| 10000 | - 2.5 |
| 12500 | - 4.3 |
| *16000 | - 6.6 |
| 20000 | - 9.3 |

*Octave Bands

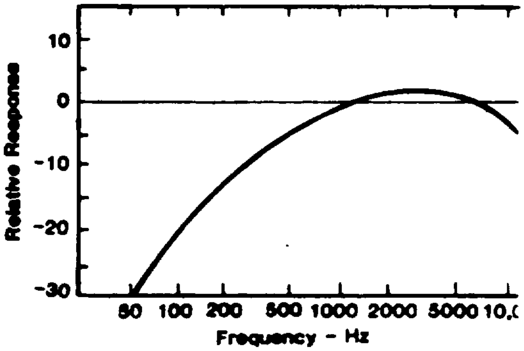

FIGURE SLA-2. A-WEIGHTIN

TABLE SLA-2

EXAMPLE OF A-WEIGHTED SOUND LEVEL CALCULATIONS FROM ONE-THIRD OCTAVE BAND MEASUREMENTS OF AIRCRAFT FLYOVER*

| Frequency Hz | Band Level dB | Correction for A-Weighting (from Table 1) | Corrected Level dB | $10^{\frac{LA}{10}}$ [Eq. 3] |
|---|---|---|---|---|
| 50 | 63 | -30.2 | 32.8 | .001 X $10^6$ |
| 63 | 71 | -26.2 | 44.8 | .030 " " |
| 80 | 74 | -22.5 | 51.5 | .141 " " |
| 100 | 79 | -19.1 | 59.9 | .977 " " |
| 125 | 79 | -16.1 | 62.9 | 1.940 " " |
| 160 | 80 | -13.4 | 66.6 | 4.570 " " |
| 200 | 80 | -10.9 | 69.1 | 8.120 " " |
| 250 | 79 | - 8.6 | 70.4 | 10.960 " " |
| 315 | 79 | - 6.6 | 72.4 | 17.370 " " |
| 400 | 78 | - 4.8 | 73.2 | 20.890 " " |
| 500 | 77 | - 3.2 | 73.8 | 23.980 " " |
| 630 | 78 | - 1.9 | 76.1 | 40.730 " " |
| 800 | 77 | - 0.8 | 76.2 | 41.680 " " |
| 1000 | 78 | 0.0 | 78.0 | 63.090 " " |
| 1250 | 78 | 0.6 | 78.6 | 72.440 " " |
| 1600 | 80 | 1.0 | 81.0 | 125.890 " " |
| 2000 | 81 | 1.2 | 82.2 | 165.950 " " |
| 2500 | 96 | 1.3 | 97.3 | 5370.310 " " |
| 3150 | 86 | 1.2 | 87.2 | 524.800 " " |
| 4000 | 78 | 1.0 | 79.0 | 79.430 " " |
| 5000 | 83 | 0.5 | 83.5 | 223.870 " " |
| 6300 | 67 | - 0.1 | 66.9 | 4.890 " " |
| 8000 | 62 | - 1.1 | 60.9 | 1.230 " " |
| 10000 | 52 | - 2.5 | 49.5 | .089 " " |

*Turbofan jet aircraft at 1000 ft (305 m)

Equation [2]

$$\text{Total} = 6803.48 \times 10^6$$

$$= 10 \log_{10} (6803.48 \times 10^6)$$

$$L_A = 98.3 \text{ dB}$$

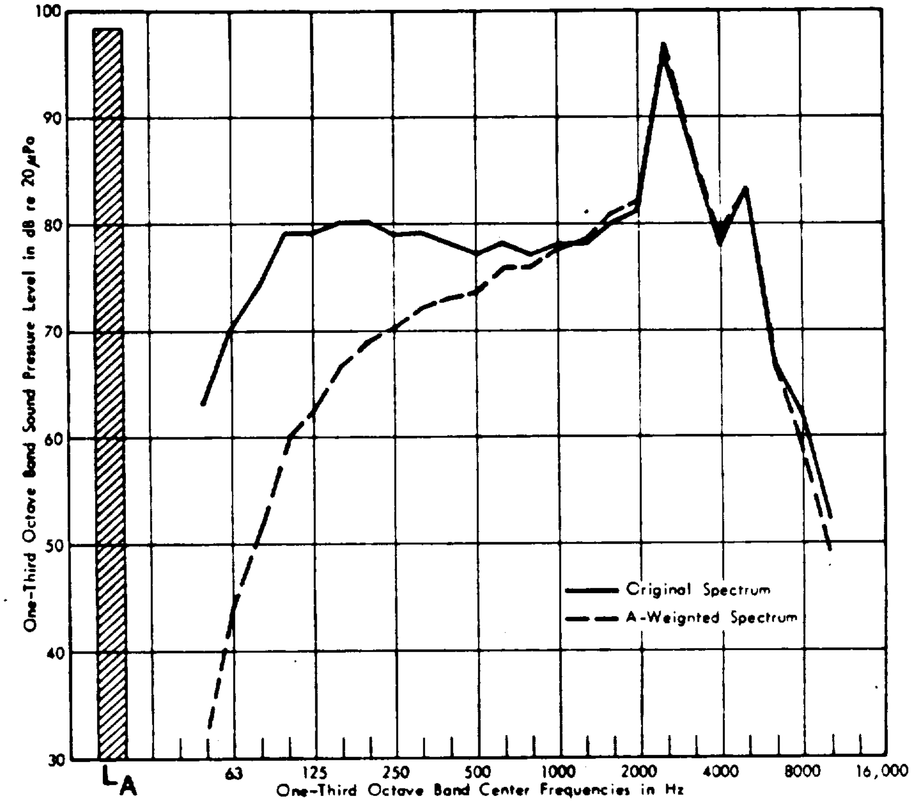

FIGURE SLA-3. EXAMPLE OF EFFECT OF A-WEIGHTING CORRECTIONS ON JET TURBOFAN AIRCRAFT FLYOVER SPECTRUM

STANDARDS

1) American National Standards Institute (ANSI), "American Standard Specification for Sound Level Meters", S1.4-1971.

2) International Electrotechnical Commission, "Precision Sound Level Meters", IEC/179 (1973).

3) International Electrotechnical Commission, "Recommendations for Sound Level Meters", IEC/123 (1961).

4) International Electrotechnical Commission, "Recommendation for Octave, Half-Octave, and Third-Octave Band Filters Intended for the Analysis of Sounds and Vibration", IEC/225 (1966).

5) American National Standards Institute (ANSI), "American Standard Specification for Octave, Half-Octave and Third-Octave Band Filter Sets", S1.11-1966.

6) American National Standards Institute (ANSI), "Letter Symbols and Abbreviations for Quantities Used in Acoustics", Y10.11-1979.

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2) U.S. Environmental Protection Agency, "Fundamentals of Noise: Measurement, Rating Schemes, and Standards", NTID300.15 (December 1971).

3) Peterson, A. P. G. and E. E. Gross, "Handbook of Noise Measurement". Seventh Ed. General Radio Company, c. 1972.

4) Environmental Protection Agency, "Community Noise", NTID300.3 (December 1971).

5) Environmental Protection Agency, "Public Health and Welfare Criteria for Noise", NCD 73.1 (July 1973).

|  |  |
|---|---|
| TITLE | B-WEIGHTED SOUND LEVEL |
| ABBREVIATION | SLB |
| SYMBOL | $L_B$ |
| UNIT | Decibel (dB)* |
| GEOGRAPHICAL USAGE | International |
| DEFINITION | B-weighted sound level is sound pressure level modified to de-emphasize the low frequency portion of sounds. The weighting employed is depicted in Figure SLB-2. It is one of several such weightings (A, B, C, D) found on a sound level meter which attempts to approximate the human ear's response to sound. |
| PURPOSE | B-weighted sound level was developed to approximate the relative loudness of medium level sounds. |

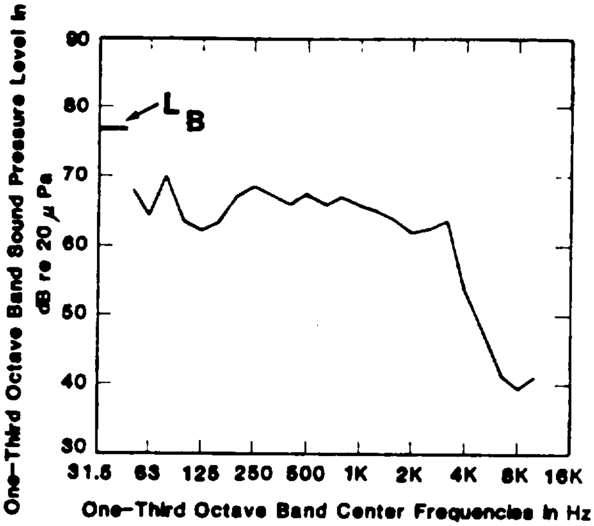

FIGURE SLB-1. AIRCRAFT FLYOVER SPECTRUM

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*It is often seen in the literature as dBB or dB(B). However, according to ANSI Y10.11-1979, the correct unit is decibels without a modifier.

Currently SLB is not usually employed for noise measurement purposes.

**BACKGROUND**

In an effort to provide a better correlate with the loudness of sounds, three weighting networks were designed into sound level meters to modify sound pressure levels in accordance with equal loudness contours.

The B-weighting shown in Figure SLB-2 was one of the weighting networks used. The B-weighting network has the response characteristics that are approximately the inverse of the 70 phon equal loudness contour for pure tones. The B-weighting was to be used if the readings on the sound level meter were between 55 to 85 dB. Figure SLB-1 shows a typical airplane spectrum and the resulting B-lev

**CALCULATION METHOD**

B-weighted sound level can either be calculated using the values in Table SLB-1 (Figure SLB-2) or can be measured using a sound level meter with a B-weighted network. The calculation procedure is identical to the A-weighting procedure, thus allowing the B-weighted value to be determined from octave or one-third octave band frequency measurements.

**EXAMPLE**

Follow the same procedures outlined in the section for A-weighted sound level (Table SLA-2). Figure SLB-3 in this section on B-weighting shows the

## TABLE SLB-1

## B-WEIGHTING CORRECTION FUNCTIONS

| Frequency Hz | A-Weighting Relative Response dB |
|---|---|
| 10 | -38.2 |
| 12.5 | -33.2 |
| *16 | -28.5 |
| 20 | -24.2 |
| 25 | -20.4 |
| *31.5 | -17.1 |
| 40 | -14.2 |
| 50 | -11.6 |
| *63 | - 9.3 |
| 80 | - 7.4 |
| 100 | - 5.6 |
| *125 | - 4.2 |
| 160 | - 3.0 |
| 200 | - 2.0 |
| *250 | - 1.3 |
| 315 | - 0.8 |
| 400 | - 0.5 |
| *500 | - 0.3 |
| 630 | - 0.1 |
| 800 | 0 |
| *1000 | 0 |
| 1250 | 0 |
| 1600 | 0 |
| *2000 | - 0.1 |
| 2500 | - 0.2 |
| 3150 | - 0.4 |
| *4000 | - 0.7 |
| 5000 | - 1.2 |
| 6300 | - 1.9 |
| *8000 | - 2.9 |
| 10000 | - 4.3 |
| 12500 | - 6.1 |
| *16000 | - 8.4 |
| 20000 | -11.1 |

*Octave Bands

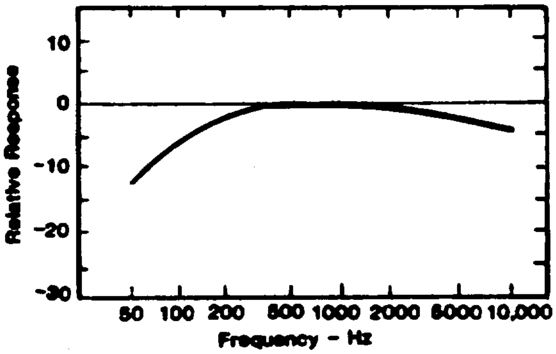

FIGURE SLB-2. B-WEIGHTING

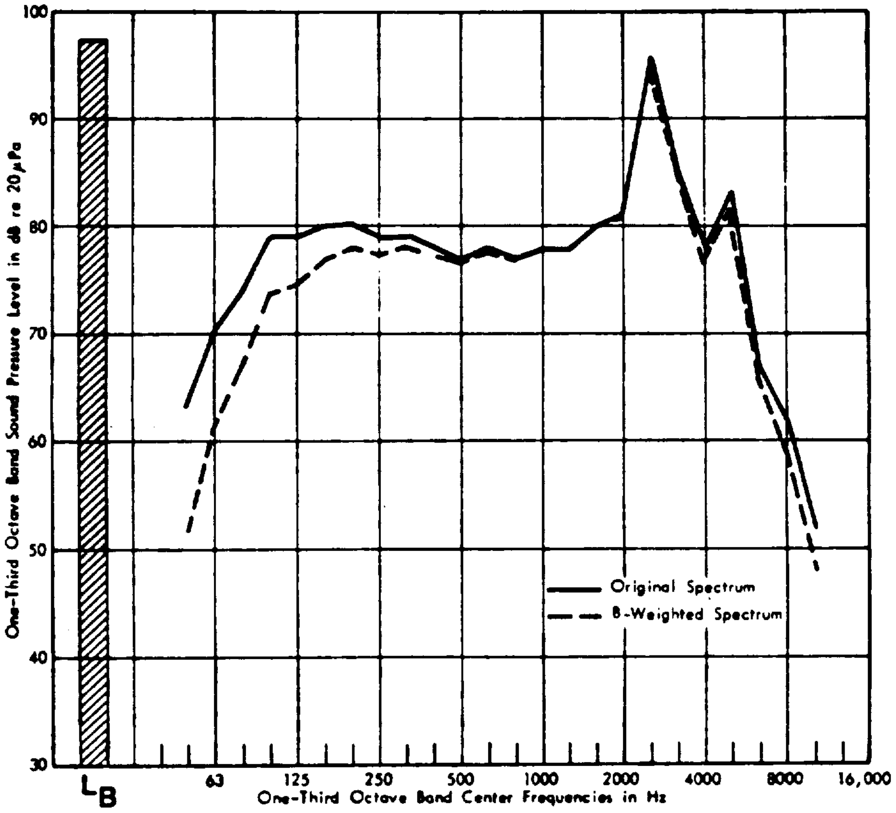

FIGURE SLB-3. EXAMPLE OF EFFECT OF B-WEIGHTING CORRECTIONS ON JET TURBOFAN AIRCRAFT FLYOVER SPECTRUM effect of applying a B-weighted correction spectrum to an aircraft flyover spectrum. The resulting sound level is:

$$L_B = 97.1 \text{ dB.}$$

**EQUIPMENT**

1) Sound level meter (ANSI S1.4-1971)
2) Or, tape recorder and octave or one-third octave band analyzer.

**STANDARDS**

1) American National Standards Institute (ANSI), "American Standard Specification for Sound Level Meters", S1.4-1971.
2) International Electrotechnical Commission, "Precision Sound Level Meters", IEC/179 (1973).
3) International Electrotechnical Commission, "Recommendations for Sound Level Meters", IEC/123 (1961).
4) International Electrotechnical Commission, "Recommendation for Octave, Half-Octave, and Third-Octave Band Filters Intended for the Analysis of Sounds and Vibration", IEC/225 (1966).
5) American National Standards Institute (ANSI), "American Standard Specification for Octave, Half-Octave and Third-Octave Band Filter Sets", S1.11-1966.

**REFERENCES**

1) Peterson, A. P. G., and E. E. Gross, "Handbook of Noise Measurement". Seventh Ed. General Radio Company, c. 1972.

2) Beranek, L., Acoustics, McGraw-Hill, New York (1954).

3) Harris, C. M., Handbook of Noise Control, Second Edition, McGraw-Hill, New York (1979).

| | |
|---|---|
| TITLE | C-WEIGHTED SOUND LEVEL |
| ABBREVIATION | SLC |
| SYMBOL | $L_C$ |
| UNIT | Decibel (dB)* |
| GEOGRAPHICAL USAGE | International |

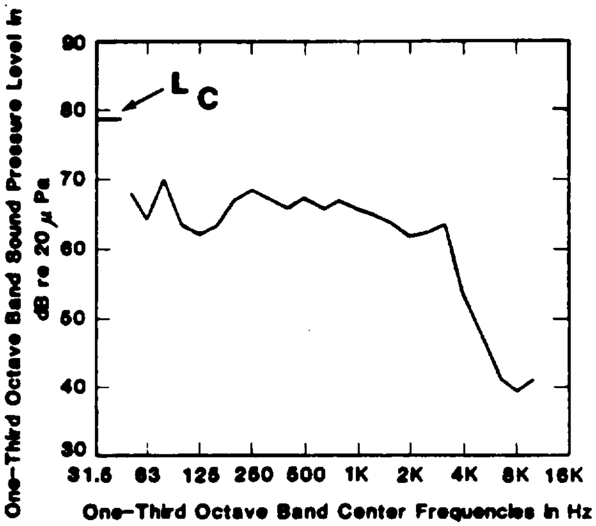

FIGURE SLC-1. AIRCRAFT FLYOVER SPECTRUM

| | |
|---|---|
| DEFINITION | C-weighted sound level is sound pressure level modified to limit the low and high frequency portion of sounds. The weighting employed is depicted in Figure SLC-2. It is one of several such weightings (A, B, C, D) found on a sound level meter which attempts to approximate the human ear's response to sound. |
| PURPOSE | The C-weighted sound level was developed to approximate the relative loudness level of high level |

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*It is often seen in the literature as dBC or dB(C). However, according to ANSI Y10.11-1979, the correct unit is decibels without a modifier.

sounds. Currently it is primarily used to approximate overall sound pressure level where the frequency range of interest is between 31.5 Hz and 8000 Hz. Frequency weightings are 3 dB or less in that range.

**BACKGROUND**

In an effort to provide a better correlate with the loudness of sounds, three weighting networks were designed into sound level meters to modify sound pressure levels in accordance with equal loudness contours

The C-weighting shown in Figure SLC-2 was one of the weighting networks used. It is essentially flat and therefore provides a reasonable approximation for estimating the loudness level of high level sounds. Like the A-weighting and B-weighting, the C-weighting relates to the equal loudness contours. Specifically, it is the inverse of the 100 phon loudness contour. Initially the C-weighting was to be used if readings on the sound level meter were above 85 dB.

The C-weighting scale is fairly uniform in response from 31.5 Hz to 8000 Hz; it must be noted that the weighting factors shown in Table SLC-1 will yield a slightly different result from measurements done with a linear scale which contains no corrections. However, if the sound level meter does not have a linear scale selection, it would be fairly safe to use the C-weighting as an estimate of the overall sound pressure level. Figure SLC-1 shows a typical airplane spectrum and the resulting C-level.

### *Relation to Other Ratings*

A comparison of the three weighting networks for a

TABLE SLC-1

C-WEIGHTING CORRECTION FUNCTIONS

| Frequency Hz | A-Weighting Relative Response dB |
|---|---|
| 10 | -14.3 |
| 12.5 | -11.2 |
| *16 | - 8.5 |
| 20 | - 6.2 |
| 25 | - 4.4 |
| *31.5 | - 3.0 |
| 40 | - 2.0 |
| 50 | - 1.3 |
| *63 | - 0.8 |
| 80 | - 0.5 |
| 100 | - 0.3 |
| *125 | - 0.2 |
| 160 | - 0.1 |
| 200 | 0 |
| *250 | 0 |
| 315 | 0 |
| 400 | 0 |
| *500 | 0 |
| 630 | 0 |
| 800 | 0 |
| *1000 | 0 |
| 1250 | 0 |
| 1600 | - 0.1 |
| *2000 | - 0.2 |
| 2500 | - 0.3 |
| 3150 | - 0.5 |
| *4000 | - 0.8 |
| 5000 | - 1.3 |
| 6300 | - 2.0 |
| *8000 | - 3.0 |
| 10000 | - 4.4 |
| 12500 | - 6.2 |
| *16000 | - 8.5 |
| 20000 | -11.2 |

*Octave Bands

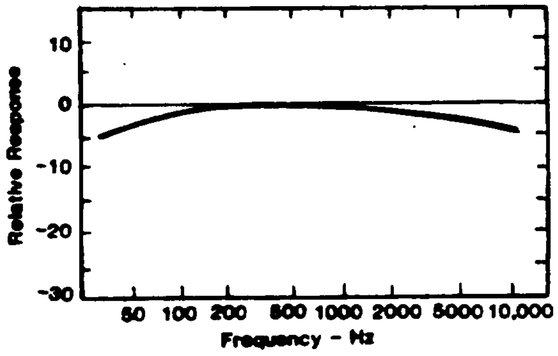

FIGURE SLC-2. C-WEIGHTING

given sound allows one to characterize the frequency components. For example, if C-weighted sound level greater than A- and B-weighted sound level measurements of the same noise signal, then this is an indication that the frequency components below 1000 Hz predominate.

**CALCULATION METHOD**

C-weighted sound level can be calculated using the values in Table SLC-1 or can be measured using a sound level meter with a C-network. The calculation procedure is identical to the A-weighting method.

**EXAMPLE**

Follow the same procedure outlined in the section for A-weighted sound level (Table SLA-2). Figure SLC-3 in this section on C-weighting shows the effec of applying a C-weighted correction spectrum to an aircraft flyover spectrum. The resulting sound level for this example is:

$$L_C = 97.3 \text{ dB}$$

**EQUIPMENT**

1) Sound level meter (ANSI S1.4-1971).
2) Or, tape recorder and octave or one-third octave band analyzer.

**STANDARDS**

1) American National Standards Institute (ANSI), "American Standard Specification for Sound Level Meters", S1.4-1971.
2) International Electrotechnical Commission, "Precision Sound Level Meters", IEC/179 (1973).

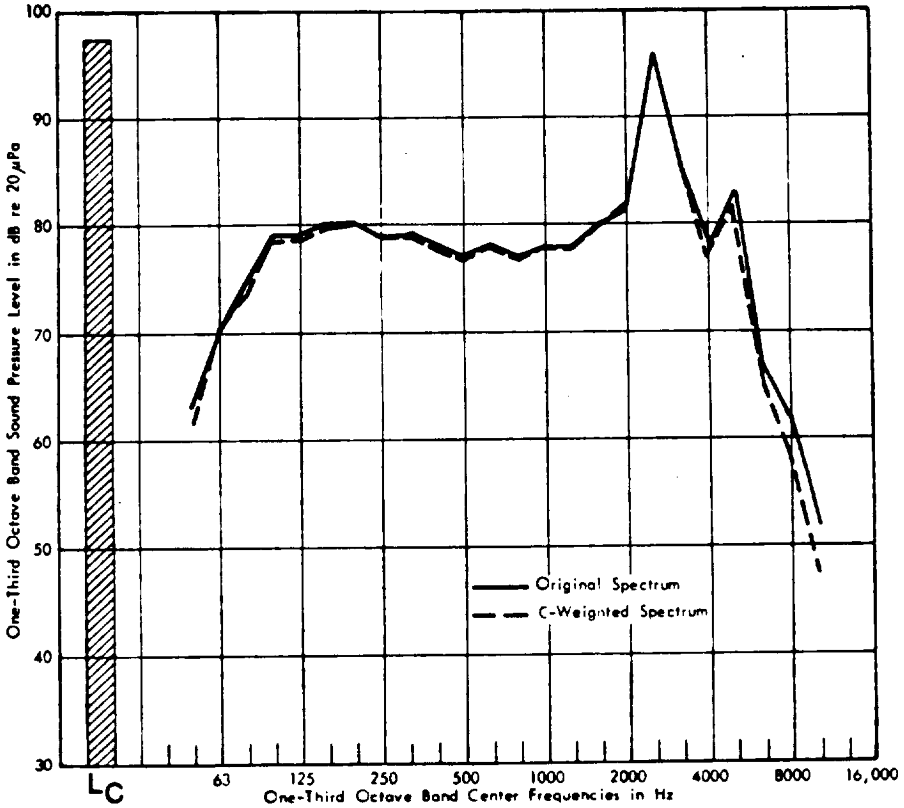

FIGURE SLC-3. EXAMPLE OF EFFECT OF C-WEIGHTING CORRECTIONS ON JET TURBOFAN AIRCRAFT FLYOVER SPECTRUM

3) International Electrotechnical Commission, "Recommendations for Sound Level Meters", IEC/123 (1961).

4) International Electrotechnical Commission, "Recommendation for Octave, Half-Octave, and Third-Octave Band Filters Intended for the Analysis of Sounds and Vibration", IEC/225 (1966)

5) American National Standards Institute (ANSI), "American Standard Specification for Octave, Half-Octave and Third-Octave Band Filter Sets", S1.11-1966.

## REFERENCES

1) Peterson, A. P. G., and E. E. Gross, Jr., "Handbo of Noise Measurement". Seventh Ed. General Radi Company, c. 1972.

2) Beranek, L., Acoustics, McGraw-Hill, New York (1954).

3) Harris, C. M., Handbook of Noise Control, Second Edition, McGraw-Hill, New York (1979).

| | |
|---|---|
| TITLE | D-WEIGHTED SOUND LEVEL |
| ABBREVIATION | SLD |
| SYMBOL | $L_D$ |
| UNIT | Decibel (dB)* |
| GEOGRAPHICAL USAGE | International |
| DEFINITION | D-weighted sound level is sound pressure level modified to de-emphasize the low frequency and emphasize the high frequency portion of sounds. The weighting employed is depicted in Figure SLD-2. It is one of several such weightings (A, B, C, D) found on a sound level meter which attempts to approximate the human ear's response to sound. |
| PURPOSE | D-weighted sound level was developed as a simple approximation of perceived noise level. Further, it |

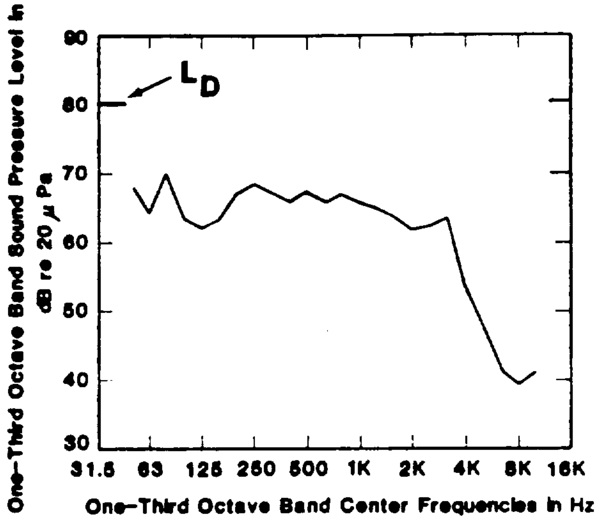

FIGURE SLD-1. AIRCRAFT FLYOVER SPECTRUM

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*It is often seen in the literature as dBD or dB(D). However, according to ANSI Y10.11-1979, the correct unit is decibels without a modifier.

was intended to be a more precise measure than A-weighted sound level to approximate the relative noisiness or annoyance of many commonly occurring sounds.

**BACKGROUND**

Because the calculation procedures for perceived noise level (PNL) is fairly complicated, it was thought that a similar more direct measure that would allow an immediate estimate of the effect of an aircraft flyover should be developed. This measure was initially designated as N-level and was to be incorporated into a sound level meter, like the A-, B- and C-weightings. The weighting network for this new measure was the inverse of the 40 noy contour developed by K. Kryter. However, the N-weighting, unlike A, B and C, had no reference at 1000 Hz. Thus the measurements made with the N-weighting had to be calibrated by determining N-level and PNL from several aircraft flyovers and using the average difference for subsequent N-level measurements. Average N-levels were then, by definition, equal to PNL values.

To eliminate the uncertainty in the N-level, it was suggested that the inverse noy curve weighting be equal to 0 at 1000 Hz (similar to A, B and C), and the Technical Committee No. 29 (Electroacoustics) of the International Electrotechnical Commission (IEC/TC29) further suggested that the letter "D" be adopted to replace the "N". This recommendation ha been implemented. Figure SLD-1 shows a typical air plane flyover spectrum and the resulting D-level.

*Relation to Other Ratings*

**Perceived Noise Level (PNL) ($L_{PN}$)**

The D-weighting can be made to approximate perceived noise level by using the following formula:

$$L_D \cong L_{PN} - 7 \; (\pm 2 \text{ dB})$$

**CALCULATION METHOD**

D-weighted sound level can be calculated using the values in Table SLD-1 or it can be measured using a sound level meter with a D-network. The calculation procedure is identical to the A-weighting method.

**EXAMPLE**

Follow the same procedure outlined in the section for A-weighted sound level (Table SLA-2). Figure SLD-3 in this section on D-weighting shows the effect of applying a D-weighted correction spectrum to an aircraft flyover spectrum. The resulting sound level for this example is:

$$L_D = 107.4 \text{ dB}$$

**EQUIPMENT**

1) Sound level meter (ANSI S1.4-1971).
2) Or, tape recorder and octave or one-third octave band analyzer.

**STANDARDS**

1) International Electrotechnical Commission, "Frequency Weighting for the Measurement of Aircraft Noise (D-Weighting)", IEC/537 (1976).

## TABLE SLD-1

## D-WEIGHTING CORRECTION FUNCTIONS

| Frequency Hz | D-Weighting Relative Response dB |
|---|---|
| 50 | -12.8 |
| *63 | -10.9 |
| 80 | - 9.0 |
| 100 | - 7.2 |
| *125 | - 5.5 |
| 160 | - 4.0 |
| 200 | - 2.6 |
| *250 | - 1.6 |
| 315 | - 0.8 |
| 400 | - 0.4 |
| *500 | - 0.3 |
| 630 | - 0.5 |
| 800 | - 0.6 |
| *1000 | 0 |
| 1250 | 2.0 |
| 1600 | 4.9 |
| *2000 | 7.9 |
| 2500 | 10.6 |
| 3150 | 11.5 |
| *4000 | 11.1 |
| 5000 | 9.6 |
| 6300 | 7.6 |
| *8000 | 5.5 |
| 10000 | 3.4 |

*Octave Bands

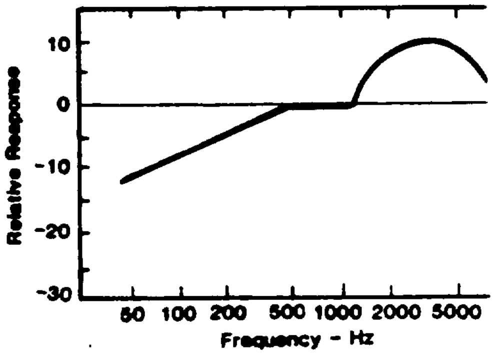

FIGURE SLD-2. D-WEIGHTI

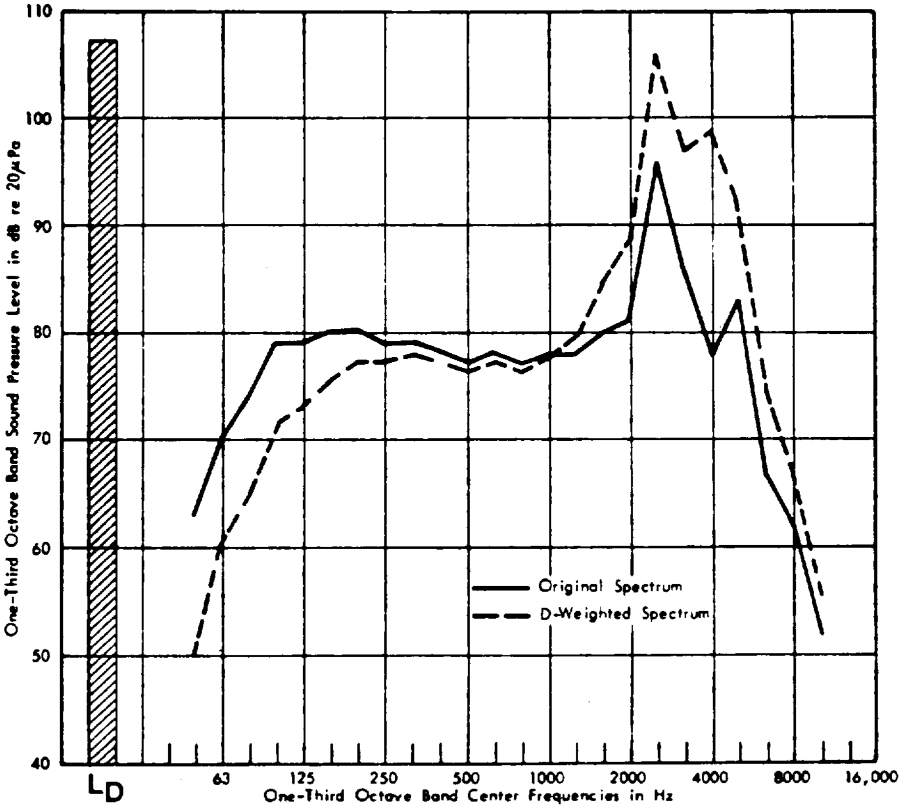

FIGURE SLD-3. EXAMPLE OF EFFECT OF D-WEIGHTING CORRECTIONS ON JET TURBOFAN AIRCRAFT FLYOVER SPECTRUM

2) Society of Automotive Engineers, Inc. (SAE), "Frequency Weighting Network for Approximation of Perceived Noise Level for Aircraft Noise", ARP/1080 (1969).

3) International Electrotechnical Commission, "Recommendation for Octave, Half-Octave, and Third-Octave Band Filters Intended for the Analysis of Sounds and Vibration", IEC/225 (1966)

## REFERENCES

1) Kryter, K., The Effects of Noise on Man, Academic Press, New York, 1970.

2) Batchelder, L., "Standards Note: D- and N-Weighted Sound Levels", JASA, Vol. 44, No. 4, P. 1159 (1968).

3) Harris, C. M., Handbook of Noise Control, Second Edition, McGraw-Hill, New York (1979).

| | |
|---|---|
| TITLE | E-WEIGHTED SOUND LEVEL |
| ABBREVIATION | SLE |
| SYMBOL | $L_E$ |
| UNIT | Decibel<br>(dB) |
| GEOGRAPHICAL USAGE | Limited |
| DEFINITION | E-weighted sound level is sound pressure level modified to de-emphasize the low frequency and emphasize the high frequency portion of a sound. The frequency response of the weighting network is shown in Figure SLE-2 and listed in Table SLE-1. This measure has been proposed as another attempt to approximate the human ear's response to sound in a manner very similar to D-weighted sound level. |
| PURPOSE | E-weighted sound level, in its proposed form, was designed to provide a close estimate to Stevens' (Ref. 1) perceived level. It was designed to measure the noisiness or loudness of sounds such as aircraft flyovers. |

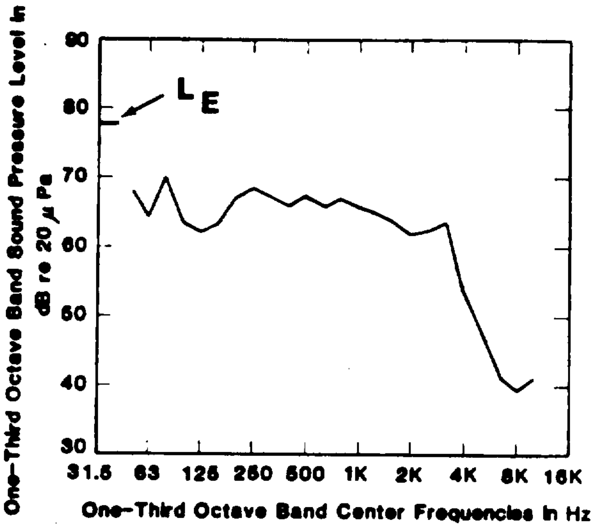

FIGURE SLE-1. AIRCRAFT FLYOVER SPECTRUM

**BACKGROUND**

The concept of E-weighted sound level was proposed by Stevens in his work on perceived level in 1972. He had found that sound measured with this "ear-weighted" frequency response was closely related (± 2 dB) to the perceived level calculated according to Stevens' Mark VII procedure (Ref. 1). E-weighting reflects the basic 20 sone contour used in Mark VII with a standard reference band at 1000 Hz. The accuracy of the E-weighting to predict perceived level is particularly good for sounds of medium level.

E-weighting is as yet a draft standard only recently published by the American National Standard Institute in August of 1978 for comments and criticism. No proposal was made in this draft to incorporate E-weighting as an addition to the American Standard sound level meter. It was merely specified as a frequency weighting which could be used with any general sound measurement system which has a flat frequency response over the frequency range of interest to the experimenter. Figure SLE-1 shows a typical aircraft flyover spectrum and the resulting E-level.

*Relation to Other Ratings*

**D-weighted Sound Level (SLD) ( $L_D$)**

E-weighting is closely related to D-weighted sound level and can be estimated by it.

$$L_E \cong L_D \ (\pm\ 2\ \text{dB})$$

TABLE SLE-1

E-WEIGHTING CORRECTION FUNCTIONS

| Frequency Hz | E-Weighting Relative Response dB |
|---|---|
| 10 | -42.7 |
| 12.5 | -38.8 |
| *16 | -34.9 |
| 20 | -31.1 |
| 25 | -27.4 |
| *31.5 | -23.9 |
| 40 | -20.5 |
| 50 | -17.4 |
| *63 | -14.5 |
| 80 | -11.8 |
| 100 | - 9.4 |
| *125 | - 7.3 |
| 160 | - 5.3 |
| 200 | - 3.6 |
| *250 | - 2.2 |
| 315 | - 1.1 |
| 400 | - 0.3 |
| *500 | 0.1 |
| 630 | 0.1 |
| 800 | 0 |
| *1000 | 0 |
| 1250 | 0.7 |
| 1600 | 2.1 |
| *2000 | 4.0 |
| 2500 | 5.9 |
| 3150 | 7.6 |
| *4000 | 8.7 |
| 5000 | 9.1 |
| 6300 | 8.3 |
| *8000 | 6.5 |
| 10000 | 3.8 |
| 12500 | 0.6 |
| *16000 | - 2.9 |
| 20000 | - 6.7 |

*Octave Bands

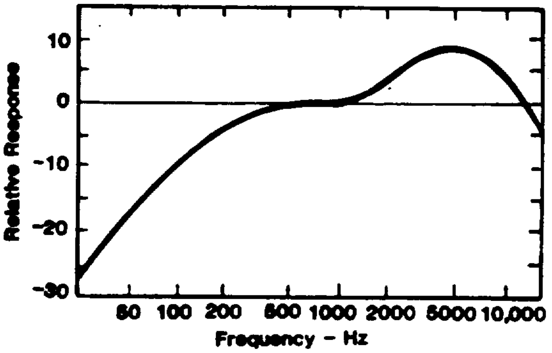

FIGURE SLE-2. E-WEIGHTING

## Perceived Level (PL) ($L_{PL}$)

Since E-weighting was designed to estimate perceived level, the relationship is as follows:

$$L_E \cong L_{PL} \ (\pm 2 \text{ dB})$$

**CALCULATION METHOD**

E-weighted sound level for a measured sound can be calculated using the values in Table SLE-1 (Figure SLE-2). The E-weighted value can be obtained using octave or one-third octave band noise levels. The weighting factors are added to each band level and then all band levels are energy summed to obtain a single number.

The procedure for calculating E-weighted sound level is identical to the method used for A-weighted sound level (Table SLA-2).

**EXAMPLE**

The flyover spectrum for E-weighted sound level is the same one used for the other instantaneous measures. Figure SLE-3 shows a plot of the spectrum both before and after the weighting network has been added. The results for this example are:

$$L_E = 103.2 \text{ dB}$$

**EQUIPMENT**

1) Tape recorder (for single event).
2) Octave or one-third octave band analyzer.

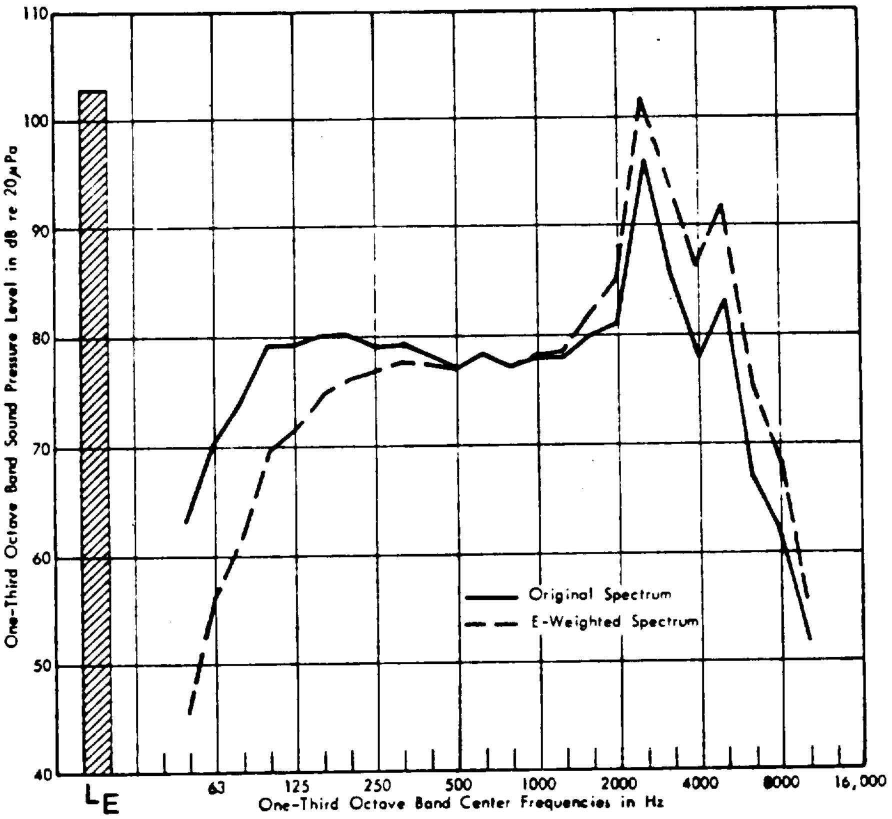

FIGURE SLE-3. EXAMPLE OF EFFECT OF E-WEIGHTING CORRECTIONS ON JET TURBOFAN AIRCRAFT FLYOVER SPECTRUM

| | |
|---|---|
| **STANDARDS** | 1) American National Standards Institute (ANSI), Draft, "E-Weighting Network for Noise Measurement", ANSI S1.27 (August 1978). |

**REFERENCES**

1) Stevens, S. S., "Perceived Level of Noise by Mark VII and Decibels (E)", J. Acoust. Soc. Am., 51, 575-593 (1972).

2) International Electrotechnical Commission, "Frequency Weighting for the Measurement of Aircraft Noise (D-Weighting)", IEC/537 (1976).

3) International Organization for Standardization (ISO), "Procedure for Describing Aircraft Noise Around an Airport", ISO/R507 (1970).

# Part B. Computed Metrics

| | |
|---|---|
| TITLE | PERCEIVED NOISE LEVEL |
| ABBREVIATION | PNL |
| SYMBOL | $L_{PN}$ |
| UNIT | Decibel (dB)* |
| GEOGRAPHICAL USAGE | International |
| DEFINITION | Perceived noise level (PNL) is a rating of the noisiness of a sound calculated from acoustic measurements. It is computed from sound pressure levels measured in octave or one-third octave frequency bands. The PNL of a given sound is intended to be numerically equal to the level of an octave band of noise centered at 1000 Hz which is judged equally noisy to the given sound. |

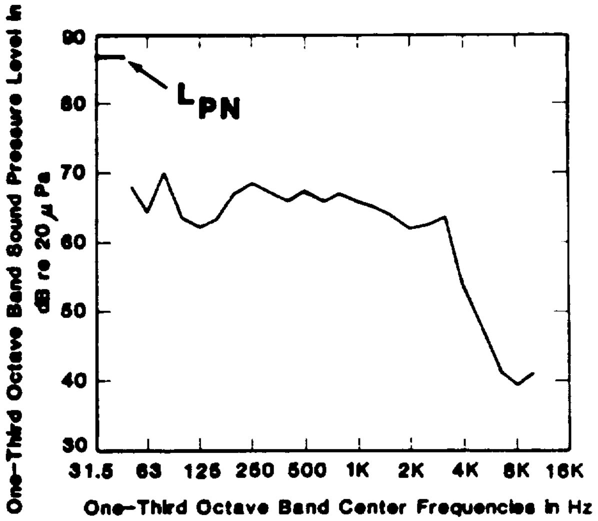

FIGURE PNL-1. AIRCRAFT FLYOVER SPECTRUM

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*The unit for the scale of perceived noisiness is the noy, while the unit for perceived noise level is the decibel. It is seen in the literature as PNdB.

**PURPOSE** PNL was developed as a method for ranking the noisiness of sounds of widely differing spectral character. It is used mainly for ranking the relative annoyance or disturbance caused by aircraft flyover noise.

**BACKGROUND** Karl Kryter introduced the perceived noise level method (Ref. 1) when it was found that loudness level calculated by Stevens' method (Ref. 2) underestimated the judged noisiness of jet aircraft relative to that of reciprocating engine aircraft. The determination of PNL is patterned after Stevens' loudness level, except that equal noisiness curves were employed instead of equal loudness curves. Two sounds of equal noisiness mean that people would be willing to accept one sound as much as the other "occurring periodically 20-30 times during the day and night at their home". The equal noisiness curves shown in Figure PNL-2 were developed by determining the levels of equal noisiness of various bands of noise at different frequencies. Figure PNL-1 shows a typical airplane flyover and the resulting PNL value.

The unit noy shown in Figure PNL-2 is used for the scale of perceived noisiness. The numerical value of 1 noy was assigned to the perceived noisiness of an octave band of random noise centered at 1000 Hz and corresponding to a sound pressure level of 40 dB. Similarly, 2 noys corresponded to a sound pressure level of an octave band of random noise at 50 dB.

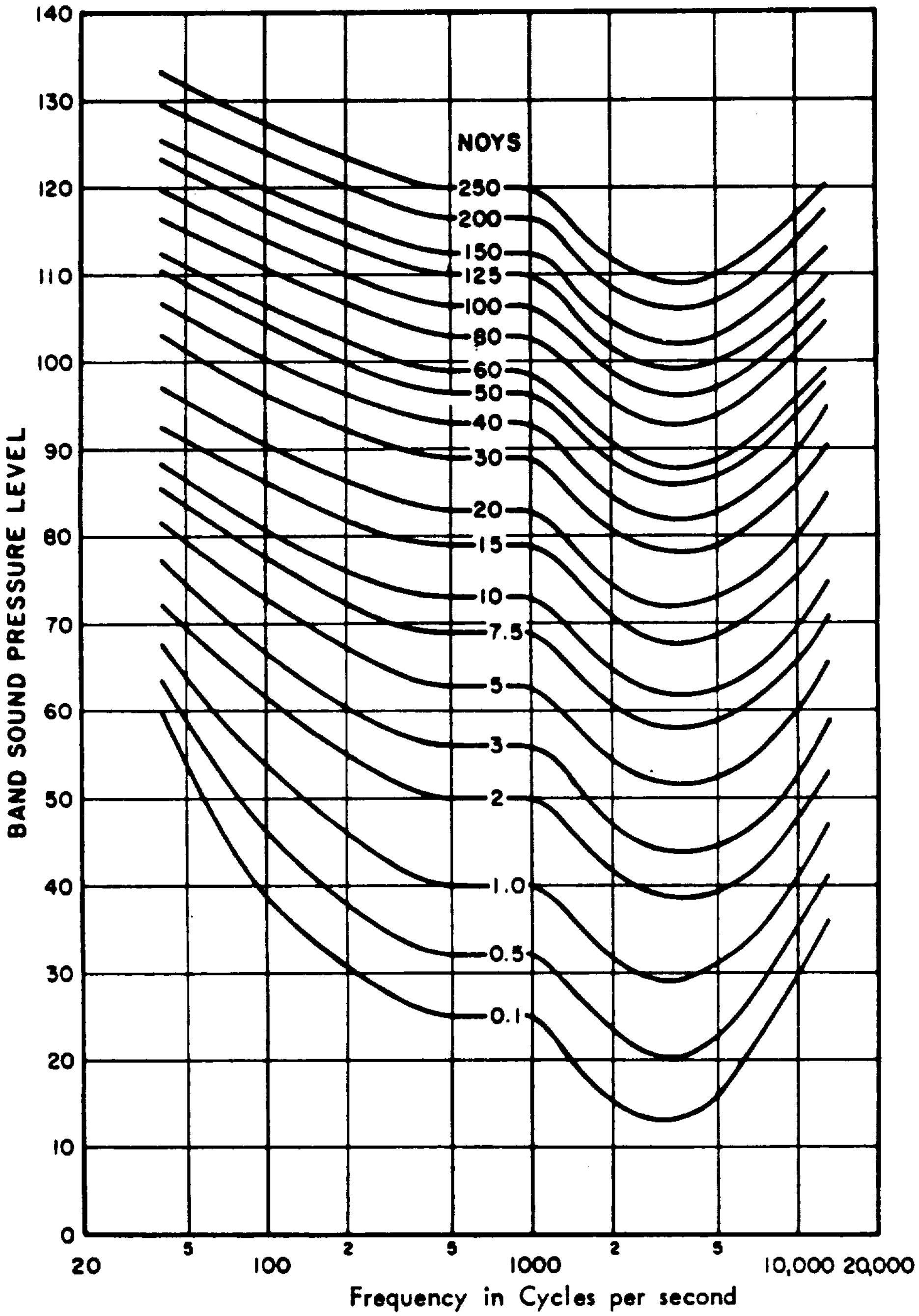

FIGURE PNL-2. NOISINESS OF BANDS OF SOUND

Thus, above the 1 noy value, an increase of 10 dB is equivalent to a doubling of the perceived noisiness as measured in noys, similar to the growth of loudness suggested by Stevens. As noted in Figure PNL-2, values less than 1 noy do not grow in the same manner, but again follow the same pattern as suggested by Stevens for the loudness measure.

Validation tests for the perceived noise level using a variety of sounds indicated that the calculation procedure did not account for the effects of pure tones such as those often present in turbofan aircraft flyovers (Refs. 3 & 4). Nor did it take into consideration the effect of the duration of a sound, since it was mainly used to rank the judged noisiness for sounds of equal duration. For these reasons, further research was conducted which eventually provided tone corrected perceived noise level (PNLT) and effective perceived noise level (EPNL), which attempt to include the effects of pure tone and duration as indicated elsewhere in this Handbook.

The method uses octave or one-third octave band noise levels. However, for certain types of sounds that vary with time, the manner in which the octave or one-third octave band levels are determined is important. Originally, the band levels were determined as the maximum levels in each band under measurement regardless of the time in which they occurred. When calculated in this manner, the result is called composite PNL (PNLC). With the advent of computer calculations for perceived noise level, band levels are determined for each point in time and perceived noise levels calculated from these measurements. In both cases, maximum perceived noise levels are determined, but differences of as much as 2 dB are observed for the different techniques.

### *Relation to Other Ratings*

**A-Weighted Sound Level (SLA) ($L_A$)**

Both A-weighted sound level and perceived noise level involve a de-emphasis of the low frequency portion of the audible spectrum relative to the high frequency portion. Perceived noise level can be estimated from A-level by the following approximation:

$$L_{PN} \cong L_A + 13 \ (\pm 3 \text{ dB})$$

**D-Weighted Sound Level (SLD) ($L_D$)**

D-weighted sound level approximates sound levels weighted by an inverted 40 noy contour (Figure PNL- and as such provides a closer estimate of PNL than A-weighted sound level. Perceived noise level may be estimated from the following approximation:

$$L_{PN} \cong L_D + 7 \ (\pm 1 \text{ dB})$$

CALCULATION METHOD

The FAA, the International Standards Organization (ISO) and the Society of Automotive Engineers (SAE) procedure for calculating perceived noise level are identical, however, the nomenclature differs slightly (Refs. 5, 6 & 7). It was decided to combine both ISO and SAE calculating procedures for this report.

Two methods are available for determining PNL. One uses noy tables and is suitable for hand calculation; the other uses equations and is adapted for computer calculations.

A) PNL From the Noy Tables and Curves

1) The sound pressure level in each one-third or full octave band from 50 to 10,000 Hz is converted to a noy value by reference to Table PNL-1.
2) These noy values are then combined according to the following formulas:

OCTAVE BANDS

$$N = n_{max} + 0.3 \left[\sum_{i=1}^{k} n - n_{max}\right] \qquad [1]$$

ONE-THIRD OCTAVE BANDS

$$N = n_{max} + 0.15 \left[\sum_{i=1}^{k} n - n_{max}\right] \qquad [2]$$

where:

N is the total perceived noisiness (total noy).

$n$ is the noy value in any given frequency band.

$n_{max}$ is the greatest noy value.

$\Sigma n$ is the sum of the noy values in all bands.

$k$ equals 8 for octave bands; equals 24 for one-third octave bands.

3) N (total perceived noisiness) is converted to perceived noise level (PNL) in dB (read PNdB) by:

a) $$L_{PN} = 40 + \frac{10 \log_{10} N}{\log_{10} 2} \qquad [3$$

or,

b) using the noy curves for values of 1.0 or greater. Read off (Figure PNL-2) at 1000 Hz the sound pressure level corresponding to the total perceived noisiness (N). The sound pressure level at 1000 Hz equals PNL.

B) <u>PNL From Equations</u>

The procedure for determining PNL with equations is the same as that used with noy tables except noy values are determined by equation as follows:

The value n, in noys, given in Table PNL-1 for a particular frequency band is related to the band sound pressure level, L, by the equation:

# TABLE PNL-1. NOYS AS A FUNCTION OF BAND SOUND PRESSURE LEVEL

| SPL | Noys, N, for 1/3-octave-band center frequencies, Hz, of – | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 50 | 63 | 80 | 100 | 125 | 160 | 200 | 250 | 315 | 400 | 500 | 630 | 800 | 1000 | 1250 | 1600 | 2000 | 2500 | 3150 | 4000 | 5000 | 6300 | 8000 | 10 000 |
| 4 | | | | | | | | | | | | | | | | | | | 0.10 | | | | | |
| 5 | | | | | | | | | | | | | | | | | | 0.10 | .11 | 0.10 | | | | |
| 6 | | | | | | | | | | | | | | | | | | .11 | .12 | .11 | 0.10 | | | |
| 7 | | | | | | | | | | | | | | | | | | .12 | .14 | .13 | .11 | | | |
| 8 | | | | | | | | | | | | | | | | | | .14 | .16 | .14 | .13 | | | |
| 9 | | | | | | | | | | | | | | | | | 0.10 | .16 | .17 | .16 | .14 | | | |
| 10 | | | | | | | | | | | | | | | | | .11 | .17 | .19 | .18 | .16 | 0.10 | | |
| 11 | | | | | | | | | | | | | | | | | .13 | .19 | .22 | .21 | .18 | .12 | | |
| 12 | | | | | | | | | | | | | | | | 0.10 | .14 | .22 | .24 | .24 | .21 | .14 | | |
| 13 | | | | | | | | | | | | | | | | .11 | .16 | .24 | .27 | .27 | .24 | .16 | | |
| 14 | | | | | | | | | | | | | | | | .13 | .18 | .27 | .30 | .30 | .27 | .19 | | |
| 15 | | | | | | | | | | | | | | | 0.10 | .14 | .21 | .30 | .33 | .33 | .30 | .22 | | |
| 16 | | | | | | | | | | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | .11 | .16 | .24 | .33 | .35 | .35 | .33 | .26 | | |
| 17 | | | | | | | | | | .11 | .11 | .11 | .11 | .11 | .13 | .18 | .27 | .35 | .38 | .38 | .35 | .30 | 0.10 | |
| 18 | | | | | | | | | 0.10 | .13 | .13 | .13 | .13 | .13 | .15 | .21 | .30 | .38 | .41 | .41 | .38 | .33 | .12 | |
| 19 | | | | | | | | | .11 | .14 | .14 | .14 | .14 | .14 | .17 | .24 | .33 | .41 | .45 | .45 | .41 | .36 | .14 | |
| 20 | | | | | | | | | .13 | .16 | .16 | .16 | .16 | .16 | .20 | .27 | .36 | .45 | .49 | .49 | .45 | .39 | .17 | |
| 21 | | | | | | | | 0.10 | .14 | .18 | .18 | .18 | .18 | .18 | .23 | .30 | .39 | .49 | .53 | .53 | .49 | .42 | .21 | 0.10 |
| 22 | | | | | | | | .11 | .16 | .21 | .21 | .21 | .21 | .21 | .26 | .33 | .42 | .53 | .57 | .57 | .53 | .46 | .25 | .11 |
| 23 | | | | | | | | .13 | .18 | .24 | .24 | .24 | .24 | .24 | .30 | .36 | .46 | .57 | .62 | .62 | .57 | .50 | .30 | .13 |
| 24 | | | | | | | 0.10 | .14 | .21 | .27 | .27 | .27 | .27 | .27 | .33 | .40 | .50 | .62 | .67 | .67 | .62 | .55 | .33 | .15 |
| 25 | | | | | | | .11 | .16 | .24 | .30 | .30 | .30 | .30 | .30 | .35 | .43 | .55 | .67 | .73 | .73 | .67 | .60 | .36 | .17 |
| 26 | | | | | | | .13 | .18 | .27 | .33 | .33 | .33 | .33 | .33 | .38 | .48 | .60 | .73 | .79 | .79 | .73 | .65 | .39 | .20 |
| 27 | | | | | | 0.10 | .14 | .21 | .30 | .35 | .35 | .35 | .35 | .35 | .41 | .52 | .65 | .79 | .85 | .85 | .79 | .71 | .42 | .23 |
| 28 | | | | | | .11 | .16 | .24 | .33 | .38 | .38 | .38 | .38 | .38 | .45 | .57 | .71 | .85 | .92 | .92 | .85 | .77 | .46 | .26 |
| 29 | | | | | | .13 | .18 | .27 | .35 | .41 | .41 | .41 | .41 | .41 | .49 | .63 | .77 | .92 | 1.00 | 1.00 | .92 | .84 | .50 | .30 |
| 30 | | | | | 0.10 | .14 | .21 | .30 | .38 | .45 | .45 | .45 | .45 | .45 | .53 | .69 | .84 | 1.00 | 1.07 | 1.07 | 1.00 | .92 | .55 | .33 |
| 31 | | | | | .11 | .16 | .24 | .33 | .41 | .49 | .49 | .49 | .49 | .49 | .57 | .76 | .92 | 1.07 | 1.15 | 1.15 | 1.07 | 1.00 | .60 | .37 |
| 32 | | | | | .13 | .18 | .27 | .36 | .45 | .53 | .53 | .53 | .53 | .53 | .62 | .83 | 1.00 | 1.15 | 1.23 | 1.23 | 1.15 | 1.07 | .65 | .41 |
| 33 | | | | | .14 | .21 | .30 | .39 | .49 | .57 | .57 | .57 | .57 | .57 | .67 | .91 | 1.07 | 1.23 | 1.32 | 1.32 | 1.23 | 1.15 | .71 | .45 |
| 34 | | | | 0.10 | .16 | .24 | .33 | .42 | .53 | .62 | .62 | .62 | .62 | .62 | .73 | 1.00 | 1.15 | 1.32 | 1.41 | 1.41 | 1.32 | 1.23 | .77 | .50 |
| 35 | | | | .11 | .18 | .27 | .36 | .46 | .57 | .67 | .67 | .67 | .67 | .67 | .79 | 1.07 | 1.23 | 1.41 | 1.51 | 1.51 | 1.41 | 1.32 | .84 | .55 |
| 36 | | | | .13 | .21 | .30 | .40 | .50 | .62 | .73 | .73 | .73 | .73 | .73 | .85 | 1.15 | 1.32 | 1.51 | 1.62 | 1.62 | 1.51 | 1.41 | .92 | .61 |
| 37 | | | | .15 | .24 | .33 | .43 | .55 | .67 | .79 | .79 | .79 | .79 | .79 | .92 | 1.23 | 1.41 | 1.62 | 1.74 | 1.74 | 1.62 | 1.51 | 1.00 | .67 |
| 38 | | | | .17 | .27 | .37 | .48 | .60 | .73 | .85 | .85 | .85 | .85 | .85 | 1.00 | 1.32 | 1.51 | 1.74 | 1.86 | 1.86 | 1.74 | 1.62 | 1.10 | .74 |
| 39 | | | 0.10 | .20 | .30 | .41 | .52 | .65 | .79 | .92 | .92 | .92 | .92 | .92 | 1.07 | 1.41 | 1.62 | 1.86 | 1.99 | 1.99 | 1.86 | 1.74 | 1.21 | .82 |
| 40 | | | .12 | .23 | .33 | .45 | .57 | .71 | .85 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.15 | 1.51 | 1.74 | 1.99 | 2.14 | 2.14 | 1.99 | 1.86 | 1.34 | .90 |
| 41 | | | .14 | .26 | .37 | .50 | .63 | .77 | .92 | 1.07 | 1.07 | 1.07 | 1.07 | 1.07 | 1.23 | 1.62 | 1.86 | 2.14 | 2.29 | 2.29 | 2.14 | 1.99 | 1.48 | 1.00 |
| 42 | | | .16 | .30 | .41 | .55 | .69 | .84 | 1.00 | 1.15 | 1.15 | 1.15 | 1.15 | 1.15 | 1.32 | 1.74 | 1.99 | 2.29 | 2.45 | 2.45 | 2.29 | 2.14 | 1.63 | 1.10 |
| 43 | | | .19 | .33 | .45 | .61 | .76 | .92 | 1.07 | 1.23 | 1.23 | 1.23 | 1.23 | 1.23 | 1.41 | 1.86 | 2.14 | 2.45 | 2.63 | 2.63 | 2.45 | 2.29 | 1.79 | 1.21 |
| 44 | | 0.10 | .22 | .37 | .50 | .67 | .83 | 1.00 | 1.15 | 1.32 | 1.32 | 1.32 | 1.32 | 1.32 | 1.52 | 1.99 | 2.29 | 2.63 | 2.81 | 2.81 | 2.63 | 2.45 | 1.98 | 1.34 |
| 45 | | .12 | .26 | .42 | .55 | .74 | .91 | 1.08 | 1.24 | 1.41 | 1.41 | 1.41 | 1.41 | 1.41 | 1.62 | 2.14 | 2.45 | 2.81 | 3.02 | 3.02 | 2.81 | 2.63 | 2.14 | 1.48 |
| 46 | | .14 | .30 | .46 | .61 | .82 | 1.00 | 1.16 | 1.33 | 1.52 | 1.52 | 1.52 | 1.52 | 1.52 | 1.74 | 2.29 | 2.63 | 3.02 | 3.23 | 3.23 | 3.02 | 2.81 | 2.29 | 1.63 |
| 47 | | .16 | .34 | .52 | .67 | .90 | 1.08 | 1.25 | 1.42 | 1.62 | 1.62 | 1.62 | 1.62 | 1.62 | 1.87 | 2.45 | 2.81 | 3.23 | 3.46 | 3.46 | 3.23 | 3.02 | 2.45 | 1.79 |
| 48 | | .19 | .38 | .58 | .74 | 1.00 | 1.17 | 1.34 | 1.53 | 1.74 | 1.74 | 1.74 | 1.74 | 1.74 | 2.00 | 2.63 | 3.02 | 3.46 | 3.71 | 3.71 | 3.46 | 3.23 | 2.63 | 1.98 |
| 49 | 0.10 | .22 | .43 | .65 | .82 | 1.08 | 1.26 | 1.45 | 1.64 | 1.87 | 1.87 | 1.87 | 1.87 | 1.87 | 2.14 | 2.81 | 3.23 | 3.71 | 3.97 | 3.97 | 3.71 | 3.46 | 2.81 | 2.18 |

# TABLE PNL-1. CONTINUED

| SPL | Noys, N, for 1/3-octave-band center frequencies, Hz, of – | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 50 | 63 | 80 | 100 | 125 | 160 | 200 | 250 | 315 | 400 | 500 | 630 | 800 | 1000 | 1250 | 1600 | 2000 | 2500 | 3150 | 4000 | 5000 | 6300 | 8000 | 10 000 |
| 100 | 27.9 | 29.9 | 34.3 | 39.4 | 42.2 | 45.3 | 52.0 | 55.7 | 59.7 | 64.0 | 64.0 | 64.0 | 64.0 | 64.0 | 73.5 | 94.9 | 109 | 125 | 134 | 134 | 125 | 117 | 94.9 | 77.2 |
| 101 | 29.9 | 32.0 | 36.8 | 42.2 | 45.3 | 48.5 | 55.7 | 59.7 | 64.0 | 68.6 | 68.6 | 68.6 | 68.6 | 68.6 | 78.8 | 102 | 117 | 134 | 144 | 144 | 134 | 125 | 102 | 82.7 |
| 102 | 32.0 | 34.3 | 39.4 | 45.3 | 48.5 | 52.0 | 59.7 | 64.0 | 68.6 | 73.5 | 73.5 | 73.5 | 73.5 | 73.5 | 84.4 | 109 | 125 | 144 | 154 | 154 | 144 | 134 | 109 | 88.6 |
| 103 | 34.3 | 36.8 | 42.2 | 48.5 | 52.0 | 55.7 | 64.0 | 68.6 | 73.5 | 78.8 | 78.8 | 78.8 | 78.8 | 78.8 | 90.5 | 117 | 134 | 154 | 165 | 165 | 154 | 144 | 117 | 94.9 |
| 104 | 36.8 | 39.4 | 45.3 | 52.0 | 55.7 | 59.7 | 68.6 | 73.5 | 78.8 | 84.4 | 84.4 | 84.4 | 84.4 | 84.4 | 97.0 | 125 | 144 | 165 | 177 | 177 | 165 | 154 | 125 | 102 |
| 105 | 39.4 | 42.2 | 48.5 | 55.7 | 59.7 | 64.0 | 73.5 | 78.8 | 84.4 | 90.5 | 90.5 | 90.5 | 90.5 | 90.5 | 104 | 134 | 154 | 177 | 189 | 189 | 177 | 165 | 134 | 109 |
| 106 | 42.2 | 45.3 | 52.0 | 59.7 | 64.0 | 68.6 | 78.8 | 84.4 | 90.5 | 97.0 | 97.0 | 97.0 | 97.0 | 97.0 | 111 | 144 | 165 | 189 | 203 | 203 | 189 | 177 | 144 | 117 |
| 107 | 45.3 | 48.5 | 55.7 | 64.0 | 68.6 | 73.5 | 84.4 | 90.5 | 97.0 | 104 | 104 | 104 | 104 | 104 | 119 | 154 | 177 | 203 | 217 | 217 | 203 | 189 | 154 | 125 |
| 108 | 48.5 | 52.0 | 59.7 | 68.6 | 73.5 | 78.8 | 90.5 | 97.0 | 104 | 111 | 111 | 111 | 111 | 111 | 128 | 165 | 189 | 217 | 233 | 233 | 217 | 203 | 165 | 134 |
| 109 | 52.0 | 55.7 | 64.0 | 73.5 | 78.8 | 84.4 | 97.0 | 104 | 111 | 119 | 119 | 119 | 119 | 119 | 137 | 177 | 203 | 233 | 249 | 249 | 233 | 217 | 177 | 144 |
| 110 | 55.7 | 59.7 | 68.6 | 78.8 | 84.4 | 90.5 | 104 | 111 | 119 | 128 | 128 | 128 | 128 | 128 | 147 | 189 | 217 | 249 | 267 | 267 | 249 | 233 | 189 | 154 |
| 111 | 59.7 | 64.0 | 73.5 | 84.4 | 90.5 | 97.0 | 111 | 119 | 128 | 137 | 137 | 137 | 137 | 137 | 158 | 203 | 233 | 267 | 286 | 286 | 267 | 249 | 203 | 165 |
| 112 | 64.0 | 68.6 | 78.8 | 90.5 | 97.0 | 104 | 119 | 128 | 137 | 147 | 147 | 147 | 147 | 147 | 169 | 217 | 249 | 286 | 307 | 307 | 286 | 267 | 217 | 177 |
| 113 | 68.6 | 73.5 | 84.4 | 97.0 | 104 | 111 | 128 | 137 | 147 | 158 | 158 | 158 | 158 | 158 | 181 | 233 | 267 | 307 | 329 | 329 | 307 | 286 | 233 | 189 |
| 114 | 73.5 | 78.8 | 90.5 | 104 | 111 | 119 | 137 | 147 | 158 | 169 | 169 | 169 | 169 | 169 | 194 | 249 | 286 | 329 | 352 | 352 | 329 | 307 | 249 | 203 |
| 115 | 78.8 | 84.4 | 97.0 | 111 | 119 | 128 | 147 | 158 | 169 | 181 | 181 | 181 | 181 | 181 | 208 | 267 | 307 | 352 | 377 | 377 | 352 | 329 | 267 | 217 |
| 116 | 84.4 | 90.5 | 104 | 119 | 128 | 137 | 158 | 169 | 181 | 194 | 194 | 194 | 194 | 194 | 223 | 286 | 329 | 377 | 404 | 404 | 377 | 352 | 286 | 233 |
| 117 | 90.5 | 97.0 | 111 | 128 | 137 | 147 | 169 | 181 | 194 | 208 | 208 | 208 | 208 | 208 | 239 | 307 | 352 | 404 | 433 | 433 | 404 | 377 | 307 | 249 |
| 118 | 97.0 | 104 | 119 | 137 | 147 | 158 | 181 | 194 | 208 | 223 | 223 | 223 | 223 | 223 | 256 | 329 | 377 | 433 | 464 | 464 | 433 | 404 | 329 | 267 |
| 119 | 104 | 111 | 128 | 147 | 158 | 169 | 194 | 208 | 223 | 239 | 239 | 239 | 239 | 239 | 274 | 352 | 404 | 464 | 497 | 497 | 464 | 433 | 352 | 286 |
| 120 | 111 | 119 | 137 | 158 | 169 | 181 | 208 | 223 | 239 | 256 | 256 | 256 | 256 | 256 | 294 | 377 | 433 | 497 | 533 | 533 | 497 | 464 | 377 | 307 |
| 121 | 119 | 128 | 147 | 169 | 181 | 194 | 223 | 239 | 256 | 274 | 274 | 274 | 274 | 274 | 315 | 404 | 464 | 533 | 571 | 571 | 533 | 497 | 404 | 329 |
| 122 | 128 | 137 | 158 | 181 | 194 | 208 | 239 | 256 | 274 | 294 | 294 | 294 | 294 | 294 | 338 | 433 | 497 | 571 | 611 | 611 | 571 | 533 | 433 | 352 |
| 123 | 137 | 147 | 169 | 194 | 208 | 223 | 256 | 274 | 294 | 315 | 315 | 315 | 315 | 315 | 362 | 464 | 533 | 611 | 655 | 655 | 611 | 571 | 464 | 377 |
| 124 | 147 | 158 | 181 | 208 | 223 | 239 | 274 | 294 | 315 | 338 | 338 | 338 | 338 | 338 | 388 | 497 | 571 | 655 | 702 | 702 | 655 | 611 | 497 | 404 |
| 125 | 158 | 169 | 194 | 223 | 239 | 256 | 294 | 315 | 338 | 362 | 362 | 362 | 362 | 362 | 416 | 533 | 611 | 702 | 752 | 752 | 702 | 655 | 533 | 433 |
| 126 | 169 | 181 | 208 | 239 | 256 | 274 | 315 | 338 | 362 | 388 | 388 | 388 | 388 | 388 | 446 | 571 | 655 | 752 | 806 | 806 | 752 | 702 | 571 | 464 |
| 127 | 181 | 194 | 223 | 256 | 274 | 294 | 338 | 362 | 388 | 416 | 416 | 416 | 416 | 416 | 478 | 611 | 702 | 806 | 863 | 863 | 806 | 752 | 611 | 497 |
| 128 | 194 | 208 | 239 | 274 | 294 | 315 | 362 | 388 | 416 | 446 | 446 | 446 | 446 | 446 | 512 | 655 | 752 | 863 | 925 | 925 | 863 | 806 | 655 | 533 |
| 129 | 208 | 223 | 256 | 294 | 315 | 338 | 388 | 416 | 446 | 478 | 478 | 478 | 478 | 478 | 549 | 702 | 806 | 925 | 991 | 991 | 925 | 863 | 702 | 571 |
| 130 | 223 | 239 | 274 | 315 | 338 | 362 | 416 | 446 | 478 | 512 | 512 | 512 | 512 | 512 | 588 | 752 | 863 | 991 | 1062 | 1062 | 991 | 925 | 752 | 611 |
| 131 | 239 | 256 | 294 | 338 | 362 | 388 | 446 | 478 | 512 | 549 | 549 | 549 | 549 | 549 | 630 | 806 | 925 | 1062 | 1137 | 1137 | 1062 | 991 | 806 | 655 |
| 132 | 256 | 274 | 315 | 362 | 388 | 416 | 478 | 512 | 549 | 588 | 588 | 588 | 588 | 588 | 676 | 863 | 991 | 1137 | 1219 | 1219 | 1137 | 1062 | 863 | 702 |
| 133 | 274 | 294 | 338 | 388 | 416 | 446 | 512 | 549 | 588 | 630 | 630 | 630 | 630 | 630 | 724 | 925 | 1062 | 1219 | 1306 | 1306 | 1219 | 1137 | 925 | 752 |
| 134 | 294 | 315 | 362 | 416 | 446 | 478 | 549 | 588 | 630 | 676 | 676 | 676 | 676 | 676 | 776 | 991 | 1137 | 1306 | 1399 | 1399 | 1306 | 1219 | 991 | 806 |
| 135 | 315 | 338 | 388 | 446 | 478 | 512 | 588 | 630 | 676 | 724 | 724 | 724 | 724 | 724 | 832 | 1062 | 1219 | 1399 | 1499 | 1499 | 1399 | 1306 | 1062 | 863 |
| 136 | 338 | 362 | 416 | 478 | 512 | 549 | 630 | 676 | 724 | 776 | 776 | 776 | 776 | 776 | 891 | 1137 | 1306 | 1499 | 1606 | 1606 | 1499 | 1399 | 1137 | 925 |
| 137 | 362 | 388 | 446 | 512 | 549 | 588 | 676 | 724 | 776 | 832 | 832 | 832 | 832 | 832 | 955 | 1219 | 1399 | 1606 | 1721 | 1721 | 1606 | 1499 | 1219 | 991 |
| 138 | 388 | 416 | 478 | 549 | 588 | 630 | 724 | 776 | 832 | 891 | 891 | 891 | 891 | 891 | 1024 | 1306 | 1499 | 1721 | 1844 | 1844 | 1721 | 1606 | 1306 | 1062 |
| 139 | 416 | 446 | 512 | 588 | 630 | 676 | 776 | 832 | 891 | 955 | 955 | 955 | 955 | 955 | 1098 | 1399 | 1606 | 1844 | 1975 | 1975 | 1844 | 1721 | 1399 | 1137 |
| 140 | 446 | 478 | 549 | 630 | 676 | 724 | 832 | 891 | 955 | 1024 | 1024 | 1024 | 1024 | 1024 | 1176 | 1499 | 1721 | 1975 | | | 1975 | 1844 | 1499 | 1219 |
| 141 | 478 | 512 | 588 | 676 | 724 | 776 | 891 | 955 | 1024 | 1098 | 1098 | 1098 | 1098 | 1098 | 1261 | 1606 | 1844 | | | | | 1975 | 1606 | 1306 |
| 142 | 512 | 549 | 630 | 724 | 776 | 832 | 955 | 1024 | 1098 | 1176 | 1176 | 1176 | 1176 | 1176 | 1351 | 1721 | 1975 | | | | | | 1721 | 1399 |
| 143 | 549 | 588 | 676 | 776 | 832 | 891 | 1024 | 1098 | 1176 | 1261 | 1261 | 1261 | 1261 | 1261 | 1448 | 1844 | | | | | | | 1844 | 1499 |
| 144 | 588 | 630 | 724 | 832 | 891 | 955 | 1098 | 1176 | 1261 | 1351 | 1351 | 1351 | 1351 | 1351 | 1552 | 1975 | | | | | | | 1975 | 1606 |
| 145 | 630 | 676 | 776 | 891 | 955 | 1024 | 1176 | 1261 | 1351 | 1448 | 1448 | 1448 | 1448 | 1448 | 1664 | | | | | | | | | 1721 |
| 146 | 676 | 724 | 832 | 955 | 1024 | 1098 | 1261 | 1351 | 1448 | 1552 | 1552 | 1552 | 1552 | 1552 | 1783 | | | | | | | | | 1844 |
| 147 | 724 | 776 | 891 | 1024 | 1098 | 1176 | 1351 | 1448 | 1552 | 1664 | 1664 | 1664 | 1664 | 1664 | 1911 | | | | | | | | | 1975 |
| 148 | 776 | 832 | 955 | 1098 | 1176 | 1261 | 1448 | 1552 | 1664 | 1783 | 1783 | 1783 | 1783 | 1783 | 2048 | | | | | | | | | |
| 149 | 832 | 891 | 1024 | 1176 | 1261 | 1351 | 1552 | 1664 | 1783 | 1911 | 1911 | 1911 | 1911 | 1911 | | | | | | | | | | |
| 150 | 891 | 955 | 1098 | 1261 | 1351 | 1448 | 1664 | 1783 | 1911 | 2048 | 2048 | 2048 | 2048 | 2048 | | | | | | | | | | |

# TABLE PNL-1. CONTINUED

| SPL | Noys, N, for 1/3-octave-band center frequencies, Hz, of – | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 50 | 63 | 80 | 100 | 125 | 160 | 200 | 250 | 315 | 400 | 500 | 630 | 800 | 1000 | 1250 | 1600 | 2000 | 2500 | 3150 | 4000 | 5000 | 6300 | 8000 | 10 000 |
| 50 | 0.12 | 0.16 | 0.49 | 0.72 | 0.90 | 1.17 | 1.36 | 1.56 | 1.76 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.30 | 3.02 | 3.46 | 3.97 | 4.26 | 4.26 | 3.97 | 3.71 | 3.02 | 2.40 |
| 51 | .14 | .20 | .55 | .80 | 1.00 | 1.26 | 1.47 | 1.68 | 1.89 | 2.14 | 2.14 | 2.14 | 2.14 | 2.14 | 2.46 | 3.23 | 3.71 | 4.26 | 4.56 | 4.56 | 4.26 | 3.97 | 3.23 | 2.63 |
| 52 | .18 | .34 | .62 | .90 | 1.05 | 1.36 | 1.58 | 1.80 | 2.03 | 2.30 | 2.30 | 2.30 | 2.30 | 2.30 | 2.64 | 3.46 | 3.97 | 4.56 | 4.89 | 4.89 | 4.56 | 4.26 | 3.46 | 2.81 |
| 53 | .21 | .39 | .70 | 1.00 | 1.18 | 1.47 | 1.71 | 1.94 | 2.17 | 2.46 | 2.46 | 2.46 | 2.46 | 2.46 | 2.83 | 3.71 | 4.26 | 4.89 | 5.24 | 5.24 | 4.89 | 4.56 | 3.71 | 3.02 |
| 54 | .25 | .45 | .79 | 1.09 | 1.28 | 1.58 | 1.85 | 2.09 | 2.33 | 2.64 | 2.64 | 2.64 | 2.64 | 2.64 | 3.03 | 3.97 | 4.56 | 5.24 | 5.61 | 5.61 | 5.24 | 4.89 | 3.97 | 3.23 |
| 55 | .30 | .51 | .89 | 1.18 | 1.38 | 1.71 | 2.00 | 2.25 | 2.50 | 2.83 | 2.83 | 2.83 | 2.83 | 2.83 | 3.25 | 4.26 | 4.89 | 5.61 | 6.01 | 6.01 | 5.61 | 5.24 | 4.26 | 3.46 |
| 56 | .34 | .59 | 1.00 | 1.29 | 1.50 | 1.85 | 2.15 | 2.42 | 2.69 | 3.03 | 3.03 | 3.03 | 3.03 | 3.03 | 3.48 | 4.56 | 5.24 | 6.01 | 6.44 | 6.44 | 6.01 | 5.61 | 4.56 | 3.71 |
| 57 | .39 | .67 | 1.09 | 1.40 | 1.63 | 2.00 | 2.33 | 2.61 | 2.88 | 3.25 | 3.25 | 3.25 | 3.25 | 3.25 | 3.73 | 4.89 | 5.61 | 6.44 | 6.90 | 6.90 | 6.44 | 6.01 | 4.89 | 3.97 |
| 58 | .44 | .77 | 1.18 | 1.53 | 1.77 | 2.15 | 2.51 | 2.81 | 3.10 | 3.48 | 3.48 | 3.48 | 3.48 | 3.48 | 4.00 | 5.24 | 6.01 | 6.90 | 7.39 | 7.39 | 6.90 | 6.44 | 5.24 | 4.26 |
| 59 | .51 | .87 | 1.29 | 1.66 | 1.92 | 2.33 | 2.71 | 3.03 | 3.32 | 3.73 | 3.73 | 3.73 | 3.73 | 3.73 | 4.29 | 5.61 | 6.44 | 7.39 | 7.92 | 7.92 | 7.39 | 6.90 | 5.61 | 4.56 |
| 60 | .59 | 1.00 | 1.40 | 1.81 | 2.08 | 2.51 | 2.93 | 3.26 | 3.57 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.59 | 6.01 | 6.90 | 7.92 | 8.49 | 8.49 | 7.92 | 7.39 | 6.01 | 4.89 |
| 61 | .67 | 1.10 | 1.53 | 1.97 | 2.26 | 2.71 | 3.16 | 3.51 | 3.83 | 4.29 | 4.29 | 4.29 | 4.29 | 4.29 | 4.92 | 6.44 | 7.39 | 8.49 | 9.09 | 9.09 | 8.49 | 7.92 | 6.44 | 5.24 |
| 62 | .77 | 1.21 | 1.66 | 2.15 | 2.45 | 2.93 | 3.41 | 3.78 | 4.11 | 4.59 | 4.59 | 4.59 | 4.59 | 4.59 | 5.28 | 6.90 | 7.92 | 9.09 | 9.74 | 9.74 | 9.09 | 8.49 | 6.90 | 5.61 |
| 63 | .87 | 1.32 | 1.81 | 2.34 | 2.65 | 3.16 | 3.69 | 4.06 | 4.41 | 4.92 | 4.92 | 4.92 | 4.92 | 4.92 | 5.66 | 7.39 | 8.49 | 9.74 | 10.4 | 10.4 | 9.74 | 9.09 | 7.39 | 6.01 |
| 64 | 1.00 | 1.45 | 1.97 | 2.54 | 2.88 | 3.41 | 3.98 | 4.38 | 4.73 | 5.28 | 5.28 | 5.28 | 5.28 | 5.28 | 6.06 | 7.92 | 9.09 | 10.4 | 11.2 | 11.2 | 10.4 | 9.74 | 7.92 | 6.44 |
| 65 | 1.11 | 1.60 | 2.15 | 2.77 | 3.12 | 3.69 | 4.30 | 4.71 | 5.08 | 5.66 | 5.66 | 5.66 | 5.66 | 5.66 | 6.50 | 8.49 | 9.74 | 11.2 | 12.0 | 12.0 | 11.2 | 10.4 | 8.49 | 6.90 |
| 66 | 1.22 | 1.75 | 2.34 | 3.01 | 3.39 | 3.98 | 4.64 | 5.07 | 5.45 | 6.06 | 6.06 | 6.06 | 6.06 | 6.06 | 6.96 | 9.09 | 10.4 | 12.0 | 12.8 | 12.8 | 12.0 | 11.2 | 9.09 | 7.39 |
| 67 | 1.35 | 1.92 | 2.54 | 3.28 | 3.68 | 4.30 | 5.01 | 5.46 | 5.85 | 6.50 | 6.50 | 6.50 | 6.50 | 6.50 | 7.46 | 9.74 | 11.2 | 12.8 | 13.8 | 13.8 | 12.8 | 12.0 | 9.74 | 7.92 |
| 68 | 1.49 | 2.11 | 2.77 | 3.57 | 3.99 | 4.64 | 5.41 | 5.88 | 6.27 | 6.96 | 6.96 | 6.96 | 6.96 | 6.96 | 8.00 | 10.4 | 12.0 | 13.8 | 14.7 | 14.7 | 13.8 | 12.8 | 10.4 | 8.49 |
| 69 | 1.65 | 2.32 | 3.01 | 3.88 | 4.33 | 5.01 | 5.85 | 6.33 | 6.73 | 7.46 | 7.46 | 7.46 | 7.46 | 7.46 | 8.57 | 11.2 | 12.8 | 14.7 | 15.8 | 15.8 | 14.7 | 13.8 | 11.2 | 9.09 |
| 70 | 1.82 | 2.55 | 3.28 | 4.23 | 4.69 | 5.41 | 6.31 | 6.81 | 7.23 | 8.00 | 8.00 | 8.00 | 8.00 | 8.00 | 9.19 | 12.0 | 13.8 | 15.8 | 16.9 | 16.9 | 15.8 | 14.7 | 12.0 | 9.74 |
| 71 | 2.02 | 2.79 | 3.57 | 4.60 | 5.09 | 5.84 | 6.81 | 7.33 | 7.75 | 8.57 | 8.57 | 8.57 | 8.57 | 8.57 | 9.85 | 12.8 | 14.7 | 16.9 | 18.1 | 18.1 | 16.9 | 15.8 | 12.8 | 10.4 |
| 72 | 2.23 | 3.07 | 3.88 | 5.01 | 5.52 | 6.31 | 7.36 | 7.90 | 8.32 | 9.19 | 9.19 | 9.19 | 9.19 | 9.19 | 10.6 | 13.8 | 15.8 | 18.1 | 19.4 | 19.4 | 18.1 | 16.9 | 13.8 | 11.2 |
| 73 | 2.46 | 3.37 | 4.23 | 5.45 | 5.99 | 6.81 | 7.94 | 8.50 | 8.93 | 9.85 | 9.85 | 9.85 | 9.85 | 9.85 | 11.3 | 14.7 | 16.9 | 19.4 | 20.8 | 20.8 | 19.4 | 18.1 | 14.7 | 12.0 |
| 74 | 2.72 | 3.70 | 4.60 | 5.94 | 6.50 | 7.36 | 8.57 | 9.15 | 9.59 | 10.6 | 10.6 | 10.6 | 10.6 | 10.6 | 12.1 | 15.8 | 18.1 | 20.8 | 22.3 | 22.3 | 20.8 | 19.4 | 15.8 | 12.8 |
| 75 | 3.01 | 4.06 | 5.01 | 6.46 | 7.05 | 7.94 | 9.19 | 9.85 | 10.3 | 11.3 | 11.3 | 11.3 | 11.3 | 11.3 | 13.0 | 16.9 | 19.4 | 22.3 | 23.9 | 23.9 | 22.3 | 20.8 | 16.9 | 13.8 |
| 76 | 3.32 | 4.46 | 5.45 | 7.03 | 7.65 | 8.57 | 9.85 | 10.6 | 11.0 | 12.1 | 12.1 | 12.1 | 12.1 | 12.1 | 13.9 | 18.1 | 20.8 | 23.9 | 25.6 | 25.6 | 23.9 | 22.3 | 18.1 | 14.7 |
| 77 | 3.67 | 4.89 | 5.94 | 7.66 | 8.29 | 9.19 | 10.6 | 11.3 | 11.8 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 14.9 | 19.4 | 22.3 | 25.6 | 27.4 | 27.4 | 25.6 | 23.9 | 19.4 | 15.8 |
| 78 | 4.06 | 5.37 | 6.46 | 8.33 | 9.00 | 9.85 | 11.3 | 12.1 | 12.7 | 13.9 | 13.9 | 13.9 | 13.9 | 13.9 | 16.0 | 20.8 | 23.9 | 27.4 | 29.4 | 29.4 | 27.4 | 25.6 | 20.8 | 16.9 |
| 79 | 4.49 | 5.90 | 7.03 | 9.07 | 9.76 | 10.6 | 12.1 | 13.0 | 13.6 | 14.9 | 14.9 | 14.9 | 14.9 | 14.9 | 17.1 | 22.3 | 25.6 | 29.4 | 31.5 | 31.5 | 29.4 | 27.4 | 22.3 | 18.1 |
| 80 | 4.96 | 6.48 | 7.66 | 9.85 | 10.6 | 11.3 | 13.0 | 13.9 | 14.6 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 18.4 | 23.9 | 27.4 | 31.5 | 33.7 | 33.7 | 31.5 | 29.4 | 23.9 | 19.4 |
| 81 | 5.48 | 7.11 | 8.33 | 10.6 | 11.3 | 12.1 | 13.9 | 14.9 | 15.7 | 17.1 | 17.1 | 17.1 | 17.1 | 17.1 | 19.7 | 25.6 | 29.4 | 33.7 | 36.1 | 36.1 | 33.7 | 31.5 | 25.6 | 20.8 |
| 82 | 6.06 | 7.81 | 9.07 | 11.3 | 12.1 | 13.0 | 14.9 | 16.0 | 16.9 | 18.4 | 18.4 | 18.4 | 18.4 | 18.4 | 21.1 | 27.4 | 31.5 | 36.1 | 38.7 | 38.7 | 36.1 | 33.7 | 27.4 | 22.3 |
| 83 | 6.70 | 8.57 | 9.87 | 12.1 | 13.0 | 13.9 | 16.0 | 17.1 | 18.1 | 19.7 | 19.7 | 19.7 | 19.7 | 19.7 | 22.6 | 29.4 | 33.7 | 38.7 | 41.5 | 41.5 | 38.7 | 36.1 | 29.4 | 23.9 |
| 84 | 7.41 | 9.41 | 10.7 | 13.0 | 13.9 | 14.9 | 17.1 | 18.4 | 19.4 | 21.1 | 21.1 | 21.1 | 21.1 | 21.1 | 24.3 | 31.5 | 36.1 | 41.5 | 44.4 | 44.4 | 41.5 | 38.7 | 31.5 | 25.6 |
| 85 | 8.19 | 10.3 | 11.7 | 13.9 | 14.9 | 16.0 | 18.4 | 19.7 | 20.8 | 22.6 | 22.6 | 22.6 | 22.6 | 22.6 | 26.0 | 33.7 | 38.7 | 44.4 | 47.6 | 47.6 | 44.4 | 41.5 | 33.7 | 27.4 |
| 86 | 9.05 | 11.3 | 12.7 | 14.9 | 16.0 | 17.1 | 19.7 | 21.1 | 22.4 | 24.3 | 24.3 | 24.3 | 24.3 | 24.3 | 27.9 | 36.1 | 41.5 | 47.6 | 51.0 | 51.0 | 47.6 | 44.4 | 36.1 | 29.4 |
| 87 | 10.0 | 12.1 | 13.9 | 16.0 | 17.1 | 18.4 | 21.1 | 22.6 | 24.0 | 26.0 | 26.0 | 26.0 | 26.0 | 26.0 | 29.9 | 38.7 | 44.4 | 51.0 | 54.7 | 54.7 | 51.0 | 47.6 | 38.7 | 31.5 |
| 88 | 11.1 | 13.0 | 14.9 | 17.1 | 18.4 | 19.7 | 22.6 | 24.3 | 25.8 | 27.9 | 27.9 | 27.9 | 27.9 | 27.9 | 32.0 | 41.5 | 47.6 | 54.7 | 58.6 | 58.6 | 54.7 | 51.0 | 41.5 | 33.7 |
| 89 | 12.2 | 13.9 | 16.0 | 18.4 | 19.7 | 21.1 | 24.3 | 26.0 | 27.7 | 29.9 | 29.9 | 29.9 | 29.9 | 29.9 | 34.3 | 44.4 | 51.0 | 58.6 | 62.7 | 62.7 | 58.6 | 54.7 | 44.4 | 36.1 |
| 90 | 13.5 | 14.9 | 17.1 | 19.7 | 21.1 | 22.6 | 26.0 | 27.9 | 29.7 | 32.0 | 32.0 | 32.0 | 32.0 | 32.0 | 36.8 | 47.6 | 54.7 | 62.7 | 67.2 | 67.2 | 62.7 | 58.6 | 47.6 | 38.7 |
| 91 | 14.9 | 16.0 | 18.4 | 21.1 | 22.6 | 24.3 | 27.9 | 29.9 | 31.8 | 34.3 | 34.3 | 34.3 | 34.3 | 34.3 | 39.4 | 51.0 | 58.6 | 67.2 | 72.0 | 72.0 | 67.2 | 62.7 | 51.0 | 41.5 |
| 92 | 16.0 | 17.1 | 19.7 | 22.6 | 24.3 | 26.0 | 29.9 | 32.0 | 34.2 | 36.8 | 36.8 | 36.8 | 36.8 | 36.8 | 42.2 | 54.7 | 62.7 | 72.0 | 77.2 | 77.2 | 72.0 | 67.2 | 54.7 | 44.4 |
| 93 | 17.1 | 18.4 | 21.1 | 24.3 | 26.0 | 27.9 | 32.0 | 34.3 | 36.7 | 39.4 | 39.4 | 39.4 | 39.4 | 39.4 | 45.3 | 58.6 | 67.2 | 77.2 | 82.7 | 82.7 | 77.2 | 72.0 | 58.6 | 47.6 |
| 94 | 18.4 | 19.7 | 22.6 | 26.0 | 27.9 | 29.9 | 34.3 | 36.8 | 39.4 | 42.2 | 42.2 | 42.2 | 42.2 | 42.2 | 48.5 | 62.7 | 72.0 | 82.7 | 88.6 | 88.6 | 82.7 | 77.2 | 62.7 | 51.0 |
| 95 | 19.7 | 21.1 | 24.3 | 27.9 | 29.9 | 32.0 | 36.8 | 39.4 | 42.2 | 45.3 | 45.3 | 45.3 | 45.3 | 45.3 | 52.0 | 67.2 | 77.2 | 88.6 | 94.9 | 94.9 | 88.6 | 82.7 | 67.2 | 54.7 |
| 96 | 21.1 | 22.6 | 26.0 | 29.9 | 32.0 | 34.3 | 39.4 | 42.2 | 45.3 | 48.5 | 48.5 | 48.5 | 48.5 | 48.5 | 55.7 | 72.0 | 82.7 | 94.9 | 102 | 102 | 94.9 | 88.6 | 72.0 | 58.6 |
| 97 | 22.6 | 24.3 | 27.9 | 32.0 | 34.3 | 36.8 | 42.2 | 45.3 | 48.5 | 52.0 | 52.0 | 52.0 | 52.0 | 52.0 | 59.7 | 77.2 | 88.6 | 102 | 109 | 109 | 102 | 94.9 | 77.2 | 62.7 |
| 98 | 24.3 | 26.0 | 29.9 | 34.3 | 36.8 | 39.4 | 45.3 | 48.5 | 52.0 | 55.7 | 55.7 | 55.7 | 55.7 | 55.7 | 64.0 | 82.7 | 94.9 | 109 | 117 | 117 | 109 | 102 | 82.7 | 67.2 |
| 99 | 26.0 | 27.9 | 32.0 | 36.8 | 39.4 | 42.2 | 48.5 | 52.0 | 55.7 | 59.7 | 59.7 | 59.7 | 59.7 | 59.7 | 68.6 | 88.6 | 102 | 117 | 125 | 125 | 117 | 109 | 88.6 | 72.0 |

$$n = A\ [10^{M_J(L-L_k)}]$$ [L

For:

$n \geq 0.1$

$L \leq 150$

Where:

| | |
|---|---|
| $M_J$<br>$L_k$<br>$A$ | depend upon level and the band center frequency as shown in Tables PNL-2 and PNL-3. |
| $L$ | band sound pressure level. |

TABLE PNL-2

NOY VALUE FORMULA FOR RANGES OF BAND LEVELS AND NOY VALUES

| BAND LEVEL RANGE | NOY VALUE FORMULA |
|---|---|
| $L_1 \leq L < L_2$ | $n = 0.1\ [10^{M_1(L-L_1)}]$ |
| $L_2 \leq L < L_3$ | $n = 10^{M_2(L-L_2)}$ |
| $L_3 \leq L < L_c$ | $n = 10^{M_3(L-L_3)}$ |
| $L_c \leq L \leq 150$ | $n = 10^{M_4(L-L_4)}$ |

Note in Table PNL-3 that for frequency bands having center frequencies from 400 to 6300 Hz inclusive, $L_3 = L_4$ and $M_3 = M_4$ (i.e., one set of values of

# TABLE PNL-3. CONSTANTS FOR DETERMINING n FROM EQUATION

| Band Center Frequency (Hz) | $L_1$ | $M_1$ | $L_2$ | $M_2$ | $L_3$ | $M_3$ | $L_c$ | $M_4$ | $L_4$ |
|---|---|---|---|---|---|---|---|---|---|
| 50 | 49 | 0.079520 | 55 | 0.058098 | 64 | 0.043478 | 91.01 | 0.030103 | 52 |
| 63 | 44 | 0.068160 | 51 | 0.058098 | 60 | 0.040570 | 85.88 | 0.030103 | 51 |
| 80 | 39 | 0.068160 | 46 | 0.052288 | 56 | 0.036831 | 87.32 | 0.030103 | 49 |
| 100 | 34 | 0.059640 | 42 | 0.047534 | 53 | 0.036831 | 79.85 | 0.030103 | 47 |
| 125 | 30 | 0.053013 | 39 | 0.043573 | 51 | 0.035336 | 79.76 | 0.030103 | 46 |
| 160 | 27 | 0.053013 | 36 | 0.043573 | 48 | 0.033333 | 75.96 | 0.030103 | 45 |
| 200 | 24 | 0.053013 | 33 | 0.040221 | 46 | 0.033333 | 73.96 | 0.030103 | 43 |
| 250 | 21 | 0.053013 | 30 | 0.037349 | 44 | 0.032051 | 74.91 | 0.030103 | 42 |
| 315 | 18 | 0.053013 | 27 | 0.034859 | 42 | 0.030675 | 94.63 | 0.030103 | 41 |
| 400 | 16 | 0.053013 | 25 | 0.034859 | 40 | 0.030103 | 100.00 | 0.030103 | 40 |
| 500 | 16 | 0.053013 | 25 | 0.034859 | 40 | 0.030103 | 100.00 | 0.030103 | 40 |
| 630 | 16 | 0.053013 | 25 | 0.034859 | 40 | 0.030103 | 100.00 | 0.030103 | 40 |
| 800 | 16 | 0.053013 | 25 | 0.034859 | 40 | 0.030103 | 100.00 | 0.030103 | 40 |
| 1000 | 16 | 0.053013 | 25 | 0.034859 | 40 | 0.030103 | 100.00 | 0.030103 | 40 |
| 1250 | 15 | 0.059640 | 23 | 0.034859 | 38 | 0.030103 | 100.00 | 0.030103 | 38 |
| 1600 | 12 | 0.053013 | 21 | 0.040221 | 34 | 0.029960 | 100.00 | 0.029960 | 34 |
| 2000 | 9 | 0.053013 | 18 | 0.037349 | 32 | 0.029960 | 100.00 | 0.029960 | 32 |
| 2500 | 5 | 0.047712 | 15 | 0.034859 | 30 | 0.029960 | 100.00 | 0.029960 | 30 |
| 3150 | 4 | 0.047712 | 14 | 0.034859 | 29 | 0.029960 | 100.00 | 0.029960 | 29 |
| 4000 | 5 | 0.053013 | 14 | 0.034859 | 29 | 0.029960 | 100.00 | 0.029960 | 29 |
| 5000 | 6 | 0.053013 | 15 | 0.034859 | 30 | 0.029960 | 100.00 | 0.029960 | 30 |
| 6300 | 10 | 0.068160 | 17 | 0.037349 | 31 | 0.029960 | 100.00 | 0.029960 | 31 |
| 8000 | 17 | 0.079520 | 23 | 0.037349 | 37 | 0.042285 | 44.29 | 0.029960 | 34 |
| 10,000 | 21 | 0.0596401 | 29 | 0.043573 | 41 | 0.042285 | 50.72 | 0.029960 | 37 |

$L_k$ and $M_j$ suffice to define noy values for $n \geq 1$ and $L \leq 150$). The values of $M_j$ and $L_k$ are tabulated in Table PNL-3.

**EXAMPLE**

PNL From Noy Tables and Curves

An example of PNL calculations using the jet turbofan aircraft flyover spectrum at some point in time is shown in Table PNL-4. Here the one-third octave band levels are tabulated and converted to noy values. Using Equation [2], the total noy value is determined by:

$$N = 94.9 + 0.15\ (450.7 - 94.9)$$

$$= 148.27 \text{ noys.}$$

Then, the total noy value is converted using Equation [3] to perceived noise level in dB (read PNdB) by:

$$L_{PN} = 40 + \left[\frac{10\ \log_{10}\left[148.27\right]}{\log_{10} 2}\right]$$

$$= 112.1 \text{ dB.}$$

**EQUIPMENT**

1) Tape recorder (necessary for single events).
2) Sound level meter (ANSI S1.4-1971).
3) Octave or one-third octave band analyzer.
4) Digital computer (optional).

**STANDARDS**

ISO 3891, SAE ARP 865A.

TABLE PNL-4

EXAMPLE OF PNL CALCULATIONS FROM ONE-THIRD OCTAVE BAND MEASUREMENTS OF AIRCRAFT FLYOVER*

| One-Third Octave Band Center Frequency (Hz) | Band Level (dB) | Perceived Noisiness (noy) |
|---|---|---|
| 50 | 63 | 0.87 |
| 63 | 71 | 2.79 |
| 80 | 74 | 4.60 |
| 100 | 79 | 9.07 |
| 125 | 79 | 9.76 |
| 160 | 80 | 11.30 |
| 200 | 80 | 13.00 |
| 250 | 79 | 13.00 |
| 315 | 79 | 13.60 |
| 400 | 78 | 13.90 |
| 500 | 77 | 13.00 |
| 630 | 78 | 13.90 |
| 800 | 77 | 13.00 |
| 1000 | 78 | 13.90 |
| 1250 | 78 | 16.00 |
| 1600 | 80 | 23.90 |
| 2000 | 81 | 29.40 |
| 2500 | 96 | 94.90 |
| 3150 | 86 | 51.00 |
| 4000 | 78 | 29.40 |
| 5000 | 83 | 38.70 |
| 6300 | 67 | 12.00 |
| 8000 | 62 | 6.90 |
| 10000 | 52 | 2.81 |

$\Sigma n = 450.70$

*Jet turbo-fan flyover at 1000 ft (305 m).

## REFERENCES

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2. Stevens, S. S., "Calculation of the Loudness of Complex Noise", JASA, Vol. 28, 807-832, 1956.
3. Kryter, Karl, K. S. Pearsons, "Some Effects of Spectral Content and Duration on Perceived Noise Level", NASA TN D-1873, April 1963.
4. Kryter, Karl, K. S. Pearsons, "Modification of Noy Tables", JASA, Vol. 36, No. 2, 1964, p. 394.
5. International Organization for Standardization ISO/DIS 3891 (July 1975), "Procedure for Describing Aircraft Noise Heard on the Ground".
6. Federal Aviation Administration (FAA), "Federal Aviation Regulations (FAR) Part 36, Noise Standards: Aircraft Type and Air Worthiness Certification" - (effective April 1978), Appendix B.
7. Society of Automotive Engineers (SAE), "Aerospace Recommended Practice ARP 865A" (1969).

| | |
|---|---|
| TITLE | TONE CORRECTED PERCEIVED NOISE LEVEL |
| ABBREVIATION | PNLT |
| SYMBOL | $L_{TPN}$ |
| UNIT | Decibel (dB)* |
| GEOGRAPHICAL USAGE | International |

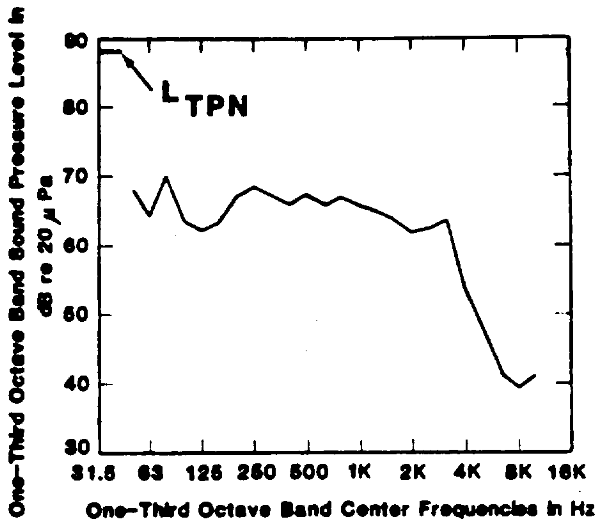

FIGURE PNLT-1. AIRCRAFT FLYOVER SPECTRUM

| | |
|---|---|
| DEFINITION | Tone corrected perceived noise level is perceived noise level with the addition of a tone correction factor. This tone correction factor is intended to account for the added annoyance due to spectrum irregularity or discrete frequency components, such as tones. |
| PURPOSE | Tone corrected perceived noise level was developed to improve the noisiness assessment for those |

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*The unit for the scale of perceived noisiness is the noy, while the unit for perceived noise level is the decibel (dB). It is seen in the literature as PNdB.

sounds with prominent discrete frequencies. Like perceived noise level, it is used in assessing the subjective response to single event aircraft fly-overs which commonly contain pure tones, such as in turbo-fan jet aircraft. However, when aircraft noise is being evaluated, EPNL is more commonly employed because it takes duration as well as discrete frequency effects into account.

## BACKGROUND

With the advent of turbo-fan jet aircraft, it became evident that perceived noise level could not evaluate the effects of the pure tone "whine" that is sometimes present in the sound from these jets. Therefore after developing the perceived noise level procedure, Kryter and Pearsons (Ref. 1) worke on a method which would compensate for these pure tones often heard in a jet aircraft flyover. Figur PNLT-1 shows a typical airplane flyover and the resulting PNLT value. Several researchers develope various schemes for compensating for the additional noisiness of these discrete frequency components. After reviewing the various correction techniques, a tone-correction procedure was finally adopted by the Federal Aviation Administration and incorporate into the FAR Part 36 in 1969 (Ref. 2).

## CALCULATION METHOD

Although tone corrected perceived noise level may be calculated by more than one method (Refs. 1-4), ISO and SAE (Refs. 3 & 4) calculation procedures will be the ones used in this Handbook and illustrated in the example. They examine the band level in a noise spectrum to detect if the level in any frequency band exceeds its adjacent bands. This in essence is a tone-to-noise ratio determination. If the ratio exceeds a certain amount, then a tone correction or discrete frequency is added to the perceived noise level. The magnitude of the correction is a function of the tone-to-noise ratio and the particular frequency band which contains the tone. It is important to note that only one tone correction is added to the perceived noise level of that interval of sound, even though more than one pure-tone may be present (i.e., more than one frequency band might contain a high tone-to-noise ratio).

The following is the procedure for the calculation of tone corrections for one-third octave band noise spectra measured at some point in time.

Step 1:

Compute: $s(j,i) = L(j) - L(i)$ where:

$i$ = 1/3 octave frequency band number;
$i = 19$, corresponding to 80 Hz, up to $i = 39$, corresponding to 8,000 Hz.

$j = i + 1$, up to $j = 40$, corresponding to 10,000 Hz.

$L(i)$ = sound pressure level in the i-th 1/3 octave frequency band at the k-th time interval.

$s(j,i)$ = numerical difference between successive band sound pressure levels, with $s(j,i) = 0$ for $i < 19$.

**Step 2:**

Encircle those values of $s(j, i)$ where:

$$|s(j,i) - s(j-1, i-1)| > 5 \text{ dB}$$

**Step 3:**

A) If the encircled $s(j, i)$ is positive and algebraically greater than $s(j-1, i-1)$ encircle $L(i+1)$; if algebraically less, disregard.

B) If the encircled $s(j, i)$ is zero or negative and algebraically less than $s(j-1, i-1)$, encircle $L(i)$.

**Step 4:**

A) For encircled values of $L(i)$ located between adjacent non-encircled values, $L(i-1)$ and $L(i+1)$:

$$\text{Set } L'(i) = \frac{L(i+1) + L(i-1)}{2}$$

If the level in the highest band, $L(40)$ is encircled:

Set $L'(40) = L(39) + s(39, 38)$ if

$L(39)$ and $L(38)$ are not encircled;

Set $L'(40) = L(39) + \frac{S(39, 37)}{2}$ if

$L(38)$ is encircled, but $L(37)$ is not;

Set $L'(40) = L(39) + \frac{s(39, 36)}{3}$ if $L(37)$ and

$L(38)$ are encircled, but $L(36)$ is not.

B) For two successive circled values, $L(i)$ and $L(i+1)$,:

$$\text{Set } L'(i) = \frac{2\,L(i-1) + L(i+2)}{3}$$

$$\text{and } L'(i+1) = \frac{L(i-1) + 2\,L(i+2)}{3}$$

If the levels in the two highest frequency bands are encircled:

Set $L'(39) = L(38) + s(38, 37)$

and $L'(40) = L(38) + 2\,s(38, 37)$, if $L(37)$ and

$L(38)$ are not encircled;

Set $L'(39) = L(38) + \frac{s(38, 36)}{2}$

and $L'(40) = L(38) + s(38, 36)$, if

$L(37)$ is encircled but $L(36)$ is not.

Set $L'(39) = L(38) + \frac{s(38, 35)}{3}$

and $L'(40) = L(38) + \frac{2\,s(38, 35)}{3}$ if

$L(36)$ and $L(37)$ are encircled, but $L(35)$ is not.

**Step 5:**

For each encircled band level determine:

$$F(i) = L(i) - L'(i) > 0$$

Where F values greater than 5 dB occur in adjacent bands, F(i), F(i+1), and provided that

$| s(i+2, i-1) | < 5$ for 2 adjacent bands,

$$\text{Set } F' = 10 \log_{10} \left(\text{antilog } \frac{F(i)}{10} + \text{antilog } \frac{F(i+1)}{10}\right)$$

Where one of two adjacent F values occur in a band outside the frequency range 500 - 5000 Hz, the value shall be halved, and the F' value ascribed to the 500 - 5000 Hz range.

**Step 6:**

For each of the 24 one-third octave bands, determine tone correction factors, C, from the sound pressure level differences, F(i), using the following table. The tone correction factors are also noted in Figure PNLT-2.

| Frequency | Level Difference F, dB | Tone Correction C, dB |
|---|---|---|
| $50 \leq f < 500$ | $0 \leq F < 20$<br>$20 \leq F$ | F/6<br>3-1/3 |
| $500 \leq f \leq 5000$ | $0 \leq F < 20$<br>$20 \leq F$ | F/3<br>6-2/3 |
| $5000 < f \leq 10000$ | $0 \leq F < 20$<br>$20 \leq F$ | F/6<br>3-1/3 |

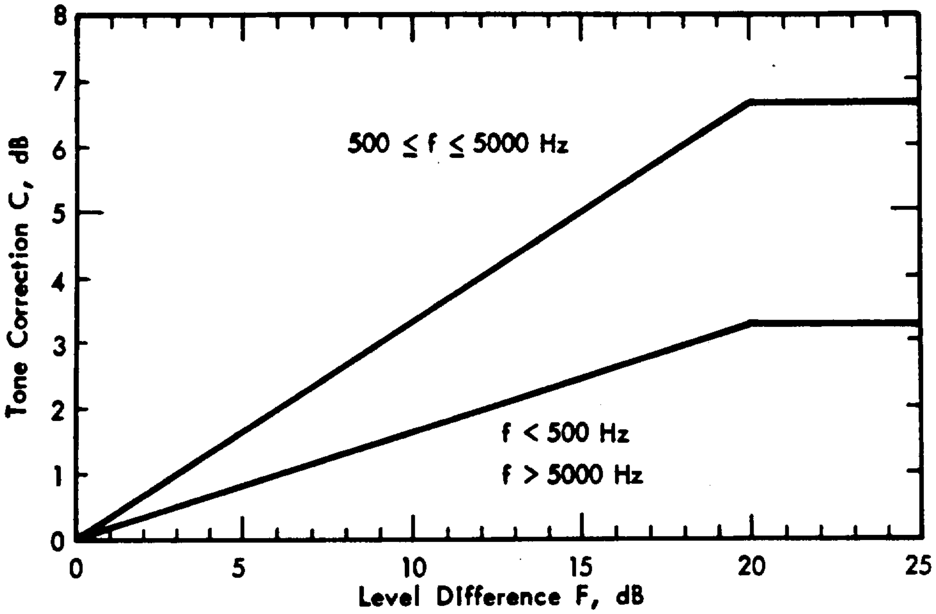

FIGURE PNLT-2. TONE CORRECTION FACTORS

### Step 7:

To determine tone corrected perceived noise level, select the maximum value of ($C_{max}$) (from Step 6). This value is the tone correction that is added to the perceived noise level of the aircraft spectr to obtain:

$$L_{TPN} = L_{PN} + L_{Cmax}$$

**EXAMPLE**

The example of the tone corrected perceived noise level calculation procedure is seen in Table PNLT-1. The aircraft flyover spectrum and the calculated perceived noise level used in this example is the same one used in the "Example" section of the perceived noise level rating on page 64.

The calculated perceived noise level is 112.1 dB an a 4.2 dB tone correction is added for the tone in the 2500 Hz frequency band.

$$L_{TPN} = 116.3 \text{ dB}.$$

**EQUIPMENT**

1) Tape recorder (necessary for single events).
2) Sound level meter (ANSI S1.4-1971).
3) Octave or one-third octave band analyzer.
4) Digital computer (optional).

**STANDARDS**

1) International Organization for Standardization, ISO/DIS 3891, "Procedure for Describing Aircraft Noise Heard on the Ground", issued July 1975.
2) Federal Aviation Administration (FAA), Federal Aviation Regulation (FAR) Part 36, "Noise Standards: Aircraft Type and Airworthiness Certification" (effective April 1978) - Appendix B.
3) Society of Automotive Engineers (SAE), Aerospace Recommended Practice, ARP 1071, issued 1972.

**REFERENCES**

1) Kryter, K. and Pearsons, K. S., "Judged Noisiness of a Band of Random Noise Containing an Audible Pure Tone", J. Acoust. Soc. Am., 38, 106-112 (1965).
2) Federal Aviation Administration (FAA), Federal Aviation Regulation (FAR) Part 36, "Noise Standards: Aircraft Type and Airworthiness Certification" (effective April 1978) - Appendix B.

   Note: Refer to this reference on how to handle
   1) narrowband analysis for spectral irregularities that might not be tones,
   2) possible tone suppressions as a result of band sharing of tones, and
   3) the pseudo-tones resulting from ground plane reflections in the 800 Hz and lower one-third octave bands.
3) International Organization for Standardization, ISO/DIS 3891, "Procedure for Describing Aircraft Noise Heard on the Ground", issued July 1975.
4) Society of Automotive Engineers (SAE), Aerospace Recommended Practice, ARP 1071, issued 1972.

## TABLE PNLT-1

## EXAMPLE OF PNLT CALCULATIONS FROM ONE-THIRD OCTAVE BAND MEASUREMENTS OF AIRCRAFT FLYOVER*

| | STEP | 3 | 1 | 2 | 4 | 5 | 5 | 6 |
|---|---|---|---|---|---|---|---|---|
| Band Number i | One-Third Octave Band Center Frequency f | Band Level L(i) | S(j,i) | S(j,i) - S(j-1,i-1) | L'(i) | F(i) | F'(i) | C |
| 17 | 50 | 63 | | | | | | |
| 18 | 63 | 71 | 0.0 | | | | | |
| 19 | 80 | 74 | 0.0 | 0 | | | | |
| 20 | 100 | 79 | +5.0 | 5 | | | | |
| 21 | 125 | 79 | 0.0 | -5 | | | | |
| 22 | 160 | 80 | +1.0 | +1 | | | | |
| 23 | 200 | 80 | 0.0 | -1 | | | | |
| 24 | 250 | 79 | -1.0 | -1 | | | | |
| 25 | 315 | 79 | 0.0 | +1 | | | | |
| 26 | 400 | 78 | +1.0 | -1 | | | | |
| 27 | 500 | 77 | -1.0 | 0 | | | | |
| 28 | 630 | 78 | +1.0 | +2 | | | | |
| 29 | 800 | 77 | -1.0 | -2 | | | | |
| 30 | 1000 | 78 | -1.0 | +2 | | | | |
| 31 | 1250 | 78 | 0.0 | -1 | | | | |
| 32 | 1600 | 80 | +2.0 | +2 | | | | |
| 33 | 2000 | 81 | +1.0 | -1 | | | | |
| 34 | 2500 | 96 | A +15.0 | +14 | 83.5 | 12.5 | | $\boxed{4.2}$ |
| 35 | 3150 | 86 | B -10.0 | -25 | | | | |
| 36 | 4000 | 78 | -8.0 | +2 | | | | |
| 37 | 5000 | 83 | A +5.0 | +13 | 72.7 | 10.3 | | 3.4 |
| 38 | 6300 | 67 | B -16.0 | -21 | 67.3 | 0.3 | | |
| 39 | 8000 | 62 | B -5.0 | +11 | | | | |
| 40 | 10000 | 52 | -10.0 | -5 | | | | |

$L_{PN}$ = 112.1 dB (from the calculations for PNL rating, page __).

$L_{TPN}$ = 112.1 + 4.2

*Turbofan jet aircraft at 1000 ft (305 m)

# CHAPTER II

# DURATION CORRECTED SINGLE EVENT METRICS

| | |
|---|---|
| TITLE | EFFECTIVE PERCEIVED NOISE LEVEL |
| ABBREVIATION | EPNL |
| SYMBOL | $L_{EPN}$ |
| UNIT | Decibel (dB)* |
| GEOGRAPHICAL USAGE | International |
| DEFINITION | Effective perceived noise level is perceived noise level (PNL) of a single event adjusted for the added annoyance due to duration and for the presence of discrete frequencies (tones). |
| PURPOSE | Effective perceived noise level assesses the noisiness of a single noise event. Since EPNL takes into consideration both the tone and duration components |

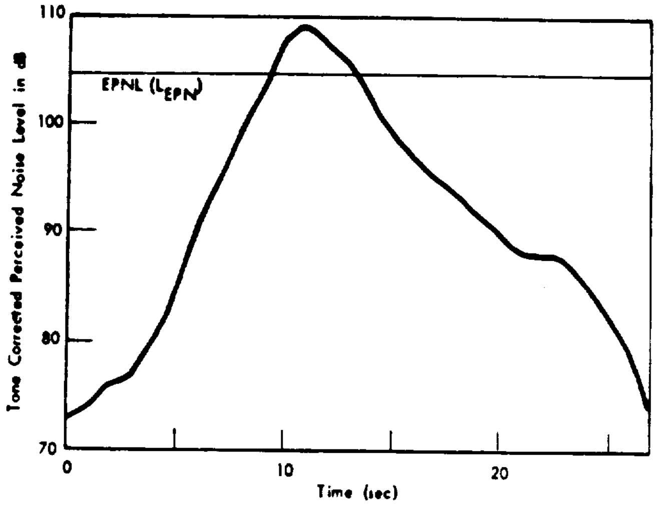

FIGURE EPNL-1. TIME HISTORY OF AIRCRAFT FLYOVER

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*The unit of effective perceived noise level is the decibel; it is commonly seen in literature as EPNdB.

of a noise, it is a convenient rating for measuring sub-sonic aircraft flyovers. The FAA has designated this rating scheme as the basis for its aircraft noise certification procedure.

**BACKGROUND**

Effective perceived noise level evolved in response to the new technological designs of jet engines. Several individuals and sponsoring organizations worked independently and together on the development of this single number rating method which uses objective acoustic measurements to estimate the effective "noisiness" response to a single aircraft flyover. Finally, through joint negotiations with FAA, ISO, and SAE, an ad hoc working committee (SAE A21) generated the procedure which computes effective perceived noise level (Refs. 1, 2, & 3).

The rationale for the development of this measure is based upon the results from several subjective judgment tests which indicated that as the duration of a sound or aircraft flyover increased, it was judged noisier. Further, the sounds with identifiable discrete tones were judged noisier than sounds without audible tonal components. Thus, it was evident that adjustment factors should be added to the perceived noise level rating to compensate for the perceived noisiness attributable to the signal time history and the presence of audible discrete frequency components.

Effective perceived noise level is calculated over the time history of a flyover at a time sequence (usually 0.5 sec. intervals) of tone-adjusted perceived noise levels which are calculated from one-third octave band noise spectra. The tone adjustments are determined from one-third octave band spectra by a procedure described under PNLT. The integration procedure results in adding 3 dB for each doubling of signal duration.

*Relation to Other Ratings*

**Sound Exposure Level (SEL) ($L_{AE}$)**

Sound exposure level is also a single event rating which takes into consideration the duration of the event, but not the discrete frequency components. However, sound exposure level can be used to estimate effective perceived noise level in most instances where the audible tones in the noise event are not excessive.

$$L_{EPN} \cong L_{AE} + 4 \ (\pm 3 \text{ dB})$$

**CALCULATION METHOD**

Effective perceived noise level for a single noise event is calculated as follows:

1) The sound pressure level for each of the 24 one-third octave bands from 50 to 10,000 Hz, is measured for a continuous sequence of 0.5 sec. time intervals throughout the duration of the aircraft or single noise event.

2) The perceived noise level ($PNL_i$) of the spectrum measured at each 0.5 sec. (or $i^{th}$) time interval is calculated according to the procedure on page 52.

3) Tone corrections ($T_i$) are determined for the audible discrete frequencies found at each 0.5 sec. (or $i^{th}$) time interval according to the procedure on page 67.

4) Tone corrected perceived noise level is computed for the perceived noise level at the 0.5 sec. (or $i^{th}$) time interval. The equation looks like:

$$L_{TPNi} = L_{PNi} + T_i \qquad [1]$$

5) Effective perceived noise level is then calculated by combining together all the values of $PNLT_i$ calculated throughout the duration of the noise event in accordance with the formula below for all $L_{TPNi}$ less than 10 dB from the maximum $L_{TPN}$.

$$L_{EPN} = 10 \log_{10} \left[ \sum_{i=0}^{n} 10^{\left(\frac{L_{TPNi}}{10}\right)} \right] -13 \qquad [2]$$

where:

13 is the normalizing constant for a duration of 10 sec.

n is the number of time samples when PNLT is within 10 dB of the maximum PNLT.

**EXAMPLE**

Table EPNL-1 and Figure EPNL-1 show an example of how effective perceived noise level is calculated for a single aircraft flyover, given tone corrected perceived noise level.

$$L_{EPN} = 10 \log_{10} (5.92 \times 10^{11}) - 13$$

$$= 104.7 \text{ dB}$$

**EQUIPMENT**

1) Sound level meter (ANSI S1.4-1971).
2) Tape recorder (necessary for single event where variation of level over time).
3) One-third octave band real time analyzer.
4) Or, one-third octave band analyzer plus graphic level recorder.
5) Digital computer (optional).

**STANDARDS**

1) Federal Aviation Administration (FAA), Federal Aviation Regulations (FAR) Part 36, "Noise Standards: Aircraft Type and Airworthiness Certification (Effective April 1978) - Appendix B.

# TABLE EPNL-1. EXAMPLE OF EPNL CALCULATION FOR AIRCRAFT FLYOVER

| Time (sec) | Sound Pressure Level | PNLT | $10^{(\frac{L_{TPN}}{10})}$ |
|---|---|---|---|
| 0.0 | 69.5 | 73.2 | |
| 0.5 | 69.7 | 73.5 | |
| 1.0 | 70.1 | 74.1 | |
| 1.5 | 71.2 | 75.5 | |
| 2.0 | 71.8 | 76.0 | |
| 2.5 | 72.1 | 76.5 | |
| 3.0 | 72.0 | 76.6 | |
| 3.5 | 72.3 | 77.3 | |
| 4.0 | 74.5 | 80.3 | |
| 4.5 | 75.4 | 82.6 | |
| 5.0 | 76.6 | 85.0 | |
| 5.5 | 78.5 | 88.9 | |
| 6.0 | 80.4 | 90.8 | |
| 6.5 | 82.2 | 94.0 | |
| 7.0 | 83.6 | 95.1 | |
| 7.5 | 85.0 | 97.2 | |
| 8.0 | 87.0 | 99.3 | 8511.38 × $10^6$ |
| 8.5 | 88.6 | 101.9 | 15488.17 " " |
| 9.0 | 90.4 | 103.6 | 22908.68 " " |
| 9.5 | 92.6 | 106.0 | 39810.72 " " |
| 10.0 | 94.5 | 108.2 | 66069.34 " " |
| 10.5 | 95.6 | 109.1 | 81283.05 " " |
| 11.0 | 96.2 | 109.1 | 81283.05 " " |
| 11.5 | 96.7 | 108.6 | 72443.60 " " |
| 12.0 | 97.1 | 107.5 | 56234.13 " " |
| 12.5 | 97.7 | 106.6 | 45708.82 × $10^6$ |
| 13.0 | 97.2 | 105.7 | 37153.52 " " |
| 13.5 | 96.4 | 104.2 | 26302.68 " " |
| 14.0 | 95.1 | 102.6 | 18197.01 " " |
| 14.5 | 93.8 | 101.0 | 12589.25 " " |
| 15.0 | 92.4 | 99.2 | 8317.64 " " |
| 15.5 | 91.2 | 97.3 | |
| 16.0 | 89.9 | 95.7 | |
| | | TOTAL | 592301.04 × $10^6$ |

$L_{EPN} = 10 \log_{10} (592301.04 \times 10^6) - 13$

$= 104.7$ dB

2) International Organization for Standardization, ISO/DIS 3891, "Procedure for Describing Aircraft Noise Heard on the Ground" (July 1975).

3) Society of Automotive Engineers (SAE), Aerospace Recommended Practice, ARP 1071 (June 1972).

**REFERENCES** (See Standards above).

| | |
|---|---|
| TITLE | SOUND EXPOSURE LEVEL |
| ABBREVIATION | SEL |
| SYMBOL | $L_{AE}$* |
| UNIT | Decibel (dB) |
| GEOGRAPHICAL USAGE | United States |
| DEFINITION | Sound exposure level is energy averaged A-weighted sound level over a specified period of time or single event, with a reference duration of 1 second. |
| BACKGROUND | Sound exposure level was developed to provide a means of measuring both the duration and the sound level associated with a particular time period or event measured at a specific site. SEL was designed to include duration because it was found from the results of subjective noise studies that longer duration noises were judged more annoying than |

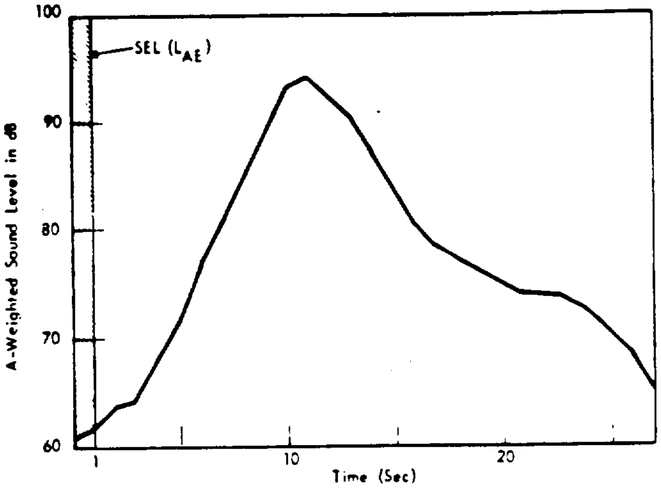

FIGURE SEL-1. TIME HISTORY OF AIRCRAFT FLYOVER

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*Sound exposure level is sometimes referred to as noise exposure (NEL) (Ref. 4). The symbol for level SEL is often seen in literature as $L_{AX}$ (Refs. 3 & 5) and $L_S$ (Ref. 6).

shorter duration noises. Thus, the SEL included the entire range of A-weighted sound levels over the period or event of interest. However, for practical purposes, when attempting to characterize an event such as an aircraft flyover by SEL, it is only necessary to measure the sound levels which are within 10 or 20 dB of the maximum A-level (Refs. 1, 2, and 3).

### Single Event Noise Exposure Level (SENEL) (California

SENEL is a special sub-set of SEL and was developed to be used exclusively in the California state airport regulations to limit excessively noisy aircraft operations (Ref. 4). SENEL is calculated exactly like SEL but is based upon only the measured A-weighted sound levels above a threshold level. This threshold level is determined by some type of legislative or administrative action. A Federal court decision in Crotti (Ref. 7) held that the Federal law pre-empted the State's power to regulate noisy aircraft operations with SENEL. The same decision noted that the airport proprietor's power to set noise limits was not affected. Conceivably, the individual proprietor, whether city or private, could still use a SENEL criteria to govern aircraft flyover noise.

### *Relation to Other Ratings*

Sound exposure level (SEL) can be estimated from other sound measures as follows:

**Community Noise Equivalent Level (CNEL) ($L_{den}$)**

$$L_{AE} \cong L_{den} - 10 \log_{10} N_{eff} + 49.4$$

where:

| | |
|---|---|
| N | is the effective number of events ($N_d + 3 N_c + 10N_n$) |
| 49.4 | is 10 $\log_{10}$ [86400] which is the number of seconds in 24 hours. |

**A-Weighted Sound Level (SLA) ($L_A$)**

$$L_{AE} \cong 10 \log_{10} [\frac{t_c - t_1}{2(1 \text{ sec})}] + L_{Amax}$$

where:

| | |
|---|---|
| $t_2 - t_1$ | is the time interval between the first and last instants the A-weighted sound level is within 10 dB of the maximum value, $L_{Amax}$. |
| $L_{Amax}$ | is the maximum A-weighted sound level. |

## CALCULATION METHOD

Sound exposure level can be calculated by two methods defined as follows:

1) Continuous Time Integration

$$L_{AE} = 10 \log_{10} \left[ \frac{\int_{t_1}^{t_2} 10^{\frac{L_A(t)}{10}} dt}{1 \text{ sec}} \right]$$

where:

$\int_{t_1}^{t_2}$ defines the time interval of integration

$L_A(t)$ is the time function of A-weighted sound level during the time for $t_1$-$t_2$.

2) Temporal Sampling

$$L_{AE} = 10 \log_{10} \left[ \sum_{i=1}^{n} 10^{\frac{L_{A(i)}}{10}} \Delta t \right]$$

where:

$L_{A(i)}$ is the instantaneous A-weighted sound level for the $i^{th}$ sample.

n is the number of samples taken during the observational period.

$\Delta t$ is the time interval between samples.

**EXAMPLE** The same aircraft flyover time history used in the EPNL example (p.82) will be used as the example for SEL. For the SEL example shown in Table SEL-1, the sampling interval was every 0.5 sec. The resulting SEL is:

## TABLE SEL-1

## EXAMPLE OF SEL CALCULATIONS FOR AIRCRAFT FLYOVER

| Time (sec) | Sound Pressure Level | $L_A$ | $10^{\frac{L_A}{10}}$ | $\Delta t$ (sec) |
|---|---|---|---|---|
| 0.0 | 69.5 | 60.6 | $1.15 \times 10^6$ | 0.5 |
| 0.5 | 69.7 | 61.0 | 1.26 " " | " |
| 1.0 | 70.1 | 61.7 | 1.48 " " | " |
| 1.5 | 71.2 | 63.5 | 2.24 " " | " |
| 2.0 | 71.8 | 63.7 | 2.34 " " | " |
| 2.5 | 72.1 | 63.9 | 2.45 " " | " |
| 3.0 | 72.0 | 64.2 | 2.63 " " | " |
| 3.5 | 72.3 | 65.3 | 3.39 " " | " |
| 4.0 | 74.5 | 68.4 | 6.92 " " | " |
| 4.5 | 75.4 | 70.4 | 10.96 " " | " |
| 5.0 | 76.6 | 71.9 | 15.49 " " | " |
| 5.5 | 78.5 | 74.7 | 29.51 " " | " |
| 6.0 | 80.4 | 76.8 | 47.86 " " | " |
| 6.5 | 82.2 | 78.9 | 77.62 " " | " |
| 7.0 | 83.6 | 80.7 | 117.49 " " | " |
| 7.5 | 85.0 | 82.5 | 177.83 " " | " |
| 8.0 | 87.0 | 84.7 | 295.12 " " | " |
| 8.5 | 88.6 | 86.6 | 457.09 " " | " |
| 9.0 | 90.4 | 88.4 | 691.83 " " | " |
| 9.5 | 92.6 | 90.9 | 1230.27 " " | " |
| 10.0 | 94.5 | 93.0 | 1995.26 " " | " |
| 10.5 | 95.6 | 94.0 | 2511.89 " " | " |
| 11.0 | 96.2 | 94.1 | 2570.40 " " | " |
| 11.5 | 96.7 | 93.6 | 2290.87 " " | " |
| 12.0 | 97.1 | 92.3 | 1698.24 " " | " |
| 12.5 | 97.7 | 91.4 | 1380.38 " " | " |
| 13.0 | 97.2 | 90.4 | 1096.48 " " | " |
| 13.5 | 96.4 | 89.0 | 794.33 " " | " |
| 14.0 | 95.1 | 87.2 | 524.81 " " | " |
| 14.5 | 93.8 | 85.4 | 346.74 " " | " |
| 15.0 | 92.4 | 83.4 | 218.78 " " | " |
| 15.5 | 91.2 | 81.5 | 141.25 " " | " |
| 16.0 | 89.9 | 79.9 | 97.72 " " | " |

Total = $18842.08 \times 10^6 \times 0.5$

Equation [2]

$$L_{AE} = 10 \log_{10} (18842.08 \times 10^6 \times 0.5)$$

$$L_{AE} = 99.8 \text{ dB}$$

$L_{AE} = 99.8$ dB

**EQUIPMENT**

1) Sound level meter (ANSI S1.4-1971).
2) Tape recorder.
3) Digital computer with sampling capability.

**STANDARDS**

ANSI S3.23-1980

**REFERENCES**

1) Environmental Protection Agency, "Impact Characterization of Noise Including Implicatio of Identifying and Achieving Levels of Cumulati Noise Exposure", Task Group 3, Aircraft/Airport Noise Study Report, NTID 73.4, July 1973.

2) Young, R. W., "Average Sound Level, Sound Exposure Level, and Noise Dose", Naval Undersea Center, San Diego, California 92132.

3) Berry, B. F., "The Concept of a Single Event Noise Exposure Level, L, and Its Use in the Description of the Overall Noise Environment", National Physical Laboratory, Proceedings of the Institute of Acoustics.

4) California Department of Aeronautics, "Noise Standards", California Administrative Code, Subchapter 6, Title 21 (Register 79, No. 21, May 26, 1979).

5) International Organization for Standardization, ISO/DIS 3891, "Procedure for Describing Aircraft Noise Heard on the Ground", July 1975.

6) Environmental Protection Agency, "Protective Noise Levels - Condensed Version of EPA Levels Document", EPA 550/9-79-100, November 1978.

7) <u>Air Transport Association of America v. Crotti</u> (N.D. Cal. 1975) 389 F. Supp. 58.

## NOTES

# CHAPTER III

## MULTIPLE EVENT METRICS

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C-2.

**TITLE** STATISTICAL SOUND LEVEL

**ABBREVIATION** $L_x$

**SYMBOL** $L_x$

**UNIT** Decibel (dB)

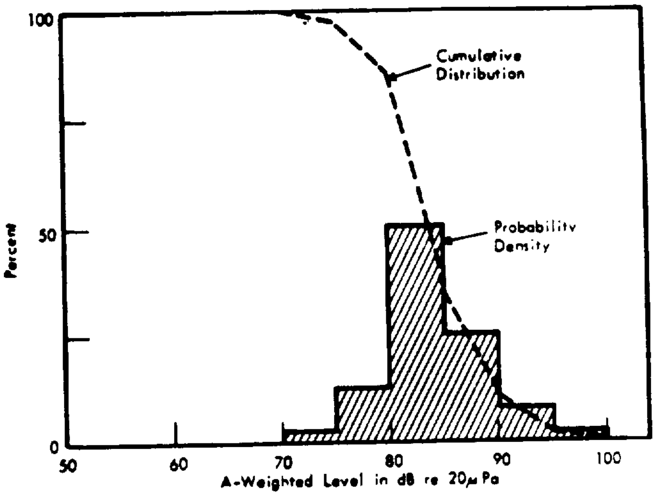


FIGURE $L_x$-1. STATISTICAL AND CUMULATIVE DISTRIBUTION OF NOISE LEVELS AT A SITE FOR A 1 HOUR PERIOD

**GEOGRAPHICAL USAGE** International

**DEFINITION** The statistical sound level is a descriptor of a noise environment measured in some time period. It is that noise level which is exceeded x percent of the time.

**PURPOSE** Statistical sound level (often referred to as centile level) provides a means of assessing the fluctuating noise levels at a point of interest. For example, it is commonly used to characterize the noise at a community location that is exposed to vehicular traffic.

**BACKGROUND**

The sound levels in most communities fluctuate depending upon, among other things, the noise source, the time of day, or the season of the year. The noise level within an hour, for example, could fluctuate from very quiet to extremely loud. Therefore, a good way to describe the levels that are present during the day at a site, or the noise exposure of that site, is to use a statistical measure which takes the time varying characteristics of the sound into account. The measure, statistical sound level, or centile level, does just that by considering the proportion of time certain noise levels are exceeded.

The relationship between time and levels exceeded is represented as a cumulative distribution of sound levels as seen in Figure $L_x$-1. The curve in this figure shows what percent of the observation period each level is exceeded. The time period can be any length, but typically it is for 1 hour or more. Further, the sound levels can be measured using various weighting factors, but usually A-weighted sound level is used (Ref. 1).

Common practice has dictated that $L_{10}$, $L_{50}$, and $L_{90}$ are most often used as statistical descriptors of the noise environment to designate levels exceeded 10 percent, 50 percent and 90 percent of the time. However, it should be noted that any other centile levels can be used such as $L_1$ (1 percent) to $L_{99}$ (99 percent) (Refs. 2 & 3). The sound pressure level exceeded 10 percent of the time, expressed as $L_{10}$, gives an approximate measure of high level and short duration noises. A measure of the median sound level is $L_{50}$ and represents the level exceeded 50 percent of the time. The background ambient level is estimated by $L_{90}$ which is the sound level exceeded 90 percent of the time. The choice of $L_{90}$ to represent the ambient noise and $L_{10}$ as the dividing line for the peak levels is somewhat arbitrary. Other countries, such as Australia, have chosen instead to designate $L_{95}$ and $L_5$ as background and peak levels (Ref. 1).

The difference between $L_{10} - L_{90}$ indicates the range within which the noise levels spend 80 percent of the time. The standard deviation of the noise levels over the defined time period is a common measure of the statistical fluctuation.

Statistical sound level measures serve as the basis for other measures which were developed to examine how the fluctuating noise relates to subjective annoyance. The traffic noise index (TNI) and noise pollution level (NPL) are both ratings which require a knowledge of statistical parameters such as the 90, 50, and 10 percent levels of cumulative distribution.

Highway traffic noise most often lends itself to a statistical distribution type measure. Early criteria used for highway noise are expressed in terms of $L_{10}$ values. In high density traffic situations the statistical distribution of sound levels can be represented by a Gaussian distribution. The $L_{10}$ value can be estimated by the median ($L_{50}$) and the standard deviation of the noise levels (s), and is given by:

$$L_{10} = L_{50} + 1.28\ s$$

*Relation to Other Ratings*

Equivalent Continuous Sound Level (QL) ($L_{eq}$)

Equivalent continuous sound level can be approximated from statistical sound levels for those cases such as traffic where the noise level distribution presumably resembles a normal or Gaussian curve. QL can be described in terms of the median ($L_{50}$) value and the standard deviation (s) of the noise level distribution.

$$L_{eq} \cong L_{50} + 0.115\ s^2$$

The difference between $L_{10}$ and $L_{eq}$ for a normal distribution situation is given as:

$$L_{10} - L_{eq} \cong 1.28\ s - 0.115\ s^2$$

However, it should be noted that traffic noise does not always follow a normal distribution of noise levels. In most cases caution should be used in relying upon the exact differences between $L_{10}$ and $L_{eq}$.

**CALCULATION METHOD**

The calculation procedure for $L_x$ is first a matter of generating a probability distribution in the form of a histogram which reflects the percentage of time each level is present. The cumulative distribution is generated from the probability distribution by the following equation.

$$C(L) = 1 - \sum_{j=1}^{L} P_j$$

where:

$C(L)$ is the cumulative distribution

$P_j$ is the percentage of time that a sound is at a level of $L_j$

$L_j$ is the sound interval.

Data collection and analysis can be done by hand or by utilizing current technology such as a statistical distribution analyzer or a high speed computer. The fluctuating sound levels at a site, as illustrated in Figure QL-1 are obtained by reading a sound level meter at prescribed time intervals. The range of measured levels is then divided and a count is made of the number of measurements falling within each interval. When normalized by the total number of samples, the result will be a probability density distribution. This information is used to generate the cumulative distribution curve illustrated in Figure $L_x$-1.

**EXAMPLE**

An example of how the statistical sound level concept is used is best illustrated in two figures: $L_x$-1 and $L_x$-2. The data in Figure $L_x$-1 represents 1 hour out of 24 hours worth of data that is represented in Figure $L_x$-2. Figure $L_x$-1 shows the probability density and cumulative distribution of the noise levels for a 1 hour observation period. The histogram portion of this example, which represents the statistical distribution of the sound over 1 hour, indicates that levels between 80-85 dB occur at least 50 percent of the time.

The conclusions derived from the cumulative distribution curve, however, are useful in determining which noise levels are exceeded x percent of the time. In Figure $L_x$-1, the level exceeded virtually 100 percent or $L_{100}$ of the time is 70 dB. The typical descriptor for the background level is $L_{90}$, the noise level exceeded 90 percent of the time, which is 78 dB for this example. The noise level exceeded half the time is 85 dB; and the level exceeded only 10 percent of the time, $L_{10}$, is 90 dB.

The slope of the cumulative distribution curve near the 50 percent level indicates how much the noise levels at this site vary over time. If there is a steep gradient at this point, it

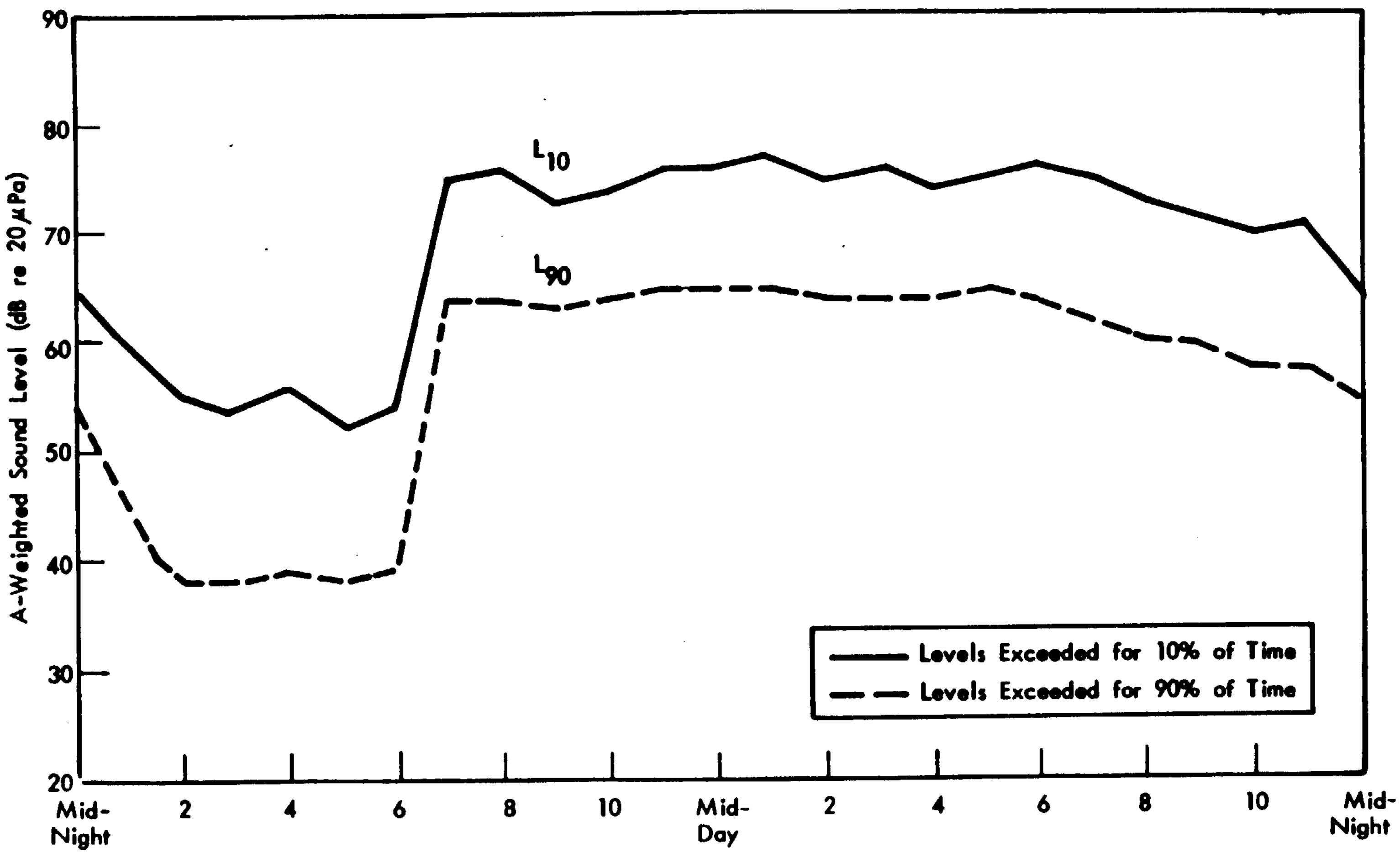


FIGURE $L_x$-2. STATISTICAL SOUND LEVELS ($L_{10}$ & $L_{90}$) AT URBAN SITE OVER A 24-HOUR PERIOD; THE $L_{10}$ AND $L_{90}$ LEVELS WERE DETERMINED FOR EACH HOUR OF THE DAY means that the noise hardly varies from the $L_{50}$ level and this reflects a steady state condition. Noise levels measured in the desert or at night in a rural community would probably resemble this type of distribution.

Conversely, if the slope of the cumulative distribution is not as steep, this indicates a difference between the background level and the level of short term intruding noises ($L_{10}$) is large. These differences might be found at an urban site near a street with intermittent traffic or in a neighborhood adjacent to an airport.

Figure $L_x$-2 contains a plot of the $L_x$ values over a 24 hour observational period. From this figure it is easy to determine what hours during the day are expected to be the noisiest or the quietest. This figure graphically illustrates the noise level fluctuations over a daily period and the relationship of the high noise levels to the background noise levels for each hour.

**EQUIPMENT**

1) Sound level meter (ANSI S1.4-1971).
2) Tape recorder.
3) Sound level meter and graphic level recorder.
4) Statistical distribution analyzer.
5) High speed computer.

**STANDARDS** None

**REFERENCES**

1) Schultz, Theodore J., "Technical Background for Noise Abatement in HUD's Operating Programs", Report No. TE/NA 172, Department of Housing and Urban Development, 1971.

2) Environmental Protection Agency, "Public Health and Welfare Criteria for Noise", NCD 73.1 (July 1973).

3) Environmental Protection Agency, "Information or Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety", 550/9-74-004 (March 1974).

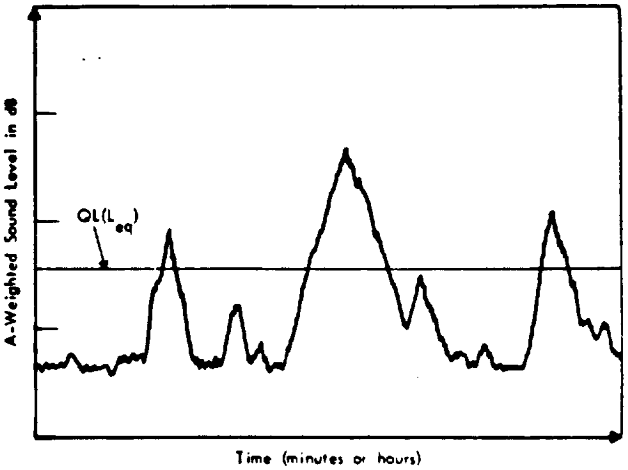


FIGURE QL-1. OUTDOOR SOUND LEVELS AT URBAN SITE

| | |
|---|---|
| TITLE | EQUIVALENT CONTINUOUS SOUND LEVEL |
| ABBREVIATION | QL* |
| SYMBOL | $L_{eq}$ |
| UNIT | Decibel (dB) |
| GEOGRAPHICAL USAGE | International |
| DEFINITION | Equivalent continuous sound level is the level of the A-weighted sound energy averaged over a specified period of time. |
| PURPOSE | Equivalent continuous sound level was developed to provide a measure of time varying or fluctuating noise. It has proven to be an effective tool for assessing people's reactions to aircraft and vehicular traffic noise. It also correlates well |

---

*Equivalent continuous sound level is also referred to as average sound level. ANSI, in proposed terminology, will symbolize average sound level or equivalent continuous sound level at $L_T$, where T is the time period over which the average is taken; previously it was symbolized as $L_{eq(T)}$.

with the degree of annoyance, hearing loss, speech and sleep interference that is generated by differend levels of noise exposure.

## BACKGROUND

Equivalent continuous sound level is one of the ratings which addresses the problem of measuring a time varying noise. It is a single number descriptor that quantifies the combination of noise magnitude, duration, and frequency response of the ear. This is achieved by averaging (that is, converting decibel levels to relative sound power, averaging, and then changing back into resultant levels in decibels) A-weighed sound level over stated period of time. This has also been called 'energy averaging' the sound levels.

This concept of energy averaging or integrating over time is the basis of equivalent continuous sound level. This is defined as the A-weighted sound level of a constant or steady state sound which contains the acoustical energy equivalent to the actual fluctuating noise existing at the location over the observation period.

Equivalent continuous sound level may be calculated for any desired time period such as 24 hours, 8 hours, 1 hour, daytime, or nighttime. It is often seen in the literature as $L_{eq(24)}$, $L_{eq(8)}$, $L_{eq(1)}$, $L_d$ and $L_n$, respectively. It is essential to always indicate the time period over which equivalent sour level is calculated (Refs. 1 & 2). Figure QL-1 illustrates the resulting QL value for sound levels measured outdoors at an urban site.

Equivalent continuous sound level is familiar to scientists in the United States and in Europe. In 1957, it was used in the original U.S. Air Force Planning Guide for noise from aircraft operations (Ref. 3). It was also referred to in the 1955 report (Ref. 4) on criteria for short term exposure of personnel to high intensity jet aircraft noise, which was the forerunner of the 1956 Air Force Regulation (Ref. 5) on "Hazardous Noise Exposure".

In 1965 it was used in Germany as a rating to evaluate the impact of aircraft noise upon the communities near airports (Ref. 6). Other countries such as Austria, East and West Germany, and Sweden have recognized its applicability for assessing the subjective effects of time varying noises of all kinds, including street traffic, railroad traffic, canal and river ship traffic, aircraft, industrial operations, playground, etc. (Refs. 7-14).

Equivalent continuous sound level is the primary metric for several more complex noise ratings. Notably it is used in community noise equivalent level (CNEL) in the form of hourly noise level which is $L_{eq(1)}$. Likewise, QL is the fundamental metric for day-night average sound level (DNL). DNL, like CNEL, has a weighting adjustment for sound levels occurring during different hours of the day.

## *Relation to Other Ratings*

Equivalent continuous sound level can be estimated from hourly noise level, statistical sound level and sound exposure level.

### Hourly Noise Level (HNL) ($L_h$)

$$L_{eq(1)} \cong L_h$$

### Statistical Sound Level ($L_x$)

(if the statistical distribution of the levels is assumed to be normal or Gaussian)

$$L_{eq} \cong L_{50} + 0.115\ s^2$$

where:

s is the standard deviation of the distribution.

### Sound Exposure Level (SEL) ($L_{AE}$)

$$L_{eq} \cong 10 \log_{10} \left[ \frac{1}{T} \left[ \sum_{i=1}^{n} 10^{\frac{L_{AE(i)}}{10}} \right] \right]$$

where:

$T$ is the sampling time period

$L_{AE(i)}$ is the sound exposure level for each event

$n$ is the number of events.

## CALCULATION METHOD

Equivalent continuous sound level can be calculated from a continuous function over time or results can be derived for discrete samples taken during a time period.

### 1) Continuous Time Integration

$$L_{eq} = 10 \log_{10}\left[\frac{1}{t_2-t_1}\left[\int_{t1}^{t2} 10^{\frac{L_A}{10}}\,dt\right]\right] \qquad [1]$$

where:

$t_2-t_1$ is the time period over which the time integration process takes place.

$L_A$ is the instantaneous A-weighted sound level.

### 2) Temporal Sampling

For individual sampling events during a specified time period:

$$L_{eq} = 10 \log_{10}\left[\frac{1}{n}\left[\sum_{i=1}^{n} 10^{\frac{L_{A(i)}}{10}}\right]\right] \qquad [2]$$

where:

$n$ is the number of samples.

$L_{A(i)}$ is A-weighted sound level of the $i^{th}$ sample.

**EXAMPLE**

The equivalent continuous sound level for six samples taken within 1 hour is shown in Table QL-1. It should be noted that more samples could be taken within the hour or the total time period could be extended ($L_{eq(24)}$, etc.).

$$L_{eq(1)} = 79.1 \text{ dB}$$

**EQUIPMENT**

1) Sound level meter (ANSI S1.4-1971) and tape recorder for single events.
2) Digital computer and special analyzing equipment capable of integrating sound level for long periods of time.

**STANDARDS**

ANSI S3.23, 1980.

**REFERENCES**

1) Environmental Protection Agency, "Impact Characterization of Noise Including Implications of Identifying and Achieving Levels of Cumulative Noise Exposure", NTID 73.4 (July 1973).
2) Environmental Protection Agency, "Fundamentals of Noise: Measurement, Rating Schemes and Standards", NTID 300.15 (December 1971).
3) Stevens, K. N., and Pietrasanta, A. C., and the Staff of Bolt Beranek and Newman Inc., "Procedures for Estimating Noise Exposure and Resulting Community Reaction From Air Base Operations", WADC Tech. Note 57-10, DTIC Doc. No. AD 110705, U.S. Air Force, April 1957.

4) Eldred, K. M., Gannon, W. J., and von Gierke, H. E., "Criteria for Short Time Exposure of Personnel to High Intensity Job Aircraft Noise", WADC Technical Note 55-355, Wright Patterson Air Force Base, Ohio (1955).

5) Air Force Regulation 160-3, "Hazardous Noise Exposure", USAF, October 29, 1956.

6) Burck, W., Grutzmacher, M., Meister, F. J., Muller, E. A. and Matschat, K., "Fluglarm, Gutachten erstattet im Auftrag des Bundesministers fur Gesundheitswesen", (Aircraft Noise: Expert Recommendations submitted under Commission from the German Federal Ministry for Public Health), Gottingen, 1965.

7) Bruckmayer, F., and Lang, J., "Storung der Bevolkerung durch Verkehrslarm" (Disturbance of the Population by Traffic Noise), Oesterreiche Ingenieur-Zeitschrift, Jg. 1967, H.8, 302-306; H.9, 338-344; and H.10, 376-385.

8) Bruckmayer, F., and Lang, J., "Storung durch Verkehrslarm in Unterrichtstraume" (Disturbance Due to Traffic Noise in Schoolrooms), Oesterreichische Ingenieur-Zeitschrift, 11(3): 73-77, 1968.

9) "Schallschutz: Begriffe" (Noise Control: Definitions), TGL 10, 687, Blatt 1 (Draft), Deutsche Bauinformation, East Berlin, November, 1970.

10) "Mittelung Zeitlich Schwankender Schallpegel (Aquivalenter Dauerschallpegal)", (Evaluation of Fluctuating Sound Levels (The Equivalent Continuous Sound Level)), DIN 54 641, (Draft), Deutsche Normen, Beuth-Vertrieb GmbH, Berlin 30 April 1971.

11) "Schallschutz: Territoriale und Stadtebauliche Planung" (Noise Control: Land Use and City Planning), TGL 10 687, Blatt 6, (Draft), Deutsche Bauinformation, East Berlin, November, 1970.

12) "Schallschutz in Stadtebau", (Noise Control in City Planning), DIN 18 005, (Draft), Deutsche Normen, Beüth-Vertrieb GmbH, Berlin 30, August, 1968.

13) Benjegard, Sven-Olaf, "Bullerdosimetern", (The Noise Dose Meter), Report 51/69, Statens Institut fur Byggnadsforskning, Stockholm, 1969

## TABLE QL-1

## EXAMPLE OF CALCULATIONS FOR EQUIVALENT SOUND LEVEL

| Samples n | $L_A$ dB | $10^{\frac{L_A}{10}}$ |
|---|---|---|
| 1 | 55 | $0.32 \times 10^6$ |
| 2 | 61 | 1.26 " " |
| 3 | 85 | 316.23 " " |
| 4 | 76 | 39.81 " " |
| 5 | 81 | 125.89 " " |
| 6 | 63 | 2.00 " " |
| | Total = | $485.51 \times 10^6$ |

*Equation 2*

$$L_{eq} = 10 \log_{10} \left[ \frac{1}{6} [485.51 \times 10^6] \right]$$

$$L_{eq} = 79.1 \text{ dB}$$

**TITLE** HOURLY NOISE LEVEL

**ABBREVIATION** HNL

**SYMBOL** $L_h$

**UNIT** Decibel (dB)

**GEOGRAPHICAL USAGE** State of California

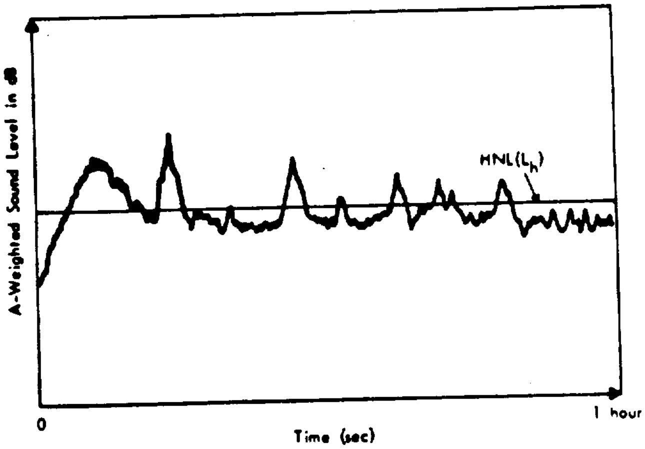


FIGURE HNL-1. OUTDOOR SOUND LEVELS AT URBAN SITE - 1 HOUR

**DEFINITION** Hourly noise level is the level of the mean-square A-weighted sound pressure over an hour period.

**PURPOSE** Hourly noise level is used to characterize the time varying noise environment on an hourly basis.

**BACKGROUND** Hourly noise level is identical to equivalent continuous sound level (QL) for an hourly period. HNL can be calculated for 1 hour or more and identified by 1HNL ($L_{1h}$) or 2HNL ($L_{2h}$). If HNL is computed for different time periods within a day, they are referred to in literature as HNLD ($L_{hd}$), HNLE ($L_{he}$) and HNLN ($L_{hn}$) (Ref. 1). Hourly noise level is the basis for one of the computational formulas for California's community noise equivalent level (CNEL) (Refs. 2 & 3). Figure HNL-1 illustrates the resulting HNL for outdoor sound levels at an urban site.

### *Relation to Other Ratings*

#### Sound Exposure Level (SEL) ($L_{AE}$)

A measure of the level of the average hourly noise can be estimated with the results from sound exposure level (SEL).

$$L_h \cong \overline{L_{AE}} + 10 \log_{10} n - 35.6$$

where:

$L_{AE}$ is the mean-square average sound exposure (SEL) for each single event.

n is the number of events per hour.

35.6 is $10 \log_{10} [3600]$ (the number of seconds in an hour).

## CALCULATION METHOD

Hourly noise level can be calculated using either a continuous time integration method, or a discrete sampling technique. If HNL is to be calculated for compliance with the California airport noise regulations, then the noise levels are sampled only when they exceed a specified threshold level.

### 1) Continuous Integration

For continuous time integration of A-weighted sound level for a one hour period the formula is:

$$L_h = 10 \log_{10}\left[\frac{1}{3600}\left[\int_0^{3600} 10^{L_A(t)/10}\, dt\right]\right]$$

where:

$L_A(t)$ is the time function of instantaneous A-weighted sound level.

$\int_0^{3600}$ defines the time interval in seconds for 1 hour.

### 2) Temporal Sampling

For discrete sample of A-weighted sound level, the formula is:

$$L_h = 10 \log_{10} \left[ \frac{1}{n} \left[ \sum_{i=1}^{n} 10^{L_{A(i)}/10} \right] \right] \qquad [2]$$

where:

$n$ is the number of A-weighted sound level samples in an hour.

$L_{A(i)}$ is the instantaneous A-weighted sound level for sample i.

EXAMPLE

Hourly noise level for a discrete number of noise samples is calculated in Table HNL-1 using Equation [2]. The HNL for one hour is:

$$L_{1h} = 90.7 \text{ dB}$$

EQUIPMENT

1) Tape recorder (for single events).
2) Sound level meter for discrete sampling (ANSI S1.4-1971).
3) Digital computer and analyzing equipment capable of integrating sound levels for one hour for the continuous integration method.

STANDARDS

ANSI S3.23-1980.

## TABLE HNL-1

## EXAMPLE OF HNL CALCULATIONS FOR SINGLE EVENTS

| Number of Events | $L_A$ dB | $10^{\frac{L_{A(i)}}{10}}$ |
|---|---|---|
| 1 | 65 | $3.16 \times 10^6$ |
| 2 | 59 | 0.79 " " |
| 3 | 75 | 31.62 " " |
| 4 | 98 | 6309.57 " " |
| 5 | 63 | 1.99 " " |
| 6 | 92 | 1584.89 " " |
| 7 | 96 | 3981.07 " " |
| 8 | 86 | 398.10 " " |
| 9 | 55 | 0.31 " " |
| 10 | 89 | 794.32 " " |
| 11 | 58 | 0.63 " " |
| | | TOTAL = $13106.49 \times 10^6$ |

*Equation 2*

$$L_{1h} = 10 \log_{10} \frac{1}{11} [13106.49 \times 10^6]$$

$$= 90.8 \text{ dB}$$

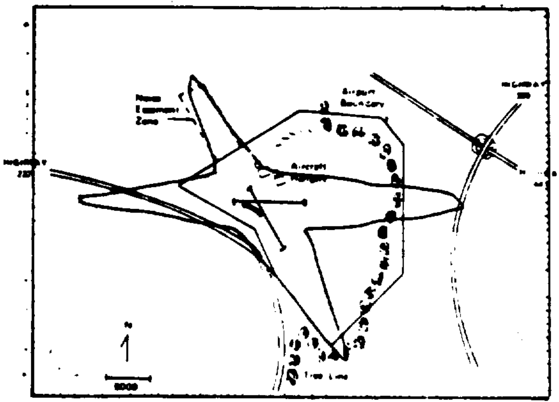
## REFERENCES

1) Wyle Laboratories Research Staff, "Supporting Information for the Adopted Noise Regulations for California Airports", WCR 70-3(R), Final Report to the California Department of Aeronautics, January 1971.

2) California Department of Aeronautics, "Noise Standards", California Administrative Code 35004, Subchapter 6, Title 21 (Register 79, No. 21, May 26, 1979).

3) Environmental Protection Agency, "Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety", 550/9-74-004, March 1974.

| | |
|---|---|
| TITLE | TIME ABOVE THRESHOLD |
| ABBREVIATION | TA |
| SYMBOL | TA |
| UNIT | Minutes |
| GEOGRAPHICAL USAGE | United States |



Federal Aviation Administration Integrated Noise Model 1 2

THIS IS A RUN FOR THE EXAMPLE AIRPORT
TA 85 dB 0.5 Min.

FIGURE TA-1. TA CONTOUR PLOT
(Ref.7)

**DEFINITION**

Time above threshold is the time of noise exposure above some preselected threshold of A-weighted soun level. For comparison purposes both the threshold level and the observational period must be stated.

**PURPOSE**

The time above threshold method was designed as a means of describing the noise exposure at locations of interest using units of measure (minutes) that could be comprehended by non-acoustics as well as acoustic experts.

**BACKGROUND**

The time above threshold method was initially incorporated into an approach called Aircraft Sound Description System (ASDS) developed by the Federal Aviation Administration (FAA) (Ref. 1) as part of an effort to provide an objective approach for describing aircraft sound levels at geographical locations around an airport. The ASDS concept used two means to carry out this approach: 1) the time above a specified threshold (TA), and 2) the situation index (SI). The time above threshold rating accounted for both the A-weighted sound levels of the aircraft events and the time that the sound levels were in excess of a specified 85 dB threshold value. The second aspect of the ASDS method, the situation index, provided a description of the noise exposure in terms of the amount of geographical area that was affected by the noise, and was expressed in units of acres-per-minute. Details of this aspect of the ASDS method are in Refs. 2-5.

The ASDS method as a whole was not widely accepted. That part of the method dealing with the situation index concept was eliminated but the time above threshold rating was retained and incorporated by the FAA into the Integrated Noise Model (INM) computer program. This program is used in airport planning whenever it is necessary to consider the environmental impact. The threshold levels for time above in the INM program are specified from 65 to 115 dB in 10 dB increments. The standard observational time periods are 24 hours, 1900-2200 and 2200-0700 (Ref. 6).

Time above threshold method provides information on the direct effects of noise generating activities such as aircraft flyovers. It enables one to obtain useful information on the total duration of a potentially interfering sound in order to analyze the effects on speech, sleep, or television viewing or determine the number of times during the day in which the interference occurs and the duration of each interference. The information on duration and intensity of sound that become fused into a single number cumulative rating (e.g., noise exposure forecast) can be differentiated by the time above threshold method.

The TA describes the noise exposure experienced at a specified geographical location; however, it is not correlated with estimates of community reaction for noise events above a certain threshold. Instea the FAA emphasized the objective basis of TA and has not sponsored any research to qualify or interpret these numerical values in order to predict people's subjective annoyance reactions.

While in theory there are many positive aspects derived from the time above threshold method, the economic cost of obtaining these results can be prohibitive for the average airport proprietor or community contemplating a new airport or modifications of an existing one. When compared to the computer processing costs for 1 contour of noise exposure forecast (NEF) (using the same input parameters such as aircraft type, operations, and tolerance held constant but the number of ground tracks increased from its base of 8) the cost for the TA results is 16 times as much (Ref. 6). This cost estimate comparison would be equally applicable to other cumulative noise ratings similar to NEF, such as equivalent sound level ($L_{eq}$), day-night average sound level (DNL), or community noise equivalent level (CNEL).

*Relation to Other Ratings*

- Statistical Sound Level ($L_X$)

For any specific threshold level, TA can be determined directly from the statistical sound level ($L_X$) curve given the total time of the observational period. The relationship is as follows:

$$TA = T_o \text{ [percent of time } L > L_T]$$

where:

$T_o$ is the total observational time.
$L$ is A-weighted sound level.
$L_T$ is the threshold A-weighted sound level.

**CALCULATION METHOD**

The time above threshold procedure can be implemented manually or with the aid of a computer. Conceivably the procedure is relatively simple. It is only necessary to set a threshold level and then note the amount of time the threshold level at the particular geographical location of interest is exceeded. TA increases in complexity if several different thresholds are set and the duration of the noise at each threshold level is measured. In fact what is computed is an $L_X$ (statistical sound level) curve similar to the one on page 94. Thus a given location near a noise source can be described in terms of the time above for various threshold levels.

TA contours can be drawn using TA and overlaying the results on a map to provide a visual picture of the area affected by the noise source. It would be necessary to specify the threshold and then connect the points of equal time above this threshold. An example of such a contour is shown in Figure TA-1. This figure contains a contour plot encompassing the area which experience noise exposure over 85 dB for 0.5 minute (Ref. 7). However, these results do not indicate what the maximum noise levels are in this area. This problem could be solved by producing contours at increased thresholds.

A manual procedure may be used for an airport with a single runway, limited numbers of operations and minor variations in aircraft types and flight paths utilized. However, for more complex airport situations a computer program is more expedient.

If TA is to be calculated for an airport situation, then it is suggested that the following items of information be required. It must be noted, of course, that this list is not comprehensive and other information would be useful if other types of community noise exposure situations are to be analyzed.

**Aircraft Noise Exposure Information**

1) A geographical map of the land area of interest.
2) A layout of the airport runways.
3) A layout of the ground tracks followed by the aircraft for takeoffs and landings.
4) Information on aircraft type and weight.
5) Number of aircraft takeoffs and landings by aircraft type for each runway under consideration.

The particular steps in the procedure used to calculate ASDS, which includes TA with a threshold of 85 dB and the situation index (SI) are listed in a report by the FAA (Ref. 3).

**EXAMPLE**

The time above threshold method can be used to describe the noise impact of aircraft operations and the results can be either a grid or contour output. The results of a TA analysis in terms of a contour for a single runway situation are illustrated in Figure TA-2 (Ref. 1). This figure shows the different areas in the vicinity of the runway that could be expected to experience noise levels

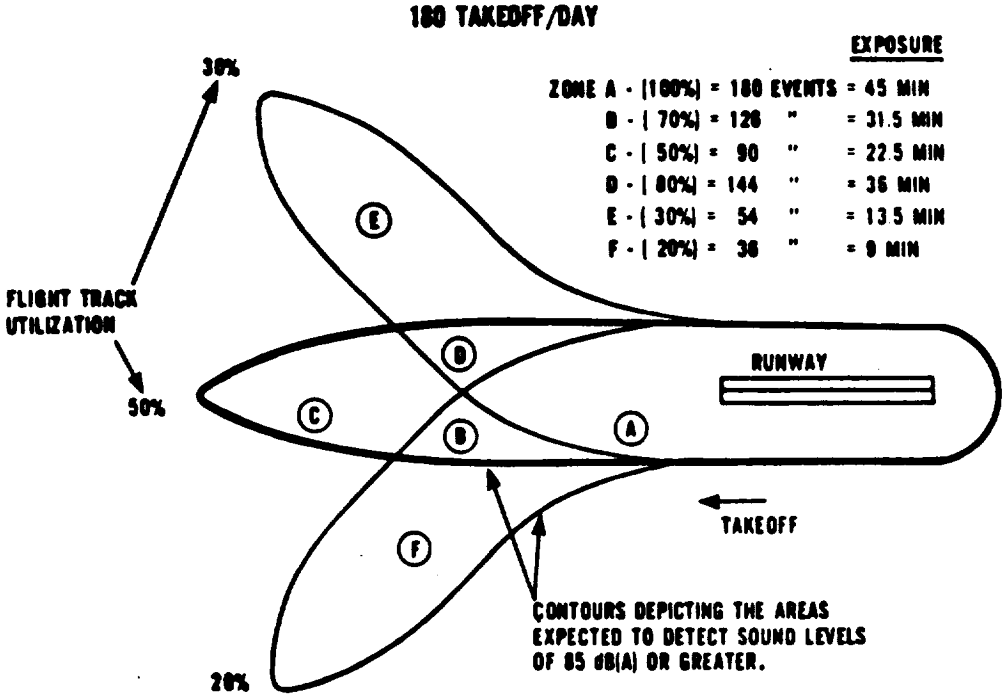


FIGURE TA-2. TA PLOT FOR SINGLE RUNWAY AIRPORT
TA 85 dB 45 Min (Ref.1)

in excess of 85 dB. The variables for this hypothetical airport are: a single runway, with one aircraft type, using three different takeoff headings, 180 takeoff operations per day, and each event in excess of 85 dB has a 15 sec. duration.

It is seen in the figure that six different noise exposure areas are defined on the basis of respective frequency of use of each flight track. The tabular data on the figure which identifies each noise area shows the total exposure time based on the number of events and the duration per event.

**EQUIPMENT**

1) Tape recorder.
2) Sound level meter (ANSI S1.4-1971).
3) High speed digital computer recommended for most airport planning situations.
4) Statistical analyzer.

**STANDARDS** None

## REFERENCES

1) Cruz, J., "Aircraft Sound Description System: Background and Application", Federal Aviation Administration, FAA-EQ-73-3, March 1973.

2) Goldman, D., and F. Maginnis, "Aircraft Sound Description System (ASDS) Application Procedures, Vol. 1 - Overview", Federal Aviation Administration, FAA-EQ-74-2, I, March 1974.

3) Goldman, D., and F. Maginnis, "Aircraft Sound Description System (ASDS) Application Procedures, Vol. 1 - Overview", Federal Aviation Administration, FAA-EQ-74-2, II, March 1974.

4) Goldman, D., and F. Maginnis, "Aircraft Sound Description System (ASDS) Application Procedures, Vol. 1 - Overview", Federal Aviation Administration, FAA-EQ-74-2, III, March 1974.

5) Goldman, D., and F. Maginnis, "Aircraft Sound Description System (ASDS) Application Procedures, Vol. 1 - Overview", Federal Aviation Administration, FAA-EQ-74-2, IV, March 1974.

6) Federal Aviation Administration Order No. 1050. 1C: "Policies and Procedures for Considering Environmental Impacts", (FR Vol. 42, No. 123, p. 32630), December 20, 1979.

7) Federal Aviation Administration, "A Basic User's Guide for the Integrated Noise Model Version 1", Analysis and Guidance Branch, AEQ-110, FAA-EQ-78-10, December 1977.

| | |
|---|---|
| TITLE | COMPOSITE NOISE RATING FOR AIRCRAFT |
| ABBREVIATION | CNR |
| SYMBOL | $L_{CNR}$ |
| UNIT | DECIBEL (dB) |
| GEOGRAPHICAL USAGE | UNITED STATES |
| DEFINITION | Composite noise rating is a calculated rating base upon perceived noise levels of all events occurring within a 24-hour period. Adjustments are made for time of day, type of aircraft, and numbers of aircraft operations occurring over an annual period. Two composite noise ratings are calculated: one f flight and one for run-up aircraft operations |
| PURPOSE | Composite noise ratings is a method used for ratin the noise exposure from aircraft operations and fo estimating community reactions. This measure take into consideration noise associated with both ground run-up and airborne operations in an attempt to predict community response. |

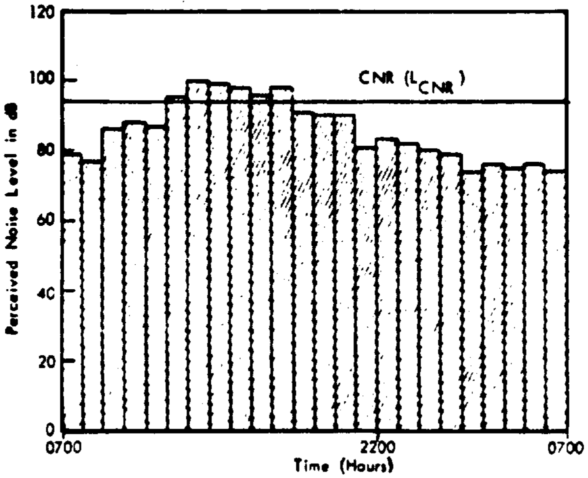


FIGURE CNR-1. CNR FOR AIRCRAF FLYOVERS

## BACKGROUND

Tracing the development of CNR over the years provides an insight into the evolution of a single measure which could be used to estimate human reactions to specific noise sources. CNR was the forerunner to other community noise prediction measures, but today is no longer used and has essentially been replaced by day-night average sound level (DNL).

The 1952 CNR and the later 1955 version was designed to predict community reaction to any noise source not exclusively aircraft noise (Ref. 1 and 2). This CNR method contained a series of rating curves plotted approximately 5 dB apart and labeled with letters (a through m) as a means of identifying the level rank of the measured noise source in question (Fig. CNR-2). This figure shows the determination of level ranks for two typical spectra. After the level rank of a noise was determined from these curves, it was adjusted for the effects of community background level, time of day and how often the noise occurred, the presence of pure tone components, impulse noise characteristics, the previous noise exposure history of the community, and the season of the year. Each of these adjustments had an associated 'correction number' which raised or lowered the level rank of the measured noise.

The 1957 CNR procedure focused on predicting the effects of aircraft ground run-ups and flight operations on the adjacent community without the necessity of field measurements. In this modification of CNR, Stevens and Pietrasanta (Ref. 3)

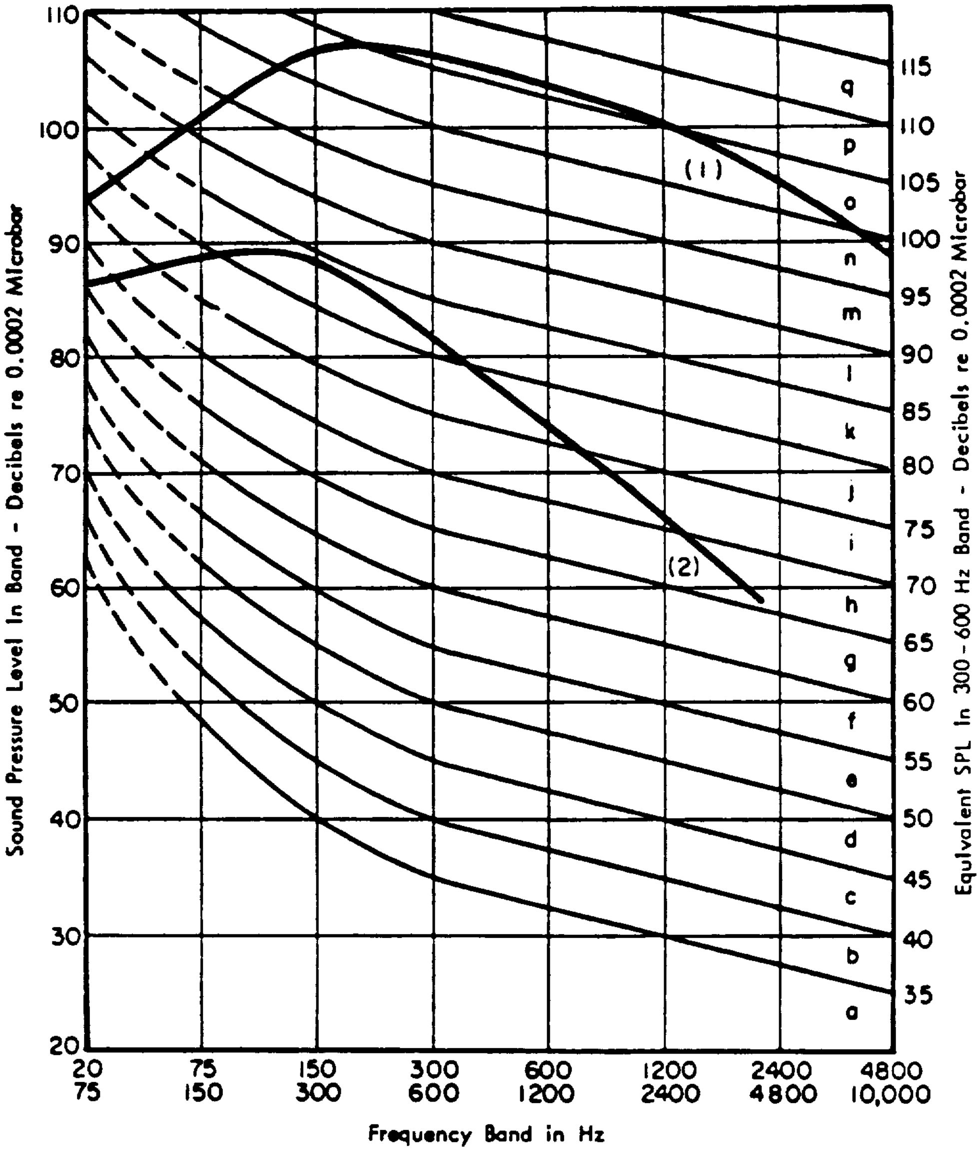


FIGURE CNR-2. DETERMINATION OF EQUIVALENT SPL IN 300-600 Hz BAND FOR TWO TYPICAL SPECTRA. VALUES ARE 105 dB FOR SPECTRUM (1) AND 80 dB FOR SPECTRUM (2) TO THE NEAREST 5 dB. (From WADC TN 57-10) attempted to describe the physical nature of the noise source itself. They found that in most instances the equivalent level for the 300 to 600 Hz frequency band of an aircraft flyover controlled the level rank referred to in the earlier CNR version.

The correction factor for tone and impulse characteristics of the aircraft noise source was eliminated from the 1957 version of CNR because they were not present or rarely occurred in these particular type of military aircraft. However, an effective duration correction for the time-varying attributes of an aircraft flyover was added. The time of day (modified into three periods: 0600-1800; 1800-2300; 2300-0600), seasons of the year, and background corrections consistent with the previous CNR method were retained. Certain sociological correction factors were carried over from the 1952 CNR and refined, such as characterization of the neighborhood (i.e., suburban, urban, or rural) and emphasis on the community's previous noise exposure and current predisposition towards the airbase.

Stevens and Pietransanta (Ref. 3) also developed a technique which would allow the prediction of a noise rating and corresponding community reaction given the information on the operational characteristics of the aircraft. They, along with Galloway (Ref. 2), developed two sets of basic $L_{eq}$(300-600 Hz) contours, one for ground run-ups and the other for airborne operations. A table was also developed which would allow for modification of these contours depending upon the specific aircraft under consideration. The contours could then be combined and overlaid on a map of the air base to determine the $L_{eq}$ (300-600 Hz) at any point on the base.

A subcommittee of the Committee on Hearing and Bioacoustics of the National Academy of Science/ National Research Council recommended that CNR be rewritten to incorporate a new psychoacoustic measure called perceived noise level (PNL). And, in 1963, Galloway and Pietrasanta produced "Land Use Planning with Respect to Aircraft Noise", (Ref. 4). This time the contours were based upon maximum PNL instead of $L_{eq}$ (300-600 Hz). And the noise contours were produced for both takeoff and approach conditions as well as ground run-ups for different aircraft classified on the basis of aircraft type, engine type, and performance.

The 1963-1964 CNR, like the previous versions, contained adjustments which took into consideration the factors that affected community reaction to the total airport operations. The total duration of noise over a specific period of time was accounted for by considering the number of aircraft operation of each class of aircraft on each runway. The time of day correction factor was modified to require only two time periods (0700-2200 and 2200-0700) instead of the previous three time periods (Tables CNR-1 and CNR-2). And in contrast to the 1957 CNR calculation procedure, the 1963 CNR eliminated the

## TABLE CNR-1. OPERATIONAL CORRECTIONS TO APPLY TO PERCEIVED NOISE LEVELS FOR TAKEOFFS AND LANDINGS

| *Number of Takeoffs or Landings per Period* | | *Correction* |
|---|---|---|
| *Day (0700-2200)* | *Night (2200-0700)* | |
| Less than 3* | Less than 2 | −10 |
| 3-9 | 2-5 | −5 |
| 10-30 | 6-15 | 0 |
| 31-100 | 16-50 | +5 |
| More than 100 | More than 50 | +10 |
| *Percent Runway Utilization* | | *Correction* |
| 31-100 | | 0 |
| 10-30 | | −5 |
| 3-9 | | −10 |
| Less than 3 | | −15 |
| *Time of Day*** | | *Correction* |
| 0700-2200 | | 0 |
| 2200-0700 | | +10 |

* If the average number of operations for an aircraft type is less than one per time period, that aircraft type should not be considered in the analysis.

** In general, the ratio of daytime-to-nighttime operations is such that daytime operations determine the Composite Noise Ratings at airports. Only when the nighttime activity is disproportionately high will the nighttime correction affect the Composite Noise Rating.

## TABLE CNR-2. OPERATIONAL CORRECTIONS TO APPLY TO PERCEIVED NOISE LEVELS FROM ENGINE RUNUP

| *Number of Single Engine Runups per Period* | | *Correction* |
|---|---|---|
| *Day (0700–2200)* | *Night (2200–0700)* | |
| 5 or less | 3 or less | 0 |
| More than 5 | More than 3 | +5 |

| *Duration of Runup (in minutes)* | *Correction* |
|---|---|
| Less than 1 | −5 |
| 1 to 5 | 0 |
| More than 5 | +5 |

| *Time of Day* | *Correction* |
|---|---|
| 0700–2200 | 0 |
| 2200–0700 | +10 |

## TABLE CNR-3. CHART FOR ESTIMATING RESPONSE OF RESIDENTIAL COMMUNITIES FROM COMPOSITE NOISE RATING

| *Composite Noise Rating* | | *Zone* | *Description of Expected Response* |
|---|---|---|---|
| *Takeoffs and Landings* | *Runups* | | |
| Less than 100 | Less than 80 | 1 | Essentially no complaints would be expected. The noise may, however, interfere occasionally with certain activities of the residents. |
| 100 to 115 | 80 to 95 | 2 | Individuals may complain, perhaps vigorously. Concerted group action is possible. |
| Greater than 115 | Greater than 95 | 3 | Individual reactions would likely include repeated, vigorous complaints. Concerted group action might be expected. |

seasonal corrections, and contained no adjustment for background noise levels nor community attitude towards the aircraft flyover operations. It was decided that such attitudinal assessments were difficult to quantify and at best would merely cloud the results. Additional information on the development of CNR can be found in Ref. 5-7.

Remember that the CNR values for airborne and run-up operations are treated separately. However before they can be computed, the 'partial' CNRs must be determined for each type and class of aircraft and for runway utilization with appropriate time of day adjustments. The 'partial' CNRs are then combined to yield a final CNR value for flight and a CNR for run-up operations. These final CNR results are then correlated with descriptions of expected community reaction.

These descriptions of expected community reaction were developed by analyzing the history of community complaints and legal action associated with 21 different civilian and military airports. The CNR value, which included all the operational and noise factors, was computed for each of these airports. Then these results were compared to the corresponding community reactions to the various airport operations. The outcome of this comparison yielded three zones of response for three ranges of CNR as seen in Table CNR-3. It should be noted that the community reaction to ground run-ups is more intense than for flyover operations. Therefore, the CNR level for ground run-ups would have to be 20 dB lower than for airborne operations in order to elic the same degree of community reaction.

## *Relation to Other Ratings*

Composite noise rating can be approximated from several other aircraft noise ratings.

- Average Maximum Perceived Noise Level ($\overline{PNL}$)($L_{\overline{PN}}$)
  In this case CNR is the computed rating at a point on the ground for a specific class of aircraft which is using a specific flight path.

$$L_{CNR} \cong L_{\overline{PN}} + 10 \log_{10} \left[ N_d + 16.67\ N_n \right] - 12$$

where:

| | |
|---|---|
| $L_{\overline{PN}}$ | is the average maximum perceived noise level at a specific ground location |
| $N_d$ | is the number of daytime events during the period 0700-2200 hours |
| $N_n$ | is the number of nighttime events during the period 2200-0700 hours |
| 16.67 | is used as a weighting factor for the number of nighttime aircraft operations |
| 12 | is an arbitrary constant |

- Community Noise Equivalent Level (CNEL)($L_{den}$) and Day-Night Average Sound Level (DNL) ($L_{dn}$)

  CNEL can be estimated directly from DNL if the nighttime operations are not significant. Therefore it can be assumed that CNR can be approximated by either of these measures from the formula:

$$L_{CNR} \cong L_{den} + 35$$

  or

$$L_{CNR} \cong L_{dn} + 35$$

- Noise Exposure Forecast (NEF) ($L_{NEF}$)

  CNR can be approximated by NEF using the following:

$$L_{CNR} \cong L_{NEF} + 70$$

## CALCULATION METHOD

Composite noise rating (1963) is a calculated quantity and is not measured directly with a sound level meter or any other sound analysis equipment. The final CNR value is determined by combining the partial CNR's which characterized the number and different types of aircraft operations (flyovers and ground run-ups, takeoffs and landings), aircraft classes, runway utilizations, as well as time of occurrence. There are essentially 6 steps in determining CNR and predicting the associated community reaction to the noise from aircraft operations. Briefly they are as follows (see Ref. 4 for further details):

### 1. Gather Data on Aircraft Operations

Obtain the information on the number of annual ai craft operations that occur or are forecast to occur at the airport in question. This information should be for the two time periods (0700-220 and 2200-0700). The data for airborne operations should include information on the total number of takeoffs and landings, for each aircraft type, related to the percent of runway and flight path utilization. The number and duration of run-up operations should be obtained for each type of aircraft, along with information on the location c the run-up area and the orientation of the aircraf

### 2. Select the Appropriate PNL Contour

Use Table CNR-4 for selecting the appropriate PNL contour as shown in Ref. 4. In this chart the aircraft category (military or civilian), type of operations (takeoff, landings, run-ups), and aircr type are taken into consideration in the determination of the correct PNL contour set.

### 3. Determining Perceived Noise Level

The appropriate PNL contour set (from Step 2) is overlaid on a map of the airport of interest which

# TABLE CNR-4. CHART FOR SELECTING NOISE CONTOURS

| *Aircraft Category* | *Operation* | *Aircraft Type* | *Contour Set* | *Correction to Contour* |
|---|---|---|---|---|
| Civil | Takeoffs | Turbojets—Trips under 2,000 mi. | 1A | 0 |
| | | Turbojets—Trips over 2,000 mi. | 1B | 0 |
| | | Turbofans—Trips under 2,000 mi. | 1A | −5 PNdB |
| | | Turbofans—Trips over 2,000 mi. | 1B | −5 PNdB |
| | | Four-engine piston | 4 | 0 |
| | | Four-engine turboprop | 4 | −5 PNdB |
| | | Helicopters (Sikorsky S-61, Vertol 107, and Vertol 44) | 5A | 0 |
| | Landings | Turbojet | 3B | 0 |
| | | Turbofan | 3B | 0 |
| | | Four-engine piston and turboprop | 3A | 0 |
| | | Helicopters—Vertol 44 | 5B | −10 PNdB |
| | | Vertol 107, Sikorsky S-61 | 5B | 0 |
| | Runups | Turbojet | 6 | 0 |
| | | Turbofan | 7 | 0 |

## TABLE CNR-4. CONTINUED

| *Aircraft Category* | *Operation* | *Aircraft Type* | *Contour Set* | *Correction to Contour* |
|---|---|---|---|---|
| Military | Takeoffs | Jets—Flight group 1 | 2A | +5 PNdB |
| | | " " 2 | 2A | 0 |
| | | " " 3 | 2A | −5 PNdB |
| | | " " 4 | 2B | +5 PNdB |
| | | " " 5 | 2B | 0 |
| | | " " 6 | 2B | −5 PNdB |
| | | " " 7 | 2C | 0 |
| | | " " 8 | 2C | −5 PNdB |
| | | " " 9 | 2C | −10 PNdB |
| | | " " 10 | 2D | 0 |
| | | Four-engine piston | 4 | 0 |
| | | Four-engine turboprop | 4 | −5 PNdB |
| | Landings | All jets | 3B | 0 |
| | | Four-engine piston and turboprop | 3A | 0 |
| | Runups | Runup group 1 | 8 | +5 PNdB |
| | | " " 2 | 8 | 0 |
| | | " " 3 | 8 | −5 PNdB |
| | | " " 4 | 7 | 0 |

indicates the runways, flight paths, and relevant areas. The PNL for the ground location of interest is then computed by noting the PNL directly from the contour and adding the operation correction factors. (Step 4).

### 4. Determine the Corrections for Operational Factors

Apply an operational correction factor to the PNL values determined in Step 3. The information gathered in Step 1 is used to determine the correction factors found in Table CNR-1 and CNR-2. These factors reflect the additional adjustments made in an effort to quantify reactions to aircraft noise.

### 5. Calculating Composite Noise Rating

The noise exposure at a specific ground location is characterized by both a CNR calculated for ground run-up operations and a CNR for flight operations. Compute the partial CNR values for each type of flight and run-up operation by algebraically adding the total of the correction factors (Step 4) to the perceived noise level from Step 3. Then, using the procedure outlined in the next paragraph, combine the partial CNRs for flight operations and separately combine the partial CNRs for run-up operations.

## Criteria for Combining Partial CNRs for Flight and Run-Up Operations

(i) If there are 3 or more CNRs within 3 dB of the maximum CNR, then add 5 dB to the maximum CNR to get total CNR.

(ii) If there are less than 3 CNRs within 3 dB of the maximum CNR, then designate the maximum CNR as total CNR.

## 6. CNR and Expected Community Response

The chart in Table CNR-3 is used for estimating the response of residential communities from CNR. The chart shows that airborne operations are treated separately from run-up operations. The results for each of these types of operations are associated with three 'zones' which in turn represent three geographical areas within the vicinity of the airport. The description of the expected responses apply only to the residential areas within these respective zones. It is possible, therefore, because of the distinction between these two types of operations, to derive two separate descriptions of expected community response for one particular geographical location.

**EXAMPLE** The example illustrated in Tables CNR-5 and CNR-6 profiles the annual aircraft operations including flight and run-up events at a hypothetical civilian airport. It demonstrates how to determine CNR at a particular ground location for takeoffs, landings, and run-up operations of different types of aircraft

## EXAMPLE OF CNR CALCULATIONS FOR AIRBORNE OPERATIONS

|  |  | Step 1 |  |  | Step 2 | Step 3 | Step 4 |  |  |  | Step 5 |
|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  |  |  | Corrections |  |  |  |  |
| Run-way | Aircraft Type | Time of Day | Average Number of Events | Percent Runway Utiliza-tion | Contour Set | PNL dB | Cont. Corr. dB | No. of Events | Percent Runway Utiliz. | Time of Day | Partial CNR |
| TAKEOFFS |  |  |  |  |  |  |  |  |  |  |  |
| 27 | Civ.Turbo-jets(>2000 miles) | 0700-2200 | 55 | 56 | 1B | 96 | 0 | +5 | 0 | 0 | 101 |
| 27 | Civ.Turbo-fans(>2000 miles) | 0700-2200 | 48 | 80 | 1B | 91 | -5 | +5 | 0 | 0 | 91 |
| 27 | Civ.Turbo-fans(<2000 miles) | 0700-2200 | 60 | 20 | 1A | 90 | -5 | +5 | -5 | 0 | 85 |
| 27 | Civ.Turbo-jets(>2000 miles) | 2200-0700 | 10 | 40 | 1B | 96 | 0 | 0 | 0 | 10 | 106 |
| LANDINGS |  |  |  |  |  |  |  |  |  |  |  |
| 27 | Civ.Turbo-jet and Turbofans | 0700-2200 | 92 | 100 | 3B | 101 | 0 | +5 | 0 | 0 | 106 |
| 27 | Civ.Turbo-jet and Turbofans | 2200-0700 | 20 | 100 | 3B | 101 | 0 | +5 | 0 | 0 | 116 |
| 37 | Piston | 0700-2200 | 100 | 100 | 3A | 90 | 0 | +5 | 0 | 0 | 95 |
| 37 | Piston | 2200-0700 | 30 | 100 | 3A | 90 | 0 | 0 | 0 | 10 | 100 |

(Step 5)

Total CNR = 116

(Step 6)

Zone 3 "Individual reactions would likely include repeated vigorous complaints. Concerted group action might be expected".

## TABLE CNR-6

## EXAMPLE OF CNR CALCULATIONS FOR GROUND RUNUP OPERATIONS

| Step 1 | | | | Step 2 | Step 3 | | Step 4 | | Step 5 |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Corrections | | | |
| Aircraft Type | Time of Day | Average Number of Events | Average Duration (minutes) | Contour Set | PNL dB | Contour Corr. dB | Number of Events | Time of Day | Partial CNR |
| Civil Turbojet | 0700-2200 | 10 | 10 | 6 | 83 | 0 | +5 | 0 | 88 |
| Civil Turbofan | 0700-2200 | 4 | 8 | 7 | 85 | 0 | +5 | 0 | 90 |
| Civil Turbojet | 2200-0700 | 3 | 10 | 6 | 84 | 0 | +5 | 10 | 99 |

(Step 5)

Total CNR = 99

(Step 6)

Zone 3 "Individual reactions would likely include repeated vigorous complaints; concerted group action might be expected."

occurring during different periods of the day, and ultimately how to relate the results to the zones of community response indicated in Table CNR-3.

Table CNR-5 contains the information and analysis for the airborne operations of different types of aircraft. The total computed CNR is 116 and in this case is based upon the maximum partial CNR calculated from the landing operations.

Table CNR-6 contains the data for the ground run-up operations. The CNR in this case is 99 for run-ups that occur during the nighttime hours. In this case, the resulting CNR values indicate that either flights or run-ups would produce the same average community reaction (Table CNR-3), which would include 'vigorous complaints, and recourse to legal action'.

EQUIPMENT

1. No equipment is necessary. CNR contours can be drawn using PNL levels for different classes of aircraft and for proposed volume of operations.

2. A high speed digital computer is recommended.

STANDARDS

None

REFERENCES

1) Rosenblith, A. W., Stevens, K. N. and the Staff of Bolt Beranek and Newman, Handbook of Acoustic Noise Control, Volume II, Noise and Man. WADC Tech. Rep. 52-204, U.S. Air Force, June 1953.

2) Stevens, K., Galloway, W. J., and Pietrasanta, A., "Noise Produced on the Ground by Jet Aircraft in Flight", JASA, Vol. 28, 163 (1956).

3) Stevens, K., and Pietrasanta, A., and the Staff of BBN, "Procedures for Estimating Noise Exposure and Resulting Community Reactions from Air Base Operations", WADC TN-57-10, Wright Patterson Air Force Base, Ohio; Wright Air Development Center (1957).

4) Galloway, W. J. and A. Pietrasanta, "Land Use Planning With Respect to Aircraft Noise". AFM 86-5, TM 5-365, NAVDOCKS p-98, Dept. Defense, 1964; also published by FAA, as TR-821. (Available from DTIC as AD 615 015.)

5) Bishop, D. E., "Noise Contours for Short and Medium Range Transport Aircraft and Business Aircraft", FAA REport ADS-35, 1965.

6) Bishop, D. E., "Development of Aircraft Noise Compatibility for Varied Land Uses", FAA SRDS Report RD-64-148, II, 1964.

| | |
|---|---|
| TITLE | NOISE EXPOSURE FORECAST |
| ABBREVIATION | NEF |
| SYMBOL | $L_{NEF}$ |
| UNIT | Decibel<br>(dB) |
| GEOGRAPHICAL USAGE | United States |

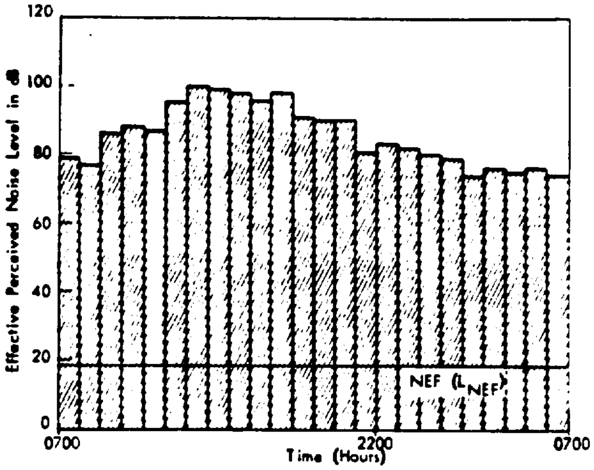


FIGURE NEF-1. AIRCRAFT FLYOVERS

| | |
|---|---|
| DEFINITION | Noise exposure forecast is a rating based upon effective perceived noise level measurements taken over a 24 hour period. Adjustments are made for time of day and for the daily number of aircraft operations averaged over an annual period. |
| PURPOSE | Noise exposure forecast is used to estimate community reaction to the noise resulting from aircraft operations. The NEF levels at various locations in a community adjacent to an airport act as guidelines for establishing compatible land use development and zoning regulations. |

**BACKGROUND** Noise exposure forecast was developed as an improvement on the 1963-1964 composite noise rating (CNR) measure but was to apply to civilian and not military aircraft (Ref. 1). However, like CNR it is no longer currently used by airport or community planners and has been replaced by day-night average sound level (DNL).

A brief comparison of CNR and NEF is useful to gain an historical perspective over these types of single number community noise measures. Both measures account for the number of aircraft operations. However, NEF uses effective perceived noise level as its basic metric which allows a better assessment of the tone and duration components associated with turbofan aircraft flyovers. The EPNL computations are more involved than the method found in CNR. Therefore, computer technique are required to analyze the discrete tone and duration parameters at each time interval in a flyover time pattern.

NEF also incorporates a time of day adjustment, dividing the hours into two periods (0700-2200 and 2200-0700), the same as CNR. It is interesting to note that this correction factor in NEF adds 12.2 d to the measured levels of the nighttime events. Th is because the multiplier of the number of nighttim events is 16.67. Compare this report to the correction factor of only 10 dB used in community nois equivalent level (CNEL) and day-night average sound level (DNL) for the same purpose, namely, to estimate the increased annoyance associated with nighttime aircraft operations.

As was done with CNR, NEF results are correlated with community reactions to noise from aircraft operations. Guided by the responses associated with CNR values, in particular, the boundaries between categories of CNR 100 and 115, a new set of response categories was developed for the NEF values. The NEF values and expected responses are shown in Table NEF-1 (Ref. 2).

|  | TABLE NEF-1 |
|---|---|
| NEF | Description of Expected Response |
| Less than 20 | No complaints expected. |
| 20 to 30 | Some noise complaints possible and noise may interfere with some activities. |
| 30 to 40 | Individual reactions may include vigorous repeated complaints and concerted group action is possibility. Construction of homes, schools, etc. should not be undertaken without a complete analysis of the situation. |
| Greater than 40 | Serious noise problems are likely. Group action probable. No activity nor building construction of any sort should be carried on without a complete analysis of the situation. |

### *Relation to Other Ratings*

- **Maximum Perceived Noise Level ($PNL_{max}$) ($L_{PNmax}$)**

Noise exposure forecast values can be estimated fo the maximum perceived noise level for a single aircraft event as well as for the total number of events for a specified runway in cases where only one or two types of aircraft dominate.

(i) Effective perceived noise level (EPNL) for th individual flyover is approximated by the following:

$$L_{EPN} \cong L_{PNmax} + 10 \log \frac{D}{20} + F$$

where:

$L_{PNmax}$ is the maximum perceived noise leve of the single aircraft flyover.

D is the time (in seconds) that the perceived noise level is within 10 dB of its maximum value.

F is the pure tone correction (if the pure tone is in the spectrum) which is typically + 3 dB.

(ii) Total NEF at a given point for daytime and nighttime operations for a specified runway where one can be estimated is as follows:

$$L_{NEF} \cong L_{\overline{EPN}} + 10 \log_{10} (N_d + 16.67 N_n) - 88$$

or,

$$L_{NEF} \cong L_{\overline{EPN}} + 10 \log_{10} (15\bar{n}_d + 150\bar{n}_n) - 88$$

where:

| | |
|---|---|
| $L_{\overline{EPN}}$ | is the energy mean value of EPNL for each flyover at the ground location of interest. |
| $N_d$, $\bar{n}_d$ | is the total number and average number per hour, respectively, of flights during the period 0700 - 2200. |
| $N_n$, $\bar{n}_n$ | is the total number and average number per hour, respectively, of flights during the period 2200-0700. |
| 16.67 | is used as a weighting factor for the number of nighttime aircraft events. |
| 88 | is a scale-changing constant (Ref. 3). |

- **Community Noise Equivalent Level (CNEL) ($L_{den}$) and Day-Night Average Sound Level (DNL) ($L_{dn}$)**

CNEL can be estimated directly from DNL if the number of nighttime operations are not significant. It follows that the NEF can be approximated from either of these two ratings by the equations:

$$L_{NEF} \cong L_{den} - 35$$

or,

$$L_{NEF} \cong L_{dn} - 35$$

- **Composite Noise Rating (CNR) ($L_{CNR}$)**

NEF correlates highly with CNR and can be predicted from CNR by using:

$$L_{NEF} \cong L_{CNR} + 70$$

## CALCULATION METHOD

Noise exposure forecast values for different ground positions can be calculated from EPNL measurements of the various aircraft flyovers which occur during the daytime (0700-2200) and nighttime (2200-0700).

### Field Measurements

If the noise exposure measures of the aircraft flyovers are made at the ground location, then the following formula is used:

$$L_{NEF} = 10 \log_{10} \left[ \sum_{i=1}^{N_d} 10^{\frac{L_{EPN(i)}}{10}} + 16.67 \sum_{i=1}^{N_n} 10^{\frac{L_{EPN(i)}}{10}} \right] - 88$$

where:

| | |
|---|---|
| $L_{EPN(i)}$ | is the effective perceived noise level of each event (i). |
| $N_d$ | is the total number of daytime events during the period 0700-2200. |
| $N_n$ | is the total number of nighttime event during the period 2200-0700. |
| 16.67 | is a weighting factor for the number o nighttime aircraft operations. |
| 88 | is a scale-changing constant (Ref. 3). |

## Calculated Measures

Noise exposure forecast values can also be determined from information on the noise characteristics, takeoff, and landing performance of the different classes of aircraft.

The noise characteristics of each class of aircraft can be described in terms of a set of EPNL versus distance curves and a set of takeoff and landing profiles. Thus the total noise exposure from aircraft operations at a given point on the ground is a summation (in the mean square sense) of the NEF values produced by different aircraft classes flying along different flight paths. This can be expressed using the following equations:

First, calculate the "partial" NEF values, i.e., NEF(ij) for an aircraft class (i) on flight path (j):

$$L_{NEF(ij)} = L_{EPN(ij)} + 10 \log_{10} [N_{d(ij)} + 16.67 N_{n(ij)}] - 88 \quad [2]$$

where:

$i$ is the particular aircraft class.

$j$ is the particular flight path.

$L_{EPN(ij)}$ is the EPNL produced at a given ground point by aircraft class (i) flying along flight path segment (j).

| | |
|---|---|
| $N_{d(ij)}$ | is the total number of flights during the period 0700-2200 of aircraft class (i) flying along flight path (j). |
| $N_{n(ij)}$ | is the total number of flights during the period 2200-0700 of aircraft class (i) flying along flight path (j). |
| 16.67 | is a weighting factor for the number of nighttime aircraft events. |
| 88 | is a scale-changing constant (Ref. 3). |

The "total" NEF value at a given ground position is determined by summing (in the mean squared sense) all the particular NEF (ij) values as follows:

$$L_{NEF} = 10 \log_{10} \left[ \sum_{i}^{n} \sum_{j}^{m} 10^{\frac{L_{NEF(ij)}}{10}} \right]$$

where:

| | |
|---|---|
| $L_{NEF(ij)}$ | is the NEF value at a specified groun location for a particular class of aircraft (i) flying along the flight path (j). |
| n | is the number of aircraft classes. |
| m | is the number of flight paths. |

**EXAMPLE**

Table NEF-2 contains an example using individually measured aircraft data expressed in terms of EPNL values. Table NEF-3 uses available information on aircraft classes and aircraft flight paths to determine NEF.

## TABLE NEF-2

## EXAMPLE OF CALCULATIONS FOR NEF FROM SINGLE-AIRCRAFT FLYOVERS

| Event (i) | Time | $L_{EPN}$ | $10^{\left(\frac{L_{EPN(i)}}{10}\right)}$ | Weighting Factor |
|---|---|---|---|---|
| 1 | 2200-0100 | 88.0 | 630.96 X $10^6$ | 16.67 |
| 2 | 0100-0400 | 91.0 | 1258.93 " " | 16.67 |
| 3 | 0400-0700 | 86.0 | 398.11 " " | 16.67 |
| 4 | 0700-1000 | 95.0 | 3162.27 " " | |
| 5 | 1000-1300 | 83.0 | 199.53 " " | |
| 6 | 1300-1600 | 86.0 | 398.11 " " | |
| 7 | 1600-1900 | 97.0 | 5011.87 " " | |
| 8 | 1900-2200 | 95.0 | 3162.27 " " | |

Equation [1]

$$L_{NEF} = 10 \log_{10} [(11934.06 + 38140.79) \times 10^6] - 88$$

$$= 10 \log_{10} [50074.85 \times 10^6] - 88$$

$$L_{NEF} = 19.0 \text{ dB}$$

## TABLE NEF-3

## EXAMPLE OF CALCULATIONS FOR NEF USING AIRCRAFT CLASS AND FLIGHT PATH DATA

| | | | Total Number of Flights | | | |
|---|---|---|---|---|---|---|
| Aircraft Class (i) | Flight Path j | $L_{EPN(ij)}$ | Day-time $N_d$ | Night-time $N_n$ | Weighting Factor | $L_{NEF(ij)}$ Equation [2] |
| Turbojet (< 2000 Mi) | 27 | 96 | 30 | 10 | 16.67 | 30.94 |
| Turbojet (> 2000 Mi) | 28 | 98 | 35 | 5 | 16.67 | 30.73 |
| Turbofan (< 2000 Mi) | 27 | 91 | 42 | 6 | 16.67 | 24.52 |
| Turbofan (> 2000 Mi) | 28 | 90 | 39 | 4 | 16.67 | 22.24 |

Equation [3]

$$L_{NEF} = 10 \log_{10} [2896.14]$$

$$L_{NEF} = 34.6 \text{ dB}$$

The total NEF shown in Table NEF-2 for noise levels measured for different aircraft flyovers over a 24 hour period is NEF = 19.0. According to the expected community reaction guidelines (Table NEF-1), "no complaints are expected".

The total NEF shown in Table NEF-3 for available aircraft class and flight path data is NEF = 34.6. In this case, there is a possibility of individual and organized group action (Table NEF-1). According to the response in Table NEF-1, careful consideration should also be given to sound insulation of schools, homes, churches, etc., where there is a likelihood of speech or activity interference.

### STANDARDS

None

### EQUIPMENT

(If field measurements are used)

1) Sound level meter (ANSI S1.4-1971).
2) Tape recorder.
3) One-third octave band real time analyzer.
4) Digital computer.

### REFERENCES

1) Galloway, W. J., and A. Pietrasanta. "Land Use Planning With Respect to Aircraft Noise". AFM 86-5, TM 5-365, NAVDOCKS P-98, Dep. Defense, 1964; also published by FAA, as TR-821. (Available from DTIC as AD 615 015.)

2) Bishop, D. and R. Horonjeff, "Procedures for Developing Noise Exposure Forecast Areas for Aircraft Flight Operations", FAA Report DS 67-10 Washington, D. C., August 1967.

3) Galloway, W. and D. Bishop, "Noise Exposure Forecast: Evolution, Evaluation, Extensions, and Land Use Interpretations", FAA-NO-70-9, August 1970.

| | |
|---|---|
| TITLE | DAY-NIGHT AVERAGE SOUND LEVEL |
| ABBREVIATION | DNL |
| SYMBOL | $L_{dn}$ |
| UNIT | Decibel (dB) |
| GEOGRAPHICAL USAGE | United States |

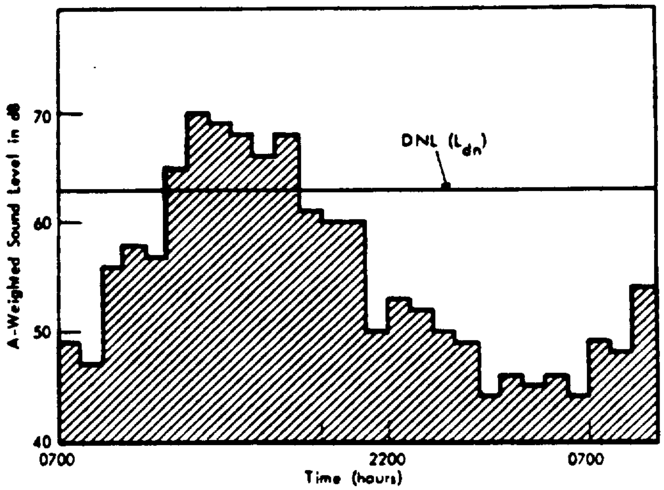


FIGURE DNL-1. DAY/NIGHT AVERAGE SOUND LEVEL OVER 24 HOURS

| | |
|---|---|
| DEFINITION | Day-night average sound level is energy averaged A-weighted sound level over a 24-hour period with a 10 dB adjustment added to the sound levels between 2200 and 0700. This time weighting is applied in an effort to account for the assumed increased sensitivity to noise intrusions during the nighttime hours. |
| PURPOSE | Day-night average sound level is a single number descriptor that is used to predict community reaction to noise exposure from aircraft and road traffic. This measure is used for evaluating the total community noise environment. It provides guidelines for assessing compatible land uses and zoning recommendations. |

**BACKGROUND**

Day-night average sound level assesses the physical sound environment by taking into account both the sound levels and the number of noise producing events. The physical characteristics of sound such as the level, frequency components, and duration are measured with A-weighted sound level averaged on an energy basis over a stated period of time. This is referred to as equivalent continuous sound level (abbreviated as QL and symbolized as $L_{eq}$) and is defined as the constant level of sound during a specified time period that is equivalent to the same amount of sound energy as the actual time-varying sound signal. These two sounds of 'equal energy' both have the same average or equivalent sound levels.

Day-night average sound level is based upon equivalent continuous sound level and enhanced by an adjustment factor for nighttime noise disturbances. Results from community complaint surveys have indicated that the same noise environment may be considered by people as more annoying during the nighttime than during the day time. It is reasonable to assume that high level noises are more detectable inside the home, and consequently more annoying at night, due to a combination of lower exterior background noise levels, decreased activity inside the home, and raised expectations for rest and relaxation. In order to account for this presumed annoyance generated by intrusive noises, an adjustment factor of 10 decibels is applied (between

10 p.m. and 7 a.m.) to all nighttime noise levels. Essentially, this 10 decibel penalty results in characterizing the nighttime noises as being noisier than actually measured. Typical hourly noise levels along with the DNL value are seen in Figure DNL-1.

Day-night average sound level is calculated for 24 hours, but it can be computed for a longer time period such as a week or a year. It is recommended that the day-night average sound level be averaged over a yearly period in order to estimate the long term environmental impact. In such a case it is abbreviated as YDNL and symbolized as $L_{dny}$.

DNL is widely accepted as an effective environmental descriptor by many agencies at both the federal and state government level. It is recommended by the Environmental Protection Agency as the primary measure for community noise exposure (Refs. 1 & 2). The National Research Council Committee on Hearing, Bioacoustics and Biomechanics (CHABA) also favors DNL as one of the fundamental measures for assessing a noise environment potentially requiring an Environmental Impact Statement (Ref. 3). The Department of Defense uses DNL in describing the noise exposure in the vicinity of military air bases; and it is one of the noise measures used by the Federal Aviation Administration (FAA) in describing the noise environment around airports (Refs. 4 & 5). Recently, the Department of Housing and Urban Development (HUD) revised its noise policy regulations and recommended that DNL be used as the criterion measure to protect people in the community from excessive noise (Ref. 6). The State of Oregon and soon Illinois are considering incorporating DNL in their proposed state airport noise control regulations (Refs. 7 & 8).

*Relation to Other Ratings*

Day-night sound level is highly correlated to other cumulative noise measures. However, there are slight differences between DNL, community noise equivalent level (CNEL), composite noise rating (CNR), and noise exposure forecast (NEF) due to 1) the use of different primary metrics: A-weighted sound level versus perceived noise level, or effective perceived noise level; 2) the different frequency weightings associated with these metrics; 3) the different correction methods for duration; and 4) the different evening and nighttime penalties for noise. However, in practice, approximations are often made from results using these other measures. The conversion is as follows:

- **Community Noise Equivalent Level (CNEL) ($L_{DEN}$)**

  $$L_{dn} \cong L_{den}$$

- **Composite Noise Rating (CNR) ($L_{CNR}$)**

  $$L_{dn} \cong L_{CNR} - 35$$

.Noise Exposure Forecast (NEF) ($L_{NEF}$)

$$L_{dn} \cong L_{NEF} + 35$$

**CALCULATION METHOD**

Day-night average sound level can be calculated using three different methods

1) Continuous Time Integration

$$L_{dn} = 10 \log_{10}\left[\frac{1}{86400}\left[\int_{0700}^{2200} 10^{\frac{L_A}{10}}\,dt + \int_{2200}^{0700} 10^{\frac{L_A+10}{10}}\,dt\right]\right] \quad [1]$$

where:

| | |
|---|---|
| 86400 | is the number of seconds in 24 hours. |
| $\int_{0700}^{2200}$ | defines the time interval during which $L_A$ is sampled. |
| $L_A$ | is instantaneous A-weighted sound level. |

2) Temporal Sampling

DNL can be calculated from individual noise samples in terms of equivalent continuous sound level ($L_{eq}$) over a finite period of time such as 1 hour ($L_h$). The following equation can be used:

$$L_{dn} = 10 \log_{10}\left[\frac{1}{24}\left[\underset{\substack{\text{daytime}\\ 0700-2200}}{\sum_{i=1}^{15} 10^{\frac{L_{h(i)}}{10}}} + 10 \underset{\substack{\text{nighttime}\\ 2200-0700}}{\sum_{j=1}^{9} 10^{\frac{L_{h(j)}}{10}}}\right]\right] \quad [2]$$

where

| | |
|---|---|
| $L_{h(i)}$ | is the equivalent continuous sound level for each hour during the period 0700-2200 hours. |
| $L_{h(j)}$ | is the equivalent continuous sound level for each hour during the period 2200-0700 hours. |

3) Discrete Noise Events

**Sound Exposure Level (SEL) ($L_{AE}$)**

DNL can be calculated by sound exposure level (SEL) where discrete noise events not necessarily of the same type dominate the noise environment.

$$L_{dn} = 10 \log_{10}\left[\frac{1}{86400}\left[\underset{\substack{\text{day}\\ 0700-2200}}{\sum_{i=1}^{n} 10^{\frac{L_{AE(i)}}{10}}} + 10 \underset{\substack{\text{night}\\ 2200-0700}}{\sum_{j=1}^{n} 10^{\frac{L_{AE(j)}}{10}}}\right]\right]$$

where:

| | |
|---|---|
| $n$ | is the number of events measured in each time period. |
| $L_{AE(i)}$ | is sound exposure level (SEL) for the period 0700-2200 hours. |
| $L_{AE(j)}$ | is sound exposure level (SEL) for the period 2200 to 0700 hours. |
| 86400 | is the number of seconds in 24 hours. |

**EXAMPLE**

The following example shown in Table DNL-1 is DNL calculated over 24 hours. The hourly noise level ($L_h$) represents discrete time periods composed of 3 hour periods.

$$L_{dn} = 81.7 \text{ dB}$$

**EQUIPMENT**

1) Sound level meter (ANSI S1.4-1971).
2) Tape recorder for single events.
3) Digital computer and analyzing equipment capable of integrating sound level for long periods of time.

**STANDARDS**

ANSI S3.23-1980.

**REFERENCES**

1) Environmental Protection Agency (EPA), "Impact Characterization of Noise Including Implications of Identifying and Achieving Levels of Cumulative Noise Exposure", NTID 73.4 (July 1973).
2) Environmental Protection Agency (EPA), "Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety", Report 550/9-74-004 (March 1974).

## TABLE DNL-1
## EXAMPLE OF CALCULATIONS FOR DNL

| Sample 1 | Time | $L_h$ | Hrs. $10^{\frac{L_{h(i)}}{10}}$ | Weighting Factor |
|---|---|---|---|---|
| 1 | 2200-0100 | 55.0 | 3 X 0.31 X $10^6$ | 10 |
| 2 | 0100-0400 | 68.0 | 3 X 6.30 " " | 10 |
| 3 | 0400-0700 | 75.0 | 3 X 31.62 " " | 10 |
| 4 | 0700-1000 | 86.0 | 3 X 398.10 " " | 1 |
| 5 | 1000-1300 | 84.0 | 3 X 251.18 " " | 1 |
| 6 | 1300-1600 | 81.0 | 3 x 125.89 " " | 1 |
| 7 | 1600-1900 | 74.0 | 3 X 25.11 " " | 1 |
| 8 | 1900-2200 | 69.0 | 3 X 7.94 " " | 1 |

*Equation 2*

$$L_{dn} = 10 \log_{10} \frac{1}{24} [(242.47 + 114.74) \times 10^7]$$

$$= 10 \log_{10} \frac{1}{24} (357.22 \times 10^7)$$

$$L_{dn} = 81.7 \text{ dB}$$

3) National Research Council Committee on Hearing, Bioacoustics, and Biomechanics (CHABA), "Guidelines for Preparing Environmental Impact Statements on Noise", Report of Working Group 69 (1977).

4) Department of Defense (DOD), "Environmental Protection: Planning in the Noise Environment", AFM 19-10, TM 5-803-2, NAVFAC P-970 (June 1978).

5) DOT-FAA Advisory Circular 150/5050-6, "Airport Land Use Compatability Planning", December 30, 1977.

6) Department of Housing and Urban Development, "Environmental Criteria and Standards", 24 CFR Part 51, Federal Register, Vol. 44, No. 135, July 12, 1979.

7) State of Oregon proposed noise regulation, Oregon Department of Environmental Quality, "Proposed Noise Control Regulations for Airport", July 15, 1979.

8) State of Illinois proposed noise regulation, Environmental Control Division, "Technical Review of Proposed Airport Noise Regulations for the State of Illinois" (September 1979).

| | |
|---|---|
| TITLE | COMMUNITY NOISE EQUIVALENT LEVEL |
| ABBREVIATION | CNEL |
| SYMBOL | $L_{den}$ |
| UNIT | Decibel<br>(dB) |
| GEOGRAPHICAL USAGE | State of California |

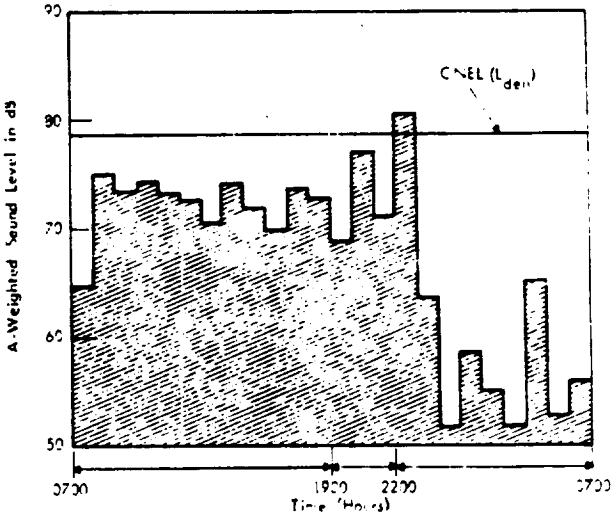


FIGURE CNEL-1. CNEL OVER 24 HOUR

| | |
|---|---|
| DEFINITION | Community noise equivalent level is a 24-hour noise rating which is based upon A-weighted sound level. Two separate adjustment factors are added to the sound levels measured during the evening and the nighttime periods in an attempt to account for the assumed increased annoyance caused by noise during these hours. |
| PURPOSE | Community noise equivalent level is used to estima community reaction to noise exposure resulting frc aircraft operations. CNEL ratings for various locations in a community adjacent to an airport provide guidelines for making recommendations or to determine compatible land use development, and zoning regulations. |

## 3ACKGROUND

Community noise equivalent level like DNL seems to be an appropriate measure for land use compatibility planning because it takes into consideration the magnitude and the durations of the noise events as well as the frequency of occurrence. Like DNL it weights some time periods in the 24 hour day differently than others in an attempt to estimate peoples' annoyance to noise during the nighttime hours. A 5 decibel adjustment is added to the sound levels measured between the hours of 7 p.m. to 10 p.m. and a 10 decibel adjustment is added to the levels measured between 10 p.m. and 7 a.m.

CNEL can be calculated on a daily, weekly, or yearly basis. It is most often employed as an annual rating for purposes of assessing the impact of aircraft noise exposure. Given the necessary information, such as sound levels and number of events, CNEL contours can be drawn to establish a geographical reference for community noise exposure levels.

CNEL was introduced as one of the regulatory measures incorporated into the California Noise Standards (Refs. 1 and 2). The regulation imposes a CNEL of 65 dB on noise from new airports and for military airports being converted to civilian use. The 65 CNEL limitation for existing civilian airports will not take effect until January 1, 1986.

An effort was made to related measured values of CNEL to observed community reactions by adding correction factors to measured CNEL to obtain what one report referred to as 'normalized' CNEL (Ref. 3). This normalization procedure with some modifications i similar to the Rosenblith and Stevens method developed for Composite Noise Rating (Ref. 4). However, normalized CNEL is rarely used in assess community reactions to certain levels and we recommend that only measured CNEL be used.

*Relation to Other Ratings*

Community noise equivalent level can be approximated by other sound measures as follows:

- Composite Noise Rating (CNR) ($L_{CNR}$)

  $$L_{den} \cong L_{CNR} - 35$$

- Day-Night Level (DNL) ($L_{dn}$)

  $$L_{den} \cong L_{dn}$$

- Average Sound Exposure Level ($\overline{SEL}$) ($\overline{L_{AE}}$)

  Where one type of aircraft and one flight path dominate the noise exposure level, CNEL can be estimated using the following equations:

  $$L_{den} \cong \overline{L_{AE}} + 10 \log_{10} [N_d + 3N_e + 10N_n] - 49.4$$

  or

  $$L_{den} \cong \overline{L_{AE}} + 10 \log_{10} [12\bar{n}_d + 9\bar{n}_e + 90\bar{n}_n] - 49$$

  where:

  $\overline{L_{AE}}$ is the energy averaged sound exposure level for the type of aircraft and flight path that dominates the noise exposure.

$N_d$, $\bar{n}_d$ is the total number, and average number per hour, respectively, of flights during the period 0700 to 1900 hours.

$N_e$, $\bar{n}_e$ is the total number, and average number per hour, respectively, of flights during the period 1900-2200 hours.

$N_n$, $\bar{n}_n$ is the total number, and average number per hour, respectively, of flights during the period 2200 to 0700 hours.

49.4 is $10 \log_{10} [86400]$ seconds in 24 hours.

- **Sound Exposure Level (SEL) ($L_{AE}$)**

CNEL using sound exposure level (SEL) for discrete noise events <u>not</u> necessarily of the same type.

$$L_{den} \cong 10 \log_{10} \left[ \frac{1}{86400} \left[ \underset{\substack{\text{0700-1900}\\ \text{Daytime}}}{\sum_{i=1}^{n} 10^{\frac{L_{AE(i)}}{10}}} + \underset{\substack{\text{1900-2200}\\ \text{Evening}}}{3\sum_{j=1}^{n} 10^{\frac{L_{AE(j)}}{10}}} + \underset{\substack{\text{2200-0700}\\ \text{Nighttime}}}{10\sum_{k=1}^{n} 10^{\frac{L_{AE(k)}}{10}}} \right] \right]$$

where:

$n$ is the number of events measured in each time period.

$L_{AE(i)}$ is sound exposure level (SEL) for period 0700-1900 hours.

| | |
|---|---|
| $L_{AE(j)}$ | is sound exposure level (SEL) for period 1900 to 2200 hours. |
| $L_{AE(k)}$ | is sound exposure level (SEL) for period 2200 to 0700 hours. |
| 86400 | is the number of seconds in 24 hours. |

### CALCULATION METHOD

Daily and yearly community noise equivalent level is computed according to the following formulas. The alternate version of the equations is specifically found in the California Noise Standards (Ref. 2

1) CNEL using hourly noise levels (HNL) ($L_h$)

$$L_{den} = 10 \log_{10} \left[ \frac{1}{24} \left[ \sum_{i=1}^{12} 10^{\frac{L_{hd(i)}}{10}} + 3\sum_{j=1}^{3} 10^{\frac{L_{he(j)}}{10}} + 10\sum_{k=1}^{9} 10^{\frac{L_{hn(k)}}{10}} \right.\right.$$

(alternately)

$$L_{den} = 10 \log_{10} \left[ \frac{1}{24} \left[ \sum_{i=1}^{12} \text{antilog} \frac{L_{hd(i)}}{10} + 3\sum_{j=1}^{3} \text{antilog} \frac{L_{he(j)}}{10} + 10\sum_{k=1}^{9} \text{antilog} \frac{L_{hn(k)}}{10} \right] \right]$$

where:

| | |
|---|---|
| $L_{hd(i)}$ | is hourly noise level for period 0700 to 1900 hours. |

| | |
|---|---|
| $L_{he(j)}$ | is hourly noise level for period 1900 to 2200 hours. |
| $L_{hn(k)}$ | is hourly noise level for period 2200 to 0700 hours. |

2) Annual CNEL using daily or monthly CNEL over a 12 month period.

$$\text{Annual } L_{den} = 10 \log_{10}\left[\frac{1}{365}\left[\sum_{i=1}^{365} 10^{\frac{L_{den(i)}}{10}}\right]\right] \qquad [2]$$

(alternately)

$$\text{Annual } L_{den} = 10 \log_{10}\left[\frac{1}{365}\left[\sum_{i=1}^{365} \text{antilog } \left(\frac{L_{den(i)}}{10}\right)\right]\right]$$

where:

| | |
|---|---|
| $L_{den(i)}$ | is the daily CNEL continuously sampled over a 12-month period. |
| Or, | it can be the average monthly CNEL (calculated from daily CNEL measures) in which case the sum would be divided by 12. |

**EXAMPLE** Community noise equivalent level is calculated in Table CNEL-1 and illustrated in Figure CNEL-1 using hourly noise level data and in Table CNEL-2 using average monthly CNEL data. The results are as follows:

## TABLE CNEL-1

## EXAMPLE OF CALCULATION FOR CNEL USING HOURLY NOISE LEVELS

| Time | $L_h$ | $10^{\frac{L_{h(i)}}{10}}$ | Weighting Factor |
|---|---|---|---|
| 0000 | 51.7 | 0.15 X $10^6$ | 10 |
| 0100 | 58.3 | 0.68 " " | 10 |
| 0200 | 54.9 | 0.31 " " | 10 |
| 0300 | 51.3 | 0.13 " " | 10 |
| 0400 | 65.0 | 3.16 " " | 10 |
| 0500 | 52.6 | 0.18 " " | 10 |
| 0600 | 55.8 | 0.38 " " | 10 |
| 0700 | 64.6 | 2.88 " " | 1 |
| 0800 | 75.0 | 31.62 " " | 1 |
| 0900 | 73.3 | 21.38 " " | 1 |
| 1000 | 74.2 | 26.30 " " | 1 |
| 1100 | 73.1 | 20.42 " " | 1 |
| 1200 | 72.5 | 17.78 " " | 1 |
| 1300 | 70.3 | 10.72 " " | 1 |
| 1400 | 74.2 | 26.30 " " | 1 |
| 1500 | 71.8 | 15.14 " " | 1 |
| 1600 | 69.9 | 9.77 " " | 1 |
| 1700 | 73.5 | 22.39 " " | 1 |
| 1800 | 72.9 | 19.50 " " | 1 |
| 1900 | 68.6 | 7.24 " " | 3 |
| 2000 | 77.0 | 50.12 " " | 3 |
| 2100 | 70.8 | 12.02 " " | 3 |
| 2200 | 80.6 | 114.82 " " | 10 |
| 2300 | 63.5 | 2.24 " " | 10 |

Equation [1] $L_{den} = 10 \log_{10}\left[\frac{1}{24}\,[(208.14 + 224.20 + 1220.5) \times 10^6\right.$

$= 10 \log_{10}\left[\frac{1}{24}\,(1652.84 \times 10^6)\right]$

$L_{den} = 78.4$ dB

## TABLE CNEL-2

## EXAMPLE OF CALCULATION FOR CNEL USING AVERAGE MONTHLY CNEL

| Time Month | CNEL ($L_{den}$) | $10^{\frac{L_{den}}{10}}$ |
|---|---|---|
| Jan | 58.0 | $6.31 \times 10^5$ |
| Feb | 57.4 | 5.50 " " |
| Mar | 57.5 | 5.62 " " |
| Apr | 57.0 | 5.01 " " |
| May | 59.0 | 7.94 " " |
| June | 58.1 | 6.46 " " |
| July | 57.9 | 6.17 " " |
| Aug | 58.4 | 6.92 " " |
| Sept | 57.5 | 5.62 " " |
| Oct | 57.7 | 5.89 " " |
| Nov | 56.7 | 4.68 " " |
| Dec | 59.2 | 8.32 " " |
|  | Total: | $74.43 \times 10^5$ |

Equation [2] $L_{den} = 10 \log_{10} [\frac{74.43}{12} \times 10^5]$

$= 10 \log_{10} (6.20 \times 10^5)$

Annual $L_{den} = 57.9$ dB

**CNEL using hourly noise levels from Table CNEL-1**

$L_{den} = 78.4$ dB

**Annual CNEL using monthly CNEL from Table CNEL-2**

Annual $L_{den} = 57.9$ dB

**EQUIPMENT**

1) Sound level meter (ANSI S1.4-1971).
2) Take recorder for single events.

**STANDARDS** None

**REFERENCES**

1) Wyle Laboratories Research Staff, "Supporting Information for the Adopted Noise Regulations for California Airports", WCR 70-3(R) Final Report to the California Department of Aeronautics, January 1971.
2) California Department of Aeronautics, "Noise Standards", California Administrative Code, Subchapter 6, Title 21 (Register 79, No. 21, May 26, 1979) § 5004 (p. 219).
3) Environmental Protection Agency, "Community Noise", NTID 300.4, December 31, 1971.
4) Rosenblith, W. A., Stevens, K. N., and the Staff of Bolt Beranek and Newman Inc., "Handbook of Acoustic Noise Control, Volume II, Noise and Man", WADC Tech. Rep. 52-205, U.S. Air Force, June, 1953.

| | |
|---|---|
| TITLE | NOISE AND NUMBER INDEX |
| ABBREVIATION | NNI |
| SYMBOL | $L_{NNI}$ |
| UNIT | Decibel (dB)* |
| GEOGRAPHICAL USAGE | United Kingdom |

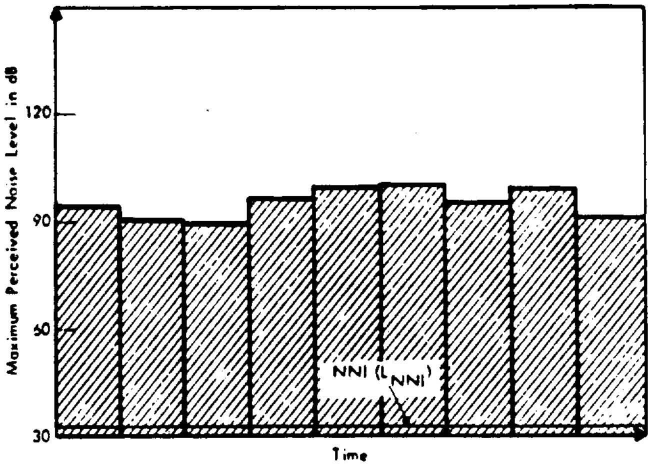


FIGURE NNI-1. NNI FOR AIRCRAFT FLYOVERS

| | |
|---|---|
| DEFINITION | Noise and number index is based upon the average maximum perceived noise level for aircraft flyovers occurring within a time period. |
| PURPOSE | The noise and number index was developed as the appropriate measure to be used in Great Britain for assessing the effects of aircraft noise exposure on community reactions. |

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*It has been suggested that the unit should be PNdB because the primary metric in NNI is perceived noise level. However, like PNL, it was decided that the unit would be the decibel.

## BACKGROUND

The noise and number index was one of the outcomes of an extensive study concerning aircraft noise conducted in the vicinity of London's Heathrow Airport. This study combined physical measurements made of the noise exposure at 85 locations within 10 miles of Heathrow with results from interviews of 2000 people living in this same area. The noise level measurements were reported in terms of a statistical distribution of level and time. The social survey questionnaire focused on peoples' reaction to their immediate living environment taking into consideration the influence of the airport as well as other sociological variables (Ref. 1).

NNI was an attempt to describe the total noise exposure at a site, and it used as its basic metric peak perceived noise level. Consequently, there is no allowance for the duration of the individual aircraft events nor for pure tones which conceivably could be present in jet aircraft flyovers.

According to Schultz (Ref. 2) the concept of background noise is implicitly included in NNI by the stipulation that the adjustment for the number of aircraft events be the "number of aircraft flyovers <u>heard</u>" during the specified time period. However, typically only those aircraft with $L_{PN} > 80$ which occur within a time period are considered. Additiona background information is contained in References 3-6

In determining the effect of the number of flyovers, it was estimated that doubling the number of events was equivalent to raising the noise level by 4.5 dB. Therefore, the factor of 15 was used in the term $15 \log_{10} N$ to adjust for the number of events. The constant 80 is subtracted because it was concluded in the original survey that there was zero annoyance response when the aircraft noise levels were less than 80 dB (PNdB). In fact, in the Heathrow study the lowest aircraft level considered was 84 dB (PNdB).

The analyses of the social survey resulted in the identification of 58 socio-psychological variables which in turn were used to develop a scale representing a continuous measure of annoyance. The noise measurements initially defined 14 parameters which were later reduced to two factors: average peak (maximum) noise level and number of aircraft heard in the day or nighttime periods. In a final step, the annoyance scale and the two physical correlates were combined in an attempt to predict the effect of aircraft noise and frequency operations on people's annoyance reactions.

Additional results from the social survey were further analyzed and correlated with the noise and number index to determine people's reactions to aircraft noise in comparison with their reactions to other sources of dissatisfaction in their living environment. These results were analyzed in an attempt to estimate the point at which the noise exposure became unreasonable. A more indepth coverage is found in Noise - Final Report (Ref. 1).

*Relation to Other Ratings*

**A-weighted Sound Level (SLA) ($L_A$)**

If perceived noise level is approximated by A-weighted sound levels, then peak (maximum) A-weighted level is used and the relation is given by:

$$L_{\overline{A}max} = 10 \log_{10} \left[ \frac{1}{N} \left[ \sum_{i=1}^{N} 10^{\frac{L_{A(i)max}}{10}} \right] \right]$$

and

$$L_{NNI} \cong L_{\overline{A}max} + 15 \log_{10} N - 67$$

where

| | |
|---|---|
| $L_{A(i)max}$ | is the peak (maximum) A-level for each flyover. |
| N | is the number of flyovers in a time period (day or evening). |
| 67 | is the normalizing constant. The 13 dB difference (80 - 67 = 13) is based upon the estimated difference between PNL and SLA by $L_{PN} = L_A + 13$. |

**CALCULATION METHOD**

The noise and number index is based upon the single event measured perceived noise level and the total number of aircraft operations which occur during these two periods.

The following equation is used to calculate the noise level:

$$L_{\overline{PN}\text{max}} = 10 \log_{10} \left[ \frac{1}{N} \left[ \sum_{i=1}^{N} 10^{\frac{L_{PN(i)\text{max}}}{10}} \right] \right] \qquad [1]$$

where

| | |
|---|---|
| $N$ | is the number of aircraft flyovers that occur during a time period. |
| $L_{PN(i)\text{max}}$ | is the maximum noise level for each aircraft flyover (in the Heathrow study $L_{PN}{>}80$). |

The NNI is then determined for the time period by the following equation:

$$L_{NNI} = L_{\overline{PN}\text{max}} + 15 \log_{10} N - 80 \qquad [2]$$

where

| | |
|---|---|
| $L_{\overline{PN}\text{max}}$ | is the average maximum perceived level for all aircraft events which occur during a time period. |
| $N$ | is the number of aircraft flyovers that occur during the time period. |
| 80 | is the normalizing constant. |

**EXAMPLE**

The example for NNI is seen in Table NNI-1 and Fig. NNI-1 for 9 aircraft operations occurring during 24 hours. The result is:

$$L_{NNI} = 32.2 \text{ dB}$$

**EQUIPMENT**

1) Sound level meter (ANSI S1.4-1971).
2) Tape recorder (for single event).
3) Octave or one-third octave band analyzer.

**STANDARDS**

None

**REFERENCES**

1) Committee on the Problem of Noise, "Noise-Final Report", Her Majesty's Stationery Office, July 1963.
2) Schultz, T. J., "Technical Background for Noise Abatement in HUD's Operating Programs", Report No. TE/NA 172, Department of Housing and Urban Development (1971).
3) Galloway, J. W., and Bishop, D. E., "Noise Exposure Forecasts: Evolution, Evaluation, Extensions and Land Use Interpretations", FAA-NO-70- August 1970.
4) Peterson, A. P. G., and Gross, E. E., Jr., "Handbook of Noise Measurement", General Radio, Seventh Edition (1972).
5) Robinson, D. W., "Practice and Principle in Env ronmental Noise Rating", National Physical Labo tory, NPL Acoustics Report AC 81, April 1977.

## TABLE NNI-1

## EXAMPLE OF CALCULATIONS FOR NNI FROM SINGLE AIRCRAFT FLYOVERS

| Event (i) | $L_{PN(max)}$ (i) | $10^{(\frac{L_{PN(i)max}}{10})}$ |
|---|---|---|
| 1 | 95.0 | $3162.27 \times 10^6$ |
| 2 | 91.0 | 1258.92 " " |
| 3 | 89.0 | 794.32 " " |
| 4 | 97.0 | 5011.87 " " |
| 5 | 101.0 | 12589.25 " " |
| 6 | 103.0 | 19952.62 " " |
| 7 | 95.0 | 3162.27 " " |
| 8 | 99.0 | 7943.28 " " |
| 9 | 92.0 | 1584.89 " " |

*Equation 1*

$$L_{\overline{PN}max} = 10 \log_{10} \frac{1}{9} (55459.73 \times 10^6)$$

$$= 97.9 \text{ dB}$$

*Equation 2*

$$L_{NNI} = 97.9 + 15 \log_{10} 9 - 80$$

$$= 32.2 \text{ dB}$$

6) Robinson, D. W., "A New Basis for Aircraft Noise Rating", National Physical Laboratory, Environmental Unit, NPL Aero Report AC 49, March 1971.

| | |
|---|---|
| ITLE | WEIGHTED EQUIVALENT CONTINUOUS PERCEIVED NOISE LEVEL |
| BBREVIATION | WECPNL |
| YMBOL | $L_{WECPN}$ |
| NIT | Decibel (dB) |
| EOGRAPHICAL SAGE | International |

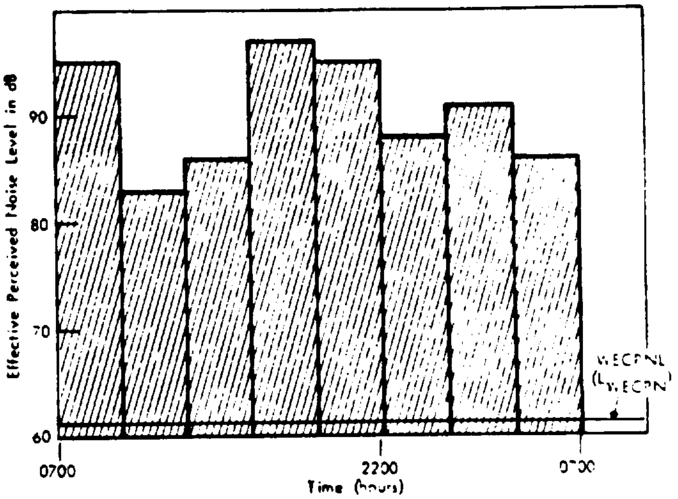

FIGURE WECPNL-1. WECPNL FOR ONE AIRCRAFT OPERATION PER THREE HOURS

| | |
|---|---|
| EFINITION | Weighted equivalent continuous perceived noise level is a cumulative rating scheme which is based upon effective perceived noise level (EPNL). The adjustments incorporated into this measure account for some of the variables associated with aircraft noise such as discrete tonal frequencies, as well as time of day and season of the year. |
| URPOSE | Weighted equivalent continuous perceived noise level was developed to assess the total noise exposure from aircraft noise. It is not often used in the United States and is not as widely accepted as the noise exposure forecase (NEF) measure. The principal use is in ICAO analyses. |

**BACKGROUND**

In a 1969 winter meeting of the International Civil Aviation Organization (ICAO), several seminars were held concerning aircraft noise (Ref. 1). One of the agreements reached at this meeting was the adoption of ICAO reference units for total noise exposure from aircraft noise. This measure was designed to take into consideration the number of aircraft events, the occurrence of the events during the day or night periods, and the effect of the time of the year.

Like the noise exposure forecast rating (NEF), weighted continuous equivalent perceived noise level (WECPNL) was based upon the effective perceived noise level (EPNL) of each flyover. The EPNL value for each event was summed together on an energy basis and then normalized to 10 sec. to achieve a 'total noise exposure level' (TNEL). The various TNELs could then be converted to 'equivalent continuous perceived noise level' (ECPNL) for different noise exposure time periods. This conversion was necessary to achieve the 'weighted equivalent continuous perceived noise level' which used ECPNL for different periods in a 24-hour day (Refs. 2 & 3).

The aircraft levels measured in the evening or night hours were 'corrected' or penalized in the sense that 5 or 10 dB was added to the ECPNL. The rational for this adjustment was that aircraft flyovers heard at night are judged more annoying than the same flyovers heard during the day. If WECPNL was calculated on the basis of a two period 24 hour day, there was a 10 dB adjustment for the levels during the night period (2200 to 0700). WECPNL could also be calculated for a three period day. In this case there was a 5 dB correction for the evening hours (1900 to 2200) and a 10 dB correction for the nighttime hours (2200 to 0700).

WECPNL also included what was termed a seasonal correction. This was an adjustment for the noise reduction achieved inside the home assuming the windows were closed during the winter, as opposed to open. (Hopefully this window condition corresponds to the correct season of the year.) Thus, if WECPNL was computed for the months during the summer, there would be a 5 dB added adjustment.

### CALCULATION METHOD

Three different but interdependent terms comprise WECPNL. The first term is an expression for the total aircraft noise exposure. The second term adds an adjustment which allows the total noise exposure for different periods of time to be compared. WECPNL is the final term which contains corrections for time of day and season of the year.

#### A) Total Noise Exposure Level (TNEL) ($L_{TNE}$)

The TNEL for a number of aircraft flyovers is expressed in terms of the effective perceived noise level (EPNL) for each aircraft event. The equation is as follows:

$$L_{TNE} = 10 \log_{10}\left[\sum_{i=1}^{n} 10^{\frac{L_{EPN(i)}}{10}}\right] + 10 \log_{10}\left[\frac{T_o}{t_o}\right]$$

where:

$n$ is the number of aircraft events.

$L_{EPN(i)}$ is the effective perceived noise level (EPNL for each $i^{th}$ event.

$T_o$ is time = 10 sec.

$t_o$ is time = 1 sec.

## B) Equivalent Continuous Perceived Noise Level (ECP
($L_{EC}$

The ECPNL calculation allows a comparison of various total noise exposure results for different time periods.

$$L_{ECPN} = L_{TNE} - 10 \log_{10}\left[\frac{T}{t_o}\right]$$

where:

$L_{TNE}$ is the total noise exposure for the total number of aircraft flyovers.

$T$ is the total period of time under consideration (e.g., day, night, month, or year) in seconds.

$t_o$ is 1 second.

### C) Weighted Continuous Equivalent Continuous Perceived Noise Level (WECPNL) ($L_{WECPN}$)

WECPNL is the total aircraft noise exposure which is weighted for daily and seasonal adjustments. The following equation contains the adjustment for a two period daily noise exposure. The seasonal adjustments are contained in Table WECPNL-1.

$$L_{WECPN} = 10 \log_{10} \left[ \underset{\substack{\text{daytime} \\ (0700-2200)}}{\frac{5}{8} \left(10^{\frac{L_{ECPN}}{10}}\right)} + \underset{\substack{\text{nighttime} \\ (2200-0700)}}{\frac{3}{8} \left(10^{\frac{L_{ECPN}+10}{10}}\right)} \right] + S \quad [3]$$

where:

$L_{ECPN}$ is the effective continuous perceived noise level for the day period: 0700 to 2200 hours.

$L_{ECPN}+10$ is the effective continuous perceived noise level with a 10 dB correction for the night period: 2200 to 0700

$S$ is the seasonal correction.

WECPNL can also be calculated for a three period daily noise exposure. The seasonal adjustments are in Table WECPNL-1.

$$WECPN = 10 \log_{10}\left[\underbrace{\tfrac{1}{2}\left(10^{\frac{L_{ECPN}}{10}}\right)}_{\substack{\text{daytime}\\(0700-1900)}} + \underbrace{\tfrac{1}{8}\left(10^{\frac{L_{ECPN}+5}{10}}\right)}_{\substack{\text{evening}\\(1900-2200)}} + \underbrace{\tfrac{3}{8}\left(10^{\frac{L_{ECPN}+10}{10}}\right)}_{\substack{\text{nighttime}\\(2200-0700)}}\right] + S$$

where:

| | |
|---|---|
| $L_{ECPN}$ | is the effective continuous perceived noise level for the day period: 0700 to 1900 hours. |
| $L_{ECPN}+5$ | is the effective continuous perceived noise level with a 5 dB correction for the evening period: 1900-2200 hours. |
| $L_{ECPN}+10$ | is the effective continuous perceived noise level with a 10 dB correction for the night period: 2200 to 0700 hours. |
| S | is the seasonal correction (Table WECPNL- |

The average yearly WECPNL is obtained by averaging the various WECPNLs for the different seasonal perio

TABLE WECPNL-1

SEASONAL CORRECTIONS

| Seasonal Adjustment S (decibels) | Description |
|---|---|
| -5 | for months which there are normally less th 100 hours at or above 20° C (68°F). |
| 0 | for months in which there are normally more 100 hours at or above 20° C (68°F) and less 100 hours at or above 25.6° C (78°F). |
| 5 | for months in which there are normally more 100 hours at or above 25.6° C (78°F). |

**EXAMPLE**

The following example in Table WECPNL-2 is for eight aircraft flyovers occurring once each three hours during a 24-hour period in the winter months. The monthly temperature averages about 63° F. The total noise exposure level calculated for the daytime period is:

$$L_{TNE} = 110.8 \text{ dB}$$

for the nighttime period is:

$$L_{TNE} = 103.6 \text{ dB}$$

The equivalent continuous perceived noise level for the daytime period is:

$$L_{ECPN} = 63.5 \text{ dB}$$

for the nighttime period is:

$$L_{ECPN} = 58.5 \text{ dB}$$

The weighted equivalent continuous perceived noise level for both periods is: (See Fig. WECPNL-1)

$$L_{WECPN} = 61.1 \text{ dB.}$$

**EQUIPMENT**

1) Tape recorder (single events).
2) Sound level meter (ANSI S1.4-1971).
3) One-third octave band analyzer.
4) Digital computer.

**STANDARDS**

ICAO Annex 16.

## TABLE WECPNL-2

### EXAMPLE OF CALCULATIONS FOR WECPNL FROM SINGLE AIRCRAFT FLYOVER EVEN

| Event $i$ | Time | $L_{EPN(i)}$ | $10^{\left(\frac{EPNL(i)}{10}\right)}$ |
|---|---|---|---|
| 1 | 2200-0100 | 88 | $630.95 \times 10^6$ |
| 2 | 0100-0400 | 91 | 1258.92 " " |
| 3 | 0400-0700 | 86 | 398.10 " " |
| 4 | 0700-1000 | 95 | 3162.27 " " |
| 5 | 1000-1300 | 83 | 199.52 " " |
| 6 | 1300-1600 | 86 | 398.10 " " |
| 7 | 1600-1900 | 97 | 5011.87 " " |
| 8 | 1900-2200 | 95 | 3162.27 " " |

*Equation 1* - TNEL

(0700-2200 hrs) $L_{TNE} = 10 \log_{10} (11934.06 \times 10^6) + 10 \log_{10} (\frac{1}{T}$

$= 110.8$ dB

(2200-0700 hrs) $L_{TNE} = 10 \log_{10} (2287.99 \times 10^6) + 10 \log_{10} (\frac{10}{T})$

$= 103.6$ dB

*Equation 2* - ECPNL

(0700-2200 hrs) $L_{ECPN} = 110.8 - 10 \log_{10} (\frac{54000}{T})$

$= 110.8 - 47.3$

$= 63.5$ dB

*Equation 2 (cont'd)*

$$\text{(2200-0700 hrs) } L_{ECPN} = 103.6 - 10 \log_{10} \left(\frac{32400}{1}\right)$$

$$= 103.6 - 45.1$$

$$= 58.5 \text{ dB}$$

*Equation 3* - WECPNL

$$L_{WECPN} = 10 \log_{10} \left[ \frac{5}{8} \left(10^{\left(\frac{63.5}{10}\right)}\right) + \frac{3}{8} \left(10^{\left(\frac{58.5+10}{10}\right)}\right) \right] - 5$$

$$= 10 \log_{10} (4053997.4) - 5$$

$$= 61.1 \text{ dB}$$

## REFERENCES

1) Report on the Special Meeting on Aircraft Noise in the Vicinity of Aerodromes, ICAO Doc. 8857 Noise (1969).

2) International Civil Aviation Organization (ICAO) "Total Noise Exposure Level (TNEL) Produced by a Succession of Aircraft", Annex 16, Appendix 5, Third Edition (July 1978).

3) Galloway, W. J., and Bishop, D. E., "Noise Exposure Forecasts: Evolution, Evaluation, Extensions and Land Use Interpretations", FAA-NO-70-9, Federal Aviation Administration, Office of Noise Abatement (August 1970).

# CHAPTER IV

# SPEECH COMMUNICATIONS METRICS

| | |
|---|---|
| TITLE | ARTICULATION INDEX |
| ABBREVIATION | AI |
| UNIT | None |
| GEOGRAPHICAL USAGE | United States |

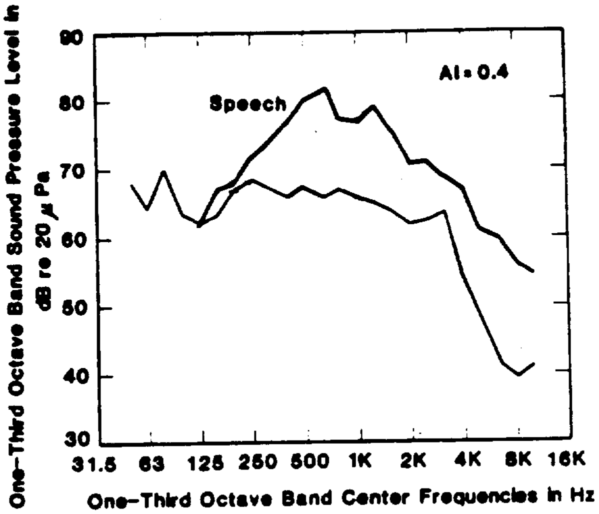

FIGURE AI-1. AIRCRAFT FLYOVER SPECTRUM WITH SPEECH PEAK SPECTRUM

| | |
|---|---|
| DEFINITION | Articulation index is a calculated measure which weights the difference between the speech signal and the background masking noise in an effort to estimate the proportion of normal speech signal that is available to a listener for communication purposes. The results for AI range from 0 to 1.0 where 1.0 is equated with 100-percent speech intelligibility. |
| PURPOSE | Articulation index can be used to estimate how much the background noise found in an environment or communication system will interfere with speech communication as measured by speech intelligibility tests. |

**BACKGROUND**

The articulation index was initially conceived by French and Steinberg (Ref. 1) and later modified by K.Kryter (Ref. 2). In turn, Kryter's version of AI is the basis of the American National Standard (ANSI) (Ref.3) which provides a detailed account of the computational procedures for AI. Conceptually, the AI calculation method is relatively straight forward. However, as a practical matter it is difficult for the ordinary person to interpret in order to evaluate an environment where speech communication would take place.

AI is based upon determining how much of the speech spectrum is masked by the background noise present during normal intercourse between a talker and listener. In order to make this determination the frequency range of the speech spectrum is divided into bands (in the range of approximately 200 to 7000 Hz). Then the difference between the average speech level in these bands and the average noise level in the comparable bands for the background noise is computed. These differences first are weighted and then combined to yield a single index number which can be compared to an estimated amount of speech intelligibility present for a specified environment of interest.

Historically, there are two methods for computing AI. The original procedure advocated by French and Steinberg (Ref. 1) examines the speech to noise ratio in 20 contiguous frequency bands (frequency range of 200-6100 Hz) which for equal signal to noise ratios contribute equally to intelligibility.

The second method analyzes the speech to noise ratio for octave or third octave bands and applies various weighting factors to account for the relative contribution of each band to speech intelligibility.

It is interesting to note several caveats that should be considered when using AI. It is not advisable to use AI as a measure for estimating the effectiveness of a communication system or environment where female talkers or children are involved because AI was based upon, and has been principally validated against, intelligibility tests using male talkers and trained listeners. This should be a consideration when interpreting AI results for thos situations where female talkers or children are present such as typical home or work environments.

Further, while AI is an adequate predictor of speec intelligibility in a steady-state ambient background, it is not effective in predicting the intelligibility of speech in the presence of fluctuating noise levels. However, the Standard (Ref. 3) does list some provisions for determining the effec of noise having a definite off-on duty cycle. Caution should be exercised in situations where there might be reduced speech intelligibility due to reverberant room acoustics, varying vocal effort of the speaker, or multiple transmission paths.

### CALCULATION METHOD

As stated previously, there are two methods current standardized for computing AI. However, the octave or third-octave band method is most popular and wil be the focus of this discussion. (For detail on the 20-band method see Reference 1).

## OCTAVE BAND AND THE ONE-THIRD OCTAVE BAND METHOD

AI can be computed from acoustical measurements, and/or estimates, of the speech spectrum and the accompanying background noise. The computational steps are briefly as follows. (For additional detail concerning communication systems it is recommended that the Standard be used (Ref. 3).

Step 1. Use Figures AI-2 and 3. Figure AI-2 is a worksheet for the one-third octave band method, and Figure AI-3 is for the octave band method (seen in the Standard (Ref.3) as Preferred Frequencies).

Plot the band pressure levels of the speech peaks measured at the listener's ear. Approximate the spectrum of the speech peaks by:

(1) Adding 12 dB to the band pressure level measured at the listener's ear, OR
(2) Raise the idealized speech peak spectrum* found on Figures AI-2 and 3 by an amount equal to the difference between the overall long term rms for speech as measured or estimated and 65 dB (which is the overall long-term rms sound pressure level of the idealized speech spectrum).

---

*The idealized speech spectrum in Figures AI-2 and 3 is based upon measurement at one meter from the talker's lips, in an essentially non-reverberant, noise-free environment. The shape of the spectrum is reasonably accurate for speech measured from a point one inch to one meter in front of the talker's lips.

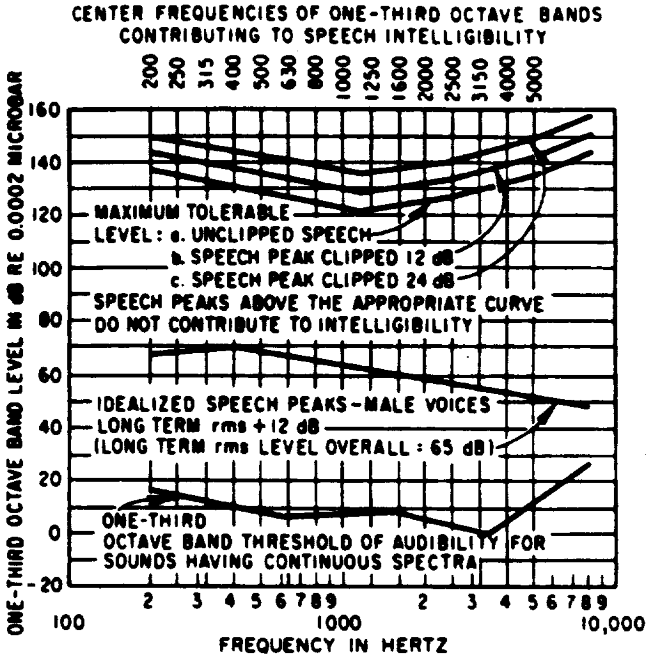

FIGURE AI-2. WORK SHEET FOR AI, ONE-THIRD OCTAVE BAND METHOD

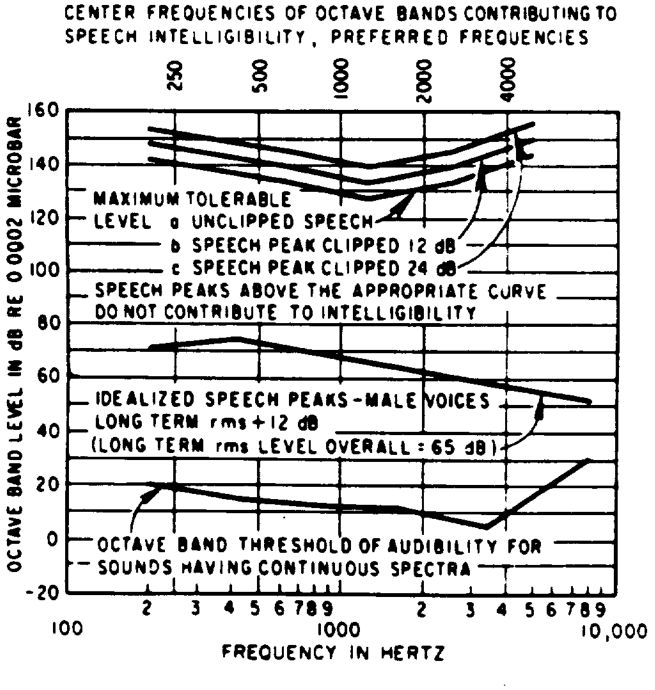

FIGURE AI-3. WORK SHEET FOR AI, OCTAVE BAND METHOD, PREFERRRED FREQUENCIES

Step 2. Use Figures AI-2 or 3. Plot the band levels of the background noise as measured at the listener's ear.

Step 3. Use Tables AI-1 or 2. These are worksheets for the respective one-third octave and octave methods. Calculate, at the center frequency of each band indicated in Figures AI-2 or 3, the difference in decibels between the band pressure level of the speech peaks and the band pressure level of the noise. The articulation index can be computed by the formula:

$$AI = \sum_{i=1}^{n} D_i W_i \qquad [1]$$

where:

D is a function of the difference between the speech peaks and the background levels at each frequency band.

W is the weighting factor (see Table AI-1 or 2).

n is the number of relevant frequency bands.

$\Delta_i$ is the difference between the speech peaks and background noise levels (i.e. speech peak level - noise level).

| Difference | Results |
|---|---|
| $\Delta_i \leq 0$ | $D = 0$ |
| $0 < \Delta_i \leq 30$ | $D = \Delta$ |
| $\Delta_i > 30$ | $D = 30$ |

## TABLE AI-1. ARTICULATION INDEX CALCULATION FORM FOR ONE-THIRD OCTAVE BANDS

| Col 1 | | Col 2 | Col 3 | Col 4 |
|---|---|---|---|---|
| One-Third Octave Band (Hz) | Center Frequency (Hz) | Speech Peak-to-Noise Difference in dB (from 4.2.3) | Weight | Col 2 x Col 3 |
| 180-224 | 200 | ________ | 0.0004 | ________ |
| 224-280 | 250 | ________ | 0.0010 | ________ |
| 280-355 | 315 | ________ | 0.0010 | ________ |
| 355-450 | 400 | ________ | 0.0014 | ________ |
| 450-560 | 500 | ________ | 0.0014 | ________ |
| 560-710 | 630 | ________ | 0.0020 | ________ |
| 710-900 | 800 | ________ | 0.0020 | ________ |
| 900-1120 | 1000 | ________ | 0.0024 | ________ |
| 1120-1400 | 1250 | ________ | 0.0030 | ________ |
| 1400-1800 | 1600 | ________ | 0.0037 | ________ |
| 1800-2240 | 2000 | ________ | 0.0038 | ________ |
| 2240-2800 | 2500 | ________ | 0.0034 | ________ |
| 2800-3550 | 3150 | ________ | 0.0034 | ________ |
| 3550-4500 | 4000 | ________ | 0.0024 | ________ |
| 4500-5600 | 5000 | ________ | 0.0020 | ________ |
| | | | AI = | ________ |

## TABLE 7. ARTICULATION INDEX CALCULATION FORM FOR OCTAVE BANDS - PREFERRED FREQUENCIES

| Col 1 | | Col 2 | Col 3 | Col 4 |
|---|---|---|---|---|
| Octave Band (Hz) | Center Frequency (Hz) | Speech Peak-to-Noise Difference in dB (from 4.2.3) | Weight | Col 2 x Col 3 |
| 180-355 | 250 | ________ | 0.0024 | ________ |
| 355-710 | 500 | ________ | 0.0048 | ________ |
| 710-1400 | 1000 | ________ | 0.0074 | ________ |
| 1400-2800 | 2000 | ________ | 0.0109 | ________ |
| 2800-5600 | 4000 | ________ | 0.0078 | ________ |
| | | | AI = | ________ |

Step 4. Use Table AI-1 or 2. Multiply the difference functions for the respective bands determined in Step 3 by the weighting factors in Column 3 of Tables AI-1 or 2. Write the result in Column 4 of the respective tables.

Step 5. Use Table AI-1 or 2. Sum Column 4 in these tables. The resulting number is the AI for that particular speech spectrum as measured at the listener's ear in that particular background noise.

**EXAMPLE**

The one-third octave band method example is shown in Table AI-3. A speech spectrum representative of measured average male voices speaking in a 'loud' voice (as defined in Ref. 4) is plotted in Fig. AI-1 along with an aircraft spectrum. The calculation procedure in Table AI-3 yields an AI of 0.4.

**EQUIPMENT**

1. Sound Level Meter (ANSI SI.4-1971)
2. Tape Recorder
3. Octave or One-Third Octave Band Analyzer

**STANDARD**

Acoustical Society of America (ANSI), "American National Standard Methods for the Calculation of the Articulation Index", ANSI S3.5-1969, January 1969.

**REFERENCES**

1) French, N., and Steinberg, J., "Factors Governing the Intelligibility of Speech Sounds", J. Acoust. Soc. Am., 19, 90-119 (1957).

## TABLE AI-3

## EXAMPLE OF AN AI BY ONE-THIRD OCTAVE BAND METHOD

| One-Third Octave Band Hz | Avg.* Male Speech +12dB dB | Aircraft Spectrum dB | Speech Peaks Minus Noise $D_i$ | Weighting Factor $W_i$ | $D_iW_i$ |
|---|---|---|---|---|---|
| 200 | 68.0 | 67.0 | 1.0 | 0.0004 | 0.0004 |
| 250 | 72.0 | 68.0 | 4.0 | 0.0010 | 0.004 |
| 315 | 74.0 | 67.0 | 7.0 | 0.0010 | 0.01 |
| 400 | 77.0 | 66.0 | 11.0 | 0.0014 | 0.02 |
| 500 | 80.0 | 67.0 | 13.0 | 0.0014 | 0.02 |
| 630 | 81.0 | 65.5 | 15.5 | 0.0020 | 0.03 |
| 800 | 77.5 | 67.0 | 10.5 | 0.0020 | 0.02 |
| 1000 | 77.0 | 65.5 | 11.5 | 0.0024 | 0.03 |
| 1250 | 79.0 | 65.0 | 14.0 | 0.0030 | 0.04 |
| 1600 | 76.0 | 64.0 | 12.0 | 0.0037 | 0.04 |
| 2000 | 71.0 | 62.0 | 9.0 | 0.0037 | 0.03 |
| 2500 | 71.0 | 62.5 | 8.5 | 0.0034 | 0.03 |
| 3150 | 69.5 | 63.0 | 6.5 | 0.0034 | 0.02 |
| 4000 | 67.0 | 54.0 | 13.0 | 0.0024 | 0.03 |
| 5000 | 61.0 | 47.0 | 14.0 | 0.0020 | 0.03 |
| | | | | | $\sum = 0.35$ |

Equation [1]

$$\text{AI} = 0.35$$

$$= 0.4$$

---

* Spectrum Representive of Average Male Speech using 'Loud' Vocal Effort (Ref.4)

2) Kryter, K., "Methods for the Calculation and Use of the Articulation Index", J. Acoust. Soc. Am., 34, 1689-1697 (1962).

3) Acoustical Society of America (ANSI), "American National Standard Methods for the Calculation of the Articulation Index", ANSI S3.5-1969, January 1969.

4) Pearsons, K., and Bennett, R., "Speech Levels in Various Noise Environments", EPA, 600/1-77-025, May 1977.

| | |
|---|---|
| **TITLE** | SPEECH INTERFERENCE LEVEL |
| **ABBREVIATION** | SIL |
| **SYMBOL** | $L_{SI}$ |
| **UNIT** | Decibel (dB) |
| **GEOGRAPHICAL USAGE** | International |

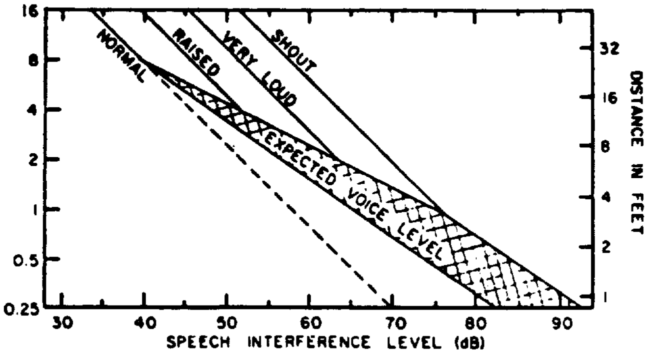

FIGURE SIL-1. SPEAKER TO LISTENER DISTANCES FOR JUST RELIABLE COMMUNICATION

| | |
|---|---|
| **DEFINITION** | Speech interference level is the arithmetic averag of the sound pressure levels in the four octave bands centered at the frequencies 500, 1000, 2000, and 4000 Hz of the interfering noise in question. |
| **PURPOSE** | Speech interference level is a useful measure for determining the necessary vocal effort for face-to face communication. This measure has also been recommended as a means for estimating speech intelligibility in an environment with various background noises by rank ordering the noises according to their speech interference level. |

## BACKGROUND

Speech interference level appears to be a compromise between simple A-weighted sound level and the more complicated calculation procedure Articulation Index (AI) in predicting the speech masking ability of a large variety of background noises. SIL was initially developed by Beranek (Ref. 1) in 1947 in an effort to formulate a simplified method of estimating the quality of speech communication for aircraft passengers. This method provided an approximation of the general masking quality of the background noise. However, unlike A-weighted sound level, SIL ignored the contributions of the low and high frequencies in the noise spectrum in terms of their potential speech interference effect.

When SIL was first introduced, it was defined as the arithmetic average of the sound pressure levels in the octave bands identified as 600-1200, 1200-2400, and 2400-4800 Hz. Later new preferred octave band designations, referred to as the preferred speech interference level (PSIL), replaced the old octave band method and was calculated from the average sound pressure level in three preferred octave bands centered at 500, 1000, and 2000 Hz. The ANSI standard (Ref. 2) advocates four octave bands (referred to as the 4-Band Method) centered at 500, 1000, 2000, and 4000 Hz as the best method of estimating the masking capability of the background noise.

In order to distinguish among the many different versions for calculating SIL, a precise nomenclature was developed (Ref. 2). For example, if the old octave band method is used then the SIL is identified by the abbreviation SIL (0.85, 1.7, 3.4). In turn, the preferred speech interference level method includes the notation SIL (0.5, 1, 2, 4). It is recommended that this type of notation be used if there is an opportunity for confusion as to which octave bands were used to compute SIL.

The ANSI standard (S3.14-1977, Ref. 2) refers to two applications of SIL. The obvious situation to apply SIL is in determining the quality of face-to-face communication. The parameters to consider include speech interference level as well as talker-to-listener distance and voice level required for "just reliable communication". The ANSI standard defines "just reliable communication" as a 70-percent speech intelligibility score for monosyllabic words (Ref. 3).

Intuitively one can conclude that, for most environmental conditions, as the distance between the speaker and listener increase, the voice level necessary for just reliable communication must also increase. Table SIL-1 and Figure SIL-1 illustrate the relationship between SIL and distance between communicators for various categories of vocal effort. The information summarized here was developed by Webster for voice levels measured

## TABLE SIL-1

## RELATIONS AMONG SIL, VOICE EFFORT, AND BACKGROUND NOISE

| Distance Between Talker and Listener ft (m) | | Speaker's Voice Effort | | | |
|---|---|---|---|---|---|
| | | Normal | Raised | Very Loud | Shouting |
| | | SIL, dB | SIL, dB | SIL, dB | SIL, dB |
| 0.5 | (0.15) | 73 | 79 | 85 | 91 |
| 1 | (0.3) | 67 | 73 | 79 | 85 |
| 2 | (0.6) | 61 | 67 | 73 | 79 |
| 4 | (1.2) | 55 | 61 | 67 | 73 |
| 6 | (1.8) | 51 | 57 | 63 | 69 |
| 12 | (3.7) | 45 | 51 | 57 | 63 |

outdoors (Ref. 4). The four voice levels are identified as <u>normal</u>, <u>raised</u>, <u>very loud</u>, and <u>shout</u>. There is approximately a 6 decibel difference in level between each category of voice level. The cross hatched area on the graph indicates the range of expected voice levels due to the normal raising of one's voice in a noisy environment.

It must be noted that the relationships shown in this figure are only approximations of speech efforts. Other variables such as familiarity with speech material, the listener's interest in hearing the talker, visual cues, and the noise characteristics in the environment, among others, all influence the speech levels necessary for just reliable communication. SIL is not an adequate predictor of speech intelligibility if the background noise is not steady state or it contains discrete frequency components.

The ANSI standard (Ref. 2) also recommended using SIL as a method to rank order potentially interfering noises for the purpose of determining speech intelligibility. The application of this concept is based upon the rationale that noises with the same SIL reduce speech intelligibility by approximately the same amount. Thus two noises with the same SIL result will yield approximately the same speech intelligibility factor.

The ANSI standard (Ref. 2) formulated a rough guide for deriving which noises are potentially more interfering to speech intelligibility. If the SIL results for one of two noises is 5 dB or greater than the other noise, then it is assumed that the first noise is probably more destructive of speech intelligibility. Conversely, if the two noises differ by less than 5 decibels in their SIL results, then both noises are assumed to be equally disruptive of speech intelligibility.

### *Relation to Other Ratings*

As stated at the outset, SIL is closely related to A-weighted sound level and the more complex measure of speech intelligibility - the Articulation Index.

- A-Weighted Sound Level (SLA) ($L_A$)

SLA de-emphasizes the low and high frequencies in a noise spectrum and thus is a useful index of noise masking when SIL is not available. The difference between SIL and SLA will depend on the exact noise spectrum of the interfering noise. Several researchers (Klumpp and Webster (Ref. 5) and Kryter (Ref. 6)) have examined different spectra in an attempt to determine an average conversion number for an "average" noise. The estimated difference is:

$$L_{SI} \approx L_A - 8$$

. **C-Weighted Sound Level (SLC) ($L_C$)**

The same spectral considerations are present for SLC as with SLA. However, since C-weighting includes more high and low frequencies, it is a worse approximation of SIL. SIL can be estimated from SLC by:

$$L_{SI} \cong L_C - 13$$

**CALCULATION METHOD**

The 4-Band Method advocated by the ANSI standard (Ref. 2) is simply the arithmetic average of the sound pressure levels of the interfering noise in the relevant octave bands: 500, 1000, 2000 and 4000 Hz.

**EXAMPLE**

The SIL in Table SIL-2 is calculated for the same airplane flyover spectrum used in illustrating the effects of the instantaneous sound level weighting such as A-weighted sound level (refer to Figure SLA-3).

The relationship between vocal effort and backgrou noise tabulated in Table SIL-1 shows that the resulting SIL of 87.4 dB will allow come communication (if you could call it that) if the speaker shouts at the listener at a distance of about 1 foot or less.

**STANDARDS**

American National Standards Institute (ANSI) "Rati Noise with Respect to Speech Interference", ANSI S3.14-1977.

# TABLE SIL-2

## EXAMPLE OF CALCULATIONS OF SIL FOR JET TURBOFAN AIRCRAFT FLYOVER SPECTRUM

### 4-Band Method

| Octave Band Center Frequency Hz | Flyover Spectrum dB | Sound Levels for Speech Frequency Bands dB |
|---|---|---|
| 63 | 76.0 | |
| 125 | 84.1 | |
| 250 | 84.1 | |
| *500 | 82.5 | 82.5 |
| *1000 | 82.5 | 82.5 |
| *2000 | 96.2 | 96.2 |
| *4000 | 88.2 | 88.2 |
| 8000 | 68.3 | |
| | | TOTAL: 349.4 |

$$\text{SIL} = \frac{349.4}{4} = 87.4 \text{ dB}$$

**EQUIPMENT**

1) Sound level meter (ANSI S1.4-1971)
2) Octave band analyzer

**REFERENCES**

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3. American National Standards Institute (ANSI), "Method for Measurement of Monosyllabic Word Intelligibility", ANSI S3.2-.960 (R1976).

4. Webster, J. C., "Effects of Noise on Speech Intelligibility", Am. Speech and Hearing Asso Report No. 4, 49-73 (1969).

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