HANDBOOK OF AIRCRFT NOISE METRICS

BOLT BERANEK AND NEWMEN INC.
CANOGA PARK, CA

1981

NASA Contractor Report 3406   N81-21871

Handbook of Aircraft Noise Metrics

Ricarda L. Bennett and Karl S. Pearsons
Bolt Beranek and Newman Inc.
Canoga Park, California

NASA

National Aeronautics
and Space Administration

**Scientific and Technical
Information Branch**

1981

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA CR-3406		
4. Title and Subtitle		5. Report Date
HANDBOOK OF AIRCRAFT NOISE METRICS		March 1981
		6. Performing Organization Code
7. Author(s)		8. Performing Organization Report No.
Ricarda L. Bennett and Karl S. Pearsons		4215
9. Performing Organization Name and Address		10. Work Unit No. (TRAIS)
BOLT BERANEK AND NEWMAN INC.		11. Contract or Grant No.
21120 Vanowen Street		NAS1-14611 - Task 30
Canoga Park, California 91303		13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address		Contractor Report
National Aeronautics and Space Administration		
Washington, DC 20546		14. Sponsoring Agency Code

15. Supplementary Notes

Langley Technical Monitor: Sherman A. Clevenson
Final Report for Task 30

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.

17. Key Words		18. Distribution Statement
Aircraft	Community	Unclassified - unlimited
Acoustics	Measures	
Noise Metrics		Subject Category 71
Speech Measures		

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	218	A10

i

TABLE OF CONTENTS

Preceding page blank   iii

TABLE OF CONTENTS
(Continued)

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 rela-
tively rare in real-life situations, most sounds consist in-
stead of a complex mixture of many frequencies. The frequency
content of these sounds is characterized by a band of fre-
quencies, 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

2

times greater in sound pressure than the least audible sound.
In decibels, this 10 million to 1 ratio is simplified logarith-
mically 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, impulsive-
ness, 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 air-
craft 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 attri-
butes 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
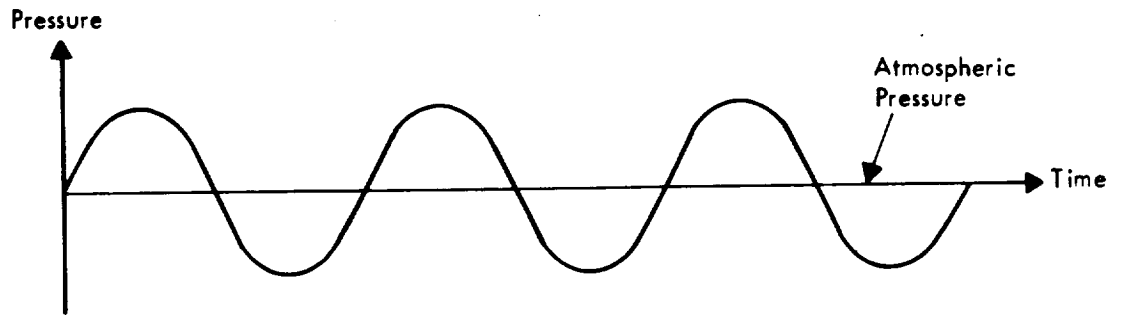frequencies and levels changing with the times, it is sometimes

4

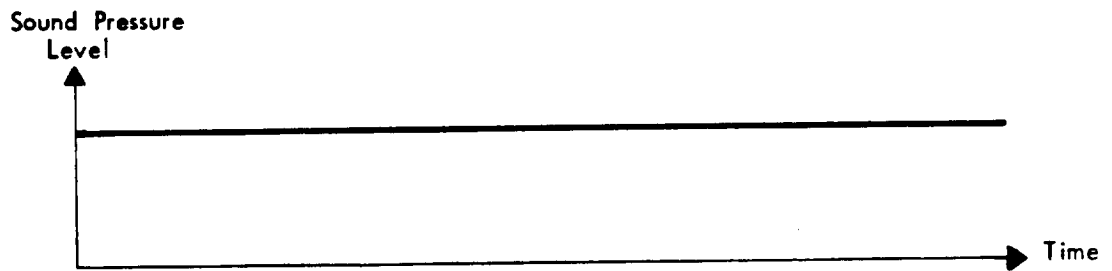FIGURE 1.   SOUND PRESSURE OF TONE

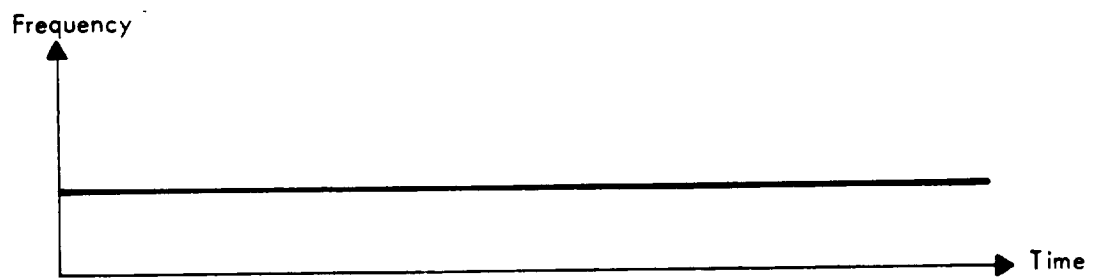FIGURE 2.   SOUND PRESSURE LEVEL OF TONE
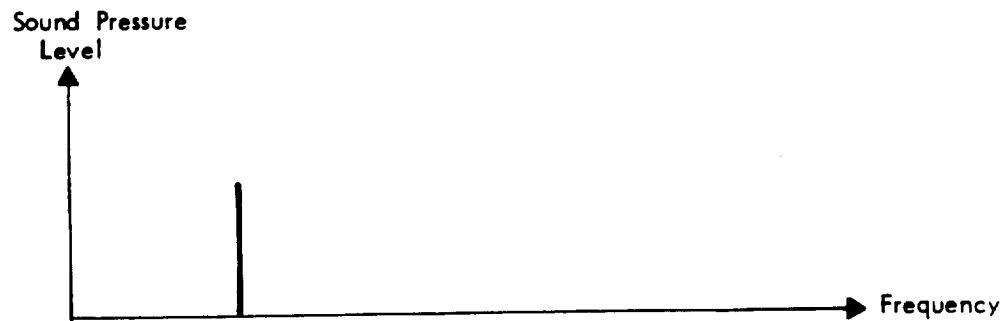

FIGURE 3.   FREQUENCY OF TONE

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)

6
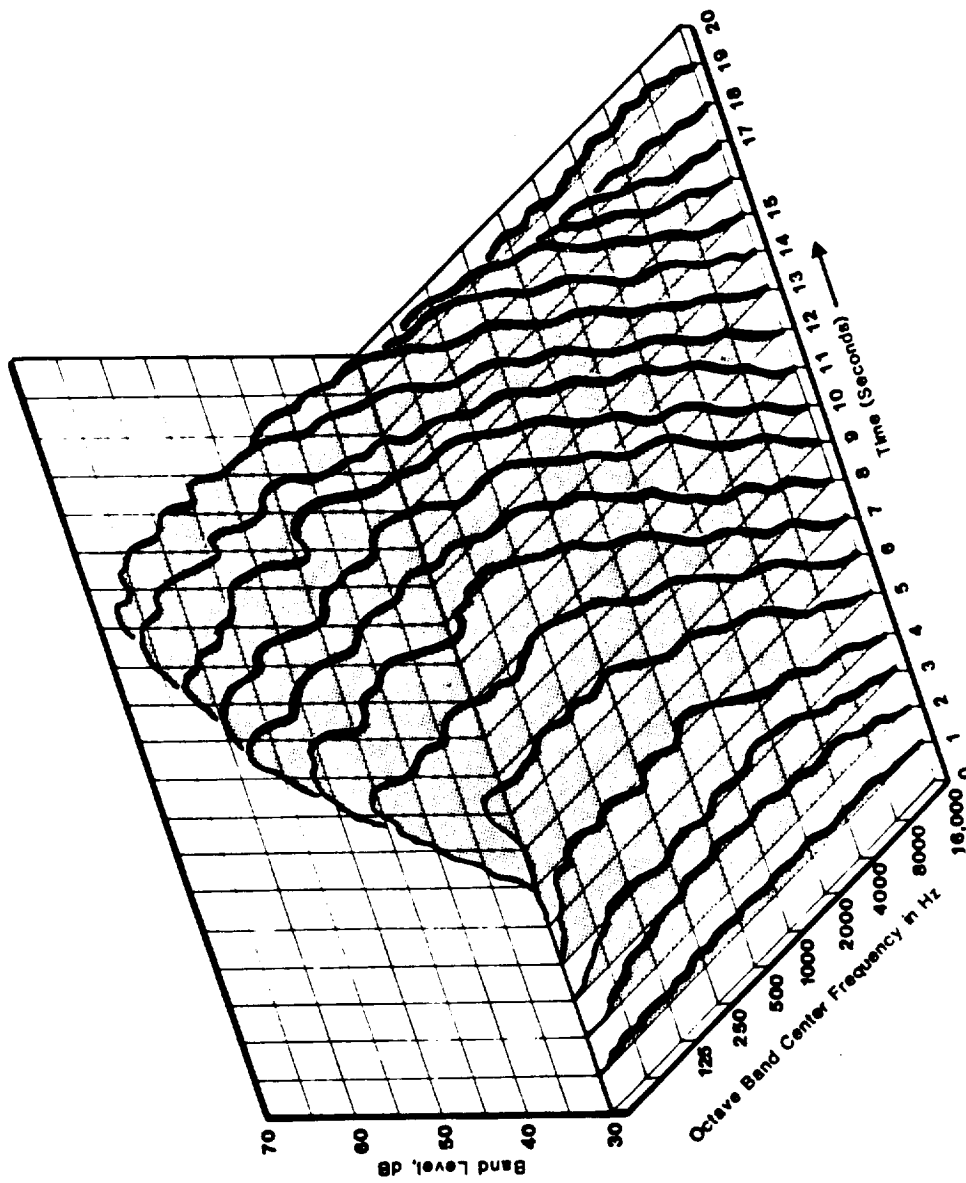
FIGURE 5. TIME VARYING AIRCRAFT SPECTRA
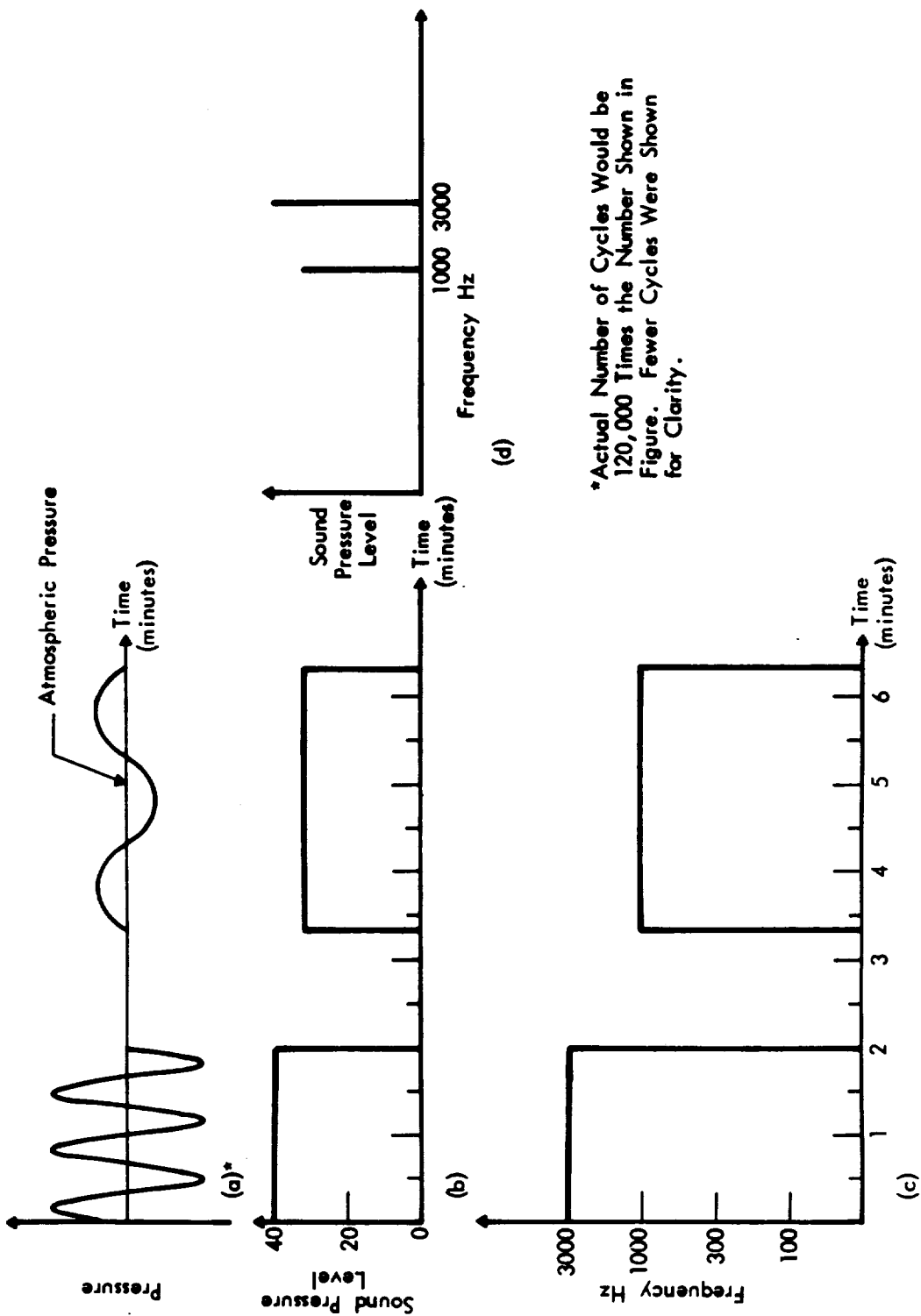
7

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

8

Frequency (Hz)

Sound Pressure Level

Time* (minutes)

(a)

Sound Pressure Level

Time (minutes)

(b)

Frequency (Hz)

3000

1000

300

100

Time (minutes)

(c)

3000

1000

300

100

Sound Pressure Level

(d)

*Scale is Enlarged to Show Detail
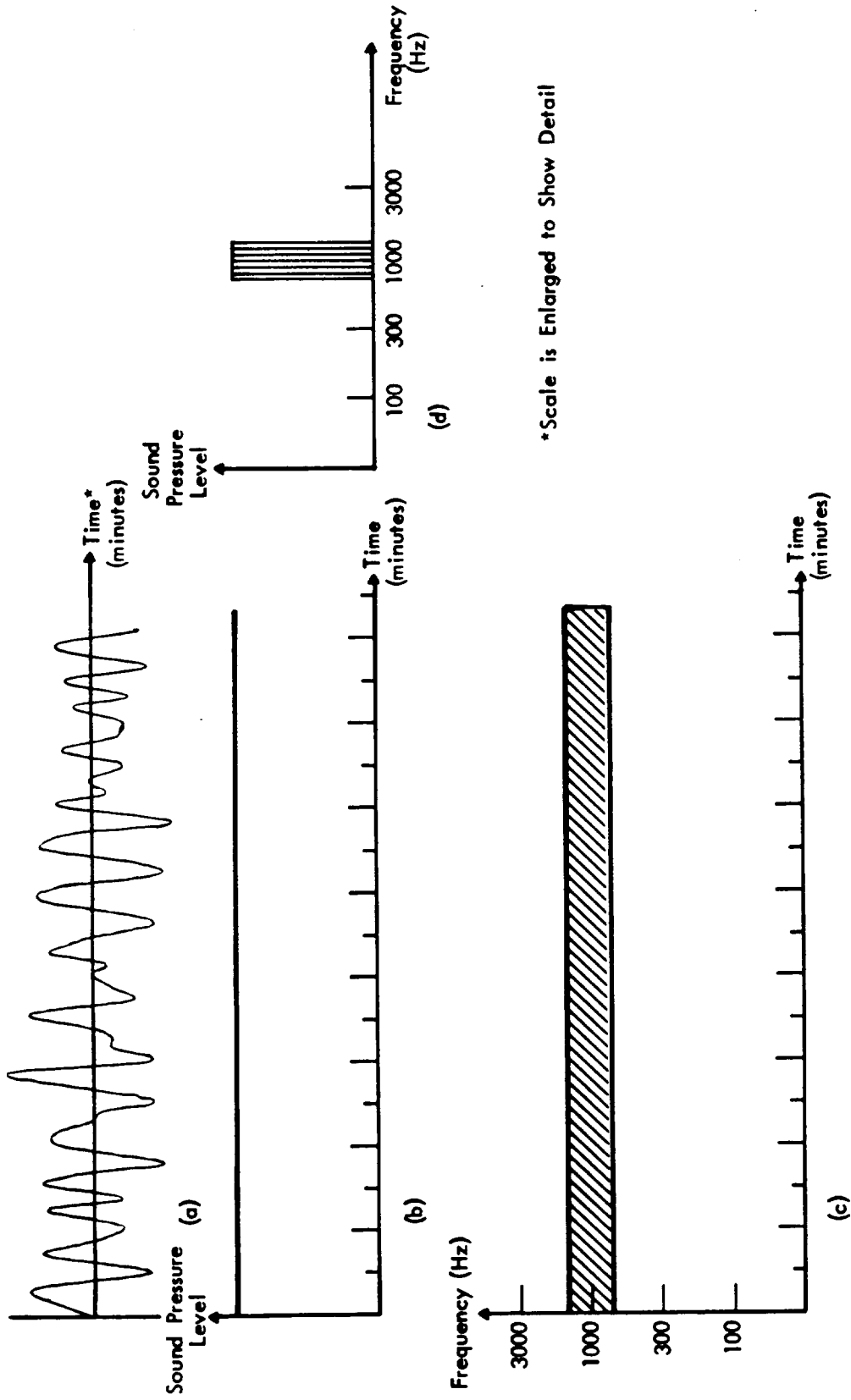
FIGURE 7. OCTAVE BAND OF NOISE AT 1000 Hz

9

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

10

(a)

(b)

(c)

(d)

Sound Pressure Level

Time *
(minutes)

Band
Sound
Pressure
Level

Time
(minutes)

Frequency Band Hz

63 125 250 500 1K 2K 4K 8K

100 300 1000 3000 10,000

Time
(minutes)

Frequency Hz

10,000

3000

1000

300

100

* Scale is Enlarged to Show Detail
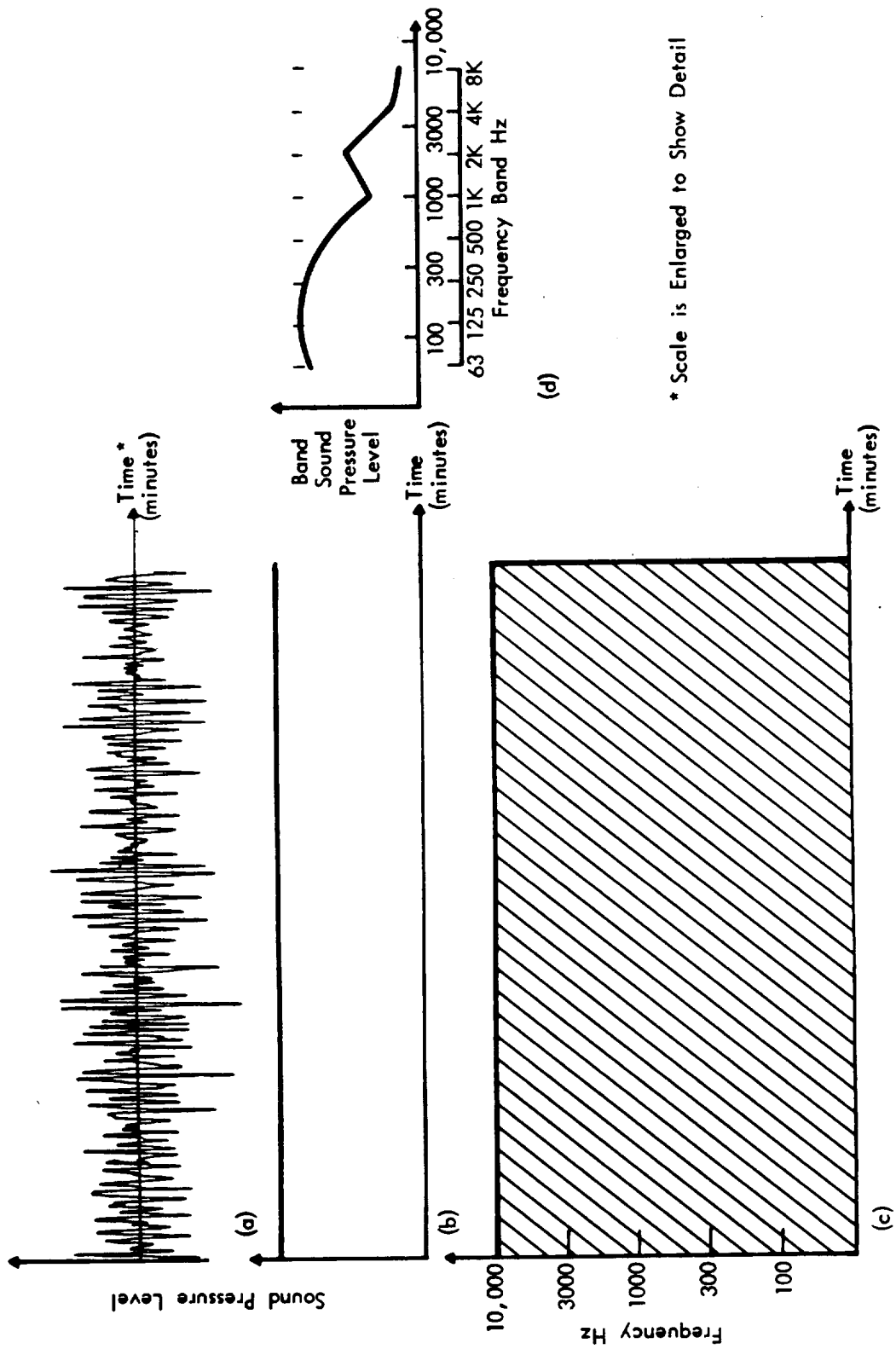
FIGURE 8.   BROAD BAND OF NOISE

11

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

12

NUMERICAL DIFFERENCE BETWEEN TOTAL AND LARGER LEVEL DECIBELS

NUMERICAL DIFFERENCE BETWEEN TWO LEVELS BEING ADDED

DECIBELS

NUMERICAL DIFFERENCE BETWEEN TOTAL AND SMALLER LEVELS
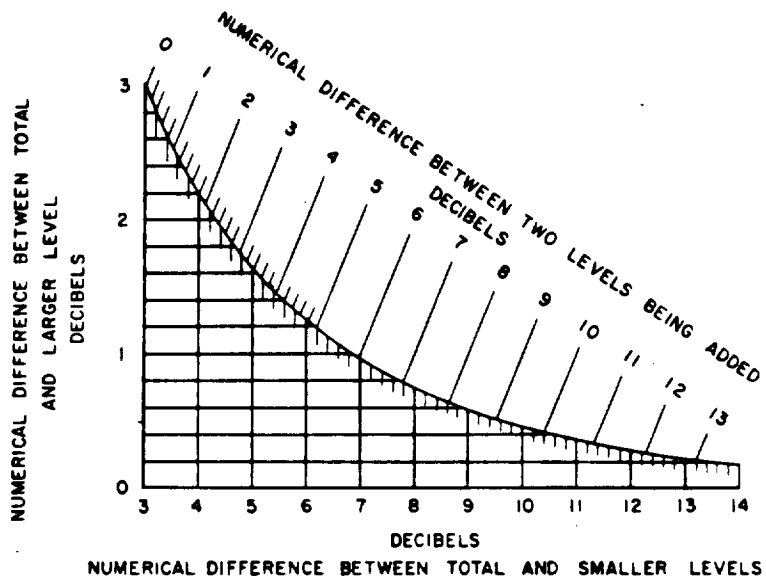
* Ref. Peterson A.P.G. and E.E. Gross,
  "Handbook of Noise Measurement",
  Seventh ed. General Radio Company, 1972

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

15

Part A. Frequency Weighted Metrics

TITLE   A-WEIGHTED SOUND LEVEL

ABBREVIATION   SLA

SYMBOL L_A

UNIT   Decibel
               (dB)*
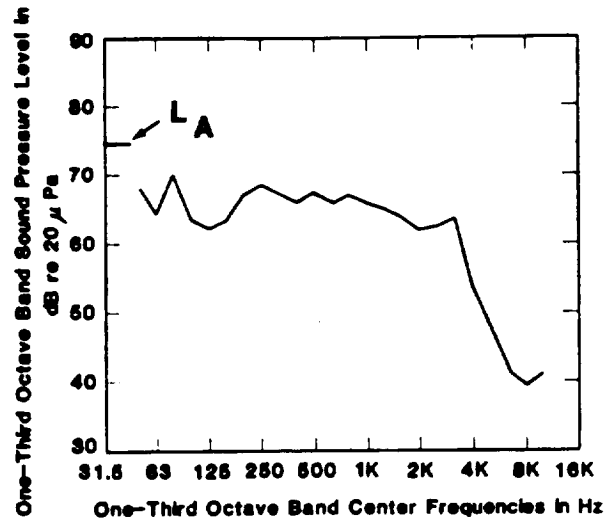
GEOGRAPHICAL   Inter-
USAGE   national   FIGURE SLA-1.   AIRCRAFT FLYOVER
                                              SPECTRUM

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

---

*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

18

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 ith 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 ith 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

20

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
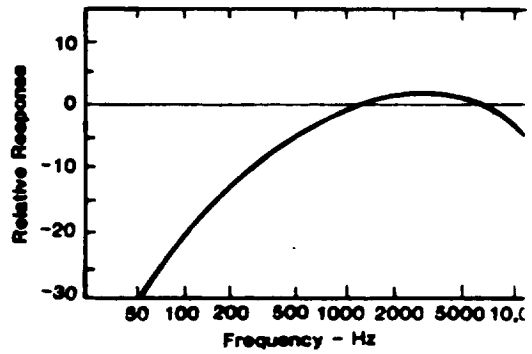
FIGURE SLA-2. A-WEIGHTIN

22

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]

Total = 6803.48 x 10^6

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

L_A = 98.3 dB

23

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

24

STANDARDS

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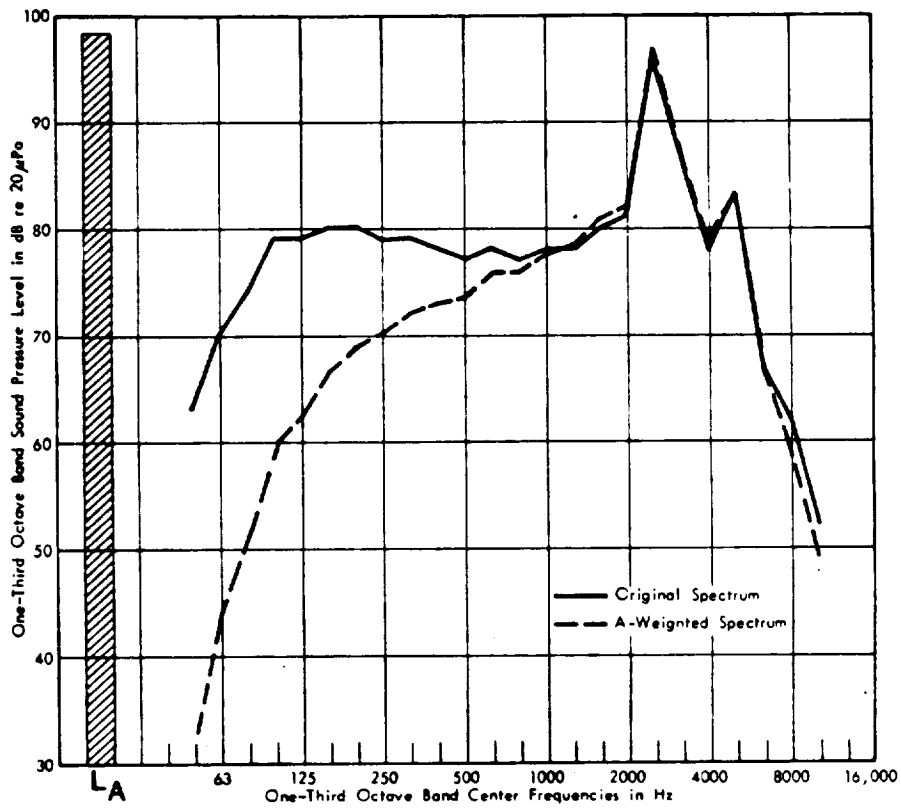   Level Meters", S1.4-1971.

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.

REFERENCES

1) Schultz, Theodore J., "Technical Background for
    Noise Abatement in HUD's Operating Programs",
    for U.S. Department of Housing and Urban Develop-
    ment, BBN Report No. 2005 (September 1970).

2) U.S. Environmental Protection Agency, "Funda-
    mentals 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).

26

TITLE   B-WEIGHTED SOUND LEVEL

ABBREVIATION   SLB

FIGURE SLB-1. AIRCRAFT FLYOVER SPECTRUM

SYMBOL L_B

UNIT   Decibel (dB)*

GEOGRAPHICAL   Inter-
USAGE   national

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 approxi-
                mate the relative loudness of medium level sounds.

*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 net-
                  work 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   B-weighted sound level can either be calculated
METHOD   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

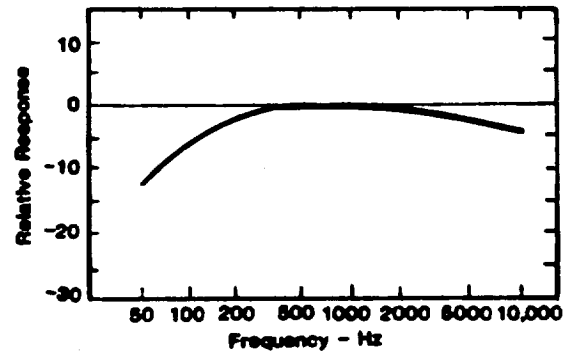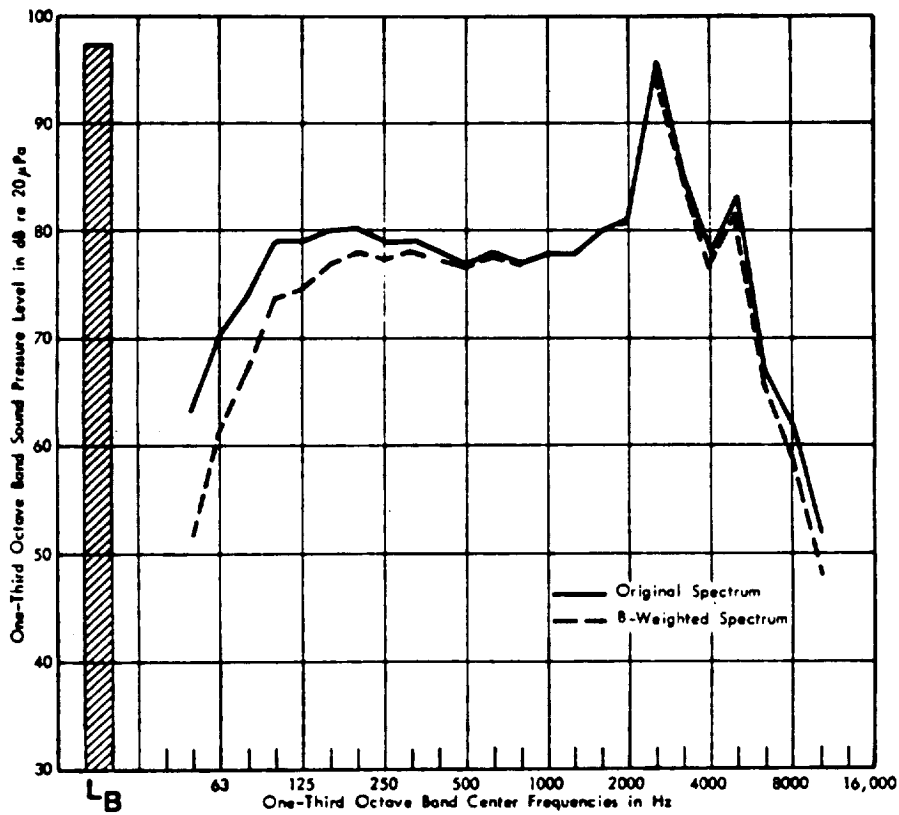| Frequency Hz	A-Weighting Relative Response dB
10	-38.2
12.5	-33.2
*16	-28.5
20	-24.2
25	-20.4
*31.5	-17.1
40	-14.2
50	-11.6
*63	- 9.3
80	- 7.4
100	- 5.6
*125	- 4.2
160	- 3.0
200	- 2.0
*250	- 1.3
315	- 0.8
400	- 0.5
*500	- 0.3
630	- 0.1
800	0
*1000	0
1250	0
1600	0
*2000	- 0.1
2500	- 0.2
3150	- 0.4
*4000	- 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

30

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., <u>Acoustics</u>, McGraw-Hill, New York
   (1954).

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

32

TITLE   C-WEIGHTED SOUND LEVEL

ABBREVIATION   SLC

SYMBOL L_C

UNIT   Decibel
                (dB)*

GEOGRAPHICAL   Inter-
USAGE   national
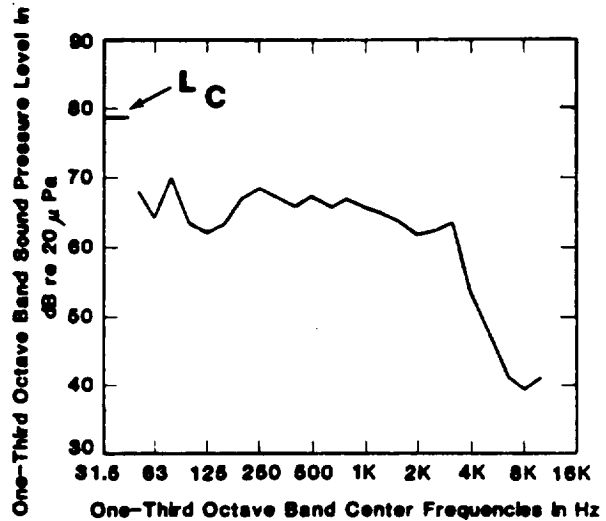
FIGURE SLC-1.   AIRCRAFT FLYOVER
                SPECTRUM

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 approxi-
                mate the relative loudness level of high level

---

*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

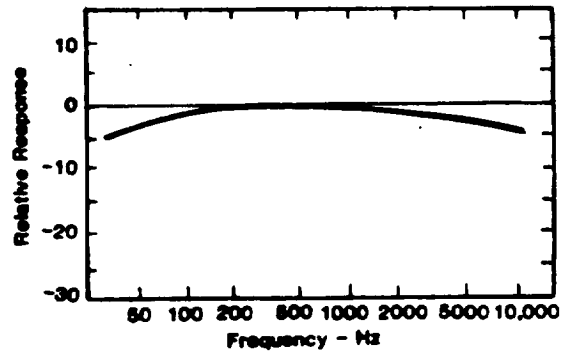| Frequency Hz	A-Weighting Relative Response dB
10	-14.3
12.5	-11.2
*16	- 8.5
20	- 6.2
25	- 4.4
*31.5	- 3.0
40	- 2.0
50	- 1.3
*63	- 0.8
8ʋ	- 0.5
100	- 0.3
*125	- 0.2
160	- 0.1
200	0
*250	0
315	0
400	0
*500	0
630	0
800	0
*1000	0
1250	0
1600	- 0.1
*2000	- 0.2
2500	- 0.3
3150	- 0.5
*4000	- 0.8
5000	- 1.3
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).

36
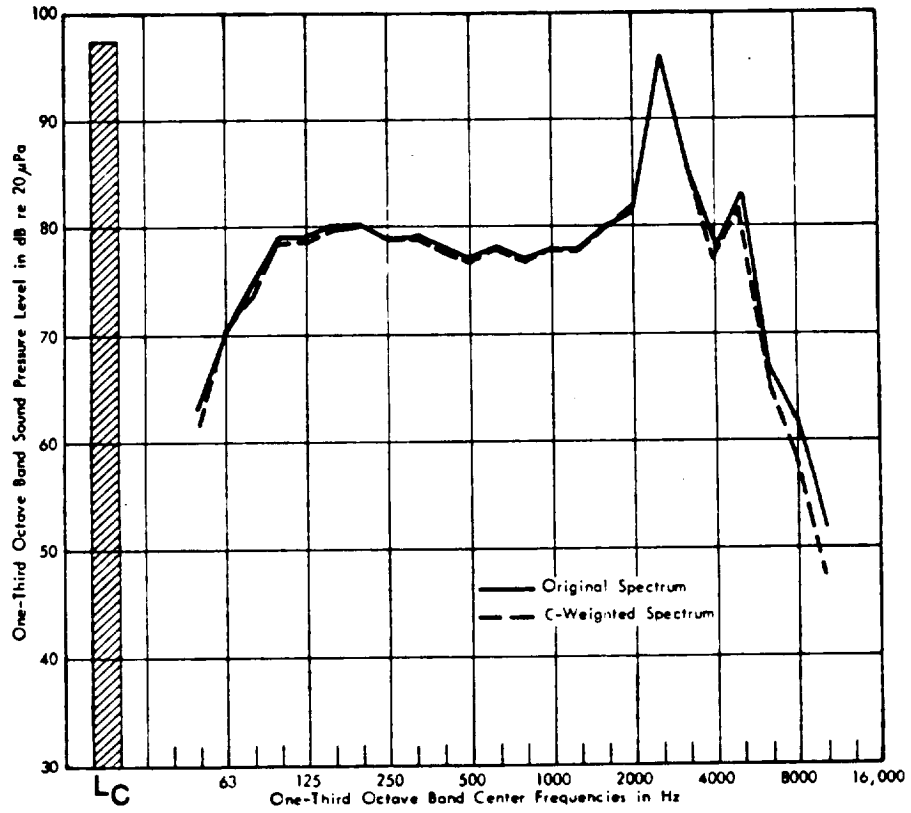
FIGURE SLC-3. EXAMPLE OF EFFECT OF C-WEIGHTING
CORRECTIONS ON JET TURBOFAN
AIRCRAFT FLYOVER SPECTRUM

37

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).

38

ABBREVIATION   SLD

SYMBOL L_D

UNIT   Decibel
(dB)*

GEOGRAPHICAL   Inter-
USAGE   national
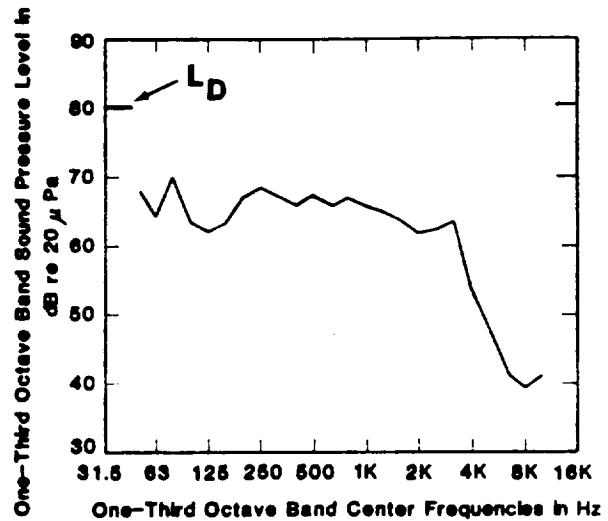
FIGURE SLD-1.   AIRCRAFT FLYOVER
SPECTRUM

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

---

*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 defi-nition, 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 has been implemented. Figure SLD-1 shows a typical air plane flyover spectrum and the resulting D-level.

40

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
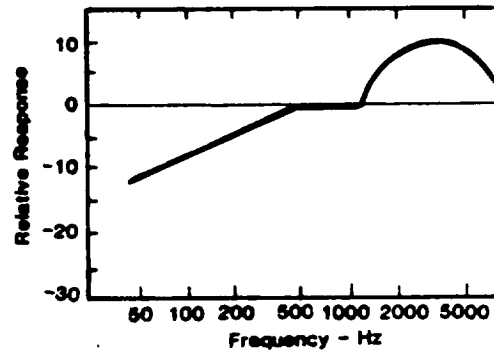
FIGURE SLD-2. D-WEIGHTI

42
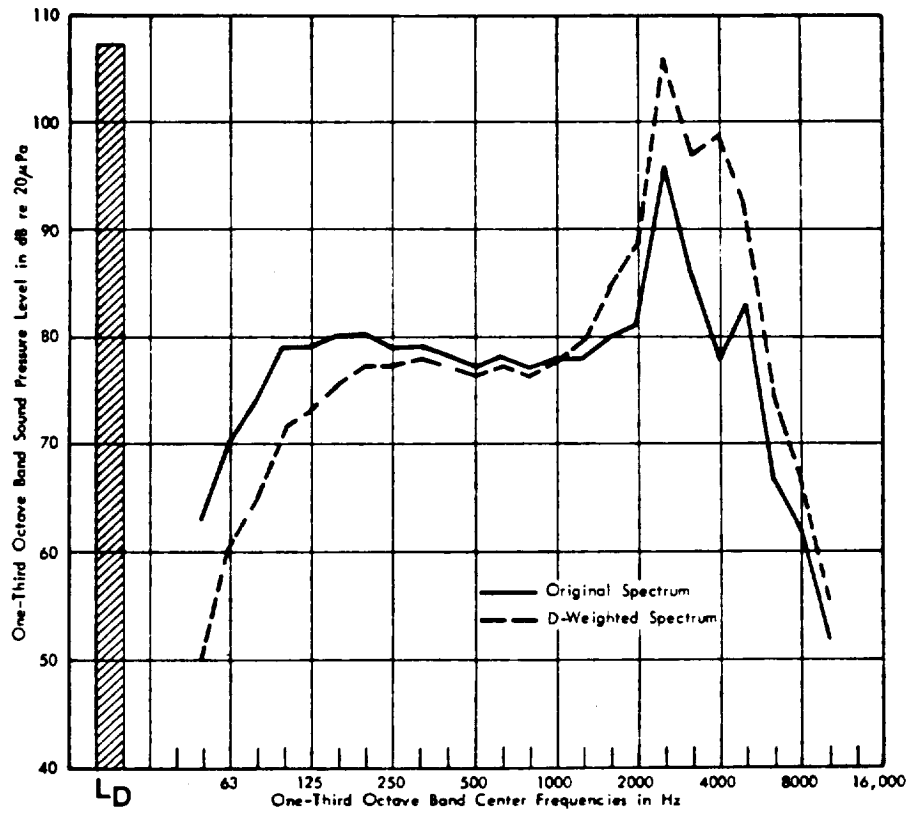
FIGURE SLD-3. EXAMPLE OF EFFECT OF D-WEIGHTING
CORRECTIONS ON JET TURBOFAN
AIRCRAFT FLYOVER SPECTRUM

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
(dB)
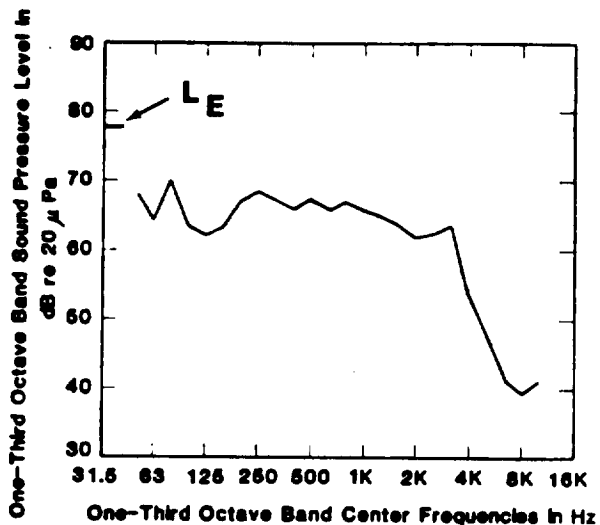
FIGURE SLE-1.   AIRCRAFT FLYOVER
SPECTRUM

GEOGRAPHICAL   Limited
USAGE

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.

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 ($\pm$ 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.

$$L_E \cong L_D \ (\pm \ 2 \ dB)$$

46

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
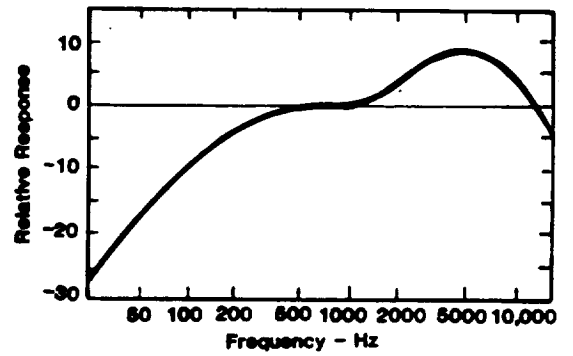
FIGURE SLE-2.   E-WEIGHTING

Perceived Level (PL) (L_{PL})

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

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

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:

$$L_E = 103.2 \ dB$$

EQUIPMENT

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

48
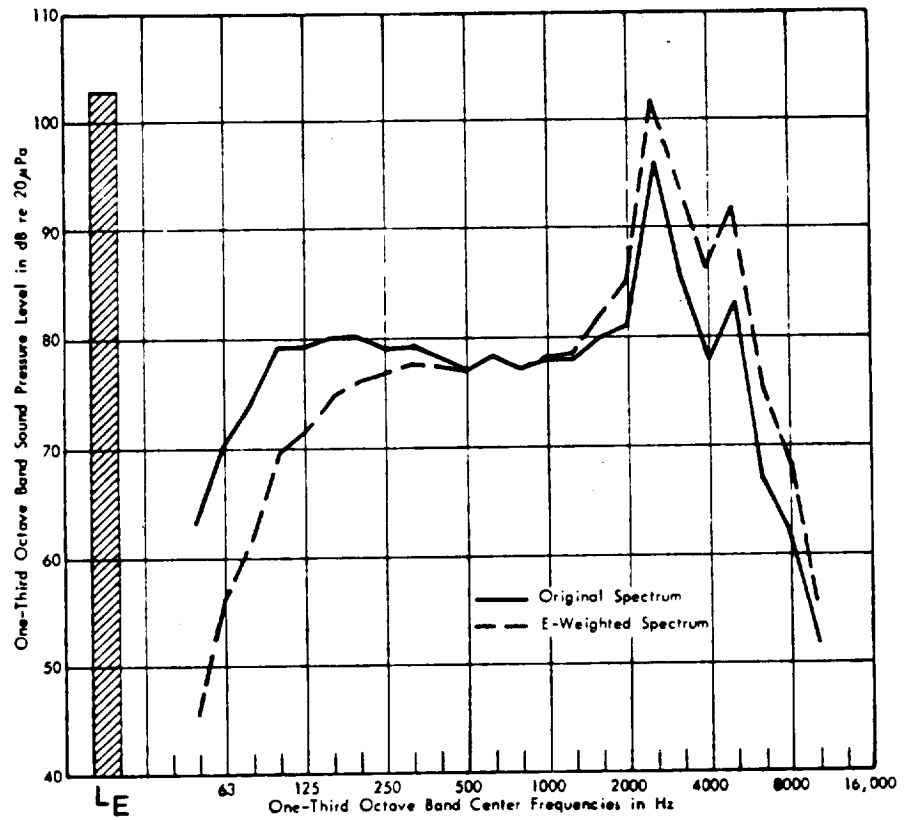
FIGURE SLE-3.   EXAMPLE OF EFFECT OF E-WEIGHTING
CORRECTIONS ON JET TURBOFAN
AIRCRAFT FLYOVER SPECTRUM

49

STANDARDS   1) American National Standards Institute (ANSI),
                    Draft, "E-Weighting Network for Noise Measure-
                    ment", 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)*
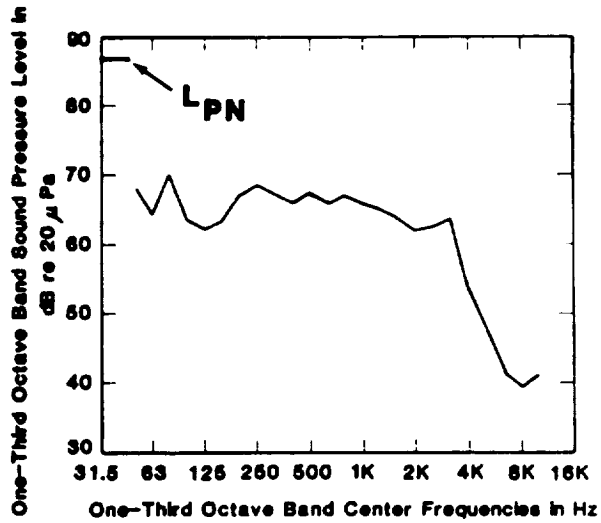
FIGURE PNL-1. AIRCRAFT FLYOVER SPECTRUM

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.

---

*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) under-estimated 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.

53
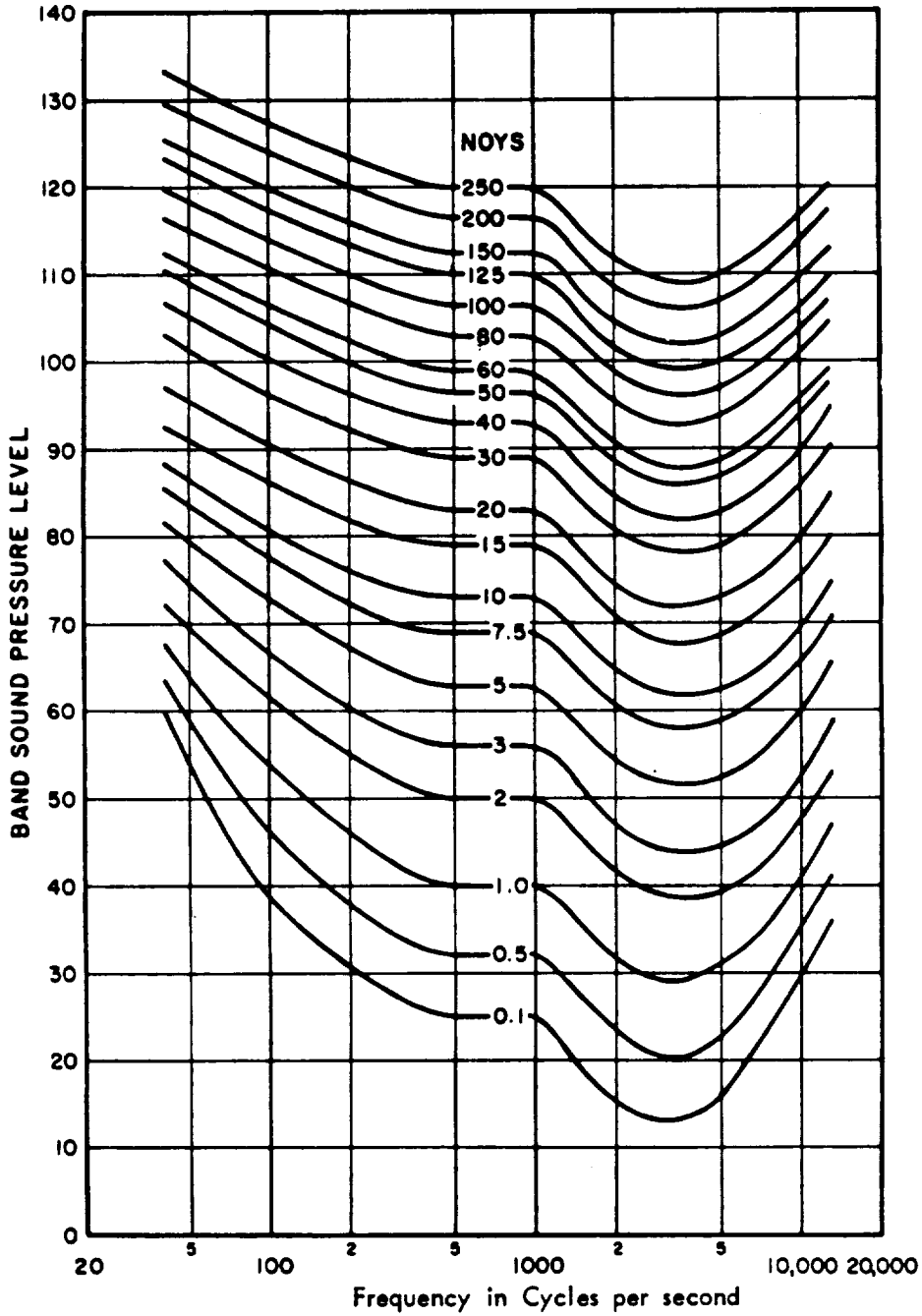
FIGURE PNL-2. NOISINESS OF BANDS OF SOUND

54

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 calcu-
lations for perceived noise level, band levels
are determined for each point in time and per-
ceived 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:

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

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:

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

56

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).

57

n   is the noy value in any given frequency band.

n_{max} is the greatest noy value.

Σn 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) $L_{PN} = 40 + \dfrac{10 \ \log_{10} N}{\log_{10} 2}$ [

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:

NOYS AS A FUNCTION OF BAND SOUND PRESSURE LEVEL

Noys, N, for 1/3-octave-band center frequencies, Hz, of —

SPL	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

TABLE PNL-1. CONTINUED

Noys, N, for 1/3-octave-band center frequencies, Hz, of -

SPL	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000

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	0.18	0.49	0.72	0.90	1.17	1.38	1.58	1.70	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	.26	.55	.80	1.00	1.26	1.47	1.68	1.86	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	1.10	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	1.26	1.58	1.85	2.08	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	1.19	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	1.19	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	35.7	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:

$\left. \begin{array}{l} M_J \\ L_k \\ A \end{array} \right)$ 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
$L_1 \leq L < L_2$	$n = 0.1 [10^{M_1(L-L_1)}]$
$L_2 \leq L < L_3$	$n = 10^{M_2(L-L_2)}$
$L_3 \leq L < L_c$	$n = 10^{M_3(L-L_3)}$
$L_c \leq L < 150$	$n = 10^{M_4(L-L_4)}$

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 turbo-fan 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).

65

REFERENCES

1. Kryter, Karl, "Scaling Human Reactions to the Sound from Aircraft", JASA, Vol. 31, No. 11, 1959, pp. 1415-1429.

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).

ABBREVIATION   PNLT

SYMBOL L_{TPN}

UNIT   Decibel
                 (dB)*
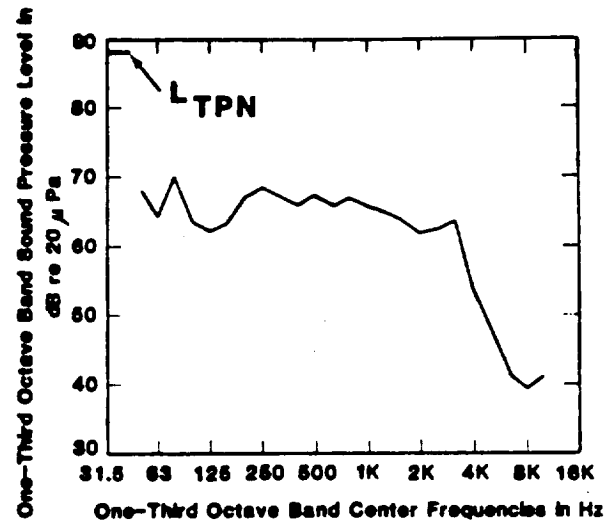
FIGURE PNLT-1.   AIRCRAFT FLYOVER
                 SPECTRUM

GEOGRAPHICAL   Inter-
USAGE   national

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

---

*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 be-came 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 illus-trated in the example. They examine the band level in a noise spectrum to detect if the level in any

68

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.

<u>Step 1</u>:

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 alge-
braically 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 encir-
cled:

70

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

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

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

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

Set $L'(40) = L(39) + \dfrac{s(39, 36)}{3}$ 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),:

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

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

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

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

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

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

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

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

<u>Step 5</u>:

For each encircled band level determine:

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

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

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

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

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.

<u>Step 6</u>:

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
$50 \leq f < 500$	$0 < F < 20$ $20 \leq F$	F/6 3-1/3
$500 \leq f \leq 5000$	$0 < F < 20$ $20 \leq F$	F/3 6-2/3
$5000 < f \leq 10000$	$0 < F < 20$ $20 \leq F$	F/6 3-1/3

72
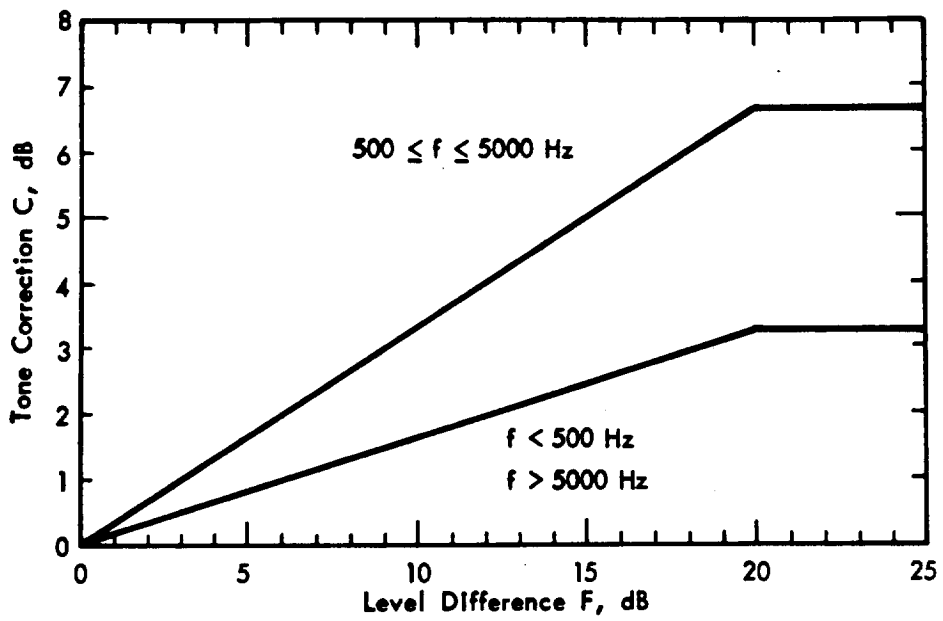
FIGURE PNLT-2. TONE CORRECTION FACTORS

<u>Step 7</u>:

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 per-
ceived 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).

74

STANDARDS   1) International Organization for Standardization,
                     ISO/DIS 3891, "Procedure for Describing Air-
                     craft 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., $\underline{38}$, 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 irre-
                               gularities 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 1	One-Third Octave Band Center Frequency f	Band Level $L(1)$	$S(j,1)$	$S(j,1) - S(j-1,1-1)$	$L'(1)$	$F(1)$	$F'(1)$	C
17	50	63	0.0					
18	63	71	0.0	0				
19	80	74	+5.0	5				
20	100	79	0.0	-5				
21	125	79	0.0	+1				
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	0				
27	500	77	-1.0	+2				
28	630	78	+1.0	-2				
29	800	77	-1.0	+2				
30	1000	78	-1.0	-1				
31	1250	78	0.0	+2				
32	1600	80	+2.0	-1				
33	2000	81	+1.0	+14	83.5	12.5		4.2
34	2500	96 — A	(+15.0)	-25				
35	3150	36 — B	(-10.0)	+2				
36	4000	78	-8.0	+13				
37	5000	83 — A	(+5.0)	-21	72.7	10.3		3.4
38	6300	67 — B	(-16.0)	+11	67.3	0.3		
39	8000	62 — B	(-5.0)	-5				
40	10000	52	-10.0					

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

77

TITLE	EFFECTIVE PERCEIVED NOISE LEVEL

<table>
<tr><td>ABBREVIATION</td><td>EPNL</td></tr>
<tr><td>SYMBOL</td><td>L_{EPN}</td></tr>
<tr><td>UNIT</td><td>Decibel
(dB)*</td></tr>
<tr><td>GEOGRAPHICAL
USAGE</td><td>Inter-
national</td></tr>
</table>
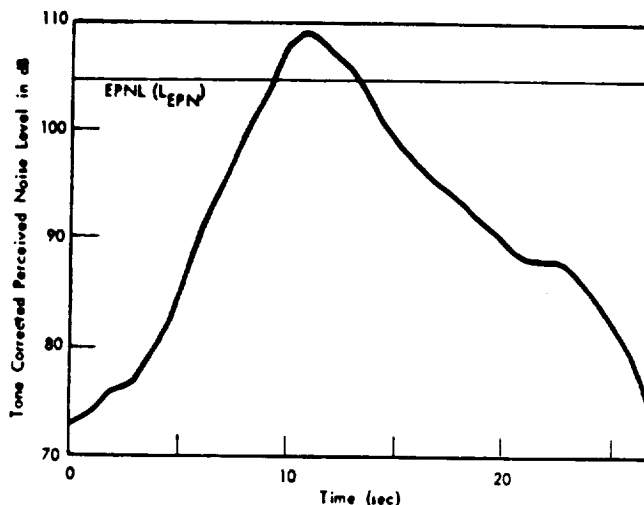
FIGURE EPNL-1. TIME HISTORY OF AIRCRAFT FLYOVER

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

---

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

78

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.

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

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

80

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 Cer-
tification (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	$8511.35 \times 10^{?}$
8.5	88.6	101.9	15443.17 " "
9.0	90.4	103.6	23308.65 " "
9.5	92.6	106.0	39810.71 " "
10.0	94.5	108.2	66069.34 " "
10.5	95.6	109.1	81283.05 " "
11.0	96.2	110.1	81283.05 " "
11.5	96.7	109.6	72443.60 " "
12.0	97.1	107.5	56234.13 " "
12.5	97.7	106.6	$45709.50 \times 10^{?}$
13.0	97.2	105.7	37153.50 " "
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}

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

$$= 104.7 \text{ dB}$$

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
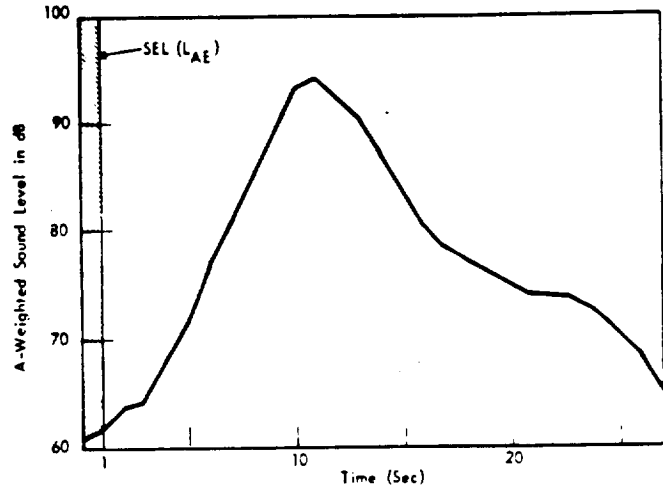
FIGURE SEL-1. TIME HISTORY OF AIRCRAFT FLYOVER

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

*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 charac-
terize 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 mea-
sured 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. Con-
ceivably, 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 ith sample.

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

Δt 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	$10^{\frac{L_A}{10}}$	Δt (sec)
0.0	69.5	60.6	1.15×10^6	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]

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

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

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

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 Implicatior 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) Air Transport Association of America v. Crotti (N.D. Cal. 1975) 389 F. Supp. 58.

NOTES

92

CHAPTER III

MULTIPLE EVENT METRICS

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	Inter-national

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 cen-tile 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.

94

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

95

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 fluctua-
tion.

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:

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

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 pre-
sumably 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.

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

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

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

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

98

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
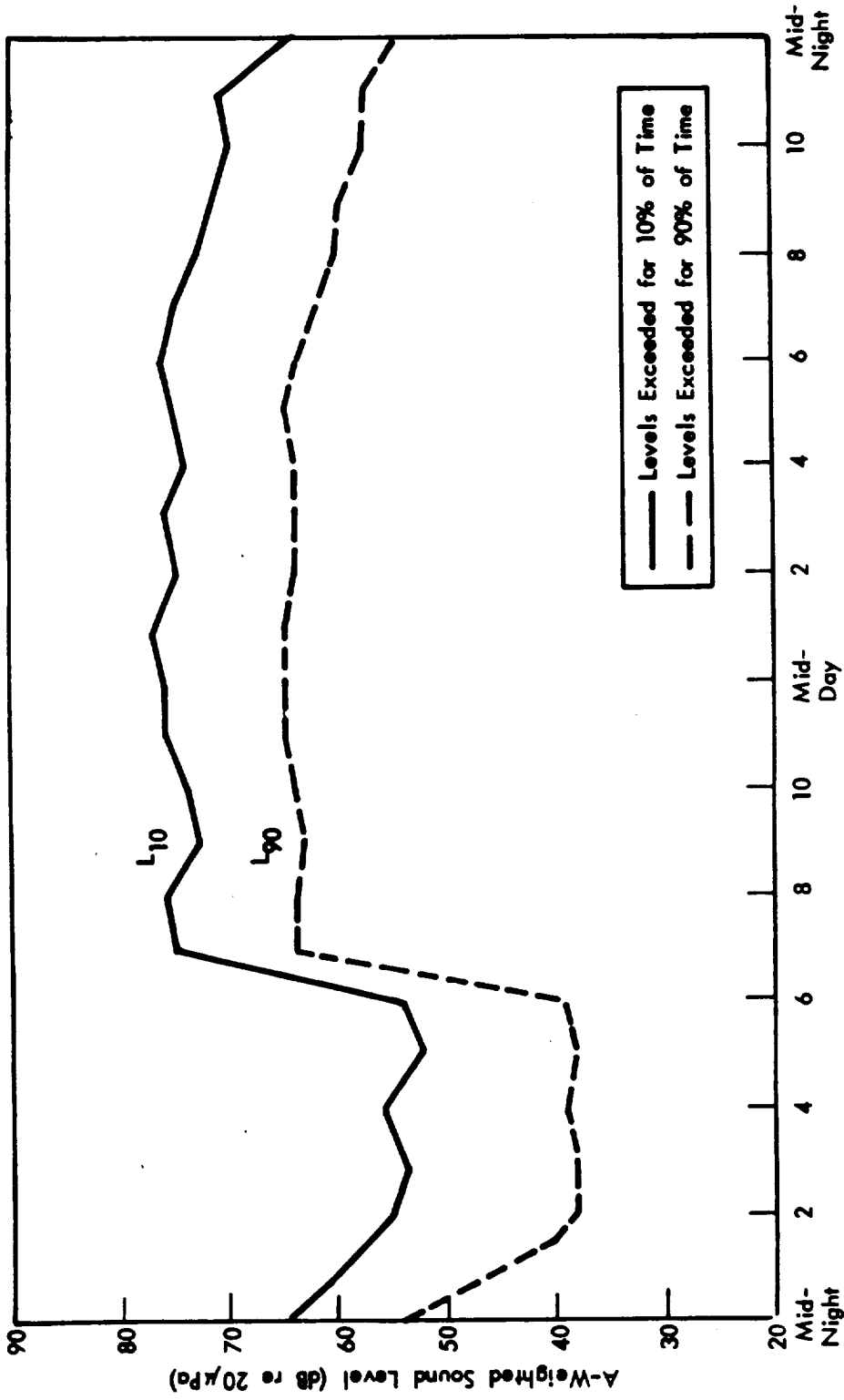
FIGURE L_x-2.   STATISTICAL SOUND LEVELS (L_{10} & L_{90}) AT URBAN SITE OVER A 24-HOUR PERIOD; THE L_{10} AND L_{90} LEVELS WERE DETERMINED FOR EACH HOUR OF THE DAY

100

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 distri-
bution 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 neigh-
borhood 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).

TITLE	EQUIVALENT CONTINUOUS SOUND LEVEL

ABBREVIATION   QL*

SYMBOL L_{eq}

UNIT   Decibel (dB)

GEOGRAPHICAL USAGE   International
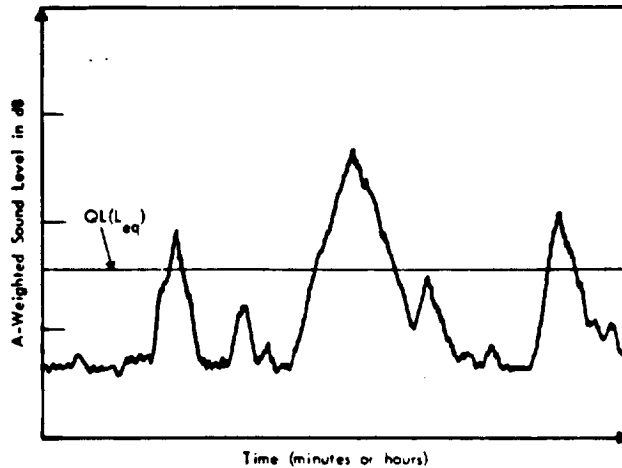
FIGURE QL-1. OUTDOOR SOUND LEVELS AT URBAN SITE

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 differ-
end 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.

104

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, in-
dustrial 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

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

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:

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

where:

n   is the number of samples.

$L_{A(i)}$ is A-weighted sound level of the ith 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 dB

EQUIPMENT   1) Sound level meter (ANSI S1.4-1971) and tape
                       recorder for single events.

                   2) Digital computer and special analyzing equip-
                       ment capable of integrating sound level for
                       long periods of time.

STANDARDS   ANSI S3.23, 1980.

REFERENCES   1) Environmental Protection Agency, "Impact Char-
                       acterization of Noise Including Implications
                       of Identifying and Achieving Levels of Cumu-
                       lative 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., "Proce-
                       dures 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 Bundes-
ministers 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), Oester-
reichische 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, Beuth-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 X 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 X 10^6

Equation 2

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

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

TITLE   HOURLY NOISE LEVEL

ABBREVIATION   HNL

SYMBOL L_h

UNIT   Decibel
               (dB)

GEOGRAPHICAL   State of
USAGE   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

112

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:

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

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:

114

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

$L_{1h} = 90.7$ 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	3.16×10^6
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 = 13106.49×10^6

Equation 2

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

$$= 90.8 \text{ dB}$$

116

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
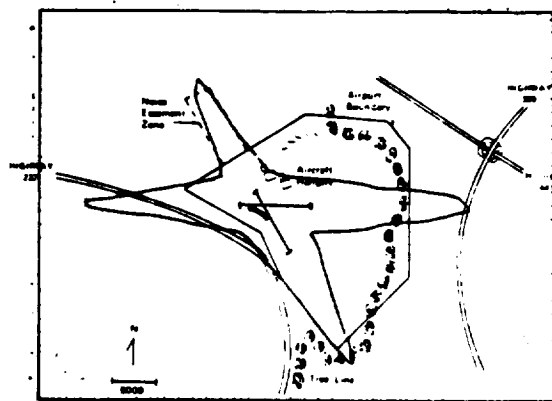
Federal Aviation Administration Integrated Noise Model 1 2

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

GEOGRAPHICAL   United
USAGE   States

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

118

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 appli-
cable 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 imple-
mented 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 experiences
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 situa-
tions a computer program is more expedient.

122

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

180 TAKEOFF/DAY

EXPOSURE

ZONE A - (100%) = 180 EVENTS = 45 MIN
B - (70%) = 126   "   = 31.5 MIN
C - (50%) = 90   "   = 22.5 MIN
D - (80%) = 144   "   = 36 MIN
E - (30%) = 54   "   = 13.5 MIN
F - (20%) = 36   "   = 9 MIN

30%

FLIGHT TRACK UTILIZATION

50%

20%

RUNWAY

TAKEOFF

CONTOURS DEPICTING THE AREAS
EXPECTED TO DETECT SOUND LEVELS
OF 85 dB(A) OR GREATER.
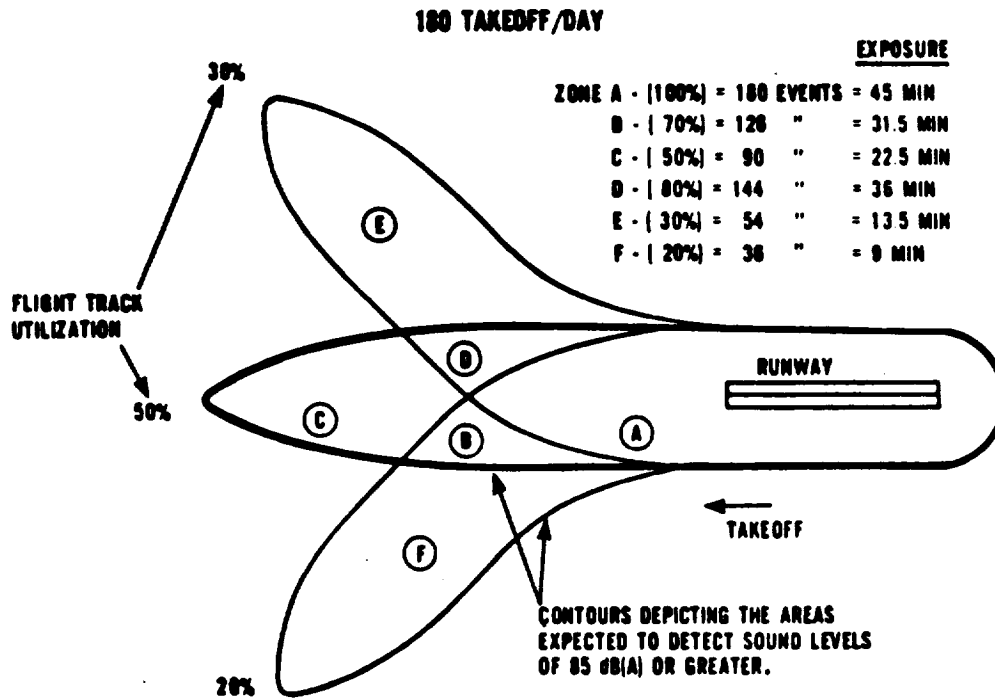
FIGURE TA-2. TA PLOT FOR SINGLE RUNWAY AIRPORT
TA 85 dB 45 Min (Ref.1)

124

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 respec-
tive 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
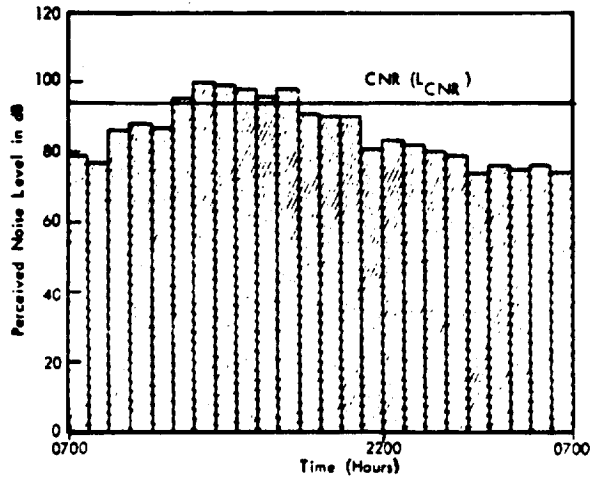
FIGURE CNR-1.   CNR FOR AIRCRAFT FLYOVERS

DEFINITION   Composite noise rating is a calculated rating based 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 for flight and one for run-up aircraft operations

PURPOSE   Composite noise ratings is a method used for rating the noise exposure from aircraft operations and for estimating community reactions.   This measure takes into consideration noise associated with both ground run-up and airborne operations in an attempt to predict community response.

128

BACKGROUND   Tracing the development of CNR over the years pro-
                    vides 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 essen-
                    tially 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 commun-
                    ity 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 associ-
                    ated '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 modifi-
                    cation of CNR, Stevens and Pietrasanta (Ref. 3)
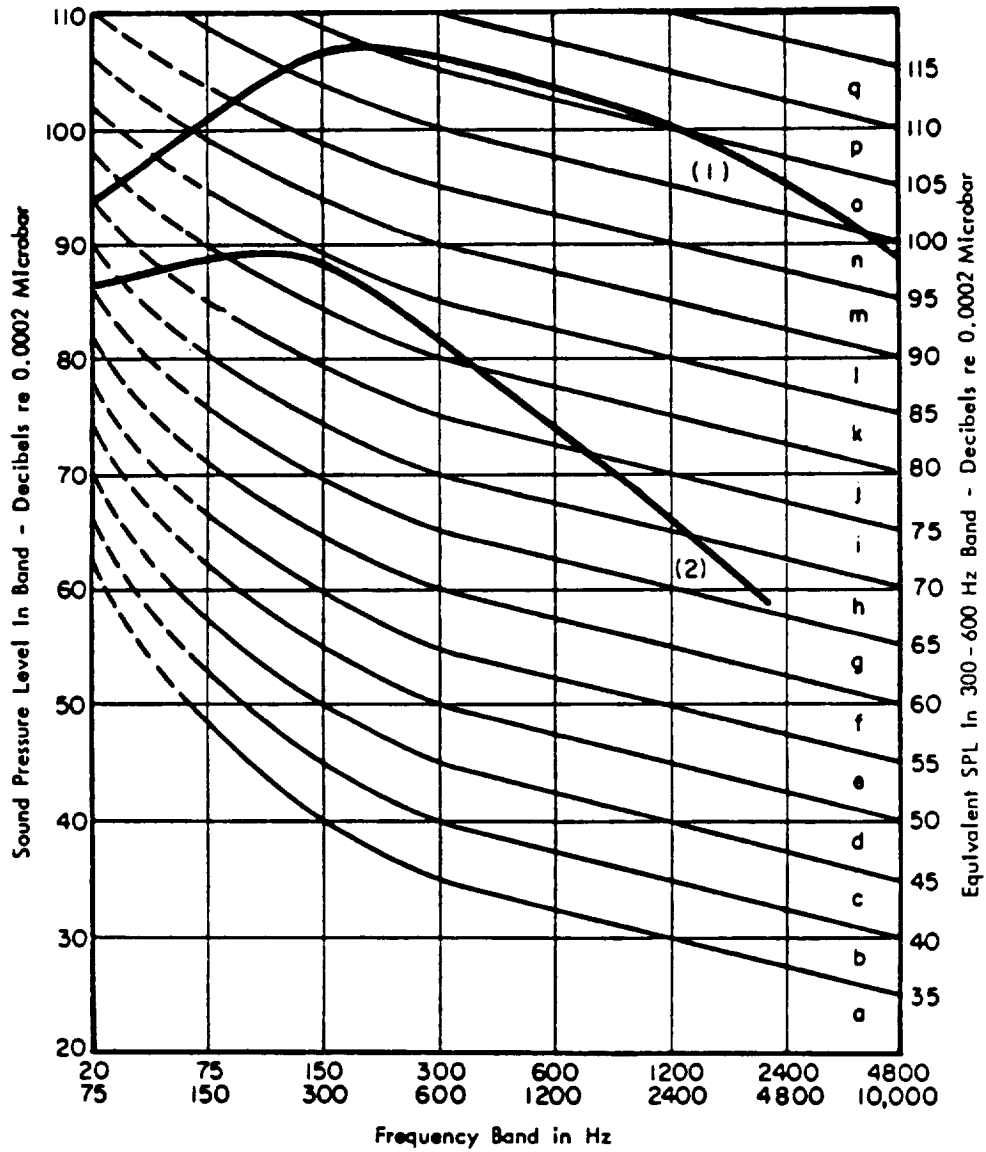
FIGURE CNR-2. DETERMINATION OF EQUIVALENT SPL IN 300-600 Hz BAND FOR TWO TYPICAL SPECTRA. VALUES ARE 105 dB FOR SPECTRUM (1) AND 80 dB FOR SPECTRUM (2) TO THE NEAREST 5 dB. (From WADC TN 57-10)

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 charac-
teristics of the aircraft noise source was elimin-
ated 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 attri-
butes 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 character-
istics 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.

133

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.

134

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 develop-
ment 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 com-
bined 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 commun-
ity 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 corres-
ponding 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

137

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 informa-
tion 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 determina·
tion 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

139

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

140

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 correc-
tion 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 air-
port. 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

142

EXAMPLE OF CNR CALCULATIONS FOR INDIVIDUAL OPERATIONS

TAKEOFFS	Step 1				Step 2		Step 3	Step 4 Corrections			Step 5
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
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".

143

TABLE CNR-6

EXAMPLE OF CNR CALCULATIONS FOR GROUND RUNUP OPERATIONS

	Step 1			Step 2		Step 3	Step 4 Corrections		Step 5
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 Expo-
sure 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

FIGURE NEF-1. AIRCRAFT FLYOVERS

ABBREVIATION	NEF
SYMBOL	L_{NEF}
UNIT	Decibel (dB)
GEOGRAPHICAL USAGE	United States

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 com-
ponents 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 cor-
rection 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

148

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).

NEF	TABLE NEF-1 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 fc 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.

(1) 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.

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

150

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

or,

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

where:

$L_{\overline{EPN}}$ is the energy mean value of EPNL for each flyover at the ground location of interest.

N_d, $\overline{n}_d$ is the total number and average number per hour, respectively, of flights during the period 0700 - 2200.

N_n, $\overline{n}_n$ 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 c nighttime aircraft operations.

88   is a scale-changing constant (Ref. 3).

152

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).

153

$N_{d(ij)}$ 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.

154

TABLE NEF-2

EXAMPLE OF CALCULATIONS FOR NEF FROM
SINGLE-AIRCRAFT FLYOVERS

Event (i)	Time	L_{EPN}	$10^{(\frac{L_{EPN(i)}}{10})}$	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

| Aircraft Class (1) | Flight Path j | $L_{EPN(ij)}$ | Total Number of Flights | | Weighting Factor | $L_{NEF(ij)}$ Equation [2] |
			Day-time N_d	Night-time N_n		
Turbojet (< 2000 M1)	27	96	30	10	16.67	30.94
Turbojet (> 2000 M1)	28	98	35	5	16.67	30.73
Turbofan (< 2000 M1)	27	91	42	6	16.67	24.52
Turbofan (> 2000 M1)	28	90	39	4	16.67	22.24

Equation [3]

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

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

156

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.

158

TITLE	DAY-NIGHT AVERAGE SOUND LEVEL

ABBREVIATION	DNL

SYMBOL	L_{dn}

UNIT	Decibel (dB)

GEOGRAPHICAL USAGE	United States
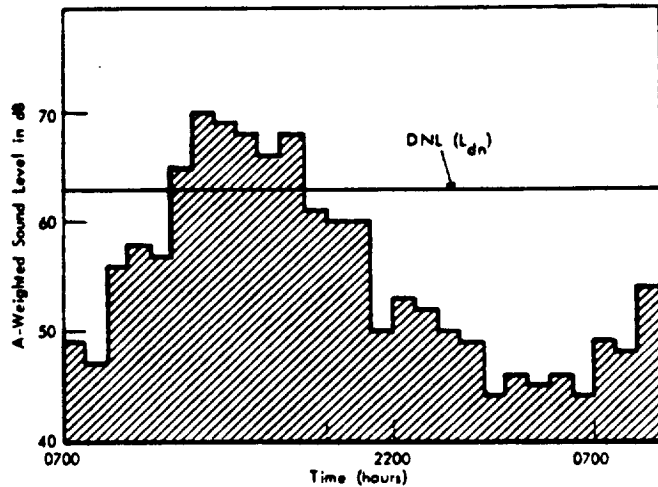
FIGURE DNL-1. DAY/NIGHT AVERAGE SOUND LEVEL OVER 24 HOURS

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.

159

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

160

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 environ-
mental 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 expo-
sure (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 poten-
tially 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 consi-
dering 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})

$$L_{dn} \approx L_{den}$$

. Composite Noise Rating (CNR) (L_{CNR})

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

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

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

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:

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

163

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 <u>not</u> necessarily
of the same type dominate the noise environment.

$$L_{dn} = 10 \log_{10}\left[\frac{1}{86400}\left[\sum_{i=1}^{n} 10^{\frac{L_{AE(i)}}{10}} + 10 \sum_{j=1}^{n} 10^{\frac{L_{AE(j)}}{10}}\right]\right]$$

$$\begin{array}{cc} \text{day} & \text{night} \\ 0700\text{-}2200 & 2200\text{-}0700 \end{array}$$

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.

164

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.

                        $L_{dn} = 81.7$ 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 Cumula-
                       tive Noise Exposure", NTID 73.4 (July 1973).

                   2) Environmental Protection Agency (EPA), "Infor-
                       mation 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).

165

TABLE DNL-1

EXAMPLE OF CALCULATIONS FOR DNL

Sample 1	Time	L_h	Hrs.	$10^{\frac{L_{h(1)}}{10}}$	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   C:IEL

SYMBOL L_{den}

UNIT   Decibel
                    (dB)

GEOGRAPHICAL   State of
USAGE   California

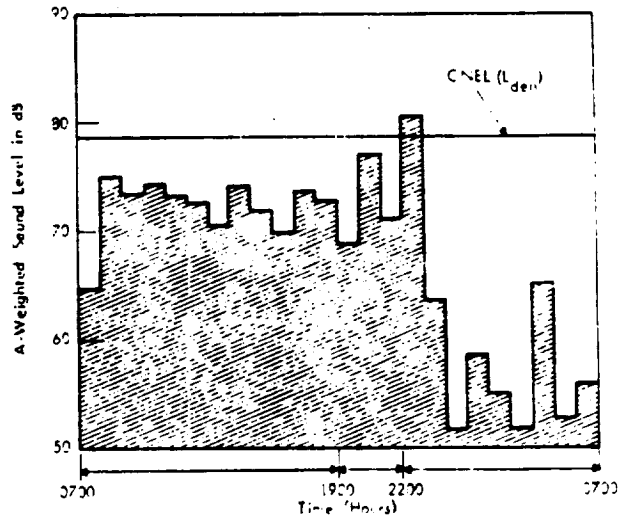FIGURE CNEL-1.   CNEL OVER
24 HOUR

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.

168

BACKGROUND
Community noise equivalent level like DNL seems
to be an appropriate measure for land use com-
patibility planning because it takes into consi-
deration 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 rat-
ing 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

169

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 approxi-
mated 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 (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

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

where:

$\overline{L_{AE}}$ is the energy averaged sound exposure

170

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.

$$L_{den} \cong 10 \log_{10}\left[\frac{1}{86400} \left[\sum_{i=1}^{n} 10^{\frac{L_{AE(i)}}{10}} + 3\sum_{j=1}^{n} 10^{\frac{L_{AE(j)}}{10}} + 10\sum_{k=1}^{n} 10^{\frac{L_{AE(k)}}{10}} \right] \right]$$

$$\begin{array}{ccc} \text{0700-1900} & \text{1900-2200} & \text{2200-0700} \\ \text{Daytime} & \text{Evening} & \text{Nighttime} \end{array}$$

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.

171

$L_{AE(j)}$ 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)

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

where:

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

172

$L_{he(j)}$ 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:

173

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

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

$L_{den} = 78.4$ 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 X 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 X 10^5

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

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

Annual $L_{den} = 57.9$ dB

CNEL using hourly noise levels from Table CNEL-1

$$L_{den} = 78.4 \text{ dB}$$

Annual CNEL using monthly CNEL from Table CNEL-2

$$\text{Annual } L_{den} = 57.9 \text{ dB}$$

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.

176

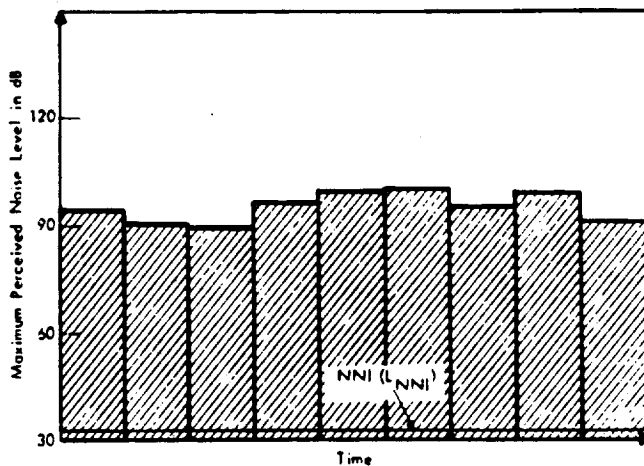|	
TITLE	NOISE AND NUMBER INDEX
ABBREVIATION	NNI
SYMBOL	L_{NNI}
UNIT	Decibel (dB)*
GEOGRAPHICAL USAGE	United Kingdom

FIGURE NNI-1. NNI FOR AIRCRAFT FLYOVERS

DEFINITION	Noise and number index is based upon the average maximum perceived noise level for aircraft fly-overs 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.

*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 distri-
bution 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 air-
craft flyovers.

According to Schultz (Ref. 2) the concept of back-
ground noise is implicitly included in NNI by the
stipulation that the adjustment for the number of
aircraft events be the "number of aircraft flyovers
heard" 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

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

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

180

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:

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

where

      N   is the number of aircraft flyovers that
             occur during a time period.

$L_{PN(i)max}$ 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:

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

where

     $L_{\overline{PN}max}$ 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:

                   $L_{NNI} = 32.2$ 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 Expo
                       sure Forecasts: Evolution, Evaluation, Exten-
                       sions 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.

182

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	3162.27×10^6
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.

3BREVIATION   WECPNL

YMBOL L_{WECPN}

NIT   Decibel
(dB)
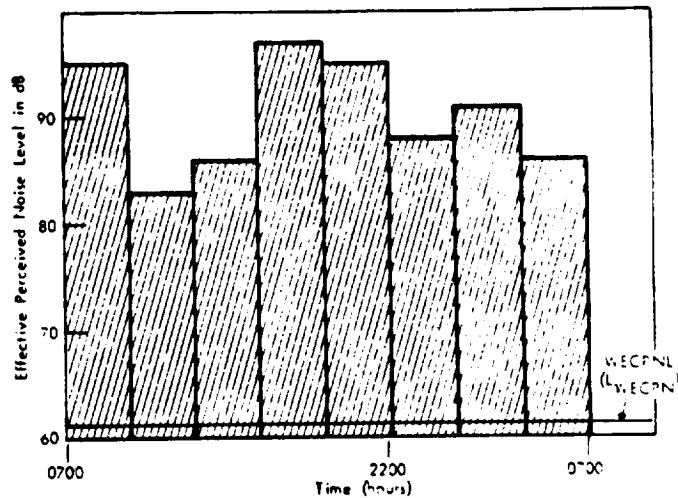
EOGRAPHICAL   Inter-
SAGE   national

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 'equiva-
              lent 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

186

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 corre-
sponds 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 com-
pared. 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 ith 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 considera-
tion (e.g., day, night, month, or year) in
seconds.

188

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.

$$L_{WECPN} = 10 \log_{10} \left[\frac{5}{8} (10^{\frac{L_{ECPN}}{10}}) + \frac{3}{8} (10^{\frac{L_{ECPN}+10}{10}}) \right] + S \quad [3]$$

daytime   nighttime
(0700-2200)   (2200-0700)

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.

189

$$\text{wECPN} = 10 \log_{10} \left[\frac{1}{2} (10^{\frac{L_{ECPN}}{10}}) + \frac{1}{8} (10^{\frac{L_{ECPN}+5}{10}}) + \frac{3}{8} (10^{\frac{L_{ECPN}+10}{10}}) \right] + S$$

daytime   evening   nighttime
(0700-1900)   (1900-2200)   (2200-0700)

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).	

190

C-3

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 1	Time	$L_{EPN(i)}$	$10^{\left(\frac{EPNL(i)}{10}\right)}$
1	2200-0100	88	630.95 X 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

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

$$= 110.8 \text{ dB}$$

$$(2200\text{-}0700 \text{ hrs}) \quad L_{TNE} = 10 \log_{10} (2287.99 \text{ X } 10^6) + 10 \log_{10} (\frac{10}{1})$$

$$= 103.6 \text{ dB}$$

Equation 2 - ECPNL

$$(0700\text{-}2200 \text{ hrs}) \quad L_{ECPN} = 110.8 - 10 \log_{10} (\frac{54000}{1})$$

$$= 110.8 - 47.3$$

$$= 63.5 \text{ dB}$$

192

Equation 2 (cont'd)

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

$\qquad\qquad\qquad$ = 103.6 − 45.1

$\qquad\qquad\qquad$ = 58.5 dB

Equation 3 − WECPNL

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

$\qquad\qquad\qquad$ = 10 $\log_{10}$ (4053997.4) − 5

$\qquad\qquad\qquad$ = 61.1 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).

194

CHAPTER IV

SPEECH COMMUNICATIONS METRICS

/95

TITLE ARTICULATION INDEX

ABBREVIATION AI

UNIT None

GEOGRAPHICAL United
USAGE States
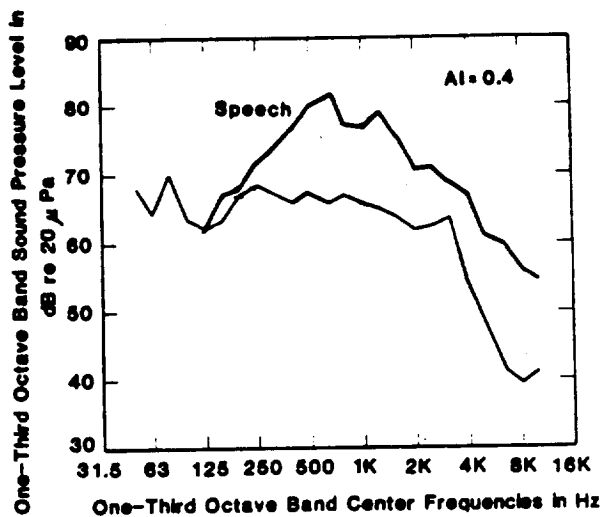
FIGURE AI-1. AIRCRAFT FLYOVER
SPECTRUM WITH SPEECH PEAK SPECTRUM

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.

196

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 com-
munication 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.

197

The second method analyzes the speech to noise
ratio for octave or third octave bands and applies
various weighting factors to account for the rela-
tive contribution of each band to speech intelligi-
bility.

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 environ-
ment 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 back-
ground, it is not effective in predicting the in-
telligibility of speech in the presence of fluctua-
ting 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   As stated previously, there are two methods current
METHOD   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).

198

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.
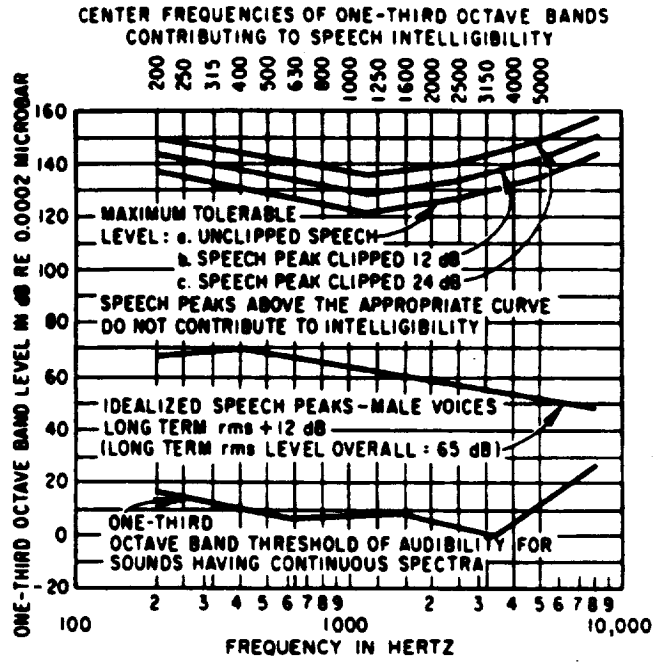
CENTER FREQUENCIES OF ONE-THIRD OCTAVE BANDS
CONTRIBUTING TO SPEECH INTELLIGIBILITY

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

CENTER FREQUENCIES OF OCTAVE BANDS CONTRIBUTING TO
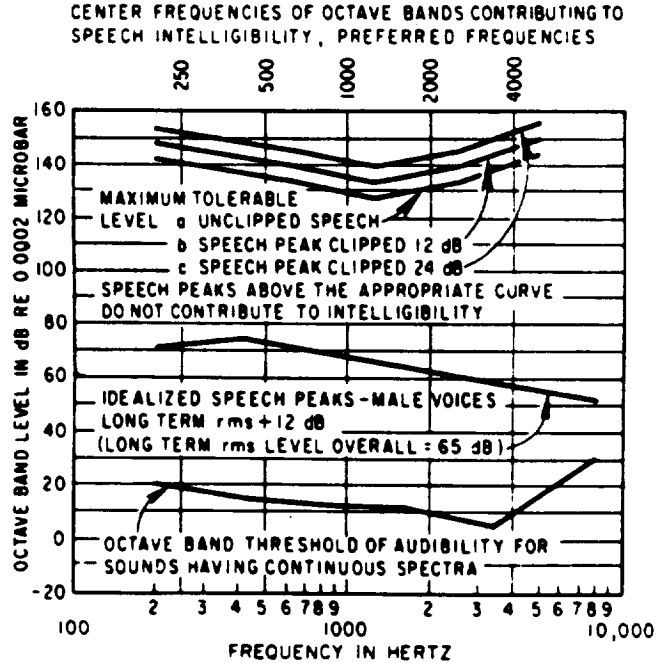SPEECH INTELLIGIBILITY, PREFERRED FREQUENCIES

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

200

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.

    Δ_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 = Δ
$\Delta_i > 30$	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 = ————

<u>Step 4</u>. 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.

<u>Step 5</u>. 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	$D_i W_i$
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]

$$AI = 0.35$$

$$= 0.4$$

[*] 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)	
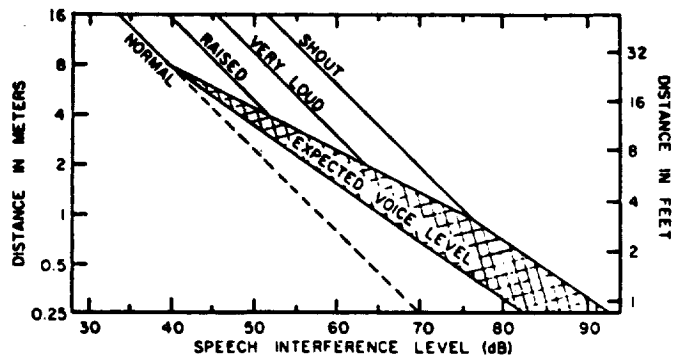
FIGURE SIL-1. SPEAKER TO LISTENER DISTANCES FOR JUST RELIABLE COMMUNICATION

GEOGRAPHICAL USAGE	International

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 back-
                  ground 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 back-
ground 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 inter-
fering 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 approxi-
mately 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 in-
cludes more high and low frequencies, it is a
worse approximation of SIL. SIL can be estimated
from SLC by:

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

**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 communi-
cation (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.

212

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   1) Beranek, L., "The Design of Speech Communicat
                     Systems", Proc. Inst. Radio Engrs. 35, 880-8ç
                     (1947).

                 2) American National Standards Institute (ANSI),
                     "Rating Noise with Respect to Speech Interfer
                     ANSI S3.14-1977.

                 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).

                 5. Beranek, L., Acoustics, McGraw Hill, New York
                     1954.

                 6. Klumpp, R. G. and J. C. Webster, "Physical
                     Measurements of Equally Speech-Interfering
                     Navy Noises", J. Acoust. Soc. Am. 35, 1328-
                     1338 (1963).

                 7. Kryter, K. D., "The Effects of Noise on Man",
                     Academic Press, New York (1970).

214

INDEX

216