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POSSIBLE MODIFICATIONS TO THE CALCULATION OF PERCEIVED NOISINESS

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16. Abstract

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POSSIBLE MODIFICATIONS TO THE CALCULATION OF PERCEIVED NOISINESS

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SUMMARY

Analysis of data from a recent large-scale experiment and reanalysis of similar data from similar or related previous experiments, provides a basis for the evaluation of the accuracy with which various units obtained from physical measurements predict the judged relative perceived noisiness of aircraft noise. On the basis of this evaluation it is concluded that the best units for estimating judged perceived noisiness are EPNdB-M and E(D_2). EPNdB-M and E(D_2) are the same as, respectively, EPNdB and EdB(D) (or EdB(N) referred to in the previous literature, except that for EPNdB-M and EdB(D_2) the sound energy below about 355 Hz is summed or weighted in ways to better account for the critical bandwidth of the ear at those frequencies. The use of tone corrections with these units appears justified but not unequivocally.

It has been found that in addition to total duration, two additional temporally related factors contribute significantly to judged perceived noisiness: (a) the time elapsing between the moment a non-impulsive noise is first above some specified threshold level and the moment it reaches its maximum level, and (b) the level above background reached within 0.5 sec by an impulsive sound. Correction values for the onset duration and impulse level of sounds, as appropriate, are proposed for consideration and possible standardization in the calculation of the units recommended for the prediction of perceived noisiness, EPNdB and EdB(D).

It is recommended that further analysis be made of existing and possibly additional new judgment data to determine whether the band summation method now used with PNdB and PNdB-M can be abandoned in favor of a somewhat simpler procedure. In this new procedure a power summation is made of the band sound pressure levels adjusted in accordance with the equal noy contours. Detailed definitions of terms and procedures as might be used for the standardization of the recommended and proposed units are given in an appendix to the paper.

INTRODUCTION

Since the introduction of the concept in 1959[11]* a number of studies have been conducted that have led to modifications to and extensions of procedures for calculating from physical measures the perceived noisiness of sound. At the present time the general relation between the sound pressure level and judged perceived noisiness as a function of the frequency content of random noise seems reasonably well established, as shown in Fig. 1. Indeed, as also shown in Fig. 1, the frequency weighting for noisiness and loudness, as given by Stevens' Mark VI Loudness Index Contours, is very similar to the equal noisiness contours. Inasmuch as the unit of PNdB uses the band summation procedure developed by Stevens for the calculation of loudness in phons, there is at present a close identity between these two units with respect to general frequency weighting and bandwidth summation. Also, ways of making or treating sound measurements to account for the role of temporal duration (at least for sounds that have onset and decline patterns that are symmetrical) and spectral (pure-tone) complexities in perceived noisiness are supported by the results of some judgment tests.

However, there are several questions that can be raised concerning the adequacy of presently used procedures for the calculation of the perceived noise level (PNL) or, as it is called when the duration is taken into account, the effective perceived noise level (EPNL) of a sound. The first question has to do with bandwidth integration and is based partly on theoretical considerations and partly on empirical data; the other questions, concerned with onset duration and impulse effects are purely empirical. An attempt will be made in this paper to answer these questions and to evaluate the relative ability of various units derived from physical measurements of sounds to predict judged perceived noisiness. In an appendix to the paper a set of definitions and procedures are given that seem to the author to be most suitable at this time for predicting from physical measurement, the perceived noisiness of sounds, and the ratings of noise environment.

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* Because of the frequent referral to authors by name and the cross referencing of publications between tables, figures, and text, referencing is accomplished by means of superscript numbers or by authors names and date of publication.

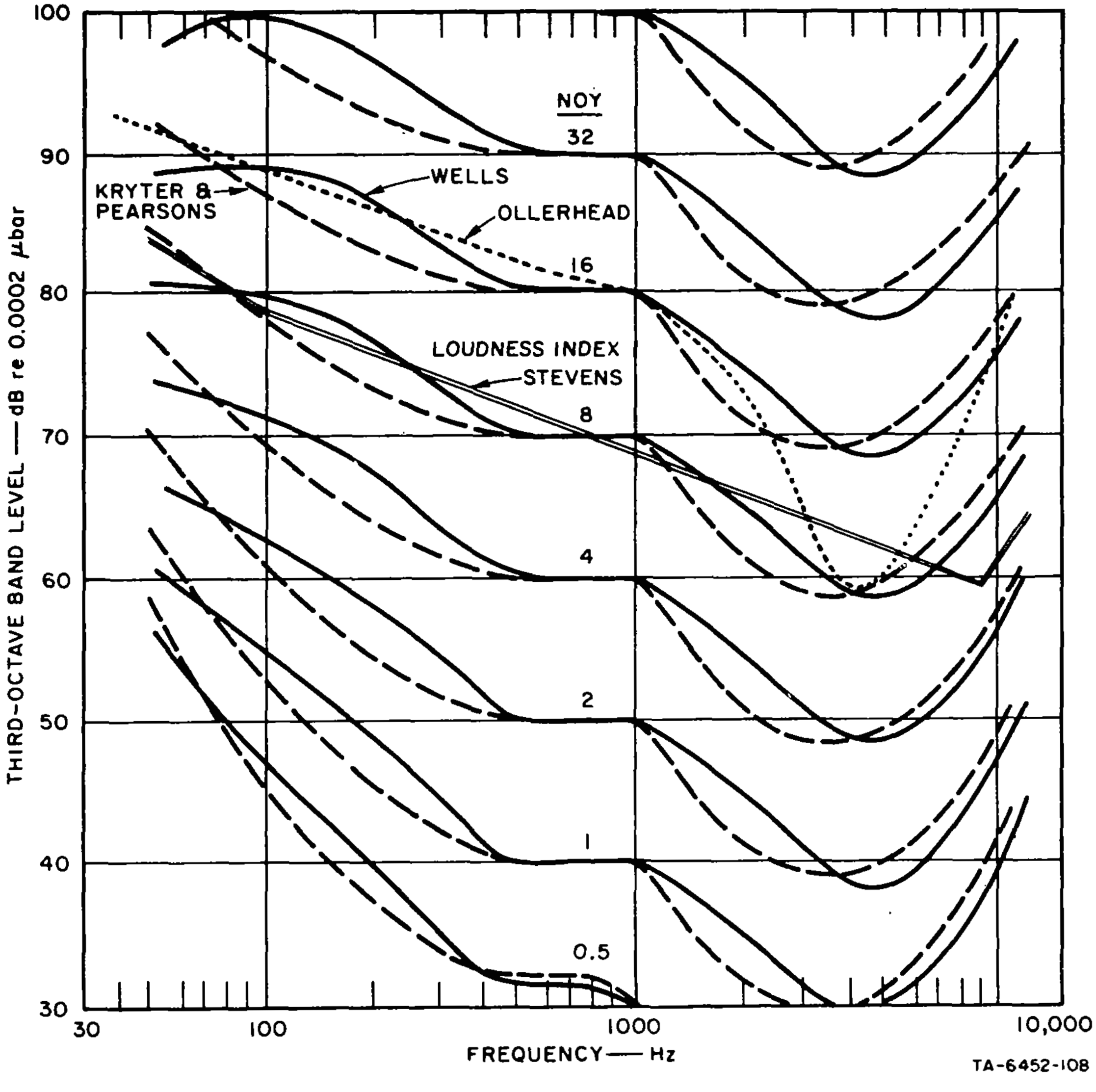

FIGURE 1 EQUAL NOISINESS CONTOURS AS FOUND BY KRYTER AND PEARSONS (14), OLLERHEAD (21) AND WELLS (30), AND EQUAL LOUDNESS INDEX CONTOUR (Stevens, 2, 29)

DISCUSSION

Critical Bandwidth of the Ear

Figure 2 shows the relations between the critical bandwidth of the ear and the width of octave and 1/3 octave band filters as a function of bank center frequency. If auditory theory is correct, sound pressure, in terms of bands containing equal numbers or portions of critical bands should be equally effective to each other, other things, of course, such as frequency weighting for noisiness, being equal. However, it is seen in Fig. 2 that below about 355 Hz the critical bandwidth of the ear stays nearly constant at about 100 Hz whereas the band filters of course do not. Above about 355 Hz there is reasonable proportional correspondence between the critical bands and the 1/3 and full octave band filters.

In retrospect, it appears unfortunate not to have utilized this fact earlier in the development of procedures for the calculation of the perceived noise level of broadband sounds, sounds whose spectra extend over a number of critical bandwidths of the ear. That such might be the case was suggested by some of the early judgment data of aircraft noise which indicated that calculated perceived noise levels based on 1/3 or octave band spectra overestimated by a few "dB" the judged perceived noise level of aircraft noise having strong low-frequency energy (noise from propeller-driven aircraft) when judged relative to aircraft noise having more intense high than low frequencies (that from jet-driven aircraft). We were of the opinion at that time that some of the discrepancies between calculated and judged perceived noisiness of these real-life sounds were possibly due to unquantified temporal and spectral complexity factors and that it would be premature to make changes then in the frequency-weighting contours.*

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* The concept and calculation of perceived noise level were not, as has been mistakenly believed by some people, predicated on tests with aircraft noise. The procedures, although first applied to the evaluation of aircraft noise, are not derived in any way from judgments of aircraft noise and are hopefully applicable to all types of noises.

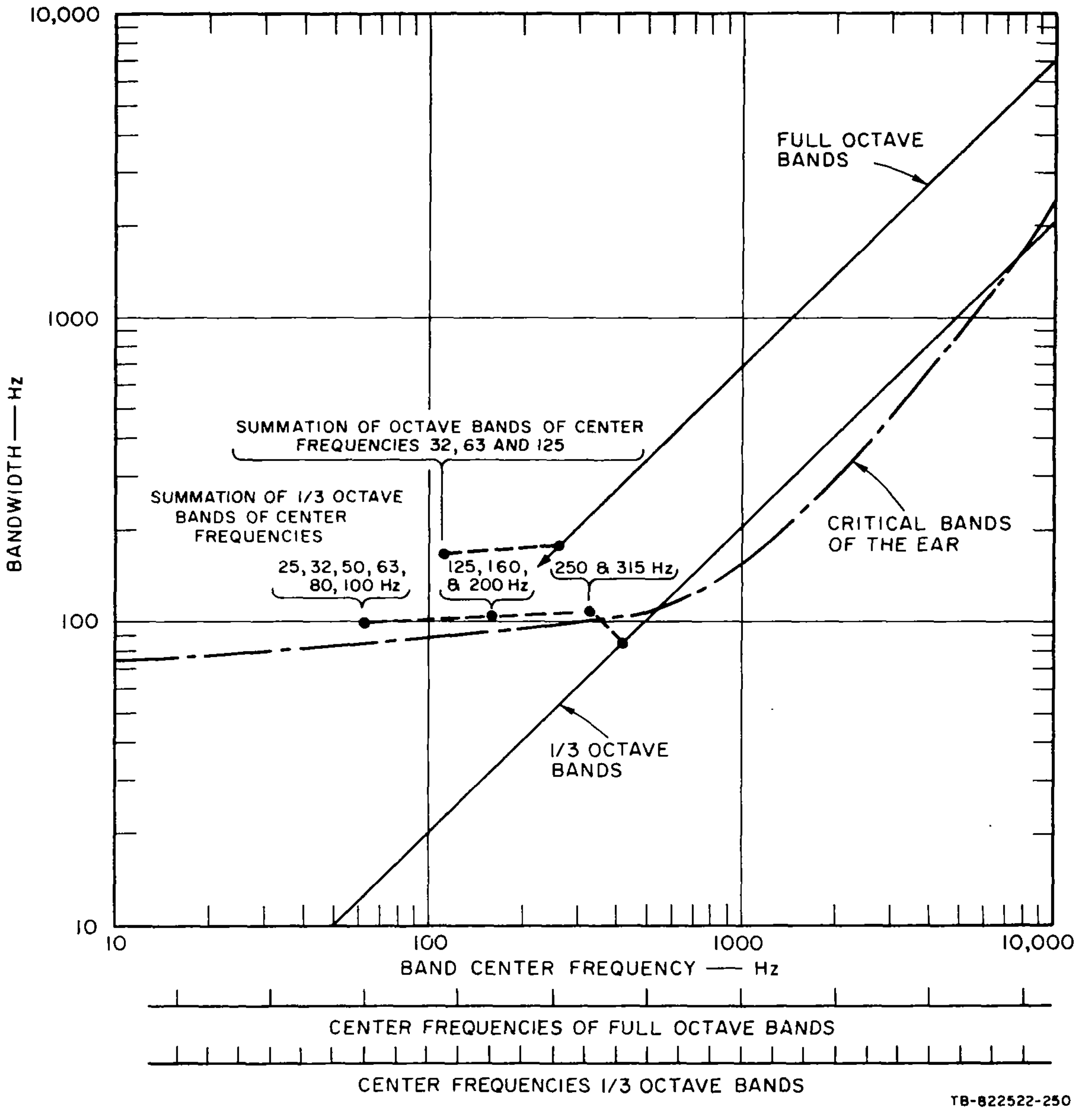

FIGURE 2 SHOWING RELATION BETWEEN CRITICAL BANDS OF THE EAR AND WIDTHS OF FULL OCTAVE AND 1/3 OCTAVE BANDS. Also shown is suggested groupings of octave and 1/3 octave bands below 355 Hz to make these bands below 355 Hz proportional to critical bands of the ear.

This deduction is consistent with the equal noisiness contours found by Wells. It is seen in Fig. 1 that Wells found the lower frequency region to be generally of lesser importance than was found from the narrow band-determined noy contours of Kryter and Pearsons. Wells' contours were based on judgments of very broadband random noise spectra shaped until all parts of it seemed to be contributing equally to its overall noisiness.

Procedures and Frequency Weightings for Obtaining Units of PNL

Band Spectra

It is herein proposed that the perceived noise level of a sound be calculated from 1/3 or full octave band spectra that are modified in the frequency region below 355 Hz as shown in Fig. 2. The procedural change is incorporated in "Step 2" given in the appendix.

Proceed from Step 2 to calculate PNL in accordance with procedures given in the appendix or in several publications.[1,14,28] In the text to follow we will call PNdB that are based on Step 2 as PNdB-M, and when Step 2 is not used, as PNdB. Fortunately this new procedure does not require any modification of presently used pure-tone correction procedures inasmuch as these corrections are zero or near zero in the affected frequency region. Note that this new procedure provides appropriate noy values, according to theory, regardless of whether broadband or narrow band sounds are being evaluated; that is, a sound consisting solely of a 1/3 octave band of random noise at, say 125 Hz, would by this new procedure, as by the old procedure, receive the same noy value.

Phons (Stevens) is calculated from octave or 1/3 octave band spectra using the procedures described in references 2 and 29. As aforementioned, the band summation procedure used for calculating PNdB is based on that proposed by Stevens for loudness level.

Frequency Weighting for Sound Level Meters

Sound level meters with particular frequency-weighting networks are sometimes used as a means of estimating the perceived noise level of a sound. It has been suggested[12] that such a frequency weighting be the converse of the 40-noy contour, as shown by D_1 in Fig. 3. Adjusting this weighting below 355 Hz according to the critical band concept would result in the D_2 weighting as shown in Fig. 3. Also shown in Fig. 3 are the familiar A, B, and C loudness-weighting and a contour D_3 which was

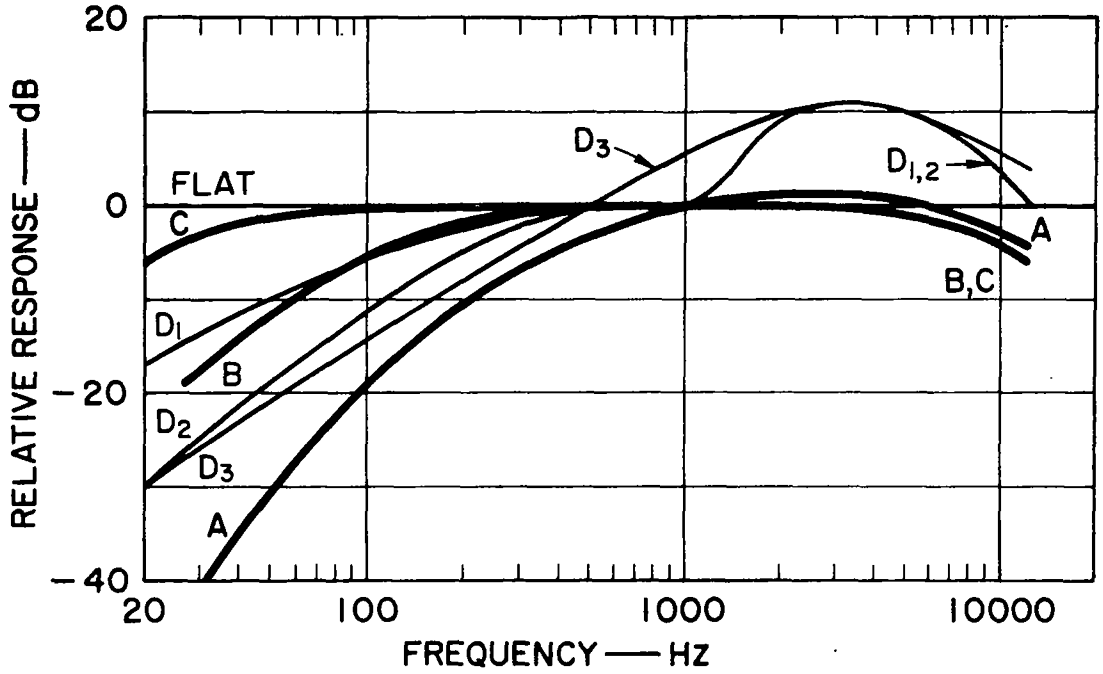

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FIGURE 3 FREQUENCY WEIGHTINGS FOR SOUND LEVEL METER. Weightings A, B, and C are for loudness (S1.4, 1961, USASI, 10 E. 40th Street, New York, N.Y.). Weightings D_1, D_2, and D_3 have been proposed for annoyance of perceived noisiness. D_3 is proposed by Young and Peterson[32] is plotted 6 dB above its normal reference *to show its close relation to* D_2 *at low and high frequencies.*

proposed (and called [RC]) by Young and Peterson.[32] The D_3 weighting has been moved in Fig. 3 upward by 6 dB at all frequencies from the usual levels used for plotting weighting functions (namely setting tham all to have equal weight at 1000 Hz) in order to make easier its comparison over all frequencies with the D_1 and D_2 frequency weightings.

It might be noted that weighting D_1 would still be the most appropriate one to be used in the evaluation of the relative noisiness of sounds consisting primarily of single octaves or 1/3 octave bands of energy, and would be appropriate for broadband sounds whose energy is predominately above 355 Hz. However, inasmuch as most noises of common interest are broadband, D_2, which makes allowance for the critical bandwidths of the ear below 355 Hz, would seem to be more practical and generally useful weighting to use with sound level meters. Some data on the relative accuracy of D_1, D_2, and D_3 in estimating the judged perceived noisiness will be given below.

To determine the relative accuracy of the different units of physical measurement for predicting the judged perceived noisiness of complex sounds it has been customary to compare the judgment data with Peak or Max PNLs. Peak PNLs are calculated from the highest band levels, as measured on a typical root-mean-square sound pressure level meter, present at any time during the occurrence of a sound. A PNL calculated from these levels is sometimes called a Peak PNL, sometimes a Composite PNL. Max PNLs are calculated from those band levels present at the 0.5-sec interval in time when the PNL calculated or measured for the successive such periods reaches its highest value. Effective PNLs represent the PNLs found in successive 0.5-sec intervals of time integrated over the duration (usually between the times PNL is less than 10 PNL below the maximum PNL) of a sound minus a constant for some specified reference duration. Later some reference will be made to a unit called Estimated Effective PNL (EEPNL). EEPNL is obtained by adding to the Peak or Max PNL of a sound a number that is 10 $\log_{10}$ duration (in secs) divided by a reference duration.

The subscripts on certain PNdB units, to be cited later, of t_1 and t_2 refer to so-called tone-correction procedures, t_1 being that proposed by Kryter and Pearsons[16] and t_2, that proposed by Sperry of the FAA.[28] Also, it is herein proposed (on the basis of laboratory findings of Nixon, von Gierke, and Rosinger,[20]) that a correction to calculated EPNL was appropriate in order to account for the fact that the noise in the period of buildup in intensity is judged more annoying than is the noise in the decreasing period, even though the durations of the two periods are comparable. This has been labeled "onset correction" and its magnitude is found by reference to Fig. 4. When the onset correction is used, the subscript 0 is added to the unit involved.

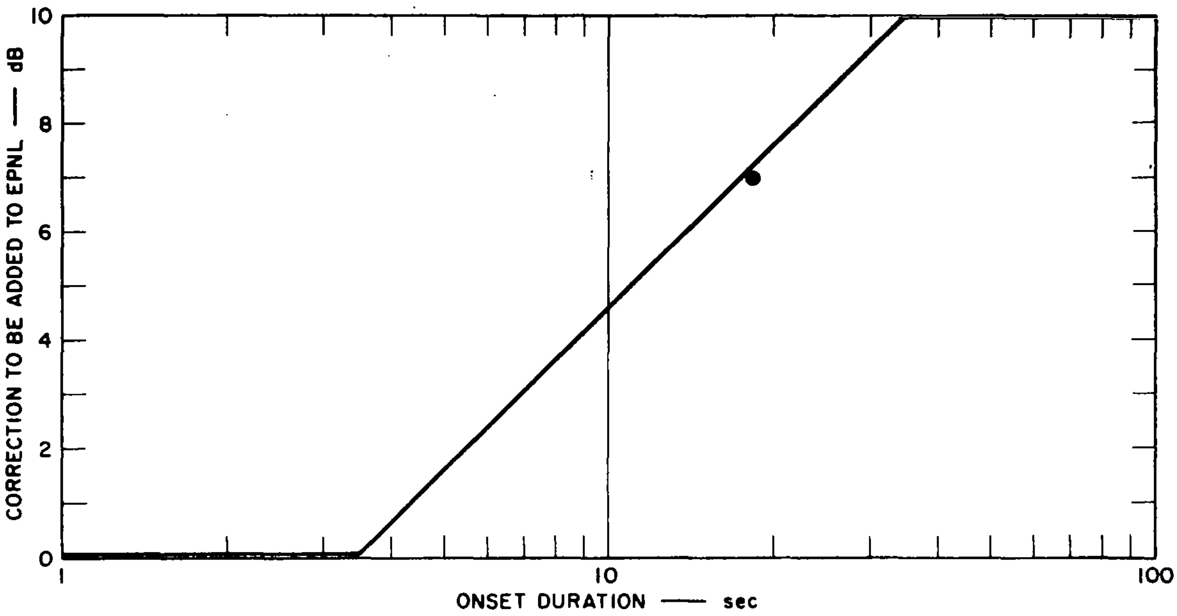

FIGURE 4 CORRECTION TO EPNL FOR CONTRIBUTION TO PERCEIVED NOISINESS OF ONSET DURATION OF NON-IMPULSIVE SOUNDS. The data plot is from Nixon, von Gierke, and Rosinger[20] plotted against a suggested standard onset duration of 3.5 secs.

Comparison of Calculated and Judged Perceived Noisiness

Various evaluations of the predictiveness of units of Peak or Max PNL (including loudness level used as a unit of PNL) for judged noisiness have been somewhat inconsistent from one group of noises and calculation procedures to another. Young and Peterson[32] recently recalculated the relative accuracy with which a number of these units predicted the results of a number of previously published judgment data on the perceived noisiness of aircraft noise. They found, as have others, that the latest versions of Max PNdB, Phons, and certain overall frequency-weighting networks predicated the results of the judgment tests with a very similar degree of average accuracy.

It is unfortunate that in nearly all of the published studies of the judged perceived noisiness or loudness of real-life noise, measurements of the band spectra that were present preceding and following the Peak or Max levels were not usually made or, if made, not reported. The duration and changes in spectra during the occurrence of a noise undoubtedly contribute to its judged perceived noisiness. As we shall see later these variables can make possible some somewhat spurious and misleading conclusions about how well a given unit of Peak or Max PNL predicts subjective perceived noisiness of a given sound or sounds.

In an attempt to determine which of these various units of measurement best predicts judged perceived noisiness of, primarily, aircraft noise, a somewhat detailed examination is made below of judgment data that can be related to Max PNL units, and data that permit the use of both Max and Effective PNL units.

Max PNL

In Table I are presented all the paired-comparison, equal noisiness data we could find that permits a comparison between judged perceived noisiness of primarily aircraft noise and Max PNL.

The judgment data were obtained in the various studies, as indicated, and the objective perceived noise levels were calculated from 1/3 or octave band spectra of the noises by means of computer routines. When not available at Stanford Research Institute or reported in the published literature, the band spectra were kindly furnished to us by the various investigators.

It is seen in Table I that, on the average, taking into account the critical bandwidth of the ear below 355 Hz either by frequency bands (PNdB-M) or overall frequency weighting (D_2) improves the general accuracy of the units of measurement in the prediction of judged perceived noisiness; that is, on the average dB(D_2) does slightly better than dB(D_1) and dB(D_3), and PNdB-M does better than PNdB. Improvements of 2-3 dB are noted in the Wallops tests when low-frequency aircraft noise (fixed-wing propeller [1049G] and helicopter) was judged against the higher-frequency noise from jet aircraft, such as the 880. As might be expected, the results of D_2 and PNdB-M with the jet aircraft vs jet aircraft noises did not differ appreciably from the results for D_1 and PNdB, respectively.

Ideally, the differences between the physical units and the psychological judgments should, of course, be zero. For any one case a difference can be due to: (1) a fundamental difference in the relative value ascribed to the spectral-temporal characteristics of noise by a unit of physical measurement and by the human listeners, and (2) experimental error, either in the physical measurements and treatment of those data, and/or in subject unreliability.

Table I

SHOWING THE AVERAGE DIFFERENCE BETWEEN REFERENCE AND COMPARISON NOISES (Col. D) and STANDARD DEVIATION (Col. S)
OF THE DIFFERENCES FOR EACH UNIT OF MAX PNL, 136 AIRCRAFT, 1 DIESEL TRAIN, AND 6 FILTERED RANDOM NOISES
From Kryter[462]

Experiment		Max dB(D_2)		Max PNdB-M		Max Phons		Max PNdB		PNdB$_{t_1}$M		PNdB$_{t_2}$M		dB(D_1)		PNdB$_{t_1}$		PNdB$_{t_2}$		dB(D_3)		dB(A)		dB(C)	
	N	(D)	(S)	(D)	(S)	(D)	(S)	(D)	(S)	(D)	(S)	(D)	(S)	(D)	(S)	(D)	(S)	(D)	(S)	(D)	(S)	(D)	(S)	(D)	(S)
Copeland et al[159]	3	1.0	1.1	1.1	1.8	1.2	2.8	1.3	2.5	1.1	1.8	2.1	1.1	1.9	2.2	1.3	2.5	-1.8	0.8	-6.7	1.2	0.6	1.3	4.0	8.1
Robinson and Bowsher[687]	5	0≠	1.6	0	1.5	0	1.5	0	1.4	0	1.2	0	2.6	0	1.7	0	1.0	0	2.5	0	2.1	0	2.0	0	3.2
Pearsons, Helio-S[610]	8	0.4	1.5	-0.4	1.6	-0.8	1.7	-0.9	1.7	-0.9	1.5	0.1	1.8	0.1	2.2	-1.3	1.7	-0.4	1.8	1.6	1.4	1.0	1.8	-0.7	3.7
Pearsons, Helio-D[610]	8	1.5	2.6	1.1	2.8	0.4	2.5	0.6	2.8	0.7	2.8	0.1	3.0	0.9	3.1	0.2	2.7	-0.4	3.0	2.6	2.5	2.3	2.8	0.4	4.4
Hinterkeuser, et al[373]	12	2.6	3.7	2.0	3.9	1.4	3.4	1.9	4.0	2.0	3.9	2.4	4.0	1.4	4.1	1.9	4.0	2.2	4.2	3.4	3.5	3.7	3.8	-0.7	5.3
Ollerhead[592]	35	1.9	3.5	-0.6	3.4	-1.8	3.1	-2.1	3.5	-1.1	3.4	4.0	3.8	0.6	3.5	-2.5	3.5	2.5	3.9	7.0	3.7	4.9	3.5	-4.4	5.0
Kryter - Indoor[444]	10	4.0	2.8	3.9	2.2	3.9	2.2	4.4	2.5	3.9	2.2	3.6	2.3	4.9	3.3	4.4	2.5	4.0	2.7	1.2	1.7	3.4	2.9	8.9	6.0
Kryter - Outdoor[444]	5	3.5	0.6	3.7	0.7	4.0	1.0	3.7	1.0	3.7	0.7	4.0	1.7	3.9	1.0	3.7	1.0	4.0	2.0	2.7	1.2	5.1	1.4	9.0	4.8
Kryter and Pearsons[465] Tbl. 1A	4	-1.6	1.9	-1.3	3.0	-2.0	2.8	-1.5	3.1	-1.3	3.0	-2.2	2.2	-1.8	2.3	-1.5	3.1	-2.4	2.3	0.2	1.5	0.6	3.3	-1.9	7.0
Kryter and Pearsons[465] Tbl. 1B	4	-1.0	2.5	-1.0	1.9	0.2	2.2	-0.9	1.8	-1.0	1.9	-1.0	3.2	-1.3	2.6	-1.3	2.0	-1.3	3.2	0.2	2.2	0.2	1.5	-1.8	5.4
Kryter and Pearsons[465] Tbl. 2A	4	5.7	0.9	-7.4	1.1	7.2	1.0	7.4	1.2	7.4	1.1	5.9	1.5	6.6	0.9	7.4	1.2	5.9	1.6	4.6	1.1	7.8	1.8	14.8	2.8
Kryter and Pearsons[465] Tbl. 2B	4	1.6	2.5	2.7	1.6	3.9	1.2	3.6	1.4	2.7	1.6	2.9	2.9	3.1	2.4	3.6	1.4	3.8	2.7	-0.3	2.2	2.8	1.5	11.8	0.7
Kryter and Pearsons[466]	8*	4.6	2.4	2.5	2.5	4.3	2.0	2.2	2.6	2.0	3.2	4.5	1.7	4.2	2.4	1.6	3.2	4.2	1.5	9.3	2.3	10.7	2.0	8.7	6.1
Hecker and Kryter[361] Tbl. XIV	11	-0.8	2.1	-3.2	1.6	-3.0	1.8	-3.8	1.6	-4.5	1.9	1.7	1.1	-0.9	2.0	-5.0	1.7	1.2	1.1	2.1	2.1	3.3	2.3	2.2	3.6
Kryter, Johnson and Young Edwards[473]	4	1.9	1.9	1.5	1.7	2.3	1.9	1.5	1.7	-3.9	3.0	-1.9	1.7	2.1	2.1	-3.7	2.3	-1.9	1.2	1.8	1.3	4.0	2.4	5.4	5.1
Kryter, Johnson and Young Wallops (880 reference)[474]	12	0.1	4.0	2.9	3.9	1.3	4.2	1.8	4.0	2.9	4.3	2.7	3.3	1.0	3.8	3.2	4.4	2.5	3.3	-0.7	3.6	-1.2	3.3	1.9	5.6
Kryter, Johnson and Young Wallops (1049G reference)[474]	6	-0.9	2.9	2.6	3.0	-5.8	2.6	-5.6	2.6	-4.4	3.8	-4.5	3.7	-5.3	2.7	-5.4	3.4	-4.8	3.3	-3.0	2.1	-6.1	2.0	-8.1	5.5
N =	143																								
Aver. Dif. (D)		1.6		0.6		0.3		0.1		0.2		2.0		1.1		-0.2		1.6		3.1		3.1		1.1	
Stand. Dev. (S)			3.3		3.6		3.8		4.0		4.0		3.7		3.7		4.3		3.7		4.2		4.3		7.3
Percentage of time a unit will predict judged PNL within ±2		41		41		40		38		38		36		39		35		37		28		28		20	
" " " " ±4		73		73		70		68		68		66		65		65		61		53		53		42	

≠ One jet aircraft, one diesel train, and six filtered random noises.

* In the Robinson and Bowsher study each of the five noises was judged against each of the other noises and the average difference is therefore set at 0.

As important as the average differences are the standard deviation values. It is, of course, possible for the average difference taken over a wide variety of noises to be near zero and yet have a relatively large standard deviation if some of the differences are positive and some negative with respect to a given reference noise. The uncertainty in predicting the subjective judgments by means of a given unit of measurement is a function of both the average difference and the deviation of these differences from a mean difference.

Relative Average Accuracy of the Units

Being based on the same fundamental band or overall spectral physical measures, the various units of PNL tend to be highly correlated, e.g., they all increase and decrease in value as the sound pressure level of a given noise increases or decreases and all the units give more weight to the mid-to-higher than lower frequencies. Because of this correlation factor the statistic "t" that is commonly used for evaluating the statistical significance between test data give results, when applied to these data, that are somewhat difficult to interpret in a meaningful way. For example, the t test, see Tables II and III, show that, except for dB(C), the average differences between all pairs of the units differ from each other at the 5% level of statistical confidence or probability. At the 1% level of probability, the mean difference in prediction accuracy between only a few pairs of units, in addition to dB(C), appear to be not different. It would appear from the t statistic that each of the units of measurement, except dB(C), has some unique relations between sets of pairs of reference and comparison noises, although the average differences for each unit taken over all the reference and comparison noises are not greatly different from each other. As a result the average of the differences between the physical unit values of the reference and comparison noises does not provide a sufficient yardstick for choosing the units of physical measurement that best predict the psychological judgments, and the standard deviations of these differences are not, according to the t test, particularly useful for this purpose because of the aforementioned correlation factor.

Relative Accuracy in Terms of Variability

A search was made by a colleague, P. J. Johnson, for a procedure whereby one could evaluate the statistical significance of differences between the variability (standard deviations) in contrast to the average accuracy of the various units of measurement. Because the various units, as aforementioned, are not independent of each other, the standard

Table II TEST ("t") OF STATISTICAL SIGNIFICANCE OF DIFFERENCES BETWEEN TWO UNITS OF PNL IN THEIR PREDICTION OF JUDGED PNL FOR DATA IN TABLE I

Units of Measurement*		Aver. Difference (d)	r	Standard Deviation of Differences [s(d)]	t**	Units of Measurement*		Aver. Difference (d)	r	Standard Deviation of Differences [s(d)]	t
A	C	2.0	.53	6.2	3.7	D2	T1	1.8	.74	2.9	7.2
A	D1	1.9	.76	2.8	8.2	D2	T2	-0.0	.83	2.1	-0.2
A	D2	1.5	.76	2.8	6.4	D2	PNM	1.0	.87	1.8	6.6
A	D3	-0.0	.85	2.3	-0.2	D2	MT1	1.3	.80	2.4	6.6
A	PHN	2.8	.63	3.5	9.7	D2	MT2	-0.5	.83	2.1	-2.8
A	PN	2.9	.58	3.8	9.2	D3	PHN	2.8	.34	4.6	7.4
A	T1	3.2	.45	4.5	8.6	D3	PN	3.0	.32	4.8	7.4
A	T2	1.5	.76	2.8	6.2	D3	T1	3.3	.25	5.2	7.5
A	PNM	2.5	.64	3.4	8.7	D3	T2	1.5	.68	3.2	5.6
A	MT1	2.8	.49	4.2	8.1	D3	PNM	2.5	.46	4.1	7.3
A	MT2	1.0	.76	2.8	4.4	D3	MT1	2.9	.37	4.6	7.4
C	D1	-0.0	.74	5.2	-0.0	D3	MT2	1.0	.77	2.7	4.7
C	D2	-0.5	.48	6.4	-0.9	PHN	PN	.1	.97	.9	1.8
C	D3	-2.0	.06	8.2	-2.9	PHN	T1	.4	.90	1.9	2.8
C	PHN	.8	.84	4.6	2.2	PHN	T2	-1.3	.76	2.6	-6.0
C	PN	1.0	.78	4.9	2.4	PHN	PNM	-0.3	.95	1.2	-3.2
C	T1	1.3	.68	5.4	2.9	PHN	MT1	.0	.87	2.0	.1
C	T2	-0.5	.55	6.1	-1.0	PHN	MT2	-1.8	.64	3.2	-6.6
C	PNM	.5	.71	5.4	1.2	PN	T1	.3	.95	1.4	2.7
C	MT1	.9	.59	5.9	1.8	PN	T2	-1.5	.76	2.7	-6.6
C	MT2	-0.9	.41	6.7	-1.7	PN	PNM	-0.5	.98	.9	-6.3
D1	D2	-0.5	.91	1.5	-3.6	PN	MT1	-0.1	.92	1.6	-0.9
D1	D3	-2.0	.57	3.7	-6.3	PN	MT2	-1.9	.64	3.3	-7.1
D1	PHN	.9	.92	1.5	6.7	T1	T2	-1.8	.75	2.9	-7.2
D1	PN	1.0	.92	1.6	7.5	T1	PNM	-0.8	.92	1.7	-5.5
D1	T1	1.3	.83	2.4	6.6	T1	MT1	-0.4	.98	.9	-5.9
D1	T2	-0.5	.87	1.9	-3.0	T1	MT2	-2.2	.63	3.5	-7.6
D1	PNM	.5	.95	1.2	5.2	T2	PNM	1.0	.80	2.3	5.4
D1	MT1	.9	.85	2.1	4.9	T2	MT1	1.4	.77	2.6	6.3
D1	MT2	-0.9	.81	2.3	-4.8	T2	MT2	-0.5	.97	.9	-6.2
D2	D3	-1.5	.70	3.0	-6.1	PNM	MT1	.3	.94	1.4	2.8
D2	PHN	1.3	.78	2.4	6.4	PNM	MT2	-1.5	.73	2.7	-6.6
D2	PN	1.4	.80	2.4	7.1	MT1	MT2	-1.8	.72	2.9	-7.3

N = 143 Significant difference at 5% level of confidence if t less than -1.9 or greater than 1.9

*A, dB(A); C, dB(C); D_1, dB(D_1); D_2, dB(D_2); D_3, dB(D_3); PHN, Phon (Stevens), PN, PNdB; T1, $PNdB_{t_1}$; T2, $PNdB_{t_2}$; PNM, PNdB-M; MT1, $PNdB_{t_1}$ M; MT2, $PNdB_{t_2}$ M.

** The test statistic does not require the assumption of independence of the two units (see W. J. Dixon and T. J. Massey, Jr., "Introduction to Statistical Analysis," McGraw-Hill, New York, 1967)

$$t = \frac{\bar{d}\sqrt{N}}{s(d)} \quad \text{where} \quad \bar{d} \text{ is } \bar{x}_1 - \bar{x}_2,$$

$$\text{and} \quad s(d) = \sqrt{\frac{\sum_{i=1}^{N} (x_{1_i} - x_{2_i})^2 - N(\bar{x}_1 - \bar{x}_2)^2}{N-1}}$$

$$\text{or, as sometimes written} \quad \sqrt{s_{x_1}^2 + s_{x_2}^2 - 2r s_{x_1} s_{x_2}}$$

$$\text{where} \quad s(x) = \sqrt{\frac{\sum_{i=1}^{N} x_i^2 - N(\bar{x})^2}{N-1}} \quad \text{and} \quad r = \frac{\sum_{i=1}^{N} x_{1_i} x_{2_i} - N\bar{x}_1\bar{x}_2}{(N-1)s(x_1)s(x_2)}$$

x_1 is the difference between the comparison and reference noise when judged equal for one measure (e.g., dB(A))

x_2 is the difference between the comparison and reference noise when judged equal for a second measure (e.g., dB(C))

Table III

UNITS OF MAX PNL THAT ARE NOT SIGNIFICANTLY DIFFERENT FROM EACH OTHER IN THEIR PREDICTIONS OF THE JUDGED PERCEIVED NOISINESS OF 136 AIRCRAFT, 1 DIESEL TRAIN, AND 6 FILTERED RANDOM NOISES

(N = 143. See Table I and Table II)

1% Probability	5% Probability
that dB(C) is not different than:	that dB(C) is not different than:
D_1, D_2, Phon, PNdB, PNdB_{t_2},	D_1, D_2, PNdB_{t_2}, PNdB-M,
PNdB-M, $\text{PNdB}_{t_1}\text{M}$, PNdB-M_{t_2}	$\text{PNdB}_{t_1}\text{M}$, $\text{PNdB}_{t_2}\text{M}$
that $\text{dB}(D_2)$ is not different than: PNdB_{t_2}	All other pairs of units differ significantly from each other at greater than 5% Level of Probability
that Phon is not different than: $\text{PNdB}_{t_1}\text{M}$	
that PNdB is not different than: $\text{PNdB}_{t_1}\text{M}$	
All other pairs of units differ significantly from each other at greater than 1% Level of Probability.	

so-called "f" test is not appropriate. Young and Peterson[30] employed, for comparing standard deviations of data similar to those at hand, a statistic called "M" which is somewhat like the t test; however, this statistic, as all others we were able to find, are not appropriate for comparing the standard deviation data because of the interdependence of the data.

Rather than attempt to use statistical tests of significance of the relative average accuracy and variability in accuracy of the different units of measurement in their prediction of judged perceived noisiness, P. J. Johnson and I developed the following argument and procedure. Let us presume that a person has taken physical measures of any pair of aircraft noises chosen at random from those tested in these studies and that these measures are, in turn, converted (or are made directly) into one of the Max units of measurement. One obvious question to be asked is which unit will be in closest agreement and how often, with respect to the judged perceived noisiness of the aircraft sounds.

To answer this question we have tabulated in Tables I and IV the percentage of time the value of each of the units of measurement would be within ±2 and ±4 "dB" units of the judged perceived noise level for any aircraft noises chosen at random from those tested. This percentage is the normal probability to be expected based on the number or portion of standard deviations of a given unit to be found between the average difference typical for that unit and the criterion of ±2 or ±4 units from exact agreement with subjective judgments. The general concept is illustrated in Fig. 5.

The bottom rows of Table I and columns 3 and 4 of Table IV can be interpreted as showing the percentage of times a given unit will have an "accuracy" in predicting judged perceived noisiness of ±2 or ±4 units of measurement (other difference criteria could, of course be utilized). For example, about the same percentage of the time (53%) Max dB(A) is within ±4 dB units, Max dB(D_2) (51%) is within ±2.5 dB units; or, in other terms, Max dB(D_2) will predict the judged perceived noisiness of about 50% of the aircraft noises within a range of 5 dB units, and Max dB(A) within a range of 8 dB units. As with all statistics, the practical significance of the differences in the summary percentage figures, as well as the standard deviation values, are a matter of judgment and the circumstances in which noise evaluations are to be made; however, an improvement of but ±0.5 (a range of 1) in "dB units" would represent a difference of about 20% in acoustical power and from a practical point of view would probably be significant. It might be noted that the average judgments of groups of 50 or more people about the relative perceived

Table IV

AVERAGE OF RESULTS OF 16 STUDIES OF JUDGED PERCEIVED NOISINESS
143 Noises. (See Table I)

Rank	Noise Measurement	% Times Between -2 and +2	% Times Between -4 and +4	Average %	Average Difference	Standard Deviation
1	Max dB(D_2)	41	73	57	1.6	3.3
2	Max PNdB-M	41	73	57	0.6	3.6
3	Max Phons	40	70	55	0.3	3.8
4	Max PNdB	38	68	53	0.1	4.0
5	Max PNdB$_{t_1}$M	38	68	53	0.2	4.0
6	Max dB(D_1)	39	65	52	1.1	3.7
7	Max PNdB$_{t_2}$M	36	66	51	2.0	3.7
8	Max PNdB$_{t_1}$	35	65	50	-0.2	4.3
9	Max PNdB$_{t_2}$	37	61	49	1.6	3.7
10	Max dB(D_3)	28	53	41	3.1	4.2
11	Max dB(A)	28	53	41	3.1	4.3
12	Max dB(C)	20	42	31	1.1	7.3

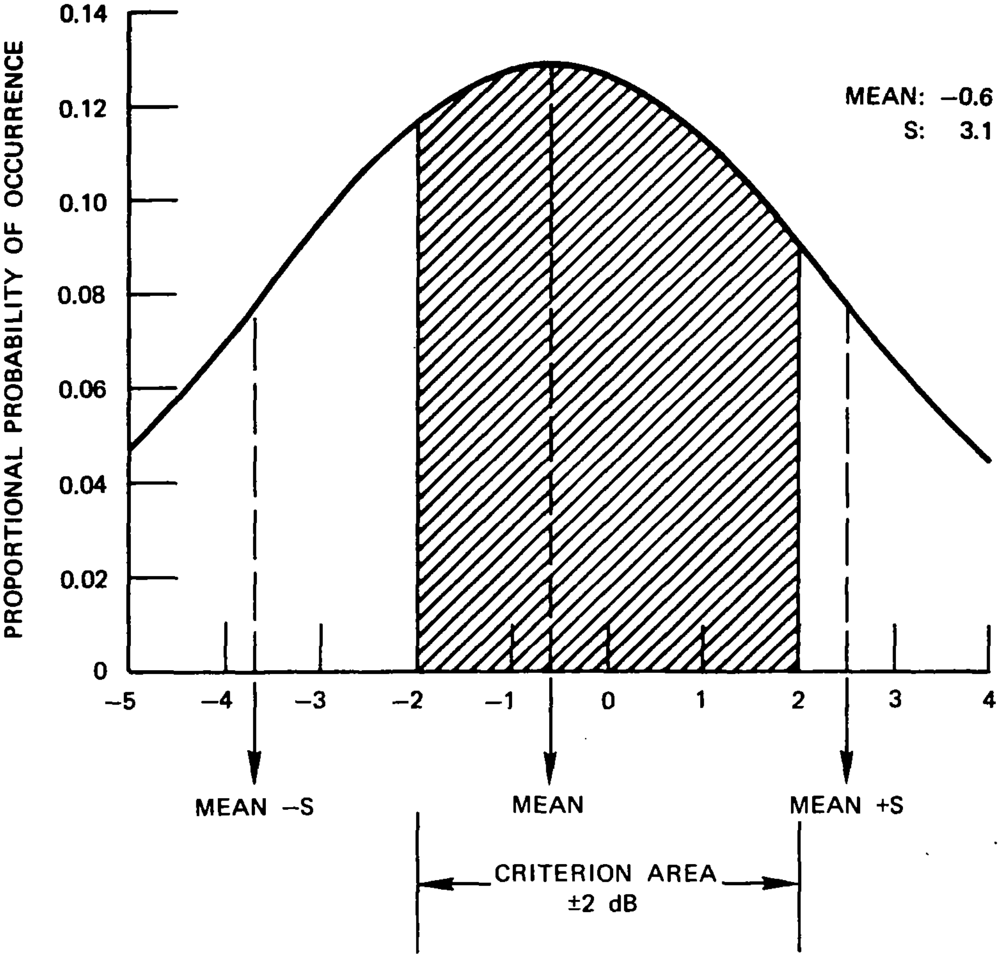

FIGURE 5 SCHEMATIC DIAGRAM SHOWING STATISTICAL METHOD USED FOR EVALUATING ACCURACY OF UNITS OF MEASUREMENT FOR ESTIMATING JUDGED PERCEIVED NOISINESS. Zero (0) on the scale is "true" subjective rating given by listeners; a -1 indicates that the physical measurement (PNdB, dB(D), Phon, etc.) underestimates the judged noisiness by a 1 "dB" unit, a +1 indicates an overestimation, etc. The curve is an example of the expected accuracy of a unit of measurement (EPNdBM) that has been found by test to have given average difference of -0.6 from judged noisiness and a given standard deviation of those differences of 3.1.

noisiness of two aircraft noises usually has a test-retest reliability such that a difference of more than .5 dB in noise level is perceived with a statistical level of confidence exceeding 1%; this follows from the fact that standard deviations of about 3 dB, and product moment correlations of about 0.5 are typical for these judgment data.

Max and Effective PNL, Including Tone and Onset Duration Corrections

Judgment tests of aircraft noise conducted at Wallops[18] provide the only extensive field tests for which are available the acoustical data that permit a comparative evaluation of the relative accuracy of both Max and Effective units of PNL in predicting judged perceived noisiness. Tables V and VI summarize in this regard the data obtained at Wallops.

Interpretation of the Data

If one accepts: (1) the criterion that a change of .5 dB in nominal sound pressure level is a matter of practical physical importance, and (2) a criterion that there must be agreement between judged and predicted perceived noisiness, some given percentage of the time it follows that a difference in predictive accuracy between two units of about 4% of the time is significant. This follows from the function in Fig. 6, where the change in percentage of time the average unit of prediction will be within a given range of accuracy is plotted for the average of the standard deviations and differences found in the Wallops study. It is seen that the slope of this function is such that a change of .5 dB in range of accuracy in prediction is equal to a change of 4 percentage points.

On the basis of this method of evaluation it would appear from a consideration of all the data presented in Tables I, IV, V, and VI that the following general conclusions are justified:

1. There is no significant difference between Phons (Peak or Max) and PNdB (Peak or Max). Peak units may possibly be slightly better than Max units.

2. PNdB-Ms (modified to take into account critical bandwidth of the ear at low frequencies) are significantly better on the average than the unmodified PNdB.

3. Modifying the overall frequency weighting (the 40-noy contour) to take into account the critical bandwidth of the ear at low

Table V

AVERAGE DIFFERENCES AND STANDARD DEVIATIONS OF PHYSICAL NOISE MEASUREMENTS OF REFERENCE AND ALL COMPARISON AIRCRAFT NOISES WHEN JUDGED EQUALLY NOISY OR UNACCEPTABLE. From Kryter, Johnson and Young[18]

Judgments and physical measurements made outdoors. Thirty-five listeners, 18 comparison aircraft. Also shown are percentage of time the various units of noise measurement would agree with ±2 and ±4 units of judged equal perceived noisiness.

Col. 1 Rank (see Col. 5)	Col. 2 Measure	Col. 3 % Times Between -2 and +2	Col. 4 % Times Between -4 and +4	Col. 5 Average of Percentages (Col. 3 and 4)	Col. 6 Average Difference	Col. 7 Standard Deviation
1	EPNdB$_{t_1}$M$_o$	52	84	68	-0.8	2.7
2	EdB(D$_2$)$_o$	46	83	64.5	-2.1	2.0
3	EPNdB-M	48	80	64	-1.3	2.8
4	EPNdB$_{t_2}$M$_o$	48	80	64	-1.3	2.8
5	EdB(D$_2$)	47	81	64	-1.9	2.3
6	EPNdB$_{t_1}$M	47	79	63	-0.6	3.1
7	EPNdB-M$_o$	49	77	63	-1.6	2.5
8	EPNdB$_{t_2}$M	46	78	62	-0.9	3.1
9	EPNdB$_{t_1 o}$	45	78	61.5	-1.1	3.1
10	EEPNdB$_{t_1}$M	45	77	61	-0.9	3.2
11	Max dB(D$_3$)	42	74	58	-1.4	3.3
12	EPNdB$_{t_1}$	41	71	56	-0.8	3.7
13	Peak dB(D$_2$)	40	71	55.5	-0.9	3.7
14	EdB(D$_1$)$_o$	40	71	55.5	-2.2	2.9
15	EdB(D$_1$)	39	70	54.5	-1.9	3.3
16	EPNdB	38	69	53.5	-1.6	3.6
17	EPNdB$_{t_2}$	38	68	53	-1.2	3.8
18	Max dB(D$_2$)	37	67	52	-1.1	4.0
19	EEPNdB$_{t_1}$	37	67	52	-1.1	4.0
20	EEPNdB$_{t_2}$	36	64	50	-1.3	4.2
21	EdB(D$_3$)	30	69	49.5	-3.0	2.0
22	Max PNdB$_{t_2}$M	34	63	48.5	0.1	4.5

Table V (concluded)

Col. 1 Rank (see Col. 5)	Col. 2 Measure	Col. 3 % Times Between -2 and +2	Col. 4 % Times Between -4 and +4	Col. 5 Average of Percentages (Col. 3 and 4)	Col. 6 Average Difference	Col. 7 Standard Deviation
23	Max dB(D_1)	33	61	47	-1.1	4.6
24	EEPNdB	33	61	47	-1.9	4.2
25	Max PNdB-M	32	60	46	-1.4	4.5
26	Max PNdB_{t_2}	33	59	46	0.1	4.8
27	Peak PNdB	32	60	46	-0.3	4.8
28	Max dB(A)	31	60	45.5	-2.8	3.7
29	Peak Phons	32	58	45	-0.7	4.9
30	EdB$(D_3)_o$	28	61	44.5	-3.3	2.4
31	Max PNdB	31	58	44.5	-0.7	5.0
32	Max Phons	31	57	44	-1.0	5.0
33	EdB(A)	29	57	43	-3.4	3.1
34	Max $\text{PNdB}_{t_1}\text{M}$	29	54	41.5	0.4	5.4
35	EdB$(A)_o$	25	54	39.5	-3.7	2.8
36	Max PNdB_{t_1}	27	51	39	0.3	5.8
37	Max dB(B)	24	46	35	-2.4	6.3
38	Max dB(C)	21	41	31	-1.4	7.3

Table VI

SHOWING RELATION BETWEEN RESULTS WITH PHONS (Stevens) AND PNdB AND AVERAGE EFFECT OF VARIOUS MODIFICATIONS AND CORRECTIONS TO PNdB AND OVERALL FREQUENCY WEIGHTINGS

All score values are percentage of time a given unit of measurement would, for the 18 aircraft noises tested, fall within ±4 units of judged equal perceived noisiness. 35 listeners outdoors. From Kryter, Johnson and Young[18]

Units Calculated from 1/3-Octave Band Spectra

Max Phons	57%	Max PNdB	58%	Max PNdB$_{t_1}$	51%	EPNdB	69%	EPNdB$_{t_1}$	71%	EPNdB$_o$	(69)*%	EPNdB$_{t_1 o}$	78%	EEPNdB	61%	EEPNdB$_{t_1}$	67%
Peak Phons	58			Max PNdB$_{t_2}$	59			EPNdB$_{t_2}$	68			EPNdB$_{t_2 o}$	(78)*			EEPNdB$_{t_2}$	64
Aver.	58																
Max PNdB	58	Max PNdB-M	60	Max PNdB$_{t_1}$M	54	EPNdB-M	80	EPNdB$_{t_1}$M	79	EPNdB-M$_o$	77	EPNdB$_{t_1}$M$_o$	84	EEPNdB-M	(70)*	EEPNdB$_{t_1}$M	77
Peak PNdB	60			Max PNdB$_{t_2}$M	63			EPNdB$_{t_2}$M	78			EPNdB$_{t_2}$M$_o$	80			EEPNdB$_{t_2}$M	(74)*
Aver.	59																
										*Estimated, not calculated							

Units Calculated from Overall Frequency Weightings

dB(D$_1$)		dB(D$_2$)		dB(D$_3$)		dB(A)	
Max dB(D$_1$)	61	Max dB(D$_2$)	67	Max dB(D$_3$)	74	Max dB(A)	60
EdB(D$_1$)	70	EdB(D$_2$)	81	EdB(D$_3$)	69	EdB(A)	57
EdB(D$_1$)$_o$	71	EdB(D$_2$)$_o$	83	EdB(D$_3$)$_o$	61	EdB(A)$_o$	54
Aver.	67	Aver.	77	Aver.	68	Aver.	57

Average Effect of Summation over Frequency Range (Freq. Weighting plus Stevens' Band Summation vs. Freq. Weighting plus Sound Energy Summation)

All PNdBs and PNdB-Ms except for tone-corrected units	68
All PNdB$_t$s and PNdB$_t$Ms	71
All dB(D$_1$)s and dB(D$_2$)s	72
Aver. Improvement dB(D$_1$)s and dB(D$_2$)s	
vs. PNdBs and PNdB-Ms	4% pts
vs. PNdB$_t$s and PNdB$_t$Ms	1% pts

Average Effect of Frequency Modification for Critical Bandwidth of the Ear (M, D$_2$)

All PNdBs	66	All dB(D$_1$)	67
All PNdB-Ms	73	All dB(D$_2$)	77
Aver. Improvement	7% pts	Aver. Improvement	10% pts

Average Effect of Duration (Max vs. Effective (E) and Estimated Effective (EE)

All Max PNdBs and PNdB-Ms	58	All Max dB(D$_1$) and dB(D$_2$)	64
All EEPNdBs and PNdB-Ms	69	All EdB(D$_1$) and dB(D$_2$)	76
All EPNdBs and PNdB-Ms	76	Aver. Improvement	12% pts
Aver. Improvement Re/ Max:	EE 11% pts: E 18% pts		

Average Effect of Onset Duration Correction (o)

All EPNdBs and PNdB-Ms no onset correction	74	EdB(D$_1$) and dB(D$_2$) no onset correction	76
All EPNdBs and PNdB-Ms with onset correction	78	EdB(D$_1$) and dB(D$_2$) with onset correction	77
Aver. Improvement	4% pts	Aver. Improvement	1% pts

Average Effect of Tone Corrections

All PNdBs - no tone corrections	68
All PNdB$_{t_i}$ - tone-corrected	70
All PNdB$_{t_2}$ - tone-corrected	71
Aver. Improvement, t_1	2% pt
Aver. Improvement, t_2	3% pts

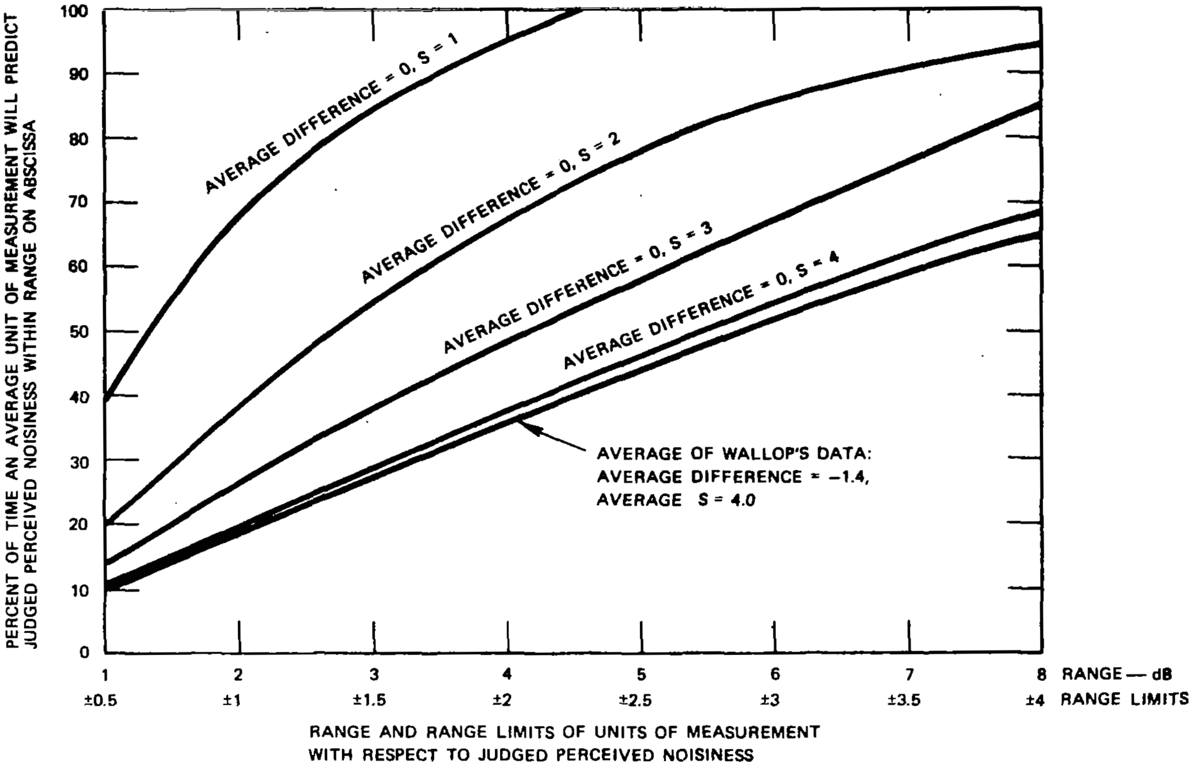

FIGURE 6 SHOWING PERCENTAGE OF TIME THE AVERAGE UNITS OF MEASUREMENT PREDICTED JUDGED PERCEIVED NOISINESS OF A VARIETY OF AIRCRAFT TESTED AT WALLOPS (Ref. 18) WITHIN THE RANGE OF UNIT ACCURACY GIVEN ON THE ABSCISSA

frequencies, D_2, provides a frequency weighting that is significantly better than D_1, D_3, or A.

4. Utilizing durational information (between the 10 PNL downpoints) by Estimated Effective (EE) units significantly improves the predictive accuracy of Max PNdBs and PNdB-Ms, and Effective (E) units are appreciably better than EE units.

5. EdB(D_1) or (D_2) are significantly better predictors than Max dB(D_1) or (D_2), respectively, but EdB(D_3) or EdB(A) are somewhat worse than Max dB(D_3) or Max dB(A), respectively.

6. The power summation over frequencies weighted according to the 40-noy contour dB(D_1) is on the borderline of being significantly better for predicting judged perceived noisiness than calculations based on band levels weighted according to the noy contours (PNdB) and the results then summed according to the formula proposed by Stevens for Phons and adopted for PNdB. About the same degree of superiority was found between dB(D_2) and PNdB-M.

7. The application of either t_1 or t_2 tone corrections gave inconsistent results with there being no significant improvement over non-tone-corrected units, on the average.

8. The application of the so-called onset duration correction provided no consistent improvement over non-onset duration corrected units.

It should be borne in mind that there was possibly present in all the studies reported above a certain amount of unavoidable experimental error due to subject variability, variability between acoustic spectra that was presumed by the experimenter to be the same (room or even outdoor acoustic conditions cause some variation in a sound as heard by subjects seated at different locations in a test room) errors in sound measurement or analysis, etc. Also, and perhaps more important, is that there were probably present differences in duration or tonal complexity amongst the sounds that could significantly influence the judgments but which do not necessarily affect the physical measurements, particularly those used for obtaining Max PNL.

Tonal Factors

For example, some of the data collected during the tests at Wallops seemed to indicate that Max PNL without tone corrections better predicted judged noisiness of a variety of aircraft noises than did Max PNL with tone corrections, as shown in Table I. However, examination of the spectra for some of the jet aircraft noise present in successive 0.5-sec intervals of time showed that some of the jet noises contained strong tonal components up to the moment the aircraft were nearly directly overhead (the tonal components were then shielded from the listeners by structures of the engine) and the band levels reached their maximum; whereas for some of the other flyovers of jet aircraft, because of differences in structure and/or flight attitude, the tones continued to be present through the maximum levels. Thus, the Max PNLs of the latter noises were corrected for tones but the Max PNLs of the former noises were not. The presence of tonal components during the onset and up to the maximum levels of the noise undoubtedly have considerable influence on the judged perceived noisiness so that the Max PNLs that contained no tone corrections underestimated the judged noisiness of these particular types of noise. The Max PNLs deliberately calculated without tone corrections for the two types of jet noises discussed, treated both noises the same and, therefore, fortuitously more correctly predicted judged relative noisiness than Max PNLs which gave tone corrections to one of the noises but not the other. That this is plausibly true is shown by the slightly greater accuracy of the Effective PNLs when tone-corrected than not tone-corrected.

Durational Factors

Another problem of attempting to evaluate the relative effectiveness of different units in predicting judged perceived noisiness is illustrated in Table VII. It is seen in Table VII that dB(C) is a better predictor of the judged noisiness of the sound from a fixed-wing propeller aircraft (a Super-Constellation vs that from a helicopter) than any of the other Max PNLs. These results, of course, appear to be inconsistent with the relative importance ascribed to different portions of the frequency scale for perceived noisiness.

The spectrum of the 204B helicopter was predominately low frequency (the highest band level was in the band centered at 63 Hz) which gave the helicopter noise relative to that of the fixed-wing aircraft a higher max level on dB(C) than on dB(A), dB(D), PNdB, or Phon. This relatively higher max level for the helicopter apparently compensated for the fact that the helicopter noise was of considerably longer duration than that of the fixed-wing aircraft, and for that reason judged noisier or less wanted. Table VII shows that the effective PNLs predict the judgments with considerably more accuracy than to Max PNLs.

Onset Duration

Perhaps of considerable importance to the judgment of the helicopter noise is the relative long duration of the noise during its onset or build-up phase. It would appear that the long onset duration made the helicopter noise more unacceptable than could be accounted for merely by the integration of the .5-sec PNLs over the total duration of the noise as reflected in the EPNLs.

Nixon, von Gierke, and Rosinger[20] have reported that increasing the onset duration of a sound relative to its total duration significantly

Table VII

DIFFERENCES IN UNIT VALUES (COMPARISON AIRCRAFT MINUS REFERENCE AIRCRAFT)
WHERE 50% OF THE LISTENERS PREFER THE COMPARISON AIRCRAFT AND 50% PREFER THE REFERENCE AIRCRAFT.

From Kryter, Johnson and Young[18]

35 Outdoor Listeners

Outdoor Physical Measurements

Reference Aircraft: 1049G (Super-Constellation) Meto Power
Comparison Aircraft: 204B Helicopter, Cruise Power

Max dB(A)	Max dB(B)	Max dB(C)	Max dB(D_1)	Max dB(D_2)	Max dB(D_3)	Max Phons	Max PNdB	Max PNdB$_{t_1}$	Max PNdB$_{t_1}$ M	Max PNdB$_{t_2}$	Peak dB(D_2)	Peak Phons	Peak PNdB	Max PNdB-M	Max PNdB$_{t_2}$ M
-8.5	-7.5	-2.5	-7.5	-4.5	-6.0	-5.5	-7.5	-7.0	-6.5	-7.0	-4.0	-4.0	-5.5	-7.0	-6.5

E_8 dB(A)	E_8 dB(A)$_o$	E_8 dB(D_1)	E_8 dB(D_1)$_o$	E_8 dB(D_2)	E_8 dB(D_2)$_o$	E_8 dB(D_3)	E_8 dB(D_3)$_o$	E_8 PNdB	E_8 PNdB$_{t_1}$	E_8 PNdB$_{t_1 o}$	E_8 PNdB$_{t_1}$ M	E_8 PNdB$_{t_1}$M$_o$	E_8 PNdB$_{t_2}$	E_8 PNdB-M	E_8 PNdB$_{t_2}$ M	E_8 PNdB-M$_o$	E_8 PNdB$_{t_2}$ M$_o$
-6.0	-1.5	-3.5	+1.0	-1.5	+3.0	-3.5	+1.0	-3.5	-4.0	+0.5	-3.5	+1.0	-4.0	-3.0	-3.5	+1.5	+1.0

increases its perceived noisiness. The explanations given this phenomena are that: (a) the longer the onset duration, the greater is the concern of the listener that the source of the sound is approaching and will reach the listener, and (b) the uncertainty on the part of the listener as to just how intense the sound may become regardless of any fear of the source. Because of the measured magnitude of the effect, equivalent to a change in peak levels of 10 dB or so, and the seeming reasonableness of its existence, it is proposed that a correction for onset duration be applied to the EPNL of sounds in accordance with the function shown in Fig. 4. This proposed addition to the calculated perceived noisiness of a sound must, of course, be based on a considerable amount of further testing before it can be considered as anything but tentative.

Onset corrections based on Fig. 4 were applied to the aircraft noises used in the tests at Wallops. Because of the nature of the flyovers used at Wallops, the noises present do not provide, nor were they planned to provide, a very good test of the effectiveness of or need for corrected onset duration. As seen in Table VI the use of the onset correction inconsistently decreased the deviation between judged and calculated perceived noisiness; however, the relatively large corrections applicable to the helicopter noises definitely improved the prediction of the judged perceived noisiness.

Impulse Level Correction

That the PNdB-M, or Phons, are reasonably accurate means of estimating the judged unacceptability or loudness of sonic booms relative to other sonic booms is shown in Figs. 7 and 8. However, calculated EPNdB-M does not predict the perceived noisiness of sonic booms when judged against more steady-state noise, such as that from subsonic aircraft.

Even after months of regular exposure and when expecting sonic booms, people rate the booms relative to the noise from subsonic aircraft somewhat less acceptable than would be predicted from the EPNLs of the two types of aircraft noise. As shown in Fig. 9, there is a difference equivalent to 15 dB or so in the EPNL of a sonic boom and the EPNL of subsonic aircraft noise. Presumably this difference is related to the "startle" felt from impulsive type sounds, such as sonic booms.

As with Fig. 4, Fig. 9 is based on a minimum of data. At the same time, these functions are seemingly logical and their use, if their validity can be substantiated, may provide procedures for calculating the perceived noisiness that can be applied to expected noises regardless of the temporal and spectral nature of the noises or the sources from which they came.

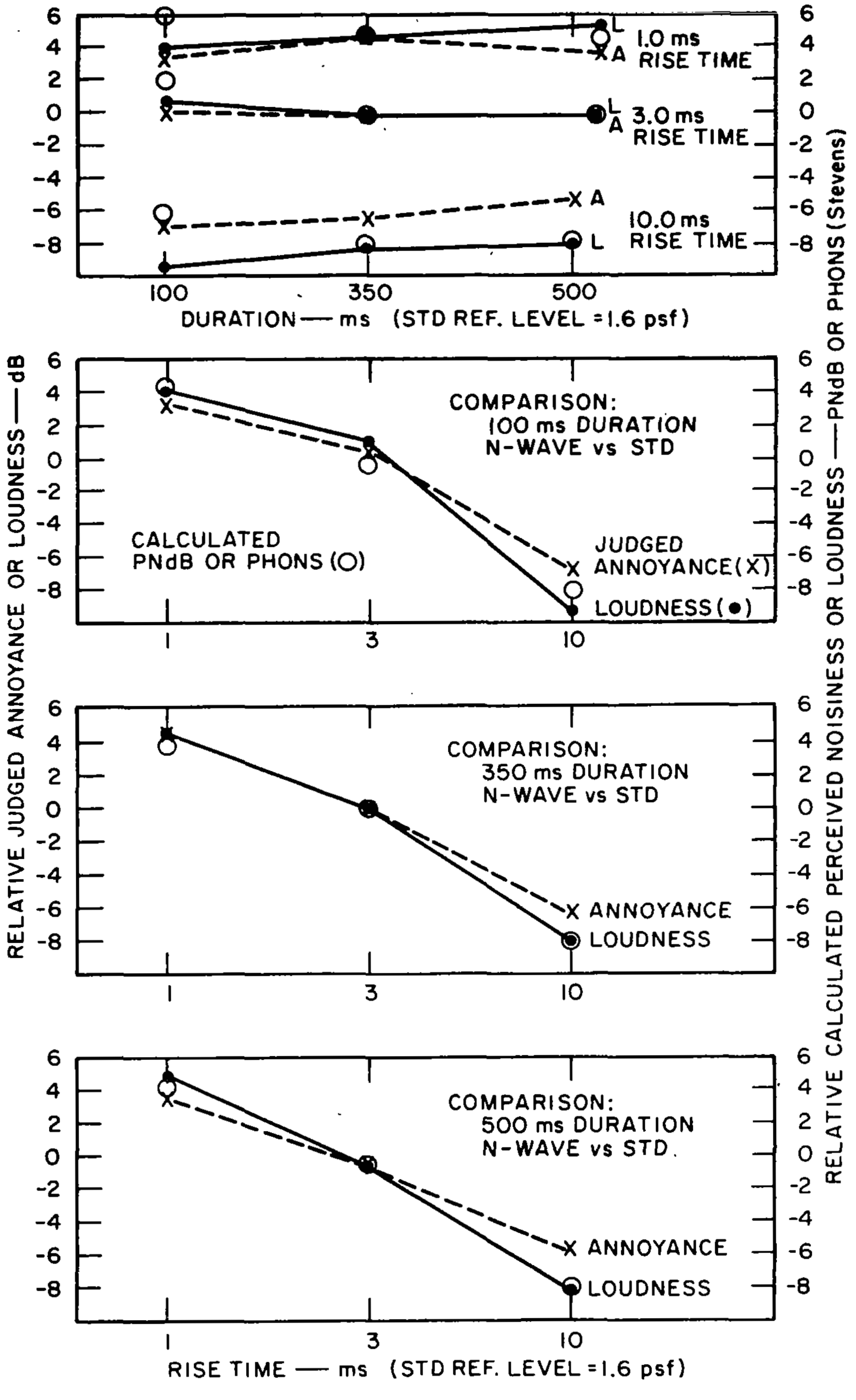

FIGURE 7 COMPARISON OF JUDGED ANNOYANCE OR LOUDNESS OF SIMULATED OUTDOOR SONIC BOOMS. Judgment data from Sheperd and Sutherland (27). Calculated PNdB and Phons by Kryter, Young and Johnson (17).

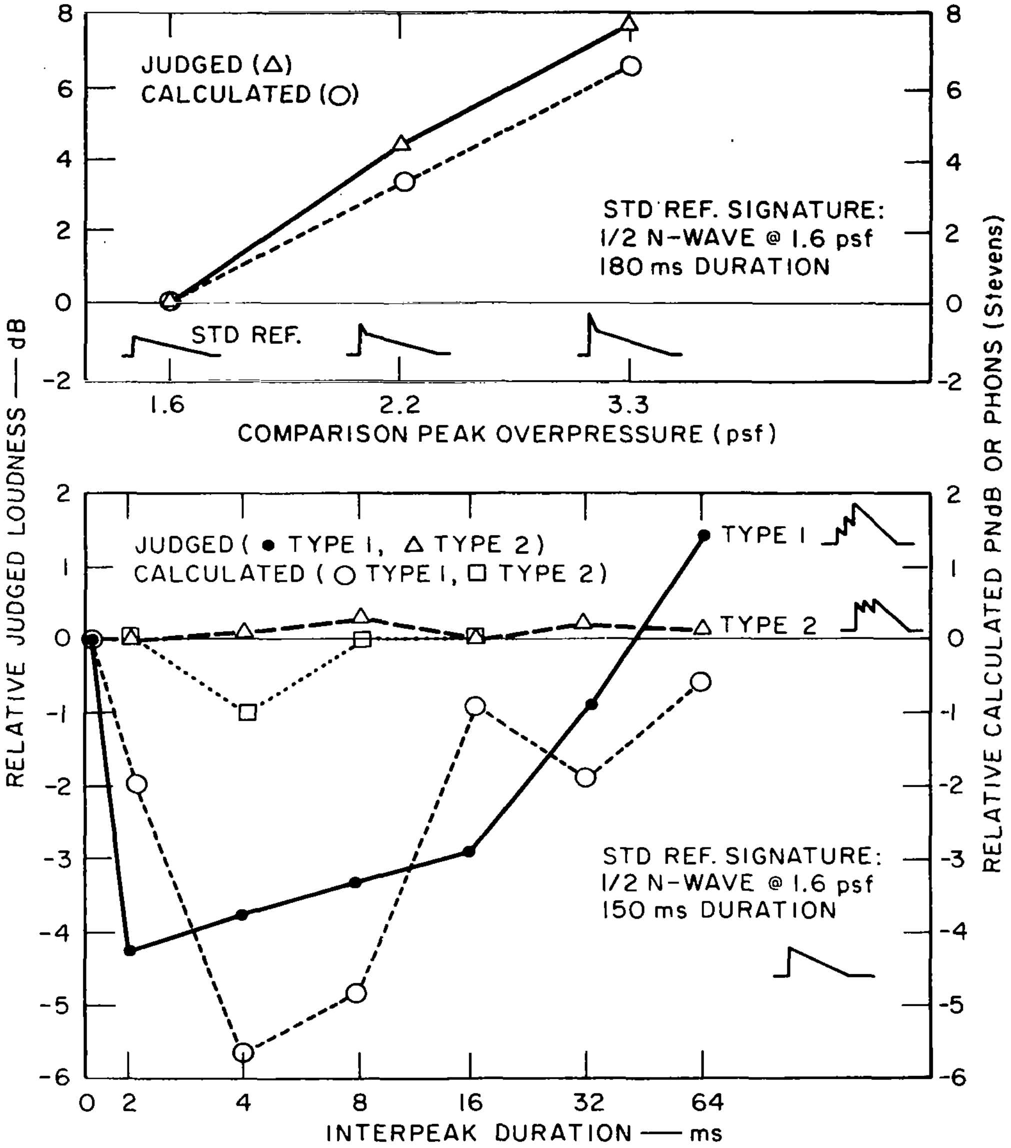

FIGURE 8 COMPARISON OF JUDGED LOUDNESS AND CALCULATED PERCEIVED NOISINESS AND LOUDNESS OF SIMULATED OUTDOOR SONIC BOOMS. Judgment data from Sheperd and Sutherland (27), calculated PNdB and Phons by Kryter, Young and Johnson (17).

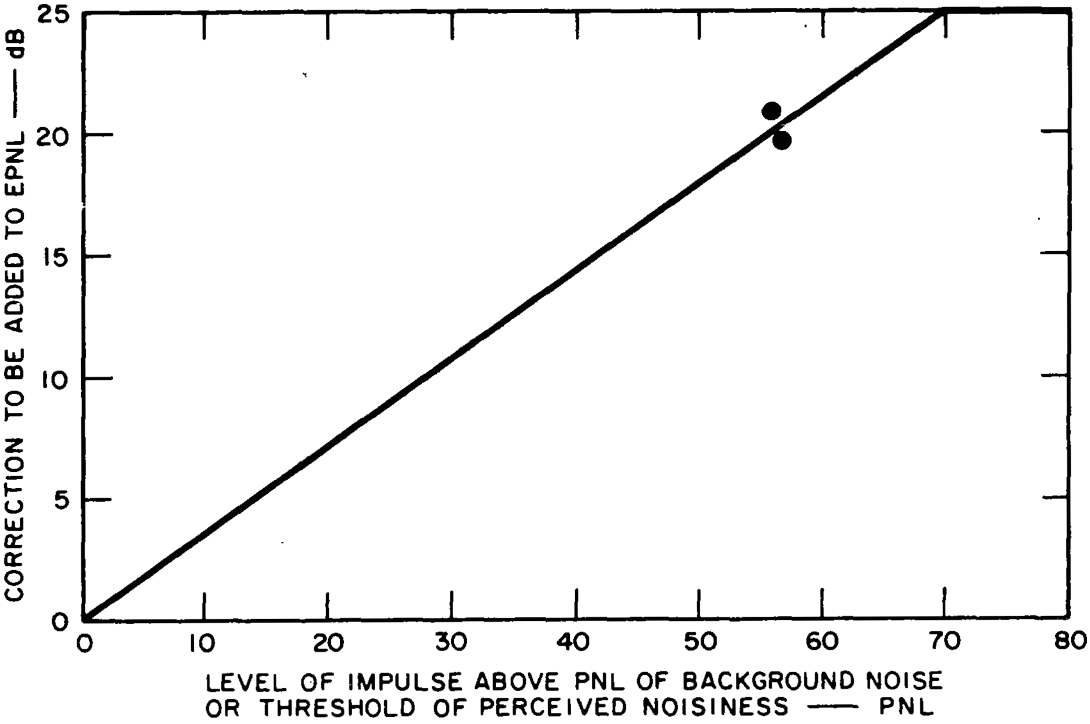

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FIGURE 9 CORRECTION TO EPNL FOR CONTRIBUTION TO PERCEIVED NOISINESS OF STARTLE TO EXPECTED IMPULSIVE SOUNDS. The level of the impulse is taken as amount, in PNL, the impulse exceeds the PNL of the background noise of the threshold of perceived noisiness, whichever is higher. The plotted points are from judgment tests, Kryter, Johnson and Young (17), of the unacceptability of sonic booms relative to the noise from subsonic jet aircraft.

Predicting Indoor Judgments from Outdoor Physical Measurements

One would assume that the unacceptability ratings given by listeners to a high-frequency noise, say from jet aircraft relative to the ratings given a low-frequency noise, say, from a helicopter or automobile, would be significantly altered when the noises were heard indoors. Because of the lesser attenuation of low compared to higher frequencies of a noise by house structures it is likely that the low frequency noises would become relatively more unacceptable indoors. In addition, possible secondary noises induced in a building because of nonlinear reactions (i.e., windows and picture rattles, etc.) would tend to disfavor the noise with the lower frequencies.

If this were the case, then units of PNL that give extra weight (weight unwarranted according to judgment tests where the noise is measured at the listeners' ears) to the lower frequencies should better predict the relative indoor ratings than would PNLs found appropriate for direct listening and direct physical measurements. Further, therefore, dB(D_1) and PNdB calculated without the proposed critical band adjustments should be better predictors of relative indoor ratings from outdoor measurements than D_2 or PNdB-M.

Judgment data from the Wallops tests are related to outdoor physical measurements of the noise in Table VIII. It is seen in Table VIII that indeed some of the units that worked particularly well for the judgments made outdoors, i.e., dB(D_2) and PNdB-M, did not do so well in estimating from outdoor noise measurements the relative judgments made by the listeners indoors; rather, now, dB(D_1) and PNdB are the best.

Whether or not a more accurate outdoor measurement-to-indoor judgment frequency weighting, either band or overall, can be specified (or even whether such a specification is desirable or necessary) remains to be determined. The Wallops data indicate that the best predictions of the relative perceived noisiness of noises ranging from low- to relatively high-frequency spectra would be provided by EPNdB-M and EdB(D_2) when the noise is measured at the position of the listener, and by EPNdB and EdB(D_1) when measured outdoors, and the listeners are indoors. The efficacy of the outdoor PNdB and dB(D_1) units, or any other outdoor units, for predicting relative judgments of noise made indoors at Wallops is obviously fortuitous.

Table VIII

SUMMARY OF AVERAGE DEVIATION FOR THE VARIOUS MEASUREMENT UNITS TAKEN OUTDOORS BETWEEN REFERENCE AND COMPARISON AIRCRAFT NOISES WHEN JUDGED EQUALLY UNACCEPTABLE BY SUBJECTS INDOORS. From Kryter, Johnson and Young[18]

Reference Aircraft	House	Table	Max dB(A)	Max dB(B)	Max dB(C)	Max dB(D_1)	Max dB(D_2)	Max dB(D_3)	Max Phons	Max PNdB	Max $PNdB_{t_1}$	Max $PNdB_{t_1}M$	Max $PNdB_{t_2}$	Peak dB(D_2)	Peak Phons	Peak PNdB
880	H-11	XII	3.3	2.3	2.1	2.3	4.4	3.8	1.7	2.0	2.8	3.1	2.2	4.0	1.4	1.8
1049G	H-11	XIII	3.2	5.2	5.7	3.8	6.5	4.8	3.4	3.8	4.5	4.9	4.2	5.8	2.8	3.3
880	K-13	XIV	3.8	2.7	2.5	2.8	4.8	4.4	2.3	2.3	3.2	3.4	2.2	4.5	1.8	2.0
1049G	K-13	XV	2.3	6.0	6.6	3.3	5.2	3.5	3.1	3.3	4.5	4.4	3.6	4.6	2.8	2.9
Aver. of Aver. Deviations			3.3	3.5	3.6	2.9	5.0	4.1	2.4	2.6	3.5	3.7	2.8	4.6	2.0	2.3

Reference Aircraft	House	Table	E_8 dB(A)	E_8 $dB(A)_o$	E_8 dB(D_1)	E_8 $dB(D_1)_o$	E_8 dB(D_2)	E_8 $dB(D_2)_o$	E_8 dB(D_3)	E_8 $dB(D_3)_o$	E_8 PNdB	E_8 $PNdB_{t_1}$	E_8 $PNdB_{t_1o}$	E_8 $PNdB_{t_1}M$	E_8 $PNdB_{t_1}M_o$	E_8 $PNdB_{t_2}$	EE_8 PNdB	EE_8 $PNdB_{t_1}$	EE_8 $PNdB_{t_1}M$	EE_8 $PNdB_{t_2}$
880	H-11	XII	3.8	4.7	2.2	3.2	4.4	5.2	5.2	6.1	1.8	2.1	3.0	2.3	3.2	1.8	2.0	1.9	2.0	1.9
1049G	H-11	XIII	2.9	2.3	2.6	2.3	2.8	2.9	2.1	1.6	2.9	3.5	3.0	3.8	3.3	3.5	2.8	3.7	4.0	3.8
880	K-13	XIV	4.3	5.2	2.5	3.4	4.8	5.7	5.7	6.7	2.0	2.1	3.1	2.4	3.3	1.8	2.1	1.8	2.0	1.8
1049G	K-13	XV	2.6	1.9	2.2	2.0	1.3	1.8	1.5	1.2	2.1	3.1	2.8	2.8	2.6	3.2	3.2	3.7	3.5	3.8
Aver. of Aver. Deviations			3.6	4.0	2.4	2.9	3.8	4.4	4.2	4.7	2.1	2.5	3.0	2.7	3.2	2.3	2.4	2.5	2.6	2.5

Band Summation

Perhaps one of the most interesting and practical findings of the analysis of the Wallops and other studies analyzed is that summing on an energy basis the sound spectrum weighted according to the D_2 function predicts judged noisiness nearly as well as the spectral information weighted the same way, but summed over 1/3 octave bands according to the formula proposed by Stevens and adopted by PNdB--namely $PNdB = 40 + 10 \log_2 PN$, where $PN = n_{\text{Band Max}} + 0.15 (\Sigma_{i}\,{}_{\text{Band}_i} - n_{\text{Band Max}})$, and where n is the noy value of each 1/3 octave band. This finding suggests that the present noy-band summation method is not, for broadband sounds, as good a model of the spectral integration characteristic of the auditory system as is the energy summed over critical bands and weighted according to the noy contours.

Indeed, it would follow, if similar results are found with reanalysis or existing and additional new judgment data that a power summation of the sound pressure levels in each frequency band or bands adjusted in accordance with the noy contours would provide a unit which we will designate here as PNdB$'$, that is simpler to calculate and which predicts judged perceived noisiness as well as or better than PNdB. The advantages of PNdB$'$ over dB(D_2) are: (a) it permits utilization of all the noy contours rather than only the 40-noy weighting of (D_2) and should be more accurate for a wider range of spectra; (b) it permits the incorporation of pure-tone corrections into the unit; and (c) it is based on band spectral information. The steps to be followed in the measurement and calculation of these various units are given in the appendix to this paper.

In formula form the above suggestions would be:

1. dB(D_2) from overall frequencies (weighted sound level meter)

$$dB(d_2) = 10 \log_{10} \left\{ \int_{45}^{11,020 \text{ Hz}} W(f) \cdot S(f) df \right\} ,$$

where W is a complex frequency power weighting for perceived noisiness (40 noy), S is a complex power spectrum of a given sound, and the variable of integration is frequency in Hz;

2. $dB(D_2)$ from band spectra,

$$dB(D_2) = 10 \log_{10} \left(\sum_{i}^{x} 10^{(SPL_i + W_{40_i})/10} \right),$$

where x is number of band filters, and W_{40_i} is the band weight for the i^{th} band, adjusted for critical bandwidth of the ear below 355 Hz (see Fig. 3), of the 40 noy contour.

3. $$PNdB' = 10 \log_{10} \left(\sum_{i}^{x} 10^{(SPL'_i/10} \right),$$

where SPL' is the SPL of 1000 Hz band having the same noy value as that for SPL in i^{th} band.

Until the unit PNdB' is evaluated, it appears that measuring broadband sounds over all frequencies by means of a frequency weighted (D_2) sound level meter and integrating such measures taken every .5 sec would be, on the average, as good a unit as is available for predicting judged perceived noisiness of the sounds. Several cautions regarding $dB(D_2)$ are justified: (a) most of results for (D_2) as well as A, D_1, and D_3 weightings, were not made with meters but with calculations performed on 1/3 octave band spectra; and (b) if and when tonal corrections are required the overall measure would not provide sufficient information for making appropriate corrections. However, one should find close agreement between overall meter readings and summed 1/3 octave band levels when comparable frequency weightings are used.

GENERAL CONCLUSIONS

From presently available data regarding aircraft noise, it is concluded that:

1. Auditory theory and the results of judgment tests indicate that good prediction of the perceived noisiness of broadband sounds when measured at the position of the listener requires: (a) the combining, prior to the calculation of the unit PNdB-M, 1/3 and full octave band sound levels below 355 Hz in certain ways to account for the critical bandwidth of the ear; or (b) the use of a sound level meter having a frequency weighting (D_2) that takes into account both the critical bandwidth of the ear and the 40-noy perceived noisiness contour.

2. Effective (time integrated) PNdB-Ms or dB(D_2)s are significantly better predictors of judged perceived noisiness than are so-called Max or Peak PNdB-Ms or dB(D_2)s.

3. Corrections should probably be applied to the EPNLs of (a) non-impulsive sounds of different tonal contents and onset durations, and (b) to impulsive sounds whose level increases background noise level more than 40 dB in 0.5 secs.

4. It is likely that some of the physical measurement procedures evaluated in this paper are more accurate than shown to be by judgment tests and that possibly somewhat more accurate, simpler, and general procedures are available or could be developed. It is possible, in this regard, that: (a) EdB(D_2) with or without tone or duration corrections may turn out to be on the average better than or as good a unit as any PNdB units now available for predicting judged perceived noisiness of most real-life noises; and (b) the use of a simpler band summation procedure than now used for PNdB may provide a PNdB' unit that is superior to (D_2) as well as present PNdB.

Appendix

PROCEDURES FOR THE MEASUREMENT OF NOISE AND NOISE ENVIRONMENT WITH RESPECT TO PERCEIVED NOISINESS (ANNOYANCE)

Purpose and Scope

This appendix describes procedures for evaluating the perceived noisiness (annoyance) of non-impulsive and impulsive noises and noise environments. These procedures might be used for:

1. The prediction from physical measures of the perceived noisiness of a noise or noise exposure, using all necessary spectral and temporal measures of the noise exposure. The basic unit of measurement used would presumably be primarily PNdB and EPNdB, and secondarily dB(D) and EdB(D).

2. The monitoring of the level of a given noise and noise environment to determine whether the noise reaches or exceeds certain prescribed levels and durations of exposure. The unit of measurement used would presumably be primarily dB(D) and EdB(D), and secondarily PNdB and EPNdB.

The unit name PNdB, which is based on band spectral measures of the noise, and dB(D), which is based on either band and overall spectral measures of the noise, are given in this appendix without suffixes or subscripts to distinguish them from some of the units described and annotated in the text elsewhere. At the time of this writing there are some data to suggest that the procedure adopted from the loudness calculation procedures of Stevens, that of summing noy values for different frequency bands, should be discarded, for perceived noisiness, in favor of a somewhat simpler procedure of summing on a power basis the SPLs of the bands adjusted according to the equal noy contours. It is suggested that PNdB units calculated by this alternative procedure, to be described below, be designated as PNdB'. If the suspected virtue of this power summation procedure is verified from a re-examination of previous judgment data and by new data, this procedure would presumably be standardized as the preferred and only means of calculating PNdB, and the prime designation could then be removed. The definition and determination of the dB(D) unit would not be affected by this potential modification to the calculation of the unit PNdB, indeed the two units should tend to be more consistent with each other.

Whether or not the state-of-the-art has reached the stage that standardization of how to obtain the units PNdB, EPNdB, dB(D), and EdB(D) for the quantity perceived noisiness is a matter of opinion. If such standardization was deemed appropriate, we would recommend that the following material be involved, with the realization that some changes and simplifications will undoubtedly take place with further research.

The inclusion in the following procedures of tone, onset duration, and impulse level corrections is debatable; they could readily be eliminated from the procedures if such simplification seems necessary. The inclusion of the somewhat less, on the average, accurate unit for perceived noisiness, of dB(A) is justified on the basis of its widespread use for this purpose, because it is available on sound level meters and roughly approximates the D-weighting prescribed herein more closely than do frequency weightings C and B.

Definitions of Terms

Impulse Intervals of Sound. When the overall sound pressure level changes during any .5-sec interval of time 40 or more dB, the sound during that interval is called impulsive.

Non-Impulsive Intervals of Sound. All .5-sec intervals of sound that are not impulsive.

Sound Pressure Level (SPL) in Decibels (dB). The sound pressure level re 0.0002 μbar as measured by means of a meter or recording device that meets the specifications of a sound level meter (SLM) set on "slow" is called dB when the flat-frequency weighting is used. The SLM characteristics are specified in document S1.4, 1961, General Purpose Sound Level Meter, American National Standards Institute, Inc., (ANSI) 1430 Broadway, New York, New York.

1/3 Octave and Octave Band Level. The SPL re 0.0002 μbar as measured on a SLM set on "slow" and flat-frequency weighting in conjunction with 1/3 octave or octave band filters having cut off frequencies as specified in ANSI document S1.6, 1967.

Sound in .5-sec Intervals of Time. The sound pressure level, band or overall, as read on a SLM set on slow is taken for purposes of this document as the sound present during a .5-sec interval.

Judged Perceived Noisiness. The attribute of sound that is judged as "unwanted" or "unacceptable" as a standard reference sound as a familiar part of one's general living environment, independently of any cognitive meaning conveyed by the sound, is called "Judged Perceived Noisiness." The term judged perceived noisiness is synonymous, for purposes of this document, with the term annoyance.

Noy. The unit of perceived noisiness is called the "Noy." Noy values, as the result of judgment tests conducted in the laboratory, have been assigned to the SPL of bands of frequencies present during an interval of .5 secs as shown in Figure A-1 and Table A-1.

Calculated Perceived Noise Level (PNL) in PNdB and Maximum PNL in Max PNdB. A means of estimating the Judged Perceived Noisiness for a .5-sec interval of a given sound from the noy value for that .5 sec of the given sound. The sum, as calculated according to prescribed procedures, of the noy values of a frequency band or frequency bands of sound is designated as Perceived Noise Level in PNdB. The highest valued of the PNdBs calculated for each .5-sec interval during the occurrence of a sound is called the Max PNdB of the sound. (Note: Two alternative methods of calculating the unit PNdB will be given below.)

PNL in dB(D) and dB(A), and Maximum PNL in Max dB(D) and Max dB(A). The level, as read on a SLM with a D- or A-frequency weighting characteristic and set on "slow" meter action designated as the PNL in dB(D) or dB(A) respectively for each .5-sec interval during the occurrence of a sound. dB(A) and dB(D) can also be found by a power summation of weighted frequency band levels. The highest valued dB(D) and dB(A) in any .5-sec interval is called Max dB(D) or Max dB(A) respectively of a given sound. See Table A-2 for D- and A-weightings; weighting D_2 is recommended above D_1 for this purpose. (Note: In order to make the units PNdB, dB(D), and dB(A) numerically equal, on the average, to each other, a constant of 6 is added to dB(D_2) and 13 to dB(A). The results are designated as dB(D') and dB(A') respectively.)

Threshold of Perceived Noisiness. A level measured during the day (the hours of 7 a.m. to 10 p.m.) indoors of 40 PNdB, dB(D'), or dB(A'), or a level measured outdoors of 60 PNdB, dB(D'), or dB(A') is specified as the threshold of perceived noisiness. This threshold during the night (the hours 10 p.m. to 7 a.m. is 10 PNdB, dB(D) or dB(A) lower than during the day.

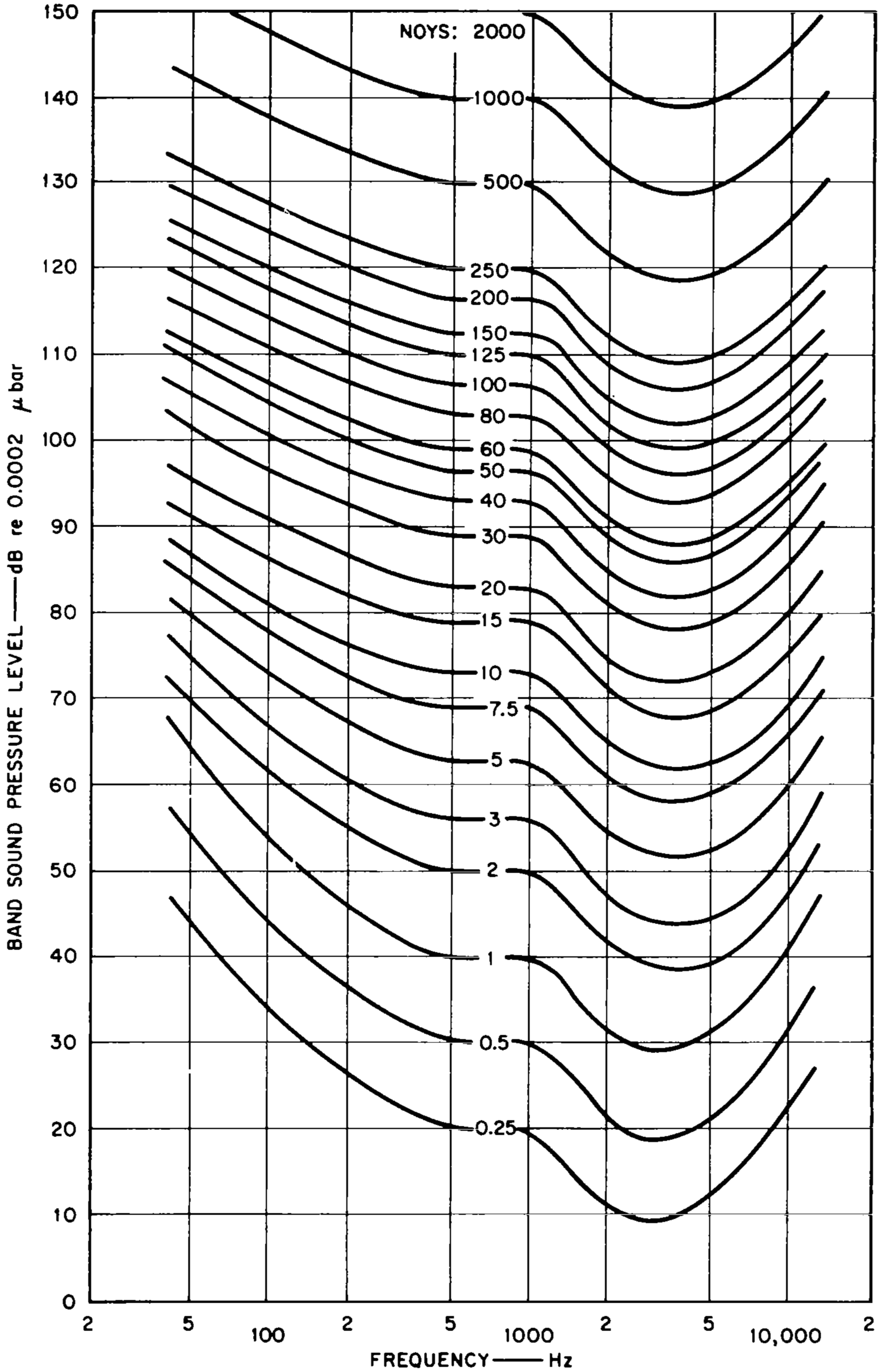

FIGURE A-1 CONTOURS OF PERCEIVED NOISINESS

Table A-1. ANTILOG (base 10) of SPL/10 AND NOYS AS A FUNCTION OF SPL

This formulation for noys represents an approximation to the contours of Fig. A-1 and is used as a practical convenience for computer calculation of perceived noisiness (R. A. Pinker, Computation of Perceived Noise Level: Mathematical Formulation of the Noy Tables. Note NT, 684, Ministry of Aviation, Farnborough, Great Britain, February 1968.)

SPL-dB	LOG_{10}^{-1} (SPL/10) (EXPON. NUMERIC FORM. EXAMPLE: 7.94E 02 ≡ 7.94 x 10^2 .)	BAND CENTER FREQUENCY																							
		50HZ	63HZ	80HZ	100HZ	125HZ	160HZ	200HZ	250HZ	315HZ	400HZ	500HZ	630HZ	800HZ	1KHZ	1.2KHZ	1.6KHZ	2KHZ	2.5KHZ	3.1KHZ	4KHZ	5KHZ	6.3KHZ	8KHZ	10KHZ
29	7.94E 02																			1.0	1.0				
30	1.00E 03																		1.0	1.1	1.1				
31	1.26E 03																		1.1	1.1	1.1	1.0			
32	1.58E 03																	1.0	1.1	1.2	1.2	1.1			
33	2.00E 03																	1.1	1.2	1.3	1.3	1.2	1.0		
34	2.51E 03																1.0	1.2	1.3	1.4	1.4	1.3	1.1		
35	3.16E 03																1.1	1.3	1.4	1.5	1.5	1.4	1.2		
36	3.98E 03																1.2	1.3	1.5	1.6	1.6	1.5	1.4		
37	5.01E 03																1.3	1.4	1.6	1.8	1.8	1.6	1.5	1.0	
38	6.31E 03															1.0	1.3	1.5	1.8	1.9	1.9	1.7	1.6	1.1	
39	7.94E 03															1.1	1.4	1.6	1.9	2.0	2.0	1.9	1.8	1.2	
40	1.00E 04										1.0	1.0	1.0	1.0	1.0	1.2	1.5	1.7	2.0	2.2	2.2	2.0	1.9	1.4	
41	1.26E 04										1.1	1.1	1.1	1.1	1.1	1.3	1.6	1.8	2.2	2.4	2.4	2.2	2.0	1.5	1.0
42	1.58E 04									1.0	1.1	1.1	1.1	1.1	1.1	1.3	1.7	2.0	2.4	2.6	2.6	2.4	2.2	1.7	1.1
43	2.00E 04									1.1	1.2	1.2	1.2	1.2	1.2	1.4	1.8	2.2	2.6	2.8	2.8	2.6	2.4	1.8	1.2
44	2.51E 04								1.0	1.1	1.3	1.3	1.3	1.3	1.3	1.5	2.0	2.4	2.8	3.0	3.0	2.8	2.6	2.0	1.4
45	3.16E 04								1.1	1.2	1.4	1.4	1.4	1.4	1.4	1.6	2.1	2.6	3.0	3.2	3.2	3.0	2.8	2.2	1.5
46	3.98E 04							1.0	1.2	1.3	1.5	1.5	1.5	1.5	1.5	1.7	2.3	2.8	3.2	3.4	3.4	3.2	3.0	2.4	1.7
47	5.01E 04							1.1	1.3	1.4	1.6	1.6	1.6	1.6	1.6	1.8	2.4	3.0	3.4	3.6	3.6	3.4	3.2	2.6	1.8
48	6.31E 04						1.0	1.2	1.4	1.5	1.7	1.7	1.7	1.7	1.7	2.0	2.6	3.2	3.6	3.9	3.9	3.6	3.4	2.8	2.0
49	7.94E 04						1.1	1.3	1.5	1.6	1.9	1.9	1.9	1.9	1.9	2.1	2.8	3.4	3.9	4.1	4.1	3.9	3.6	3.0	2.2
50	1.00E 05						1.2	1.4	1.6	1.7	2.0	2.0	2.0	2.0	2.0	2.3	3.0	3.6	4.1	4.4	4.4	4.1	3.9	3.2	2.4
51	1.26E 05					1.0	1.3	1.5	1.7	1.9	2.1	2.1	2.1	2.1	2.1	2.4	3.2	3.9	4.4	4.7	4.7	4.4	4.1	3.4	2.6
52	1.58E 05					1.1	1.4	1.6	1.9	2.0	2.3	2.3	2.3	2.3	2.3	2.6	3.5	4.1	4.7	5.0	5.0	4.7	4.4	3.6	2.8
53	2.00E 05				1.0	1.2	1.5	1.7	2.0	2.1	2.5	2.5	2.5	2.5	2.5	2.8	3.7	4.4	5.0	5.3	5.3	5.0	4.7	3.9	3.0
54	2.51E 05				1.1	1.3	1.6	1.9	2.1	2.3	2.6	2.6	2.6	2.6	2.6	3.0	4.0	4.7	5.3	5.7	5.7	5.3	5.0	4.1	3.2
55	3.16E 05				1.2	1.4	1.7	2.0	2.3	2.4	2.8	2.8	2.8	2.8	2.8	3.2	4.3	5.0	5.7	6.1	6.1	5.7	5.3	4.4	3.5
56	3.98E 05			1.0	1.3	1.5	1.9	2.2	2.4	2.6	3.0	3.0	3.0	3.0	3.0	3.5	4.6	5.3	6.1	6.5	6.5	6.1	5.7	4.7	3.7
57	5.01E 05			1.1	1.4	1.7	2.0	2.4	2.6	2.8	3.2	3.2	3.2	3.2	3.2	3.7	5.0	5.7	6.5	7.0	7.0	6.5	6.1	5.0	4.0
58	6.31E 05			1.2	1.5	1.8	2.2	2.6	2.8	3.0	3.5	3.5	3.5	3.5	3.5	4.0	5.3	6.1	7.0	7.5	7.5	7.0	6.5	5.3	4.3
59	7.94E 05			1.3	1.7	2.0	2.4	2.8	3.0	3.2	3.7	3.7	3.7	3.7	3.7	4.3	5.7	6.5	7.5	8.0	8.0	7.5	7.0	5.7	4.6
60	1.00E 06		1.0	1.4	1.8	2.2	2.6	3.0	3.2	3.5	4.0	4.0	4.0	4.0	4.0	4.6	6.1	7.0	8.0	8.7	8.7	8.0	7.5	6.1	5.0
61	1.26E 06		1.1	1.5	2.0	2.4	2.8	3.2	3.5	3.7	4.3	4.3	4.3	4.3	4.3	5.0	6.5	7.5	8.7	9.3	9.3	8.7	8.0	6.5	5.3
62	1.58E 06		1.2	1.7	2.2	2.6	3.0	3.5	3.7	4.0	4.6	4.6	4.6	4.6	4.6	5.3	7.0	8.0	9.3	10.0	10.0	9.3	8.7	7.0	5.7
63	2.00E 06		1.3	1.8	2.4	2.8	3.2	3.7	4.0	4.3	4.9	4.9	4.9	4.9	4.9	5.7	7.5	8.7	10.0	11.0	11.0	10.0	9.3	7.5	6.1
64	2.51E 06	1.0	1.5	2.0	2.6	3.0	3.5	4.0	4.3	4.6	5.3	5.3	5.3	5.3	5.3	6.1	8.0	9.3	11.0	11.0	11.0	11.0	10.0	8.0	6.5
65	3.16E 06	1.1	1.6	2.2	2.8	3.2	3.7	4.3	4.6	5.0	5.7	5.7	5.7	5.7	5.7	6.5	8.7	10.0	11.0	12.0	12.0	11.0	11.0	8.7	7.0
66	3.98E 06	1.2	1.8	2.4	3.0	3.5	4.0	4.6	5.0	5.4	6.1	6.1	6.1	6.1	6.1	7.0	9.3	11.0	12.0	13.0	13.0	12.0	11.0	9.3	7.5
67	5.01E 06	1.4	2.0	2.6	3.3	3.7	4.3	5.0	5.4	5.9	6.5	6.5	6.5	6.5	6.5	7.5	10.0	11.0	13.0	14.0	14.0	13.0	12.0	10.0	8.0
68	6.31E 06	1.6	2.2	2.8	3.6	4.0	4.6	5.4	5.9	6.4	7.0	7.0	7.0	7.0	7.0	8.0	11.0	12.0	14.0	15.0	15.0	14.0	13.0	11.0	8.7
69	7.94E 06	1.8	2.3	3.0	3.9	4.3	5.0	5.9	6.4	6.9	7.5	7.5	7.5	7.5	7.5	8.7	11.0	13.0	15.0	16.0	16.0	15.0	14.0	11.0	9.3
70	1.00E 07	2.0	2.5	3.3	4.2	4.6	5.4	6.4	6.9	7.5	8.0	8.0	8.0	8.0	8.0	9.3	12.0	14.0	16.0	17.0	17.0	16.0	15.0	12.0	10.0
71	1.25E 07	2.2	2.8	3.6	4.6	5.0	5.9	6.9	7.5	8.0	8.6	8.6	8.6	8.6	8.6	10.0	13.0	15.0	17.0	19.0	19.0	17.0	16.0	13.0	11.0
72	1.58E 07	2.3	3.0	3.9	5.0	5.4	6.4	7.5	8.0	8.7	9.2	9.2	9.2	9.2	9.2	11.0	14.0	16.0	19.0	20.0	20.0	19.0	17.0	14.0	11.0
73	2.00E 07	2.5	3.3	4.2	5.4	5.9	6.9	8.0	8.7	9.3	9.8	9.8	9.8	9.8	9.8	11.0	15.0	17.0	20.0	21.0	21.0	20.0	19.0	15.0	12.0
74	2.51E 07	2.8	3.7	4.6	5.9	6.4	7.5	8.7	9.3	10.0	10.6	10.6	10.6	10.6	10.6	12.0	16.0	19.0	21.0	23.0	23.0	21.0	20.0	16.0	13.0
75	3.16E 07	3.0	4.1	5.0	6.4	6.9	8.0	9.3	10.0	11.0	11.3	11.3	11.3	11.3	11.3	13.0	17.0	20.0	23.0	24.0	24.0	23.0	21.0	17.0	14.0
76	3.98E 07	3.3	4.5	5.4	6.9	7.5	8.7	10.0	11.0	11.0	12.0	12.0	12.0	12.0	12.0	14.0	19.0	21.0	24.0	26.0	26.0	24.0	23.0	19.0	15.0
77	5.01E 07	3.7	5.0	5.9	7.5	8.3	9.3	11.0	11.0	12.0	13.0	13.0	13.0	13.0	13.0	15.0	20.0	23.0	26.0	28.0	28.0	26.0	24.0	20.0	16.0
78	6.31E 07	4.1	5.4	6.4	8.3	9.1	10.0	11.0	12.0	13.0	14.0	14.0	14.0	14.0	14.0	16.0	21.0	24.0	28.0	30.0	30.0	28.0	26.0	21.0	17.0
79	7.94E 07	4.5	5.9	6.9	9.1	10.0	11.0	12.0	13.0	14.0	15.0	15.0	15.0	15.0	15.0	17.0	23.0	26.0	30.0	32.0	32.0	30.0	28.0	23.0	19.0
80	1.00E 08	5.0	6.4	7.5	10.0	11.0	11.0	13.0	14.0	15.0	16.0	16.0	16.0	16.0	16.0	19.0	24.0	28.0	32.0	35.0	35.0	32.0	30.0	24.0	20.0
81	1.26E 08	5.5	6.9	8.3	11.0	11.0	12.0	14.0	15.0	16.0	18.0	18.0	18.0	18.0	18.0	20.0	26.0	30.0	35.0	37.0	37.0	35.0	32.0	26.0	21.0
82	1.58E 08	6.1	7.5	9.1	11.0	12.0	13.0	15.0	16.0	17.0	19.0	19.0	19.0	19.0	19.0	21.0	28.0	32.0	37.0	40.0	40.0	37.0	35.0	28.0	23.0
83	2.00E 08	6.8	8.3	10.0	12.0	13.0	14.0	16.0	17.0	19.0	20.0	20.0	20.0	20.0	20.0	23.0	30.0	35.0	40.0	42.0	42.0	40.0	37.0	30.0	24.0
84	2.51E 08	7.5	9.1	12.0	13.0	14.0	15.0	17.0	19.0	20.0	21.0	21.0	21.0	21.0	21.0	24.0	32.0	37.0	42.0	45.0	45.0	42.0	40.0	32.0	26.0
85	3.16E 08	8.3	10.0	13.0	14.0	15.0	16.0	19.0	20.0	21.0	23.0	23.0	23.0	23.0	23.0	26.0	35.0	40.0	45.0	47.0	47.0	45.0	42.0	35.0	28.0
86	3.98E 08	9.1	12.0	13.0	15.0	16.0	17.0	20.0	21.0	23.0	24.0	24.0	24.0	24.0	24.0	28.0	37.0	42.0	47.0	50.0	50.0	47.0	45.0	37.0	30.0
87	5.01E 08	10.0	13.0	14.0	16.0	17.0	19.0	21.0	23.0	24.0	26.0	26.0	26.0	26.0	26.0	30.0	40.0	45.0	50.0	55.0	55.0	50.0	47.0	40.0	32.0
88	6.31E 08	11.0	13.0	15.0	17.0	19.0	20.0	23.0	24.0	26.0	28.0	28.0	28.0	28.0	28.0	32.0	42.0	47.0	55.0	60.0	60.0	55.0	50.0	42.0	35.0

Table A-1 Concluded

BAND CENTER FREQUENCY

SPL-dB	LOG_{10}^{-1} (SPL/10) (EXPON.NUMERIC FORM. EXAMPLE· 7.94E 02 = 7.94 x 10^2)	50HZ	63HZ	80HZ	100HZ	125HZ	160HZ	200HZ	250HZ	315HZ	400HZ	500HZ	630HZ	800HZ	1KHZ	1.2KHZ	1.6KHZ	2KHZ	2.5KHZ	3.1KHZ	4KHZ	5KHZ	6.3KHZ	8KHZ	10KHZ
89	7.94E 08	12	14	16	19	20	21	24	26	28	30	30	30	30	30	35	45	50	60	63	63	60	55	45	37
90	1.00E 09	14	15	17	20	21	23	26	28	30	32	32	32	32	32	37	47	55	63	67	67	63	60	47	40
91	1.26E 09	15	16	19	21	23	24	28	30	32	34	34	34	34	34	40	50	60	67	71	71	67	63	50	42
92	1.58E 09	16	17	20	23	24	26	30	32	35	37	37	37	37	37	42	55	63	71	75	75	71	67	55	45
93	2.00E 09	17	19	21	24	26	28	32	35	37	39	39	39	39	39	45	60	67	75	80	80	75	71	60	47
94	2.51E 09	19	20	23	26	28	30	35	37	40	42	42	42	42	42	47	63	71	80	86	86	80	75	63	50
95	3.16E 09	20	21	24	28	30	32	37	40	42	45	45	45	45	45	50	67	75	86	93	93	86	80	67	55
96	3.98E 09	21	23	26	30	32	35	40	42	45	49	49	49	49	49	55	71	80	93	100	100	93	86	71	60
97	5.01E 09	23	24	28	32	35	37	42	45	47	52	52	52	52	52	60	75	86	100	108	108	100	93	75	63
98	6.31E 09	24	26	30	35	37	40	45	47	50	56	56	56	56	56	64	80	93	108	116	116	108	100	80	67
99	7.94E 09	26	28	32	37	40	42	47	50	55	60	60	60	60	60	69	86	100	116	125	125	116	108	86	71
100	1.00E 10	28	30	35	40	42	45	50	55	60	64	64	64	64	64	74	93	108	125	133	133	125	116	93	75
101	1.26E 10	30	32	37	42	45	47	55	60	64	69	69	69	69	69	79	100	116	133	142	142	133	125	100	80
102	1.58E 10	32	35	40	45	47	50	60	64	69	74	74	74	74	74	84	108	125	142	150	150	142	133	108	86
103	2.00E 10	35	37	42	47	50	55	64	69	74	79	79	79	79	79	91	116	133	150	162	162	150	142	116	93
104	2.51E 10	37	40	45	50	55	60	69	74	79	84	84	84	84	84	97	125	142	162	173	173	162	150	125	100
105	3.16E 10	40	42	47	55	60	64	74	79	84	91	91	91	91	91	104	133	150	173	186	186	173	162	133	108
106	3.98E 10	42	45	50	60	64	69	79	84	91	97	97	97	97	97	111	142	162	186	200	200	186	173	142	116
107	5.01E 10	45	47	55	64	69	74	84	91	97	104	104	104	104	104	119	150	173	200	215	215	200	186	150	125
108	6.31E 10	47	50	60	69	74	79	91	97	104	111	111	111	111	111	128	162	186	215	232	232	215	200	162	133
109	7.94E 10	50	55	64	74	79	84	97	104	111	119	119	119	119	119	137	173	200	232	250	250	232	215	173	142
110	1.00E 11	55	60	69	79	84	91	104	111	119	128	128	128	128	128	147	186	215	250	266	266	250	232	186	150
111	1.26E 11	60	64	74	84	91	97	111	119	128	137	137	137	137	137	158	200	232	266	284	284	266	250	200	162
112	1.58E 11	64	69	79	91	97	104	119	128	137	147	147	147	147	147	169	215	250	284	300	300	284	266	215	173
113	2.00E 11	69	74	84	97	104	111	128	137	147	158	158	158	158	158	181	232	266	300	324	324	300	284	232	186
114	2.51E 11	74	79	91	104	111	119	137	147	158	169	169	169	169	169	194	250	284	324	346	346	324	300	250	200
115	3.16E 11	79	84	97	111	119	128	147	158	169	181	181	181	181	181	208	266	300	346	372	372	346	324	266	215
116	3.98E 11	84	91	104	119	128	137	158	169	181	194	194	194	194	194	223	284	324	372	400	400	372	346	284	232
117	5.01E 11	91	97	111	128	137	147	169	181	194	208	208	208	208	208	239	300	346	400	430	430	400	372	300	250
118	6.31E 11	97	104	119	137	147	158	181	194	208	223	223	223	223	223	256	324	372	430	464	464	430	400	324	266
119	7.94E 11	104	111	128	147	158	169	194	208	223	239	239	239	239	239	274	346	400	464	500	500	464	430	346	284
120	1.00E 12	111	119	137	158	169	181	208	223	239	256	256	256	256	256	294	372	430	500	532	532	500	464	372	300
121	1.26E 12	119	128	147	169	181	194	223	239	256	274	274	274	274	274	315	400	464	532	568	568	532	500	400	324
122	1.58E 12	128	137	158	181	194	208	239	256	274	294	294	294	294	294	338	430	500	568	600	600	568	532	430	346
123	2.00E 12	137	147	169	194	208	223	256	274	294	315	315	315	315	315	362	464	532	600	648	648	600	568	464	372
124	2.51E 12	147	158	181	208	223	239	274	294	315	338	338	338	338	338	388	500	568	648	692	692	648	600	500	400
125	3.16E 12	158	169	194	223	239	256	294	315	338	362	362	362	362	362	416	532	600	692	744	744	692	648	532	430
126	3.98E 12	169	181	208	239	256	274	315	338	362	388	388	388	388	388	446	568	648	744	800	800	744	692	568	464
127	5.01E 12	181	194	223	256	274	294	338	362	388	416	416	416	416	416	478	600	692	800	860	860	800	744	600	500
128	6.31E 12	194	208	239	274	294	315	362	388	416	446	446	446	446	446	512	648	744	860	928	928	860	800	648	532
129	7.94E 12	208	223	256	294	315	338	388	416	446	478	478	478	478	478	549	692	800	928	1000	1000	928	860	692	568
130	1.00E 13	223	239	274	315	338	362	416	446	478	512	512	512	512	512	588	744	860	1000	1064	1064	1000	928	744	600
131	1.26E 13	239	256	294	338	362	388	446	478	512	549	549	549	549	549	630	800	928	1064	1136	1136	1064	1000	800	648
132	1.58E 13	256	274	315	362	388	416	478	512	549	588	588	588	588	588	676	860	1000	1136	1200	1200	1136	1064	860	692
133	2.00E 13	274	294	338	388	416	446	512	549	588	630	630	630	630	630	724	928	1064	1200	1296	1296	1200	1136	928	744
134	2.51E 13	294	315	362	416	446	478	549	588	630	676	676	676	676	676	776	1000	1136	1296	1384	1384	1296	1200	1000	800
135	3.16E 13	315	338	388	446	478	512	588	630	676	724	724	724	724	724	832	1064	1200	1384	1488	1488	1384	1296	1064	860
136	3.98E 13	338	362	416	478	512	549	630	676	724	776	776	776	776	776	891	1136	1296	1488	1600	1600	1488	1384	1136	928
137	5.01E 13	362	388	446	512	549	588	676	724	776	832	832	832	832	832	955	1200	1384	1600	1720	1720	1600	1488	1200	1000
138	6.31E 13	388	416	478	549	588	630	724	776	832	891	891	891	891	891	1024	1296	1488	1720	1856	1856	1720	1600	1296	1064
139	7.94E 13	416	446	512	588	630	676	776	832	891	955	955	955	955	955	1098	1384	1600	1856	2000	2000	1856	1720	1384	1136
140	1.00E 14	446	478	549	630	676	724	832	891	955	1024	1024	1024	1024	1024	1176	1488	1720	2000			2000	1856	1488	1200
141	1.26E 14	478	512	588	676	724	776	891	955	1024	1098	1098	1098	1098	1098	1261	1600	1856					2000	1600	1296
142	1.58E 14	512	549	630	724	776	832	955	1024	1098	1176	1176	1176	1176	1176	1351	1720	2000						1720	1384
143	2.00E 14	549	588	676	776	832	891	1024	1098	1176	1261	1261	1261	1261	1261	1448	1856							1856	1488
144	2.51E 14	588	630	724	832	891	955	1098	1176	1261	1351	1351	1351	1351	1351	1552	2000							2000	1600
145	3.16E 14	630	676	776	891	955	1024	1176	1261	1351	1448	1448	1448	1448	1448	1663									1720
146	3.98E 14	676	724	832	955	1024	1098	1261	1351	1448	1552	1552	1552	1552	1552	1783									1856
147	5.01E 14	724	776	891	1024	1098	1176	1351	1448	1552	1663	1663	1663	1663	1663	1911									2000
148	6.31E 14	776	832	955	1098	1176	1261	1448	1552	1663	1783	1783	1783	1783	1783	2048									

Table A-2

A- AND D-WEIGHTING NETWORKS

(All values are in dB relative to the value of 1000 Hz)

Frequency (Hz)	Relative Response Level (dB)		Tolerance (All values are ±)
	A	D	
50	-30.2	-19	1.0
63	-26.1	-17	1.0
80	-22.3	-14	1.0
100	-19.1	-11	1.0
125	-16.2	- 9	1.0
160	-13.2	- 7	1.0
200	-10.8	- 5	1.0
250	- 8.0	- 3	1.0
315	- 6.5	- 1	1.0
400	- 4.8	0	1.0
500	- 3.3	0	1.0
630	- 1.9	0	1.0
800	- 0.8	0	1.0
1000	0	0	1.0
1250	+ 0.5	+ 2	1.0
1600	+ 1.0	+ 6	1.0
2000	+ 1.2	+ 8	1.0
2500	+ 1.2	+10	1.0
3150	+ 1.2	+11	1.0
4000	+ 1.0	+11	1.0
5000	+ 0.5	+10	1.0
6300	- 0.2	+ 9	1.5
8000	- 1.1	+ 6	1.5
10000	- 2.5	+ 3	2.0

Practical Threshold of Perceived Noisiness. For the purpose of the measurement or calculation of perceived noisiness of occurrences of individual sounds it is found sufficiently accurate to define as the threshold of perceived noisiness, the level that is 15 PNdB, dB(D) or dB(A)* below the highest (Max) level when the highest level is greater than 55 (45 at night) PNdB, dB(D'), or dB(A') when measured indoors and greater than 75 (65 at night) PNdB, dB(D') or dB(A') when measured outdoors.

Duration of the Occurrence of a Sound. The time in seconds between the moment a sound starts to rise above the threshold or practical threshold of perceived noisiness and the next succeeding moment in time it recedes to the threshold or practical threshold of noisiness.

Onset Duration. The time between the first .5-sec interval a non-impulsive sound is at Max PNL and the last preceding .5-sec interval the sound was at the PNL of the background noise, or the threshold of noisiness, or the practical threshold of noisiness, whichever is higher, is taken as the onset duration of a non-impulsive sound.

Onset Correction. The onset duration in seconds is used to determine a correction value (called oc).

Impulse Level. The difference in PNL in PNdB, dB(D) or dB(A) of an impulse from the PNL of the background noise is called the impulse level.

Impulse Level Correction. The impulse level in PNdB, dB(D) or dB(A) is used to determine a correction value (called ic).

Calculated Effective Perceived Noise Level (EPNL) in EPNdB, EdB(D) and EdB(A). The sum as calculated by formulae to be given below of PNdBs, dB(D)s, or dB(A)s in successive .5-sec intervals during the occurrence of a sound, minus 12 plus a correction for onset duration or impulse

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* 10 PNdB, dB(D) or dB(A) below the highest (Max) level has generally been used in the past as the practical threshold of perceived noisiness partly because of limited dynamic range of the physical noise measurements, and partly because for typical noises from passing aircraft and highway vehicles, tests show this to be a reasonably satisfactory threshold. However, with the advent of helicopter noises or other noises having a more erratic or more slowly changing level in time, it is believed that the 15-"dB" range is a more realistic and accurate range to use if physical measurements permit.

level, as appropriate. The sum of these calculations is called EPNdB, EdB(D), or EdB(A) respectively. The value -12 comes from the choice of 16 one-half second intervals (a duration of 8 sec) as a standard duration to which all effective levels are referred.

Composite Noise Rating (CNR) from EPNdB, EdB(D'), or EdB(A'). The sum, as measured or calculated according to the prescribed formulae, of the EPNLs during a 24-hour time cycle at a given location is designated as the Composite Noise Rating for that location.

Tolerable Limits. Maximum amount of noise that will permit effective utilization of a space for its normal use by the average person who is adapted to the noise as the result of repeated near daily exposure to noise. The use to which a space is put and, to a significant degree, the socioeconomic status of the users primarily determine the amount of noise that is tolerated.

Calculation Procedures for Perceived Noise Level (PNL), and Effective Perceived Noise Level (EPNL)

PNL in PNdB

Step 1. Determine the sound pressure level that occurs in each 1/3 or full octave band in each successive .5-sec interval of time.

Step 2: 1/3 Octave Bands. Add on a 10 $\log_{10}$ antilog basis the band levels of the 1/3 octave bands having the center frequencies of:

a. 50, 63, and 100 Hz and assign the result to the band center frequency having the greatest intensity.

b. 125, 160, and 200 Hz and assign the result to a band center frequency having the greatest intensity.

c. 250 and 315 Hz and assign the result to the band center frequency having the greatest intensity.

Note: If the greatest intensity in Step 2a, b, and c is present in more than one band within a step, assign the sum to the band with the highest frequency and a highest SPL.

[Step 2: Full Octave Bands.* Add on a 10 $\log_{10}$ antilog basis the band levels of the octave bands having the center frequencies of 63, and 125 Hz and assign the result to the band center frequency having the greatest intensity.

Note: If the intensity is the same in the two bands assign the sum to the center frequency of 125 Hz.]

Step 3. If any band (or summed bands below 355 Hz) for non-impulsive sounds is abutted above and below by bands (or summed bands below 355 Hz) that are both less intense than the in-between band, a correction is determined from the appropriate abscissa on Figure A-2 and added to the SPL of the respective bands or summed bands.

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* Steps 2 and 5 are given for both 1/3 octave and full octave bands and are to be used according to which bands are used for the band spectrum analysis of a given sound.

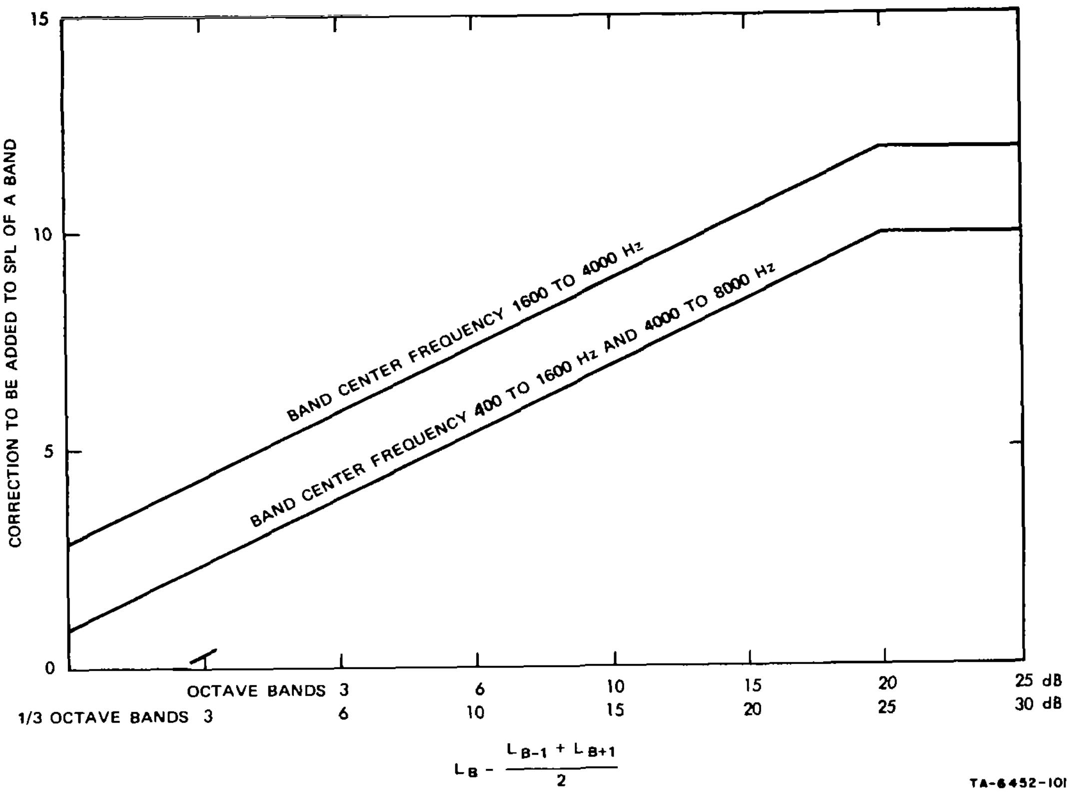


FIGURE A-2 SHOWING DECIBEL CORRECTION TO BE ADDED TO SPL OF BAND THAT EXCEEDS ADJACENT BANDS BY AMOUNT SHOWN ON ABSCISSA. See Step 3, section 2.1 of text. Parameter is band center frequency.

Note 1: In Figure A-2, the abscissa is $L_B - \left[\frac{L_{B-1} + L_{B+1}}{2}\right]$,
where L_B is the SPL in dB of band (or sum of bands below 355 Hz) B. B-1 is the abutted lower frequency band, B+1 is the abutted higher frequency band. The addition of L_{B-1} to L_{B+1} is arithmetic.

Note 2: When the highest frequency band of a sound is 3 dB more intense than the band immediately below it, L_{B+1} is taken as 3. When the lowest frequency band of a sound is 3 dB more intense than the band immediately above it, L_{B-1} is taken as 3.

Note 3: Care must be taken to ensure that the presence of a pure tone or very narrow band (less than 1/3 octave wide) of concentrated energy is not overlooked because the center frequency of the tone or narrow band of sound is at or near the crossover frequencies between two adjacent filter bands. When there are pure-tone or very narrow band spectral components at or near filter crossover points between two adjacent filter bands, add the appropriate amount found in Figure A-2 to the band of higher intensity, or to the band of higher frequency when the two adjacent bands are of equal intensity.

<ins>Step 4</ins>. Find the noy values from Table A-2 for: (1) the summed band levels, at the assigned center frequencies at and below 355 Hz as obtained in Step 2 and as corrected in Step 3; and (2) the band levels present in each band having center frequencies at and above 355 Hz, as corrected in Step 3.

<ins>Step 5: 1/3 Octave Bands</ins>. Add to the largest noy value obtained for any single band in Step 4 the sum of the noy values for all the other bands as found in Step 4 multiplied by .15. The result is called PN for that .5-sec interval of a given sound.

[<ins>Step 5: Octave Bands</ins>. Add to the largest noy value obtained for any single band in Step 4 the sum of the noy values for all the other bands as found in Step 4 multiplied by .3. The result is called PN (Oct.) for that .5-sec interval of a given sound.]

<ins>Step 6</ins>. Convert the PN for each .5-sec interval of sound into PNdB by reference to Table A-3. The result is called PNdB for each .5-sec interval of sound.

Note: All units of PNdB and EPNdB, discussed later, calculated from octave band spectra are to be designated as PNdB (Oct.), Max PNdB (Oct.), and EPNdB (Oct.). PNdB, Max PNdB, and EPNdB without qualification are those calculated from 1/3 octave band spectra.

Table A-3

PERCEIVED NOISE LEVEL IN STEPS OF 1 PNdB AS FUNCTION OF TOTAL PERCEIVED NOISINESS OF A SOUND.

PN			PNL in PNdB	PN			PNL in PNdB
Lower	Mid	Upper		Lower	Mid	Upper	
1.0	1.0	1.0	40	43.8	45.2	46.8	95
1.1	1.1	1.1	41	46.9	48.5	50.2	96
1.1	1.1	1.2	42	50.3	52.0	53.8	97
1.2	1.2	1.3	43	53.9	55.7	57.7	98
1.3	1.3	1.4	44	57.8	59.7	61.8	99
1.4	1.4	1.5	45	61.9	64.0	66.3	100
1.5	1.5	1.6	46	66.4	68.6	71.0	101
1.6	1.6	1.7	47	71.1	73.5	76.1	102
1.7	1.7	1.8	48	76.2	78.8	81.6	103
1.9	1.9	1.9	49	81.7	84.4	87.4	104
2.0	2.0	2.1	50	87.5	90.5	93.7	105
2.1	2.1	2.2	51	93.8	97.0	100.4	106
2.3	2.3	2.4	52	100.5	104.0	107.6	107
2.5	2.5	2.5	53	107.7	111.4	115.3	108
2.6	2.6	2.7	54	115.4	119.4	123.6	109
2.8	2.8	2.9	55	123.7	128.0	132.5	110
3.0	3.0	3.1	56	132.6	137.2	142.0	111
3.2	3.2	3.4	57	142.1	147.0	152.2	112
3.5	3.5	3.6	58	152.3	157.6	163.1	113
3.7	3.7	3.9	59	163.2	168.9	174.8	114
4.0	4.0	4.1	60	174.9	181.0	187.4	115
4.2	4.3	4.4	61	187.5	194.0	200.8	116
4.5	4.6	4.7	62	200.9	207.9	215.3	117
4.8	4.9	5.1	63	215.4	222.8	230.7	118
5.2	5.3	5.5	64	230.8	238.8	247.3	119
5.6	5.6	5.8	65	247.4	256.0	265.0	120
5.9	6.1	6.3	66	265.4	274.4	284.0	121
6.4	6.5	6.7	67	284.1	294.0	304.4	122
6.8	7.0	7.2	68	304.5	315.2	326.3	123
7.3	7.5	7.7	69	326.4	337.8	349.7	124
7.8	8.0	8.3	70	349.8	362.0	374.8	125
8.4	8.6	8.9	71	374.9	388.0	401.7	126
9.0	9.2	9.5	72	401.8	415.8	430.5	127
9.6	9.8	10.2	73	430.6	445.7	461.4	128
10.3	10.6	10.9	74	461.5	477.7	494.5	129
11.0	11.3	11.7	75	494.6	512.0	530.0	130
11.8	12.1	12.5	76	530.1	548.7	568.1	131
12.6	13.0	13.5	77	568.2	588.1	608.9	132
13.6	13.9	14.4	78	609.0	630.3	652.6	133
14.5	14.9	15.4	79	652.7	675.5	699.4	134
15.5	16.0	16.6	80	699.5	724.1	749.6	135
16.7	17.1	17.7	81	749.7	776.0	803.3	136
17.8	18.4	19.0	82	803.4	831.7	861.1	137
19.1	19.7	20.4	83	861.2	891.4	922.9	138
20.5	21.1	21.8	84	923.0	955.4	989.1	139
21.9	22.6	23.4	85	989.2	1024.0	1060.1	140
23.5	24.2	25.1	86	1060.2	1097.5	1136.1	141
25.2	26.0	26.9	87	1136.2	1176.2	1217.7	142
27.0	27.8	28.8	88	1217.8	1260.6	1305.1	143
28.9	29.8	30.9	89	1305.2	1351.1	1398.8	144
31.0	32.0	33.1	90	1393.9	1448.2	1499.1	145
33.2	34.3	35.5	91	1499.2	1552.1	1606.7	146
35.6	36.8	38.1	92	1606.8	1663.4	1722.1	147
38.2	39.4	40.8	93	1722.2	1782.8	1845.7	148
40.9	42.2	43.7	94	1845.8	1910.7	1978.2	149

[Alternative Step 5. Find from Table A-2 the 10 antilog_{10} values for the SPL of the band centered at 1000 Hz that has the same or closest noy value as each of the bands, or summed bands below 355 Hz, as corrected in Step 3. Sum these 10 $\log_{10}$ values.]

[Alternative Step 6. Convert the sum found in Alternative Step 5 into "dB" by reference to the left-hand columns of Table A-2. Add to this value the constant number 12. The result is called PNL in PNdB' for each .5-sec interval of time.]

PNL in dB(D) or dB(A), and dB(D′) or dB(A′)

Step 1. Read the highest value reached in each .5-sec interval of sound on a SLM with D- or A-frequency weighting and set on slow meter action. The result is called PNL in dB(D) or dB(A) for each interval of sound.

Step 2. Add a constant to these meter readings in accordance with Table A-4, as appropriate. The result is called PNL in dB(D′) or dB(A′) for each interval of sound.

Max PNL

Step 1. Find the highest valued PNL for any .5-sec interval during the occurrence of a given sound. This value is called the Max PNL.

Note: By definition PNL and Max PNL are the same for impulsive sounds.

EPNL for Impulsive and Non-Impulsive Sound

Formula 1: $$\text{EPNL} = 10\log_{10}\left[\Sigma_i \log_{10}^{-1}(\text{PNL}_i/10)\right] - 12 + \text{oc} + \text{ic}$$

where $_i$ are successive .5-sec intervals of time, oc is an onset-duration correction, and ic an impulse level correction.

Step 1. Sum on a 10 $\log_{10}$ antilog basis the PNLs found occurring in .5-sec intervals between points in time the level is above the threshold or the practical threshold or perceived noisiness.

Table A-4

ESTIMATED CONSTANT TO BE ADDED TO SLM VALUES, SLOW METER ACTION, TO APPROXIMATE PNdB

	Non-Impulsive Sounds Maximum Energy in Freq. Region			Impulsive Sounds Rise Times Shorter than 0.1 msec Duration			
	Below 400 Hz	400-1200 Hz	Above 1200 Hz	Longer than 4.0 msec	0.4 to 4.0 msec	Shorter than 0.4 msec	Average
dB(D)	6	6	6	7	6	6	6
dB(A)	12	11	15	13	11	15	13

Note: The values of the constants given in this table are for typical broadband sounds. For accuracy, particularly with sounds containing concentrations of energy in narrow frequency bands or for different classes of sounds, specific constants for dB(D) or dB(A) should be determined by means of calculations or measurements that permit comparison between dB(D) or dB(A) and PNdB.

Note 1: The practical threshold of perceived noisiness should be used as a starting point only when it exceeds the threshold of perceived noisiness.

Note 2: The practical threshold of perceived noisiness should be used only when considerations related to sound measurement procedures and indeterminate knowledge about background noise conditions makes the use of the threshold of perceived noisiness impractical.

Step 2. Subtract 12 from the number found in Step 1.

Note: The sum -12 comes from the use of 8 seconds as a reference duration, the nominal duration of the reference standard as defined; specifically, $-12 = 10 \log_{10} 8/.5$, where 8 is the reference duration, .5 is the .5-sec interval at which sound pressure levels are measured, and $10 \log_{10}$ is conversion to equivalent decibels.

Step 3. Find the onset duration of the sound in seconds above the PNL of the background noise.

Note 1: The practical threshold of noisiness shall be used in place of the PNL of the background noise when the latter is not known or has not been measured.

Step 4. Enter Figure 4 with this duration and read the correction, *oc. Add the correction to the number found in Step 2.*

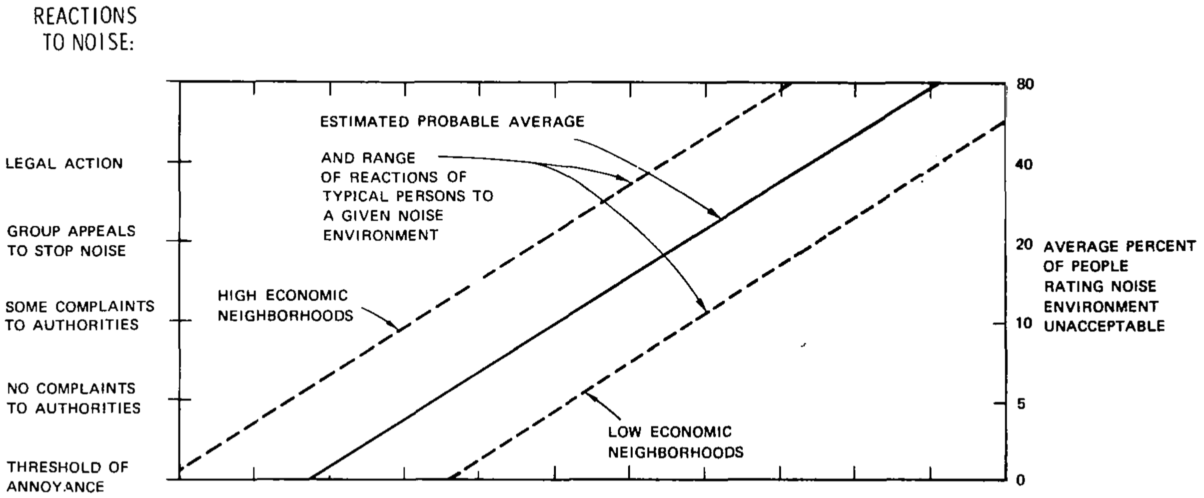
Step 5. Find the difference in PNL between the level reached during impulsive interval of sound and the PNL of the background noise.

Step 6. Find from Figure 8 of text the impulse level correction, ic, for the difference found in Step 5. Add ic to the result of Step 4 above. The result is called EPNL in EPNdB, EPNdB′, EdB(D), EdB(A), EdB(D′), or EdB(A′) depending on the basic unit of measurement used.

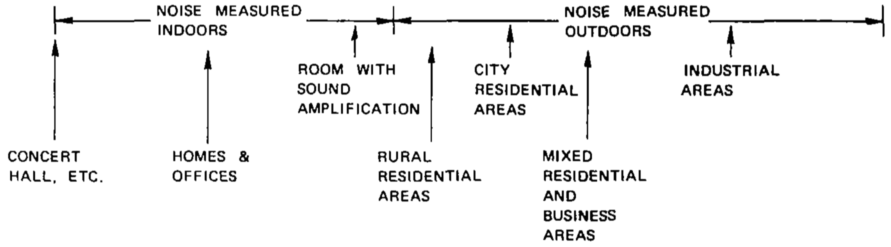
Recommended Units for Estimating Judged Noisiness

It is recommended that EPNL in EPNdB (or EPNdB′) be used as the basic unit for estimating the judged effective perceived noisiness of sounds. For general noise survey and monitoring purposes, EPNL in EdB(D) as measured on a frequency weighted sound level meter is suitable for estimating the perceived noisiness of a sound or sound environment. EdB(A) is often adequate but not generally as accurate in this regard as EPNdB or EdB(D).

Note: PNL values based on 1/3 octave band spectra are to be preferred to those based on full octave band spectra.



NOISE ENVIRONMENT OF ANY SPECTRAL OR TEMPORAL NATURE		CNR	65	70	75	80	85	90	95	100	105	110	115	120
NOISE OF ANY SPECTRUM PRESENT CONTINUOUSLY DURING THE HOURS OF:	7 AM-10 PM	EPNL	77	82	87	92	97	102	107	112	117	122	127	132
		MAX PNdB,dB(D'),dB(A')	40	45	50	55	60	65	70	75	80	85	90	95
	10 PM- 7 AM	EPNL	65	70	75	80	85	90	95	100	105	110	115	120
		MAX PNdB,dB(D'),dB(A')	30	35	40	45	50	55	60	65	70	75	80	85



TOLERABLE LIMITS

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FIGURE A-3 GENERAL REACTIONS OF PEOPLE AND COMMUNITIES TO ENVIRONMENTAL NOISE AND ESTIMATED TOLERABLE LIMITS. dB(D) equals dB(D')-6, and dB(A) equals dB(A')-13.

Calculation Procedures for Composite Noise Rating (CNR)

Calculation of CNR from EPNL Values

$$\text{Formula 2:}\quad \text{CNR} = \left[\left[\overbrace{[\text{EPNL}_1+10\ \log_{10}O_1] \oplus [\text{EPNL}_2+10\ \log_{10}O_2] \oplus \ldots \oplus [\text{EPNL}_n+10\ \log_{10}O_n]}^{7\text{ a.m.}-10\text{ p.m.}}\right]\right] -12 \oplus \left[\left[\overbrace{[\text{EPNL}_{1p}+10\ \log_{10}O_{1p}] \oplus [\text{EPNL}_{2p}+10\ \log_{10}O_{2p}] \oplus \ldots \oplus [\text{EPNL}_{np}+10\ \log_{10}O_{np}]}^{10\text{ p.m.}-7\text{ a.m.}}\right]\right] -2$$

where $O_1 \ldots O_n$ are numbers of occurrences of sounds of EPNLs 1 through n during the hours of 7 a.m. to 10 p.m., and $O_{1p} \ldots O_{np}$ are occurrences of sounds of EPNLs 1 through np during the hours of 10 p.m. to 7 a.m.

Step 1. Add arithmetically to the EPNL of each given value 10 $\log_{10}$ of number of occurrences of sounds for each given EPNL value.

Step 2. Sum on a 10 $\log_{10}$ antilog basis the results of Step 1 for the time period of 7 a.m. to 10 p.m. and subtract 12 from the sum.

Step 3. Sum on a 10 $\log_{10}$ antilog basis the results of Step 1 for the time period of 10 p.m. to 7 a.m. and subtract 2 from the sum.

Step 4. Sum on a 10 $\log_{10}$ antilog basis the results of Steps 2 and 3. The result is called the Composite Noise Rating in EPNdB, EPNdB$'$, EdB(D$'$), or EdB(A$'$) depending on the units of sound measurement used.

Calculation of CNR from PNL Values Taken Every .5 Sec.

$$\text{Formula 3:}\quad \text{CNR} = \left[10\ \log_{10}\left[\overbrace{[\Sigma_i \log_{10}^{-1}\ \text{PNL}_i/10]}^{7\text{ a.m.}-10\text{ p.m.}}\right] -24 \oplus 10\ \log_{10}\left[\overbrace{[\Sigma_i \log_{10}^{-1}\ \text{PNL}_i/10 +10]}^{10\text{ p.m.}-7\text{ a.m.}}\right]\right] -24$$

where $\oplus$ is addition on 10 $\log_{10}$ antilog basis and $_i$ is successive .5-sec intervals of time.

Step 1. Sum on a 10 $\log_{10}$ antilog basis the PNLs of all sounds that exceed 60 at a given location outdoors, or 40 indoors between the hours of 7 a.m. to 10 p.m.

Step 2. Sum on a 10 $\log_{10}$ antilog basis the PNLs of all sounds that exceed 50 at a given location outdoors, or 30 indoors between the hours of 10 p.m. and 7 a.m. and then add 10 to the sum.

Note: The addition of 10 to the sum of PNLs for the hours of 10 p.m. to 7 a.m. is based on the finding that people tend to complain more about environmental noise in those hours than for the hours 7 a.m. to 10 p.m.

Step 3. Sum on a 10 $\log_{10}$ antilog basis the results of Steps 1 and 2 and subtract 24. The result is called the Composite Noise Rating (CNR) from EPNdB, EPNdB′, EdB(D′), or EdB(A′) depending on the units of sound measurement used.

Note 1: The number 24 is a constant equivalent in the present formulation to an arbitrary constant of 12 that has traditionally been included in the calculation of CNR.

Note 2: CNRs calculated from PNL values will tend to be smaller than CNRs calculated from EPNLs and less accurate predictors of human response to environmental noises because onset duration and impulse level corrections are not included.

CNR Obtained from a Graph

Figure A-4 provides a graphic means of converting noises of a given PNL present continuously or intermittently during a 24-hour period into their equivalent, approximate CNR and EPNL value.

Note: The CNR and EPNL values thus obtained from only the Max PNLs of noises will be closely equivalent, within one unit, to those calculated from procedures given earlier whenever the rise and decay time of the noises is shorter than the duration of the noise at its Max PNL (for example, a duration at Max PNL of 5 sec with a rise and decay each of less than 5 sec). When the rise and decay times of the noise to and from their maximum levels is appreciably long compared to the duration at maximum level it is advisable to use the procedures given earlier or to enter Figure A-4 with each PNL level present during a 24-hour period for given durations.

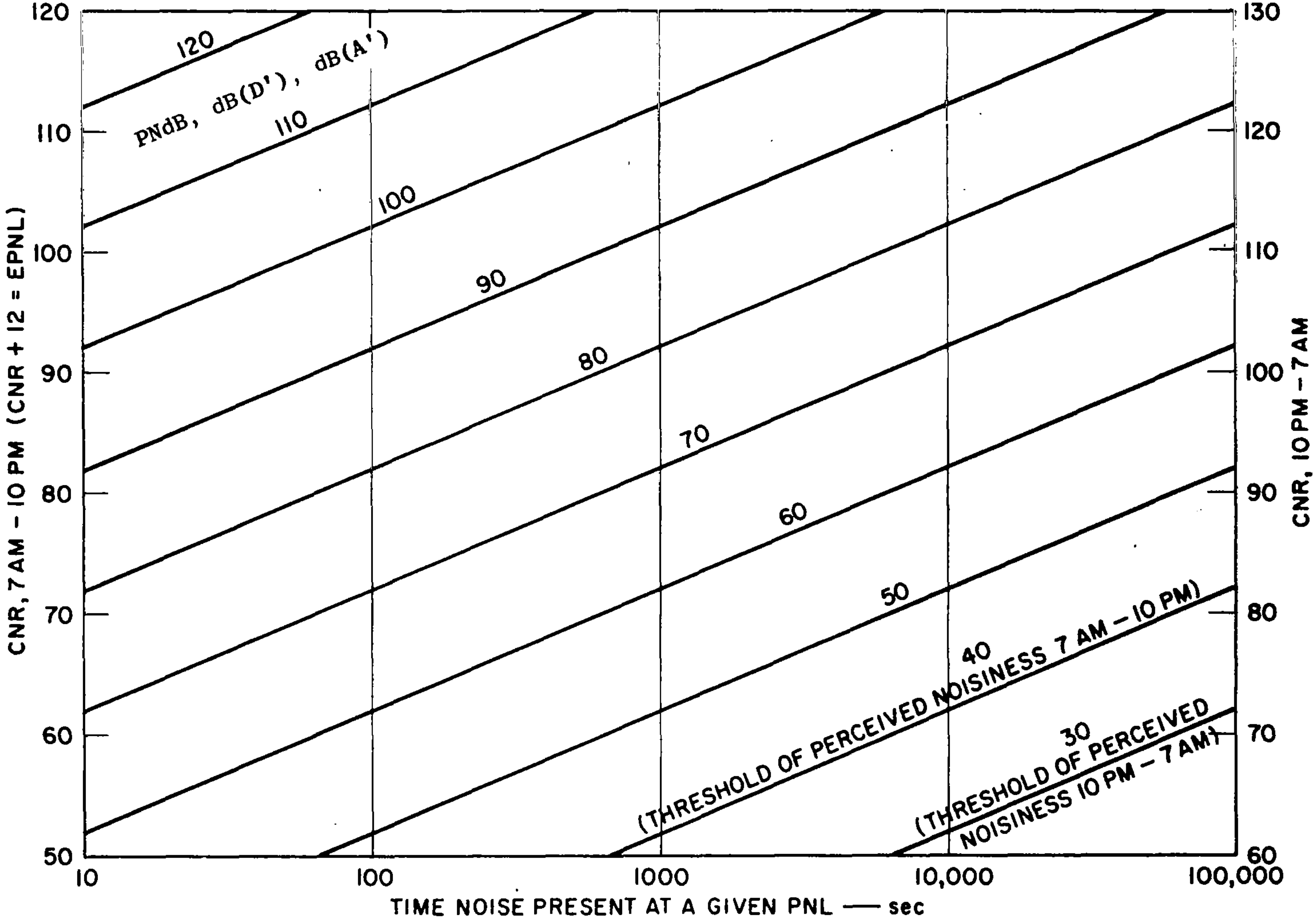

FIGURE A-4 GRAPH FOR CONVERTING NOISES PRESENT CONTINUOUSLY OR INTERMITTENTLY AT A GIVEN PNL DURING THE HOURS 7 AM TO 10 PM, LEFT-HAND ORDINATE, OR 10 PM TO 7 AM, RIGHT-HAND ORDINATE, TO AN EQUIVALENT CNR. EPNLs for noises occurring any time during 24-hour period can be found for a given PNL and duration by reading corresponding value on lift-hand ordinate and adding 12.

CNRs from Figure A-4 for noises present during the 24-hour period at different PNLs are combined into the total CNR for the 24-hour period by summing the individual CNRs on a 10 $\log_{10}$ antilog basis.

Note 1: For example, for a given neighborhood the CNR found by means of Figure A-4 of, say, the runup noise from aircraft, the CNR of the noise from, say, nearby industry, and the CNR of passing motor vehicles can be added together to give the total CNR for that neighborhood from all three sources combined.

Note 2: The procedure given earlier entailing calculation of CNR from EPNL values is the one normally to be used for measuring the CNR of an environment containing a variety of sounds from possibly unspecified sources. For example, the noise environment near a highway or airport that is used by an unspecified number of types of vehicles operating according to a variety of more or less unspecified procedures.

Note 3: One or the other of the remaining two procedures is normally to be used for calculating the CNR of an environment from knowledge of the PNLs or EPNLs of specified sources. For example, the noise environment to be expected near a highway or airport that will be used by a specified number and types of vehicles operating according to specified procedures.

Behavior of People to and Tolerable Limits of Noise Environments

The expected behavior of given percentages of people habitually living or working in a noise environment having a given CNR outdoors can be estimated by reference to Figure A-3. Max PNdB, dB(D′), or dB(A′) values given are the equivalent of the respective CNR and EPNL values only for a noise present continuously during the hours indicated. Max PNdB, dB(D′), or dB(A′) are not applicable for the relative evaluation of different noise environments where the noise changes appreciably in duration or spectrum during the time periods specified; for such noise environments, EPNL, for given daytime or nighttime periods, or CNR of day plus nighttime noise exposures should be used.

The amounts of noise in CNR, EPNL, or in Max PNdB, dB(D′), and dB(A′) units that appear to be tolerable, as defined earlier, to the average person or typical community for indoor and outdoor noise are indicated by arrows below the abscissa on Figure A-3.

Maximum levels in PNdB, dB(D′), and dB(A′) of more or less steady noise that have been recommended as tolerable for various rooms, work, and living areas are also specified in Table A-5.

Table A-5

Tolerable maximum levels or exposures in various rooms for more or less continuous noise from 7 AM to 10 PM. Max PNdB, dB(D'), and dB(A') are *equivalent to each other only when the noise has a broadband spectrum* approximately similar in shape to the 40 noy contour, and does not contain any strong pure-tone or line spectrum components. After Beranek*

Noises or noise environments of equal EPNL or equal CNR values are presumably equal *in their effects on people regardless of the spectral or* temporal complexities of the noises or noise environments they represent.

		Max PNL		EPNL	
Type of Space	dB(A)	dB(D)	PNdB	PNdB, dB(D') dB(A')	CNR
Broadcast studios	28	35	41	78	66
Concert halls	28	35	41	78	66
Legitimate theaters (500 seats, no amplification)	33	40	46	83	71
Music rooms	35	42	48	85	73
Schoolrooms (no amplification)	35	42	48	85	73
Apartments and hotels	38	45	51	88	76
Assembly halls	38	45	51	88	76
Homes	40	47	53	90	78
Motion picture theaters	40	47	53	90	78
Hospitals	40	47	53	90	78
Churches	40	47	53	90	78
Courtrooms	40	47	53	90	78
Libraries	40	47	53	90	78
Offices - Executive	35	42	48	85	73
- Secretarial (Mostly typing)	50	57	63	100	88
- Drafting	45	52	58	95	83
Meeting rooms (sound amplification)	45	52	58	95	83
Retail stores	47	64	60	97	85
Restaurants	55	62	68	105	93

Note: The noise levels outdoors from sources located outdoors (aircraft, road traffic, etc.) could be typically about 20 dB greater for the average house and 30 dB for masonry or well sound-insulated buildings than the levels given in the above table.

Note: dB(A') -13 = dB(A)

dB(D') -7 = dB(D)

*Beranek, L. L. Revised criteria for noise in buildings. Noise Control, 3:19-27 (1957)

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