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TECHNICAL NOTE

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SOME EFFECTS OF SPECTRAL CONTENT AND DURATION ON PERCEIVED NOISE LEVEL

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FOREWORD

In the following report are presented "equal noisiness contours" (necessary for the calculation of perceived noise levels) that differ somewhat from equal noisiness contours published in 1959. The equal noisiness contours, and tables related thereto, presented in this report are presumably more accurate than, and should be used in preference to, those published in 1959. However, the changes in the equal noisiness contours are modest so that perceived noise levels calculated from the new contours, as is demonstrated in this report, will usually not differ greatly from those obtained with the older contours.

In our opinion, the new equal noisiness contours are based on an adequate amount of research data and should prove to be "final." It is anticipated that in the near future methods for calculating perceived noise levels utilizing the equal noisiness contours and tables presented in this report will be proposed to the American Standards Association and the International Standards Organization for possible standardization.

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A number of experiments were conducted in which listeners equated a wide variety of sounds with respect to noisiness (equal acceptability) and loudness. The principal findings are as follows:

(1) on the basis of data obtained from approximately 250 subjects new equal noisiness contours and tables for use in the calculation of perceived noise level were determined;

(2) over a range of durations from 1 1/2 to 12 secs sounds were judged equally acceptable when the sound pressure level was reduced by 4 1/2 dB for each doubling of duration. Variations in rise and decay times from 1/2 to 4 secs did not significantly influence the judgments;

(3) combining a pure tone of sufficient intensity with a band of filtered white noise caused subjects to judge the sound as noisier than the same band of noise at the same overall sound pressure level as the tone-plus-noise. On the other hand, the judged loudness of the band of noise, keeping overall level constant, was not appreciably affected by the addition of the tone;

(4) calculated measures of perceived noise level (PNdb), loudness, and the readings on A, B, C, and "flat" scales on a sound level meter were determined for a variety of "real" and artificial sounds of equal duration when these sounds were judged to be equally noisy or acceptable. Considering both absolute values and variability in the results the order of merit, from best to worst, of the various measures for predicting the judgment data was as follows: PNdb, phons Zwicker, phons Stevens, "flat," C, B and A scale of a sound level meter.

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I. INTRODUCTION

In 1959[1] we published a set of so-called equal noisiness contours showing the sound pressure levels required of sounds of different spectra to give rise to the subjective equality of these sounds with respect to their "noisiness" or "acceptability." It was also proposed that a calculation scheme, developed by S. S. Stevens[2] for the calculation of loudness, be used in the calculation of the total perceived noise level of complex sounds of different bandwidths. These two factors -- the spectrum or frequency content of a sound and its bandwidth -- are prime determiners of the subjective magnitude of what we have chosen to call the noisiness of a sound.

Subsequent tests and experiments have tended to validate the use of perceived noise level, usually expressed in units called PNdb, as a predictor of the judged noisiness as well, in some cases, as the judged loudness, usually expressed in units called phons, of a wide variety of sounds. The method has been particularly useful in the evaluation of flyover sounds made by aircraft. At least, calculated perceived noise level of aircraft sounds was found to be a somewhat more accurate predictor of either judged noisiness or

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1. K. D. Kryter, "Scaling Human Reactions to the Sound from Aircraft," <u>JASA</u>, <u>31</u>, 1415-1429, 1959.

2. S. S. Stevens, "Calculation of the Loudness of Complex Noise," <u>JASA</u>, <u>28</u>, 807-832, 1956.

loudness than loudness level, calculated either by the Stevens or Zwicker methods, or than sound pressure level as measured on the A, B or C scale of a standard sound level meter.

However, the perceived noise level method was weak in several respects. For one thing, the shape of the equal noisiness contours was based on a rather small amount of data and did not extend to frequencies above 6800 cycles. In addition, the calculation procedure did not take into account the possible contribution to the noisiness of a sound of one or more intense pure tone components in a broader band of sound frequencies. Also, it is clear that the effects duration and rapidity of onset and decay of a sound have upon subjective noisiness should be quantified and, if possible, incorporated into the calculation of perceived noise level. We have conducted several experiments over the past two years that have been concerned with these problems. The results of these studies are presented below.

II. EQUAL NOISINESS AND EQUAL LOUDNESS TESTS - METHED OF PAIRED COMPARISONS

1. Test Description

Four groups of male and female college students, approximately 50 in each group, were used as subjects. Each group was tested separately in a large classroom (33' x 31'). The subjects were asked to judge sometimes the relative loudness and sometimes the relative noisiness or acceptability of pairs of sounds via a KLH Model 4 loudspeaker. The general plan of the experiment is given in Table 1.

Table 1
Test Schedule

	1 Test Day	2nd Test Day (1 wk later)
Group 1	Loudness	Loudness
2	Noisiness	Loudness
3	Loudness	Noisiness
4	Noisiness	Noisiness

Altogether 178 pairs of sounds were recorded on a continuous piece of magnetic tape. Each sound (except for a few recordings of "real life" sounds such as those from an aircraft) lasted 4 sec, with a 1 sec pause between members of a pair and about 5 sec between pairs. The sounds were turned on and off by an electronic switch that had a rise and decay time of about 100 millisec.

The first sound in a pair was called the "standard" and the subjects were instructed to judge whether the second member, the "comparison," was "louder" or "noisier" than the first; the detailed instructions are given in Appendix A (pp. 28 and 29). Several standard bands of noise (110 to 7500 cps, 900 to 1060 cps, 3120 to 3680 cps, 625 to 1460 cps and 3120 to 7500 cps, as measured electrically from the recording) were presented at a constant sensation level of about 90 dB. The bands were obtained from a broad band "white" noise produced by a Grason-Stadler Model 455A noise generator and filtered by a Krohn-Hite Model 330A band-pass filter. The skirts of the filters fall off at the rate of about 24 dB/octave.

The comparison bands were presented at four different levels, average difference of 3.3 dB between levels with the mean level being roughly 90 dB. The comparison bands were set according to the filter controls at widths of either 1, 5, 10, 15 or 20 "critical" bands[3] around a number of different center frequencies. As will be noted later, the acoustical spectrum reaching the listeners' ears turned out to be somewhat different than that electrically present on the recording.

One must be careful, in arranging a paired-comparison test of the type used here, not to influence or bias the subject's response by limiting the number of levels at which the comparison sound is presented. That is, the subjects may form opinions about the different levels of the comparison sound with respect to its "average" level and not strictly on how each of these levels sounds in comparison to the standard. However, we believe that this possible bias was avoided in our test. The wide variety of standard and comparison sounds involved and the fact that the pairs were presented in a randomized order (with respect to any one standard, comparison sound or level) seemed to prevent the listeners from forming any

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3. E. Zwicker, "Subdivision of the Audible Frequency Range into Critical Bands/Frequenzgruppen, L. E." JASA, 33, 248, 1961.

appreciation of the absolute variations in level of the comparison sounds. Indeed, because of the length of the test and large changes in the spectra and levels of standard and comparison sounds from pair to pair, the test seemed most confusing to the subjects.

Nevertheless, the test results, examples of which are shown in Fig. 1, were orderly. Graphs similar to those in Fig. 1 were made for all the comparison bands vs the several standards; on these graphs perpendiculars were dropped to the abscissa from the point at which the 50% line crossed the curves. The sound pressure level thus obtained from the abscissa was taken as the level required for that particular comparison band to be judged as equally loud or equally noisy, as the case might be, to that particular standard.

2. Test Results

It was obvious from inspection of the results obtained with the bands of filtered white noise that there was no essential difference, on the average, between the loudness and noisiness judgments. Plots of the equal noisiness and equal loudness contours were practically indistinguishable for the four groups. Because the results for each group were so similar, we averaged the data for the noisiness judgments over the four groups, regardless of the sequence in which the tests were administered to the different groups.

Because of the variation between the spectral shape of the critical bands of noise as electrically recorded and the shape of the acoustical signals reaching the listeners' ears we did not attempt to accurately determine the differences, if any, between the contours for sounds of different bandwidths. Analysis of the electrical signals on the recordings showed that the bands of noise, as intended, were more or less precisely 1, 5, 10, 15 or 20 critical bands wide regardless of their center frequency. However, because of room acoustics and loudspeaker characteristics the signals reaching the listeners differed somewhat from the electrical input to the loudspeakers. The acoustical spectrum to the listeners was determined from one-third octave analysis of recordings made at four positions, one in each quarter of the room during the administration of the tests. It was found that, because of the diffusivity of the room, the spectra from the four different microphone pick-ups were very similar to each other.

We grouped the acoustical spectra according to whether they fell in the range of 1-2, 3-7, 8-12, 13-17, and 18-22 critical bands in width. The number of critical bands in each noise was determined by overlaying a complete set of critical bands with 24 dB/octave skirts on a one-third octave band plot of the noise and noting the nearest whole number of critical bands which most nearly corresponded to the noise sample at the 10 dB downpoints. The results obtained with this arrangement of the data averaged over all four groups of subjects for noisiness judgments are plotted in Fig. 2. Inasmuch as the points plotted for the 1-2 and 3-7 critical bands do not differ greatly and because they approximate bandwidths around one octave (the widest band used in the measurement and calculation procedure for perceived noise level) we drew a curve of visual best fit to the data points for the narrow bands, as is also shown in Fig. 2.

As the bandwidth of our comparison signal is increased beyond that of the standard we can expect a decrease in the overall level required for the broader band signals to sound either equally loud or noisy. The displacement of the points for sounds wider than 7 critical bands wide below that of the other contour indicates that such a trend does take place.

III. EQUAL NOISINESS AND EQUAL LOUDNESS TESTS - METHOD OF INDIVIDUAL ADJUSTMENT

1. Background

One likely conclusion to be taken from the results showing no essential difference between the loudness and noisiness contours would be that the instructions for loudness and noisiness, at least as applied to these narrow bands of noise, were synonymous to these subjects. We shall see later, however, that they judged loudness and noisiness as being quite different when they judged somewhat more complex sounds.

This strong similarity between the judgments of loudness and noisiness is different than results obtained by Laird[4] and by Reese, Kryter and Stevens,[5] but is in agreement with some data reported by Rademacher.[6] Some of the difference in results may be attributed to differences in experimental procedures. In the former two experiments the subjects were able to adjust the level of the comparison sound until they felt it was equal to the standard, the so-called method of adjustment; further, the subjects were tested individually in the laboratory and had as much time as they wished for making the comparisons. In our experiment just reported and in Rademacher's study, subjects were tested using the method of paired comparison. The method of individual adjustment may be more conducive to the making of somewhat finer distinctions on the part of the subjects than the more mechanical, faster-moving, paired-comparison test method; if this is true, it would, of course, help explain the difference noted between the experiments just cited.

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4. D. A. Laird and K. Coyne, "Psychological Measurements of Annoyance as Related to Pitch and Loudness," JASA, 1, 158-163, 1929.

5. T. W. Reese, K. D. Kryter and S. S. Stevens, "The Relative Annoyance Produced by Various Bands of Noise," Psychoacoustics Lab., Harvard Univ. (March 17, 1944) P.B. No. 27,306, U.S. Dept. of Commerce, Washington, D. C.

6. H. J. Rademacher, "Die Lautstärke von Kraftfahrzereggeräuschen," Acustica, 9, 90-108, 1959.

We do not believe, however, that the differences in experimental techniques can alone explain the differences found in the experimental results. We suggest that in addition, particularly with continuous spectra sounds, groups of experimentally naive subjects may find it somewhat difficult to distinguish between the meaning of the instructions regarding these two attributes of sound.

Faced with the necessity of making a number of rapid decisions about the "equality" between two sounds, the subjects may simply judge whether they thought the comparison sound was "more" or "less" than the standard and responded accordingly, regardless of whether they were asked to judge the loudness or the acceptability of the sounds. We are suggesting, in short, that when naive subjects are asked to make equal loudness judgments, particularly with paired-comparison test procedures, they may tend to judge equal "magnitude" in terms of equal acceptability of noisiness and not solely equal intensity. Perhaps only under more rigorous laboratory conditions and procedures can we expect subjects to give valid estimates of loudness, by which is presumably meant the relative "intensity" of two sounds.

2. Test Description

In an attempt to answer this question we asked 20 subjects to make both loudness and noisiness judgments of bands of sound in the laboratory using the method of individual adjustment. The actual **instruction sets used are given in Appendix A (pp. 30 and 31).** We wished to determine: first, whether, under these conditions, a difference could be found between equal loudness and equal noisiness contours, and second, if two different contours are found, which one is more like the contour found with the paired-comparison tests administered to the four large groups of subjects. Presumably, we might be able, in this manner, to find whether the subjects in the group tests equated, if indeed they did, loudness with noisiness, or conversely, noisiness with loudness.

3. Test Results

The results of the laboratory tests, method of individual adjustment, are presented in Fig. 3. Also indicated in Fig. 3 are the averages for the noisiness judgments from the paired-comparison tests. It is seen that for frequencies above 200 cps or so the paired-comparison test results agree more with the equal noisiness contour found by the method of individual adjustment than the equal loudness contour found by the method of individual adjustment. For this reason we have assumed that the subjects in the paired-comparison tests were responding to these bands of filtered white noise more in terms of the relative acceptability of the sounds to them than in terms of their loudness, even when they were asked to judge "loudness."

IV. EXTENDED EQUAL NOISINESS CONTOURS

In Fig. 4 we have plotted the 40 noy contour published in 1959, the data points from the recent paired-comparison and individual adjustment tests, and a new 40 noy contour; we think this new 40 noy contour represents a reasonable fit or compromise among the new data joints and the 1959 contour. We have also adjusted the new contour to be appropriate for a standard reference band of 1000 cps at a level of 93 dB, and not 92 dB, as was the case in the 40 noy contour published in 1959.

Using this 40 noy contour as a starting point we proceeded to plot equal noisiness contours over the range from 0.1 to 250 noys. The results are shown graphically in Fig. 5; a table of noy values as a function of sound pressure level for a variety of band center frequencies is given in Appendix B.

The growth of this noisiness scale at different frequency regions is essentially that proposed by S. S. Stevens (Ref. 2) for loudness, although we have modified the scale somewhat at the very low sound pressure levels. The growth of noisiness as a function of octave band sound pressure level is shown for a number of different frequency bands in Fig. 6.

The new equal noisiness contours differ from those published in 1959 primarily in the octave band centered at 6800 cps, in addition to the fact that the new contours extend farther up the frequency scale. As was indicated in the 1959 article on the use of perceived noise level in the scaling of aircraft sounds the equal noisiness contours then published required verification and probably modification, particularly at the higher frequencies. We believe that these new contours are reasonably accurate and should, unless research by others indicates otherwise, require no further changes.

In our opinion these new extended contours when used for the calculation of perceived noise level do not require any special designation, other than perhaps a notation as to their date of publication.

We have calculated the PNdb's for a sample of aircraft flyover and a few other sounds using both the 1959 (Ref. 1) and the new extended range equal noisiness contours (see Appendix B, this article). The results are given in Table 2. As would be expected, a significant difference is found between the two PNdb values only for those spectra containing a relatively great amount of energy in the 4800-9600 cps octave band.

Table 2

Comparison of Calculated PNdb (1959 vs 1962)

	Noise Sample	PNdb (1959)	PNdb (1962)	Net Change
1	Noise 150-300 cps	93.0	92.5	0.5
2	Noise 600-1200 cps	94.5	94.5	0
3	Noise 2400-4800 cps	94.0	93.0	1.0
4	Noise 4800-10,000 cps	101.0	88.5	12.5
5	Noise 150-4800 cps, "Flat"	93.0	91.5	1.5
6	Noise 150-4800 cps, + 6 dB/Oct. Slope	98.5	95.0	3.5
7	Noise 150-4800 cps -12 dB/Oct. Slope	90.0	90.0	0
8	Diesel Engine	87.0	90.0	-3.0
9	Super Constelation Landing	106	105.5	.5
10	707-120B Landing	104	102.5	1.5
11	707-320 Landing	103	101	2
12	707-420 Landing	104	101.5	2.5
13	707-120 Landing	102	101	1
14	707-120B Landing (Hushkit)	94.0	92.5	1.5
15	Super Constellation Takeoff	105.5	104.5	1
16	707-120B Takeoff 8,000 lb Thrust	100	97.5	2.5
17	707-120B Takeoff 10,200 lb Thrust	102	101	1
18	707-120B Takeoff 13,700 lb Thrust	101	99.5	1.5
19	707-120 Takeoff 11,050 lb Thrust	100	99	1

V. EFFECT OF STRONG PURE-TONE COMPONENT IN A BAND OF NOISE

1. Test Description

Little[7] found that when a pure-tone component exceeded the background noise (measured in 1/24th octave bands) by 8 to 10 dB, the judged noisiness was underestimated by calculated perceived noise levels. He proposes that a correction factor (see Fig. 7) be applied to sounds with very strong pure-tone components.

In order to partially repeat Little's study, we included in our recent paired-comparison tests some pairs of sounds in which the subject judged an octave band of sound with a steady-state pure-tone component (the comparison) against the same octave band without the steady-state pure-tone component (the standard band). The level of pure tone and octave band background noise was independently varied.

2. Test Results

The results are shown in Fig. 8. Unlike the results obtained with the bands of only random noise, we see in Fig. 8 that the subjects did feel that there was a significant difference between the loudness and the acceptability or noisiness of the sound consisting of a pure tone of 4000 cps in a background of random noise provided the pure tone is approximately 1 dB more than the background when measured in octave bands and becomes progressively noisier as the pure tone level is increased relative to the background. By the time the 4000 cps pure tone exceeds the octave band background level by 10 dB, the

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7. J. W. Little, "Human Response to Jet Engine Noises," Noise Control, 7, 11-13, 1961.

subjective noisiness is likewise increased by 5 PNdb relative to noisiness of an octave band without the pure tone, but of the same overall sound pressure level as the band with the pure tone. We see that when a pure tone of 1000 cps exceeds a band of noise extending from 503-900 cps by 7 dB, the judged noisiness would be equal to the band without the pure tone at a level approximately 4 dB greater than that of the pure tone.

These results do not agree with those obtained by Little, as seen in Fig. 7, although in looking at the two sets of data we note that the slopes are comparable. Possibly the reason for disagreement in absolute levels is because the noise in Little's experiment was broad band while the data in this study was obtained using octave bands of noise. There were other differences in methodology -- Little, for example, used earphones whereas we used loudspeakers -- that may help explain the differences in the results.

Difference between Loudness and Noisiness

It might be noted in Fig. 8 that the loudness of the combination of a pure tone and random noise in which the tone exceeds the noise by 10-15 dB is about equal to the loudness of the standard band when the sound pressure level of the standard band is about 1-2 dB less than that of the combination. This is in agreement with results obtained by Stevens and Kryter (Refs. 1 and 2) who found that a pure tone had to be about 1-2 dB more intense than the overall sound pressure level of an octave band having the same center frequency to be judged equally loud.

3. Need for Pure-Tone Correction Factor

In order to properly evaluate, by means of a calculated perceived noise level, the noisiness of a sound containing strong pure-tone components, it appears necessary to add a pure-tone noisiness factor to the PNdb value obtained for the sound in accordance with the regular calculation procedures. However, we believe that before any "correction" can be accepted more data is needed to resolve the difference between our results and those of Little. Also, a suitable method for determining, with standard methods of acoustic analysis, the presence of a steady-state pure tone in a random noise remains to be found.

VI. EFFECT OF DURATION

1. Background

We have contended that for general psychoacoustic and noise control purposes it is more meaningful and valid to relate the physical characteristics of sounds to subjective judgments of how acceptable or unacceptable, or, as usually defined, how noisy various sounds are rather than how loud. Whereas the difference between loudness and noisiness, as a function of frequency may be relatively small for steady-state broad-band sounds (discounting possible semantic and methodological problems in the measurement of these two subjective attributes), the difference upon loudness and noisiness of pure-tone components in the background noise is quite sharp, as is seen in Fig. 8. Common experience indicates that varying the duration of a sound also has a very different effect upon the loudness than upon the noisiness of the sound.

Garner[8] has shown, for example, that the loudness of a tone or band of noise grows as its duration is increased up to a few tenths of a second. As the duration is further increased loudness remains relatively constant; actually, experiments on "perstimulatory fatigue"[9] show that, if anything, loudness tends to decrease with continued stimulation. On the other hand, the longer the duration of an intense "unwanted" sound, the noisier, more unacceptable, it would probably be judged.

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8. W. R. Garner, "The Loudness and Loudness Matching of Short Tones," JASA, 21, 398-403, 1949.

9. J. P. Egan, "Independence of the Masking Audiogram from the Perstimulatory Fatigue of an Auditory Stimulus," JASA, 27, 737-740, 1955.

Stevens and Pietrasanta[10] have proposed that the acceptability of the flyover sounds from aircraft could be appropriately estimated by measuring the total energy in the sound; accordingly, to this procedure doubling the duration of a sound would have the same subjective effect as increasing its level by 3 dB. However, to the best of our knowledge, what the "exchange" relation is between intensity level and duration with respect to "noisiness" has not been experimentally determined, and, of course, there is no real reason why man's auditory system needs to operate on an equal energy basis; it is well known that it does not do so when, for example, the measure of combined duration and intensity effects is auditory fatigue.[11]

2. Test Description

After conducting a number of exploratory tests, using both the methods of individual adjustment and paired-comparisons a rather lengthy paired-comparison test was recorded on magnetic tape. Four different spectra, shown in Fig. 9, were included.

We used the method of paired comparisons because our preliminary test results seemed to indicate that the paired-comparison test is a more reliable technique for getting noisiness judgments when the subjects compared sounds of different duration than is the method of individual adjustment, at least for the time patterns of sounds we wished to test. Some subjects appeared to adjust the sounds to have subjectively equal peak levels and to disregard duration effects when they used the method of individual adjustment.

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10. K. N. Stevens and A. C. Pietrasanta and Staff, Bolt Beranek and Newman Inc., "Procedures for Estimating Noise Exposure and Resulting Community Reaction from Air Base Operations," WADC Tech. Note 57-10 (Wright-Patterson Air Force Base, Ohio, April 1957).

11. W. D. Ward, A. Glorig and D. L. Sklar, "Dependence of Temporary Threshold Shift at 4 KC on Intensity and Time," JASA, 30, 944-954, 1958.

The tests were administed via earphones to 14 subjects. The subjects were asked to judge whether the first or second of a pair of sounds seemed to be the noisier (more unacceptable). They were asked to base their judgments on the total overall effect each sound had upon them and not upon peak level alone. The actual instruction set is given in Appendix A (p. 32). The subjects recorded on an answer sheet a 1 if they thought the first sound was noisier and a 2 if they thought the second was more noisy than the first.

Upon each of the spectra tested a variety of time patterns was imposed. The rise time and decay time were always made equal to each other, but varied from 1/2 sec to 4 sec (1/2, 1, 2 and 4 sec). When each sound reached its peak, that level was constantly maintained for durations varying from 1/2 to 8 sec (1/2, 1, 2, 4 and 8 sec).

Definitions of rise time, decay time and peak level duration are given graphically in Fig. 10.

Two series of tests were given; for Test 1 we used only the narrow band spectra with all possible combinations of rise times and peak level durations, while for Test 2 we used selected rise times and peak level durations for each of the four different sounds. These rise times and peak level durations were selected such that their durations, 10 db below maximum level, were evenly distributed over the entire range.

Each spectrum at the various combinations of rise-decay and peak level duration was judged against a "standard" sound; this standard had the same spectra as the comparison with a peak level duration of 2 sec and a rise and decay time of 2 sec each. The standard was presented at a sound pressure level of 100 dB measured in a 6 cc coupler; the comparisons were presented at 4 different levels, in 4 dB steps, the median level of the comparison was adjusted so that its total energy was approximately equal to that of the standard. Each sound was judged against the standard twice; once when the standard appeared first in the pair and once when it was presented second. The two judgments were averaged. The various pairs of different spectra, levels and order of standards were presented in a randomized order to counteract any stimulus biases to which the subjects might be susceptible.

3. Test Results

One might expect that for a shorter rise time, with the peak level duration held constant, the sound would become more annoying. In other words, it would have more of a startle effect. On the other hand, for shortened rise-decay times the energy in the total sound between given sound pressure levels on the rise-decay curve decreases when peak level duration is kept constant; this would presumably tend to decrease the subjective acceptability of the sound.

Whatever the contributing factors may have been, we found that for the range of rise-decay times used in these tests the noisiness changed as a function of the integrated energy and was not particularly influenced by the rise-decay time.

In an attempt to find some parameter that would account for both the possible increase in noisiness due to decreased rise time and increased peak level duration we plotted the data for the 5, 10, 15 and 20 dB down durations. The data points for the durations taken at 10 dB down defined and fit a single straight line better than did those for the other measures of duration.

In Fig. 11 we give the results of the two tests when the total duration of the comparison sounds are taken at the 10 dB downpoints on the rise and decay below the peak level.

Figure 11 shows that, for the spectra, intensities and durations tested, the equal noisiness parameter has a slope of about -4.5 dB per doubling of duration. It would also appear that all of the spectra tested provided approximately the same relationship; although, as might be expected, there were some variations in absolute levels among the comparison sounds to be judged equal to the particular standards used for these tests.

In order to display any effect the various rise-decay times have other than to change the overall energy present in the sample, we have normalized the data by the relationship indicated in Fig. 11. The results are plotted in Fig. 12 as a function of rise time with constant level duration a parameter. Notice that although there is more variation for the shorter rise time, the average is fairly constant. We conclude that for the rise-decay and peak level durations involved in these tests the variations in rise-decay times per se had no significant effect upon judged noisiness.

We hasten to note that this "trading" relation of 4.5 dB between duration and level for equal noisiness is probably not applicable to sounds presented at more moderate levels. One would expect that value to become progressively smaller as the absolute levels are considerably decreased.

Attention is invited to the fact that a decrease in the judged acceptability of a sound as its duration is increased, keeping sound pressure level constant, is contrary to what would be expected from loudness judgments. As mentioned earlier in this section, loudness reaches a constant level in a few tenths of a second and even tends to decrease in level as the duration of a sound is prolonged.

VII. SOME VALIDATION TESTS

1. Relative vs Absolute Noisiness

In the final analysis, the merit of any procedure for relating physical measurements of sound to its subjective or perceived magnitude lies in its ability to handle in a valid way this relation for as wide a variety of different types of sounds as possible. As has been pointed our previously[12] as long as one is interested only in intercomparing the relative loudnesses or noisinesses of a class of sounds, the spectra of which do not differ widely (for example, the sound from motor cars, trucks, etc.), the various loudness, noisiness and even A scale sound level meter readings are equally good.

However, the trick is to derive a procedure that will permit intercomparisons among sounds of widely different character, for example, between jet and piston aircraft or even between jet aircraft and the sounds from automobiles, dishwashers, factories, etc. This generality, we think, becomes particularly important in evaluating the noise environments in communities or neighborhoods. In short, relative accuracy, by a method or scale may not always be sufficient; the absolute values should also have some accuracy if a general standard procedure for estimating the effects of noise upon people is to be established.

2. Test Description

As a further means of checking the validity of the 1962 perceived noise level scale, equal noisiness judgment tests were obtained for several sounds, each of which had a 4 sec duration and approximately a 100 millisec rise-decay time. The spectra of the various sounds are shown in Figs. 13-15. The octave band extending from 600-1200 cps was used as a standard and the subjects were asked to adjust the level of the comparison until, to them, it was just as acceptable as

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12. K. D. Kryter, "The Meaning and Measurement of Perceived Noise Level," Noise Control, 6, 12-27, 1960.

the standard. The instruction set used is given in Appendix A (p. 33). The sounds were presented over a loudspeaker in a semi-diffuse laboratory room. All acoustical measurements of the sounds tested were made with a microphone at the position of the subject's ear, but with the subject absent.

3. Test Results

The results are shown graphically in Fig. 16. There is quite a range of responses, especially with the highest frequency band, Noise No. 4. A possible explanation for the large range is the differences among the subjects in auditory sensitivity at these high frequencies; also, the difference in center frequencies between this band and the standard is greater than for the other sound samples, which would make the subject's job more difficult. The average level of this noise is about the same as that for Noise No. 3, which is not in agreement with the noy contours given in Fig. 5. However, we feel that such a difference is probably part of the normal variation to be expected in judgment data of this kind and would be resolved if more subjects had been used for these "validation" tests.

In Table 3 we have tabulated various sound level meter readings and loudness and perceived noise levels for the averages obtained in the judgment tests (the horizontal bars in Fig. 16).

It is apparent that none of the sound level meter scales predicts as well as the calculated schemes. The loudness levels by Zwicker[13] and Stevens[14] and the perceived noise levels,[15] all do a fair job of

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13. E. Zwicker, "Über Psychologische und Methodische Grundlagen der Lautheit," Acustica, 1, 237-258, 1958.

14. Stevens' "Mark VI" method was used for calculating the phon values given in Table 4. S. S. Stevens, "Procedure for Calculating Loudness: Mark VI," PNR-253, March 1961, Psycho-Acoustic Lab., Harvard Univ., Cambridge, Mass.

15. The method used for calculating perceived noise levels in Table 3 is that given in Appendix B, this article.

Table 3. Comparison of Assessment Methods for Noises Judged to be Equally Acceptable

	Noise 150-300 cps	Standard Noise 600-1200 cps	Noise 2400-4800 cps	Noise 4800-10,000 cps	Noise 150-4800 cps "Flat"	Noise 150-4800 cps +6 dB/Oct. Slope	Noise 150-4800 cps -12 dB/Oct. Slope	Diesel Engine	707-120B Landing Turbofan with Hushkit		
	1	2	3	4	5	6	7	8	9	Range	Average Difference from Standard
Overall "Flat"	92.0	90.0	80.5	80.0	80.5	83.0	84.5	87.0	80.0	12.0 dB	-6.5 dB
A Scale	82.0	90.0	79.0	74.5	79.5	81.0	80.5	79.0	80.0	15.5	-10.4
B Scale	90.5	90.0	78.5	75.0	79.5	81.0	83.0	84.5	80.0	15.5	-8.5
C Scale	92.0	90.0	79.5	76.5	80.0	81.5	84.5	87.0	80.0	15.5	-7.4
Loud S.S.											
1/3 Octave Band	90.5	93.5	86.5	90.5	90.5	94.0	89.0	89.5	91.0	7.5 Phons	-3.3 Phons
Octave Band	89.0	93.5	88.0	90.5	92.5	90.5	87.0	88.0	89.0	6.5	-4.2
Loud E.Z.*											
1/3 Octave Band	92.5	97.0	87.0	89.0	95.5	96.5	95.5	95.0	95.5	10.0 Phons	-3.7 Phons
PNdb											
1/3 Octave Band	93.0	94.0	90.5	90.5	92.5	96.5	90.5	91.0	93.5	6.0 PNdb	-1.8 PNdb
Octave Band	92.5	94.5	93.0	88.5	91.5	95.0	90.0	90.0	92.5	6.5	-2.4

*Calculated by E. Zwicker

predicting the judged noisiness. Zwicker's loudness levels seem to show the greatest range. Also, the calculation method used by Zwicker, however accurate, is handicapped by a graphical calculation procedure which is probably not as convenient as the numerical calculation methods used to obtain Stevens phons and PNdb. The calculation of these two, as previously mentioned, is essentially the same, the only difference being in the frequency weighting function used to convert the band sound pressure levels to sones or noys, as the case may be. However, the range of results and the magnitude of the average deviation from the standard is less for perceived noise than for the loudness level in Stevens phons, indicating some superiority for perceived noise level over loudness level in predicting the results of these tests. Inasmuch as the subjects were asked to judge the noisiness and not the loudness of these sounds this result is perhaps to be expected.

Considering the rather wide variety of spectra used for these tests we feel that the predicted loudness and noisiness values agree reasonably well with the judgment data. Other studies (Ref. 12) have tended to show Stevens phons to be generally more variable and less accurate than PNdb or Zwicker phons, and that Zwicker phons, while generally showing not too much variability, are usually higher in value than one would expect.

Although techniques for rating the subjective effects of sounds on man are fairly accurate, we believe further work is required not only perhaps to improve the validity of one or more of these methods for predicting the acceptability of steady-state noise, but to extend one or more of these calculation procedures to take into account the effects of duration, impulsiveness and the presence of pure-tone or spike components upon judged acceptability.

Bolt Beranek and Newman Incorporated
Cambridge, Massachusetts, December 1, 1962

APPENDIX A

Instructions for Paired-Comparison and Method of Adjustment Judgment Tests

	Page
Paired-Comparison Type Tests	28, 29, 32
Method of Adjustment Type Tests	30, 31, 33

Instruction Sheet for Judgments of Noisiness

The purpose of these tests is to determine the relative acceptability of different sounds. The tests are part of a program research designed to obtain information that will be of aid in the planning of military and civilian airports and for noise control purposes in general.

You will hear on the recording to follow one sound followed immediately by a second sound. You are to judge which of the two sounds you think would be the most disturbing if heard regularly, as a matter of course 20 to 30 times per day in your home. If you think the second of the two sounds would be more disturbing to you, put a plus (+) after the number announced before each pair of sounds. If you think that the second of the two sounds would be less disturbing, put a minus (-) after the proper number. If you think they would be equally disturbing, please make a choice even though you feel you are guessing. After the answers that you are the least sure of, you may, if you wish, place a question mark.

Remember, your job is to judge the second of each pair of sounds with respect to the first sound in that pair. You may think that neither of the two sounds is objectionable or that both are objectionable; what we would like you to do is judge whether the second sound would be more disturbing or less disturbing than the first sound if heard in your home periodically 20 to 30 times during the day and night.

Please record your answers according to how the sounds affect you -- there are no right or wrong answers, and it is important that we find out how people differ, if they do, in their judgments of these sounds. It does not matter whether your answers agree or disagree with others taking the test as long as you make the best judgment you can for each pair of sounds.

Again, record a + if the second of the two sounds would be more disturbing to you than the first sound of that pair and a - if the second of the two sounds would be less disturbing than the first sound of that pair. In case of doubt, make the best guess you can and mark, if you wish, your answer with a question mark.

Also, please write on your answer sheet the date, your age, occupation and sex. You need not record your name -- all answer sheets, and the data taken therefrom, will remain unidentified with respect to the names of the persons taking this test.

Instruction Sheet for Judgments of Loudness

The purpose of these tests is to determine the relative loudness of different sounds. The tests are part of a program of research designed to obtain information that will be of aid in the planning of military and civilian airports and for noise control purposes in general.

You will hear on the recording to follow one sound followed immediately by a second sound. You are to judge which of the two sounds you think is the louder. If you think the second of the two sounds is louder put a plus (+) after the number announced before each pair of sounds. If you think that the second of the two sounds is less loud put a minus (-) after the proper number. If you think they are equally loud please make a choice even though you feel you are guessing. After the answers that you are the least sure of, you may, if you wish, place a question mark.

Remember, your job is to judge the second of each pair of sounds with respect to the first sound in that pair. You may think that neither of the two sounds is very loud or that both are very loud; what we would like you to do is judge whether the second sound is louder or less loud than the first sound.

Please record your answers according to how the sounds affect you -- there are no right or wrong answers, and it is important that we find out how people differ, if they do, in their judgments of these sounds. It does not matter whether your answers agree or disagree with others taking the test as long as you make the best judgment you can for each pair of sounds.

Again, record a + if the second of the two sounds seems louder to you than the first sound of that pair and a - if the second of the two sounds would be less loud than the first sound of that pair. In case of doubt, make the best guess you can and mark, if you wish, your answer with a question mark.

Also, please write on your answer sheet the date, your age, occupation and sex. You need not record your name -- all answer sheets, and the data taken therefrom, will remain unidentified with respect to the names of the persons taking this test.

Instruction Sheet for Judgments of Bands of Noise

The purpose of these tests is to determine the relative acceptability of various bands of noise.

When the test starts you will hear alternately two bands of noise presented at constant intervals. We will call the first noise the standard and the second the comparison. The comparison noise is further identified by the #2 panel light directly in front of you which will glow only while the comparison noise is present.

You cannot change the duration of either noise but you can change the overall intensity of the comparison noise by turning the knob on the attenuator that is by your right hand.

Your job is to listen to the standard noise, then to listen to the comparison noise and then to adjust the intensity of the comparison noise until it sounds as acceptable to you as the standard. By equally acceptable we mean that you would just as soon have one as the other in or outside your home periodically 20 to 30 times during the day and night. Stated another way, we mean by equally acceptable that the comparison noise would be no more nor no less disturbing to you in or outside your home than the standard noise.

You may listen to the two noises as long as you wish. It is suggested that, before you proceed to equate the comparison noise to the standard noise, you make the comparison noise (No. 2) much more intense than the standard (No. 1); then make the comparison noise much less intense than the standard. With those limits established, adjust the intensity of the comparison noise until it would be just as acceptable as the standard noise in or outside your home.

Instruction Sheet for Judgments of Bands of Noise

The purpose of these tests is to determine the relative loudness of various bands of noise.

When the test starts you will hear alternately two bands of noise presented at constant intervals. We will call the first noise the standard and the second the comparison. The comparison noise is further identified by the #2 panel light directly in front of you which will glow only while the comparison noise is present.

You cannot change the duration of either noise but you can change the overall intensity of the comparison noise by turning the knob on the attenuator that is by your right hand.

Your job is to listen to the standard noise, then to listen to the comparison noise and then to adjust the intensity of the comparison noise until it sounds as loud to you as the standard.

You may listen to the two noises as long as you wish. It is suggested that, before you proceed to equate the comparison noise to the standard noise, you make the comparison noise (No. 2) much more intense than the standard (No. 1); then make the comparison noise much less intense than the standard. With those limits established, adjust the intensity of the comparison noise until it would be just as loud as the standard noise.

Instruction Sheet for Judgments of Noise

The purpose of these tests is to determine the relative acceptability of various noises.

When the test starts you will hear two noises presented in quick succession. Your job is to mark on your answer sheet a "1" or "2" corresponding to the noise which you feel was more objectionable.

In making this judgment assume that the noise would occur in your home 20 to 30 times during the day and night. Base your judgment on the combined effect of the level and duration of each sound rather than the peak level alone.

Instructions for Judgments of Noise

The purpose of these tests is to determine the relative acceptability of various noises.

When you throw the control switch at your right hand to No. 1 you will hear a noise; this noise will repeat itself over and over until you throw the switch to position No. 2. Then you will hear a different noise. We will call the noise from switch position No. 1 the "standard" noise and that from switch position No. 2 the "comparison" noise. The overall intensity of the comparison noise may be controlled by turning the knob on the attenuator that is by your right hand.

Your job is to listen first to the standard noise at position No. 1, then to listen to the comparison noise at position No. 2, and then to adjust the intensity of the comparison noise until it sounds as acceptable to you as the standard. <u>By equally acceptable we mean that you would just as soon have one as the other in or outside your home periodically 20 to 30 times during the day and night.</u> <u>Stated another way, we mean by equally acceptable that the comparison noise would be no more nor no less disturbing to you in or outside your home than the standard noise</u>.

You may turn back and forth between the two noises as often as you wish and listen to each as long as you wish. It is suggested that before you proceed to equate the comparison noise to the standard noise you make the comparison noise (No. 2) much more intense than the standard (No. 1); then make the comparison noise much less intense than the standard. With those limits established, adjust the intensity of the comparison noise until it would be just as acceptable as the standard noise in or outside your home.

Please switch from the standard to comparison and vice versa during the brief pause that exists between the end and the beginning of each noise.

APPENDIX B

Following are tables for converting sound pressure level to noy values.

To convert the noy value of a complex sound to perceived noise level in PNdb enter column for band having center frequency of 1000 cps; the corresponding sound pressure level in dB is by definition perceived noise level in PNdb.

Perceived noise level for a complex sound can be determined by the following formulae:

1. $N_T = N_{max} + 0.3\ (\Sigma N - N_{max})$ Octave Bands

where N_T is the total noisiness in noys, N_{max} is the number of noys in the noisiest octave band and ΣN is the sum of the noisiness in all the octave bands.

2. $N_T = N_{max} + 0.2\ (\Sigma N - N_{max})$ 1/2 Octave Bands

3. $N_T = N_{max} + .15\ (\Sigma N - N_{max})$ 1/3 Octave Bands

TABLE I - SHEET 1
PERCEIVED NOISE LEVELS (NOYS) — PREFERRED FREQUENCIES

	BAND CENTER FREQUENCY IN CYCLES PER SECOND																								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
SPL	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000	12500
10																									
11																									
12																									
13																			0.1						
14																		0.1	0.1	0.1					
15																	0.1	0.1	0.2	0.2					
16																	0.1	0.2	0.2	0.2	0.1				
17																	0.2	0.2	0.3	0.3	0.2				
18																0.1	0.2	0.3	0.3	0.3	0.2				
19																0.1	0.3	0.3	0.4	0.4	0.3				
20																0.2	0.3	0.4	0.4	0.4	0.3	0.1			
21																0.2	0.4	0.4	0.5	0.5	0.4	0.2			
22															0.1	0.3	0.4	0.5	0.6	0.6	0.4	0.2			
23															0.1	0.3	0.5	0.6	0.6	0.6	0.5	0.3			
24															0.2	0.4	0.5	0.6	0.7	0.7	0.6	0.3			
25										0.1	0.1	0.1	0.1	0.1	0.2	0.4	0.6	0.7	0.7	0.7	0.6	0.4	0.1		
26										0.2	0.2	0.2	0.2	0.2	0.3	0.5	0.7	0.7	0.8	0.8	0.7	0.5	0.2		
27									0.1	0.2	0.2	0.2	0.2	0.2	0.3	0.6	0.7	0.8	0.9	0.9	0.7	0.5	0.2		
28									0.2	0.3	0.3	0.3	0.3	0.3	0.4	0.6	0.8	0.9	0.9	0.9	0.8	0.6	0.3		
29								0.1	0.2	0.3	0.3	0.3	0.3	0.3	0.4	0.7	0.8	0.9	1.0	1.0	0.9	0.7	0.3		
30								0.2	0.3	0.4	0.4	0.4	0.4	0.4	0.5	0.7	0.9	1.0	1.1	1.1	0.9	0.7	0.4	0.1	
31							0.1	0.2	0.3	0.4	0.4	0.4	0.4	0.4	0.6	0.8	0.9	1.1	1.2	1.2	1.0	0.8	0.5	0.2	
32							0.2	0.3	0.4	0.5	0.5	0.5	0.5	0.5	0.6	0.9	1.0	1.2	1.2	1.2	1.1	0.9	0.6	0.2	
33						0.1	0.2	0.3	0.4	0.6	0.6	0.6	0.6	0.6	0.7	0.9	1.1	1.2	1.3	1.3	1.2	1.0	0.6	0.3	
34						0.2	0.3	0.4	0.5	0.6	0.6	0.6	0.6	0.6	0.7	1.0	1.2	1.3	1.4	1.4	1.3	1.1	0.7	0.4	
35						0.2	0.3	0.4	0.6	0.7	0.7	0.7	0.7	0.7	0.8	1.1	1.3	1.4	1.5	1.5	1.4	1.2	0.8	0.5	0.1
36					0.1	0.3	0.4	0.5	0.6	0.7	0.7	0.7	0.7	0.7	0.9	1.2	1.3	1.5	1.6	1.6	1.5	1.4	0.9	0.6	0.2
37					0.2	0.3	0.4	0.6	0.7	0.8	0.8	0.8	0.8	0.8	0.9	1.3	1.4	1.6	1.8	1.8	1.6	1.5	1.0	0.6	0.2
38					0.2	0.4	0.5	0.6	0.7	0.9	0.9	0.9	0.9	0.9	1.0	1.3	1.5	1.8	1.9	1.9	1.7	1.6	1.1	0.7	0.3
39				0.1	0.3	0.5	0.6	0.7	0.8	0.9	0.9	0.9	0.9	0.9	1.1	1.4	1.6	1.9	2.0	2.0	1.9	1.8	1.2	0.8	0.4
40				0.2	0.3	0.5	0.6	0.7	0.9	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	0.9	0.5
41				0.2	0.4	0.6	0.7	0.8	0.9	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	0.6
42				0.3	0.5	0.6	0.7	0.9	1.0	1.2	1.2	1.2	1.2	1.2	1.3	1.7	2.0	2.4	2.6	2.6	2.4	2.2	1.7	1.1	0.6
43			0.1	0.3	0.5	0.7	0.8	0.9	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	0.7
44			0.2	0.4	0.6	0.7	0.9	1.0	1.2	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	0.8
45			0.2	0.5	0.6	0.8	0.9	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	0.9
46			0.3	0.5	0.7	0.9	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	1.0
47			0.3	0.6	0.7	0.9	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	1.1
48		0.1	0.4	0.6	0.8	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	1.2
49		0.2	0.4	0.7	0.9	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	1.4
50		0.2	0.5	0.8	1.0	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	1.5
51		0.3	0.6	0.9	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	1.7
52		0.4	0.7	0.9	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	1.8
53	0.1	0.4	0.7	1.0	1.2	1.5	1.7	2.0	2.1	2.4	2.4	2.4	2.4	2.4	2.8	3.7	4.4	5.0	5.3	5.3	5.0	4.7	3.9	3.0	2.0
54	0.2	0.5	0.8	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	2.2
55	0.2	0.6	0.9	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	2.3
56	0.3	0.6	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	2.5
57	0.4	0.7	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	2.8
58	0.4	0.8	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	3.0
59	0.5	0.9	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	3.3
60	0.6	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	3.6
61	0.7	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	3.9
62	0.8	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	4.2
63	0.9	1.3	1.8	2.4	2.8	3.2	3.7	4.0	4.3	5.0	5.0	5.0	5.0	5.0	5.7	7.5	8.7	10.0	11.0	11.0	10.0	9.3	7.5	6.1	4.6
64	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	5.0
65	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	5.3

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TABLE I - SHEET 2

	BAND CENTER FREQUENCY IN CYCLES PER SECOND																								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
SPL	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000	12500
66	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	5.7
67	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	6.1
68	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	6.5
69	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	7.0
70	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	7.5
71	2.2	2.8	3.6	4.6	5.0	5.9	6.9	7.5	8.0	8.7	8.7	8.7	8.7	8.7	10.0	13.0	15.0	17.0	19.0	19.0	17.0	16.0	13.0	11.0	8.0
72	2.3	3.0	3.9	5.0	5.4	6.4	7.5	8.0	8.7	9.3	9.3	9.3	9.3	9.3	11.0	14.0	16.0	19.0	20.0	20.0	19.0	17.0	14.0	11.0	8.7
73	2.5	3.3	4.2	5.4	5.9	6.9	8.0	8.7	9.3	10.0	10.0	10.0	10.0	10.0	11.0	15.0	17.0	20.0	21.0	21.0	20.0	19.0	15.0	12.0	9.3
74	2.8	3.7	4.6	5.9	6.4	7.5	8.7	9.3	10.0	11.0	11.0	11.0	11.0	11.0	12.0	16.0	19.0	21.0	23.0	23.0	21.0	20.0	16.0	13.0	10.0
75	3.0	4.1	5.0	6.4	6.9	8.0	9.3	10.0	11.0	11.0	11.0	11.0	11.0	11.0	13.0	17.0	20.0	23.0	24.0	24.0	23.0	21.0	17.0	14.0	11.0
76	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	11.0
77	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	12.0
78	4.1	5.4	6.4	8.2	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	13.0
79	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	14.0
80	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	15.0
81	5.5	6.9	8.3	11.0	11.0	12.0	14.0	15.0	16.0	17.0	17.0	17.0	17.0	17.0	20.0	26.0	30.0	35.0	37.0	37.0	35.0	32.0	26.0	21.0	16.0
82	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	17.0
83	6.8	8.2	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	19.0
84	7.5	9.0	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	20.0
85	8.2	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	21.0
86	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	23.0
87	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	24.0
88	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	26.0
89	12.0	14.0	16.0	19.0	20.0	21.0	24.0	26.0	28.0	30.0	30.0	30.0	30.0	30.0	35.0	45.0	50.0	60.0	63.0	63.0	60.0	55.0	45.0	37.0	28.0
90	14.0	15.0	17.0	20.0	21.0	23.0	26.0	28.0	30.0	32.0	32.0	32.0	32.0	32.0	37.0	47.0	55.0	63.0	67.0	67.0	63.0	60.0	47.0	40.0	30.0
91	15.0	16.0	19.0	21.0	23.0	24.0	28.0	30.0	32.0	35.0	35.0	35.0	35.0	35.0	40.0	50.0	60.0	67.0	71.0	71.0	67.0	63.0	50.0	42.0	32.0
92	16.0	17.0	20.0	23.0	24.0	26.0	30.0	32.0	35.0	37.0	37.0	37.0	37.0	37.0	42.0	55.0	63.0	71.0	75.0	75.0	71.0	67.0	55.0	45.0	35.0
93	17.0	19.0	21.0	24.0	26.0	28.0	32.0	35.0	37.0	40.0	40.0	40.0	40.0	40.0	45.0	60.0	67.0	75.0	80.0	80.0	75.0	71.0	60.0	47.0	37.0
94	19.0	20.0	23.0	26.0	28.0	30.0	35.0	37.0	40.0	42.0	42.0	42.0	42.0	42.0	47.0	63.0	71.0	80.0	86.0	86.0	80.0	75.0	63.0	50.0	40.0
95	20.0	21.0	24.0	28.0	30.0	32.0	37.0	40.0	42.0	45.0	45.0	45.0	45.0	45.0	50.0	67.0	75.0	86.0	93.0	93.0	86.0	80.0	67.0	55.0	43.0
96	21.0	23.0	26.0	30.0	32.0	35.0	40.0	42.0	45.0	47.0	47.0	47.0	47.0	47.0	55.0	71.0	80.0	93.0	100.	100.	93.0	86.0	71.0	60.0	46.0
97	23.0	24.0	28.0	32.0	35.0	37.0	42.0	45.0	47.0	50.0	50.0	50.0	50.0	50.0	60.0	75.0	86.0	100.	108.	108.	100.	93.0	75.0	63.0	50.0
98	24.0	26.0	30.0	35.0	37.0	40.0	45.0	47.0	50.0	55.0	55.0	55.0	55.0	55.0	64.0	80.0	93.0	108.	116.	116.	108.	100.	80.0	67.0	55.0
99	26.0	28.0	32.0	37.0	40.0	42.0	47.0	50.0	55.0	60.0	60.0	60.0	60.0	60.0	69.0	86.0	100.	116.	125.	125.	116.	108.	86.0	71.0	60.0
100	28.0	30.0	35.0	40.0	42.0	45.0	50.0	55.0	60.0	64.0	64.0	64.0	64.0	64.0	74.0	93.0	108.	125.	133.	133.	125.	116.	93.0	75.0	63.0
101	30.0	32.0	37.0	42.0	45.0	47.0	55.0	60.0	64.0	69.0	69.9	69.0	69.0	69.0	80.0	100.	116.	133.	142.	142.	133.	125.	100.	80.0	67.0
102	32.0	35.0	40.0	45.0	47.0	50.0	60.0	64.0	69.0	74.0	74.0	74.0	74.0	74.0	85.0	108.	125.	142.	150.	150.	142.	133.	108.	86.0	71.0
103	35.0	37.0	42.0	47.0	50.0	55.0	64.0	69.0	74.0	80.0	80.0	80.0	80.0	80.0	89.0	116.	133.	150.	162.	162.	150.	142.	116.	93.0	75.0
104	37.0	40.0	45.0	50.0	55.0	60.0	69.0	74.0	80.0	85.0	85.0	85.0	85.0	85.0	94.0	125.	142.	162.	173.	173.	162.	150.	125.	100.	80.0
105	40.0	42.0	47.0	55.0	60.0	64.0	74.0	80.0	85.0	89.0	89.0	89.0	89.0	89.0	100.	133.	150.	173.	186.	186.	173.	162.	133.	108.	86.0
106	42.0	45.0	50.0	60.0	64.0	69.0	80.0	85.0	89.0	94.0	94.0	94.0	94.0	94.0	108.	142.	162.	186.	200.	200.	186.	173.	142.	116.	93.0
107	45.0	47.0	55.0	64.0	69.0	74.0	85.0	89.0	94.0	100.	100.	100.	100.	100.	116.	150.	173.	200.	215.	215.	200.	186.	150.	125.	100.
108	47.0	50.0	60.0	69.0	74.0	80.0	89.0	94.0	100.	108.	108.	108.	108.	108.	125.	162.	186.	215.	232.	232.	215.	200.	162.	133.	108.
109	50.0	55.0	64.0	74.0	80.0	85.0	94.0	100.	108.	116.	116.	116.	116.	116.	133.	173.	200.	232.	250.	250.	232.	215.	173.	142.	116.
110	55.0	60.0	69.0	80.0	85.0	89.0	100.	108.	116.	125.	125.	125.	125.	125.	142.	186.	215.	250.			250.	232.	186.	150.	125.
111	60.0	64.0	74.0	85.0	89.0	94.0	108.	116.	125.	133.	133.	133.	133.	133.	150.	200.	232.					250.	200.	162.	133.
112	64.0	69.0	80.0	89.0	94.0	100.	116.	125.	133.	142.	142.	142.	142.	142.	162.	215.	250.						215.	173.	142.
113	69.0	74.0	86.0	94.0	100.	108.	125.	133.	142.	150.	150.	150.	150.	150.	173.	232.							232.	186.	150.
114	74.0	80.0	93.0	100.	108.	116.	133.	142.	150.	162.	162.	162.	162.	162.	186.	250.							250.	200.	162.
115	80.0	86.0	100.	108.	116.	125.	142.	150.	162.	173.	173.	173.	173.	173.	200.									215.	173.
116	86.0	93.0	108.	116.	125.	133.	150.	162.	173.	186.	186.	186.	186.	186.	215.									232.	186.
117	93.0	100.	116.	125.	133.	142.	162.	173.	186.	200.	200.	200.	200.	200.	232.									250.	200.
118	100.	108.	125.	133.	142.	150.	173.	186.	200.	215.	215.	215.	215.	215.	250										215.
119	108.	116.	133.	142.	150.	162.	186.	200.	215.	232.	232.	232.	232.	232.											232.
120	116.	125.	142.	150.	162.	173.	200.	215.	232.	250.	250.	250.	250.	250.											250.
121	125.	133.	150.	162.	173.	186.	215.	232.	250.																
122	133.	142.	162.	173.	186.	200.	232.	250.																	
123	142.	150.	173.	186.	200.	215.	250.																		
124	150.	162.	186.	200.	215.	232.																			
125	162.	173.	200.	215.	232.	250.																			
126	173.	186.	215.	232.	250.																				
127	186.	200.	232.	250.																					
128	200.	215.	250.																						
129	215.	232.																							
130	232.	250.																							
131	250.																								

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TABLE II

PERCEIVED NOISE LEVELS (NOYS) — COMMERCIAL OCTAVE BAND FILTERS

BOLT BERANEK & NEWMAN INC
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FREQUENCY BAND LIMITS IN CYCLES PER SECOND	37.5–75	75–150	150–300	300–600	600–1200	1200–2400	2400–4800	4800–9600
BAND CENTER FREQUENCY IN CYCLES PER SECOND								
SPL	53	106	212	425	850	1700	3400	6800
10								
11								
12								
13							0.1	
14							0.1	
15							0.2	
16							0.2	
17						0.1	0.3	
18						0.1	0.3	
19						0.2	0.4	
20						0.2	0.4	
21						0.3	0.5	
22						0.3	0.6	0.1
23						0.4	0.6	0.2
24						0.4	0.7	0.2
25				0.1	0.1	0.5	0.7	0.3
26				0.2	0.2	0.6	0.8	0.3
27				0.2	0.2	0.6	0.9	0.4
28				0.3	0.3	0.7	0.9	0.5
29				0.3	0.3	0.7	1.0	0.6
30			0.1	0.4	0.4	0.8	1.1	0.6
31			0.1	0.4	0.4	0.9	1.2	0.7
32			0.2	0.5	0.5	0.9	1.2	0.8
33			0.2	0.6	0.6	1.0	1.3	0.9
34			0.3	0.6	0.6	1.1	1.4	1.0
35			0.3	0.7	0.7	1.2	1.5	1.1
36			0.4	0.7	0.7	1.3	1.6	1.2
37			0.4	0.8	0.8	1.3	1.8	1.4
38		0.1	0.5	0.9	0.9	1.4	1.9	1.5
39		0.2	0.6	0.9	0.9	1.5	2.0	1.6
40		0.2	0.6	1.0	1.0	1.6	2.2	1.8
41		0.3	0.7	1.1	1.1	1.7	2.4	1.9
42		0.3	0.7	1.2	1.2	1.8	2.6	2.0
43		0.4	0.8	1.2	1.2	2.0	2.8	2.2
44		0.5	0.9	1.3	1.3	2.1	3.0	2.4
45		0.5	0.9	1.4	1.4	2.3	3.2	2.6
46		0.6	1.0	1.5	1.5	2.4	3.4	2.8
47		0.6	1.1	1.6	1.6	2.6	3.6	3.0
48		0.7	1.2	1.7	1.7	2.8	3.9	3.2
49		0.7	1.3	1.9	1.9	3.0	4.1	3.4
50		0.8	1.4	2.0	2.0	3.2	4.4	3.6
51		0.9	1.5	2.1	2.1	3.5	4.7	3.9
52	0.1	1.0	1.6	2.3	2.3	3.7	5.0	4.1
53	0.2	1.0	1.7	2.4	2.4	4.0	5.3	4.4
54	0.2	1.1	1.9	2.6	2.6	4.3	5.7	4.7
55	0.3	1.2	2.0	2.8	2.8	4.6	6.1	5.0
56	0.4	1.3	2.2	3.0	3.0	5.0	6.5	5.3
57	0.4	1.4	2.4	3.2	3.2	5.3	7.0	5.7
58	0.5	1.5	2.6	3.5	3.5	5.7	7.5	6.1
59	0.6	1.7	2.8	3.7	3.7	6.1	8.0	6.5
60	0.7	1.8	3.0	4.0	4.0	6.5	8.7	7.0
61	0.8	2.0	3.2	4.3	4.3	7.0	9.3	7.5
62	0.9	2.2	3.5	4.6	4.6	7.5	10.	8.0
63	1.0	2.4	3.7	5.0	5.0	8.0	11.	8.7
64	1.1	2.6	4.0	5.3	5.3	8.7	11.	9.3
65	1.2	2.8	4.3	5.7	5.7	9.3	12.	10.
66	1.4	3.0	4.6	6.1	6.1	10.	13.	11.
67	1.6	3.3	5.0	6.5	6.5	11.	14.	11.
68	1.8	3.6	5.4	7.0	7.0	11.	15.	12.
69	2.0	3.9	5.9	7.5	7.5	12.	16.	13.
70	2.2	4.2	6.4	8.0	8.0	13.	17.	14.
71	2.3	4.6	6.9	8.7	8.7	14.	19.	15.
72	2.5	5.0	7.5	9.3	9.3	15.	20.	16.
73	2.8	5.4	8.0	10.	10.	16.	21.	17.
74	3.0	5.9	8.7	11.	11.	17.	23.	19.
75	3.3	6.4	9.3	11.	11.	19.	24.	20.
76	3.7	6.9	10.	12.	12.	20.	26.	21.
77	4.1	7.5	11.	13.	13.	21.	28.	23.
78	4.5	8.2	11.	14.	14.	23.	30.	24.
79	5.0	9.1	12.	15.	15.	24.	32.	26.
80	5.5	10.	13.	16.	16.	26.	35.	28.
81	6.1	11.	14.	17.	17.	28.	37.	30.
82	6.8	11.	15.	19.	19.	30.	40.	32.
83	7.5	12.	16.	20.	20.	32.	42.	35.
84	8.3	13.	17.	21.	21.	35.	45.	37.
85	9.1	14.	19.	23.	23.	37.	47.	40.
86	10.	15.	20.	24.	24.	40.	50.	42.
87	12.	16.	21.	26.	26.	42.	55.	45.
88	13.	17.	23.	28.	28.	45.	60.	47.
89	13.	19.	24.	30.	30.	47.	63.	50.
90	14.	20.	26.	32.	32.	50.	67.	55.
91	15.	21.	28.	35.	35.	55.	71.	60.
92	16.	23.	30.	37.	37.	60.	75.	63.
93	17.	24.	32.	40.	40.	63.	80.	67.
94	19.	26.	35.	42.	42.	67.	86.	71.
95	20.	28.	37.	45.	45.	71.	93.	75.
96	21.	30.	40.	47.	47.	75.	100.	80.
97	23.	32.	42.	50.	50.	80.	108.	86.
98	24.	35.	45.	55.	55.	86.	116.	93.
99	26.	37.	47.	60.	60.	93.	125.	100.
100	28.	40.	50.	64.	64.	100.	133.	108.
101	30.	42.	55.	69.	69.	108.	142.	116.
102	32.	45.	60.	74.	74.	116.	150.	125.
103	35.	47.	64.	80.	80.	125.	162.	133.
104	37.	50.	69.	85.	85.	133.	173.	142.
105	40.	55.	74.	89.	89.	142.	186.	150.
106	42.	60.	80.	94.	94.	150.	200.	162.
107	45.	64.	85.	100.	100.	162.	215.	173.
108	47.	69.	89.	108.	108.	173.	232.	186.
109	50.	74.	94.	116.	116.	186.	250.	200.
110	55.	80.	100.	125.	125.	200.		215.
111	60.	85.	108.	133.	133.	215.		232.
112	64.	89.	116.	142.	142.	232.		250.
113	69.	94.	125.	150.	150.	250.		
114	74.	100.	133.	162.	162.			
115	80.	108.	142.	173.	173.			
116	86.	116.	150.	186.	186.			
117	93.	125.	162.	200.	200.			
118	100.	133.	173.	215.	215.			
119	108.	142.	186.	232.	232.			
120	116.	150.	200.	250.	250.			
121	125.	162.	215.					
122	133.	173.	232.					
123	142.	186.	250.					
124	150.	200.						
125	162.	215.						
126	173.	232.						
127	186.	250.						
128	200.							
129	215.							
130	232.							
131	250.							

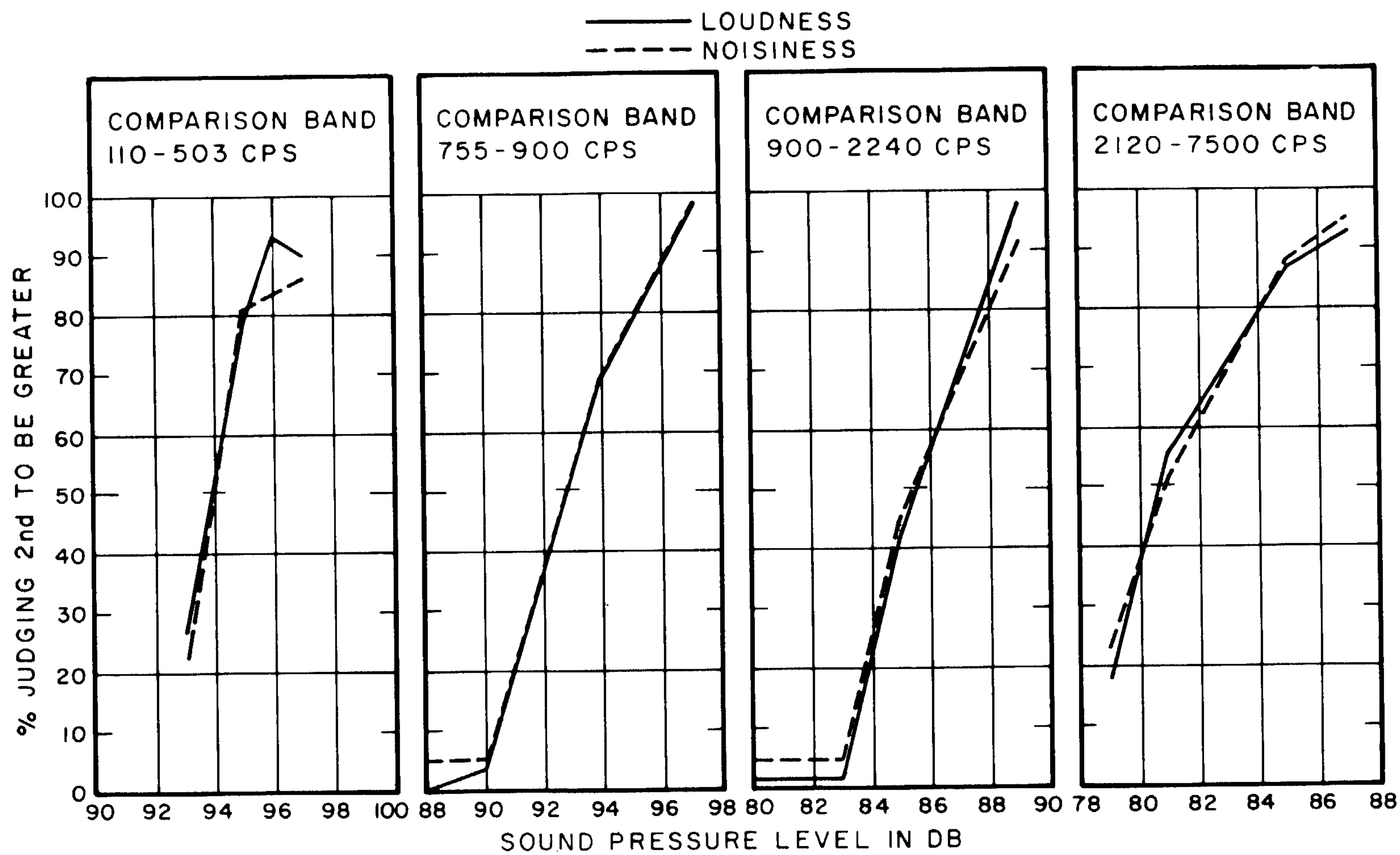

FIG. I PERCENTAGE OF SUBJECTS JUDGING 2nd (COMPARISON) OF PAIR OF SOUNDS TO BE LOUDER OR NOISIER THAN 1st (STANDARD) OF PAIR. GROUP (N=43) JUDGED LOUDNESS ON FIRST DAY AND NOISINESS ONE WEEK LATER. STANDARD WAS BAND FROM 755-900 CPS AT 94 DB

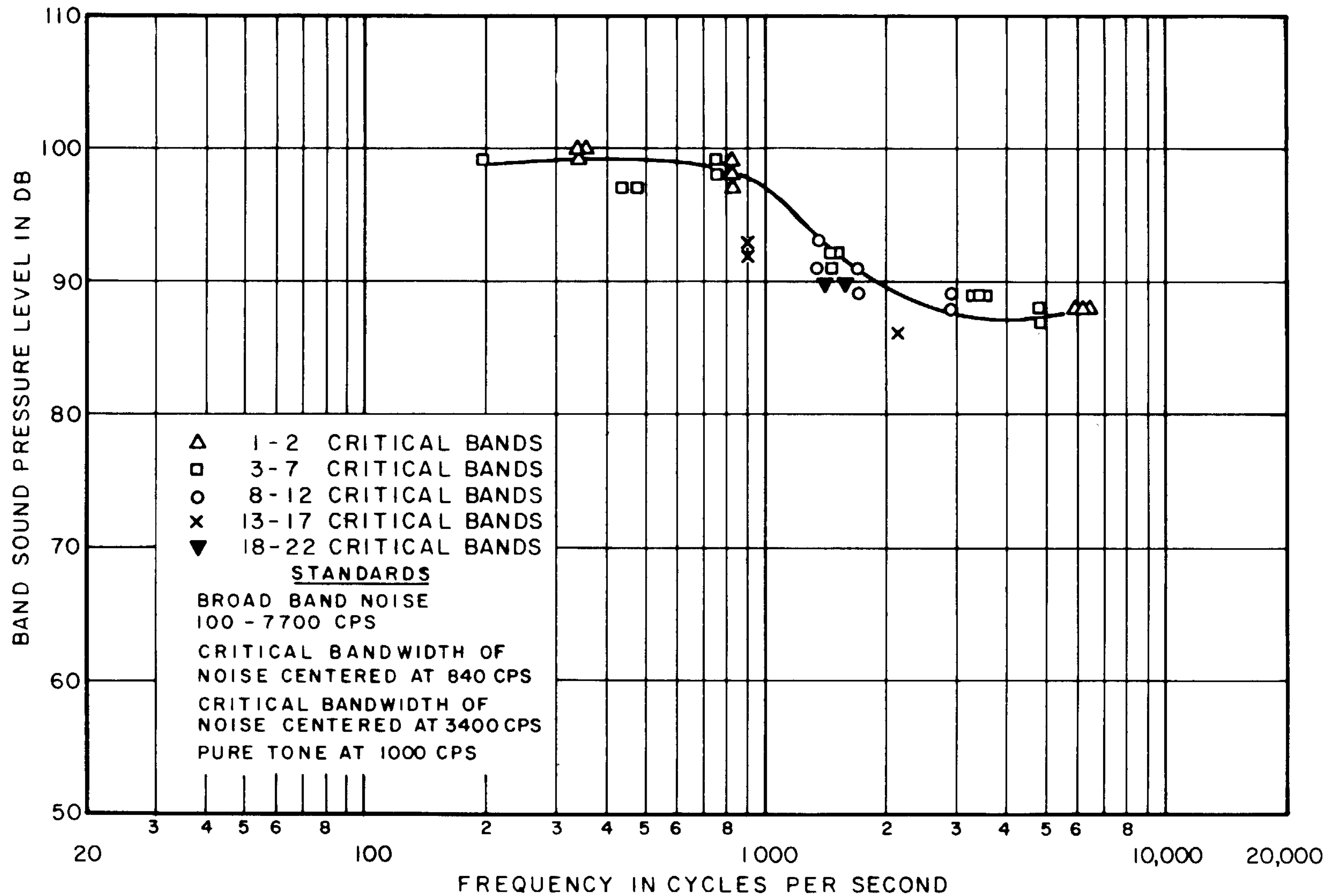

FIG. 2 SUMMARY OF DATA FOR EQUAL NOISENESS, METHOD OF PAIRED COMPARISON

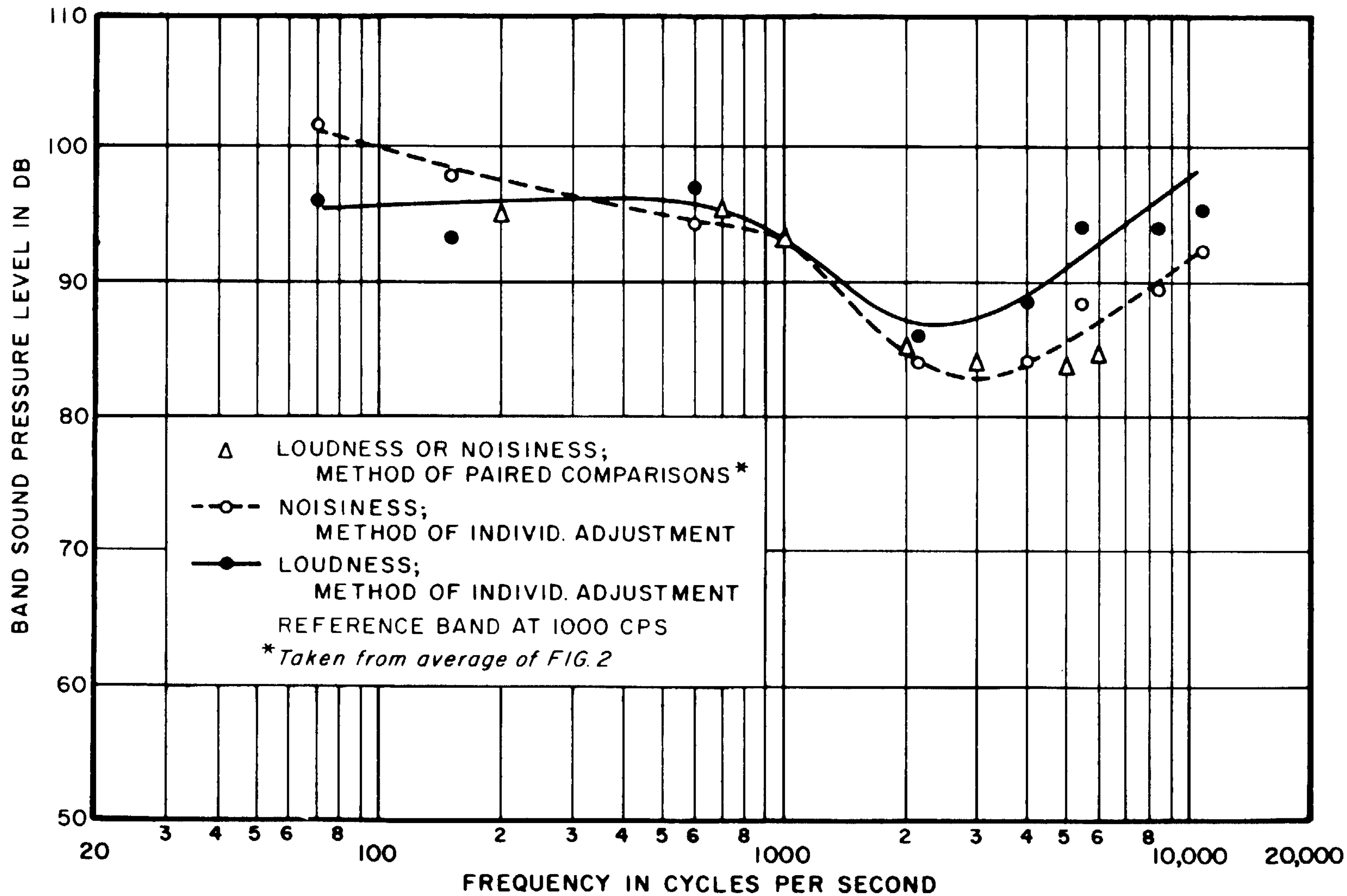

FIG. 3 EQUAL LOUDNESS AND EQUAL NOISINESS. METHOD INDIVIDUAL ADJUSTMENT

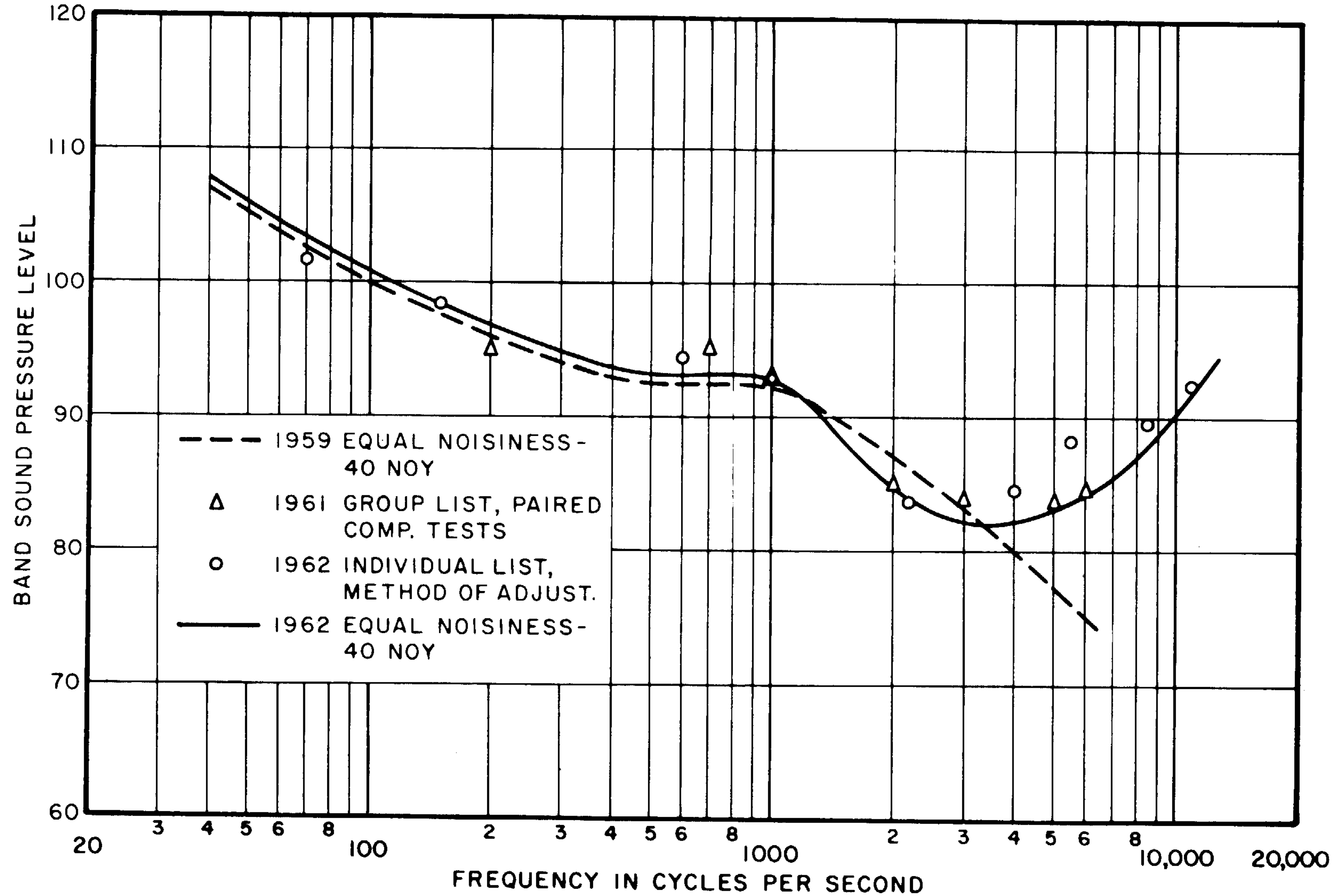

FIG. 4 COMPARISON OF EQUAL NOISINESS CONTOURS – 1959 AND 1962

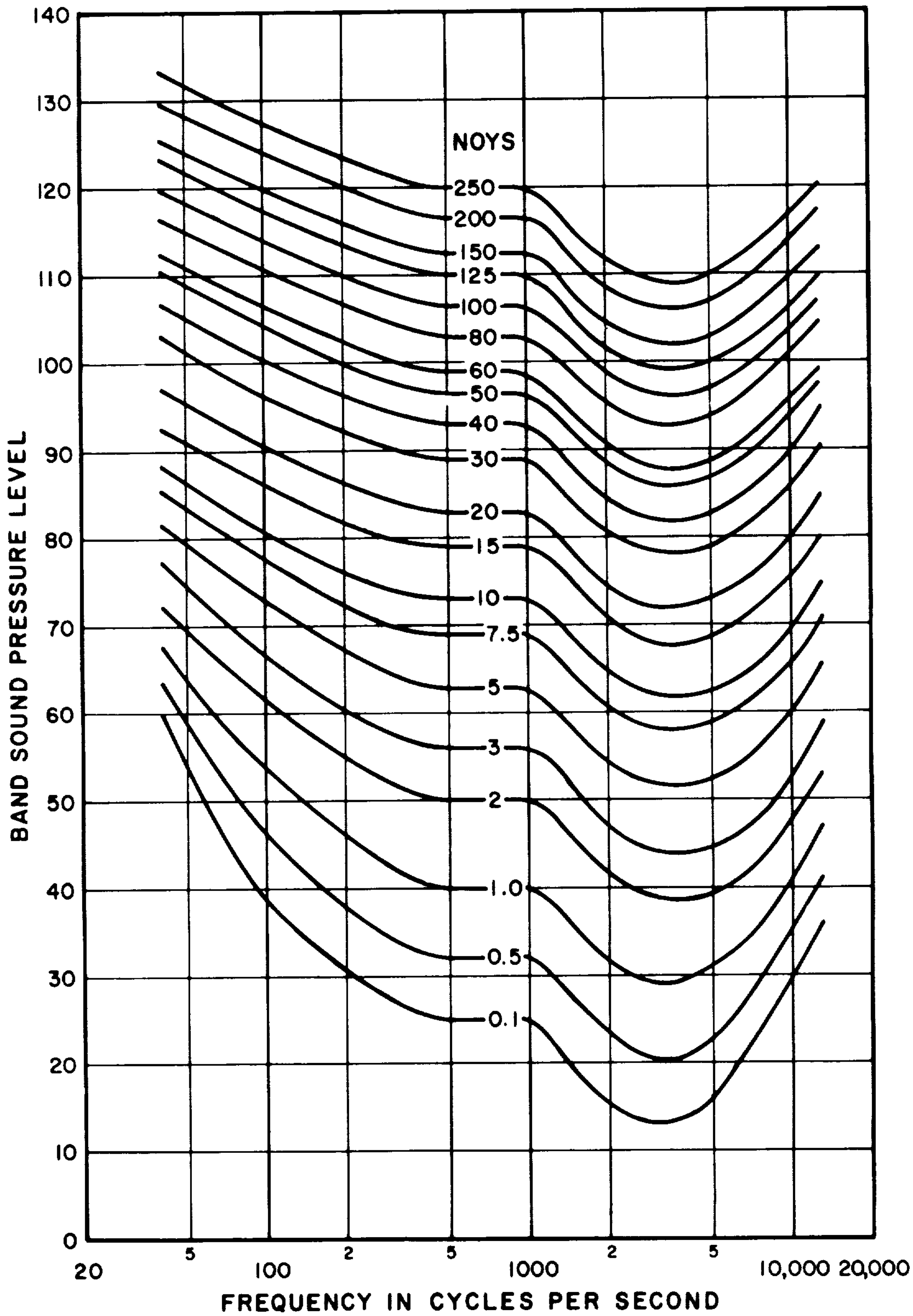

FIG. 5 NOISINESS OF BANDS OF SOUND

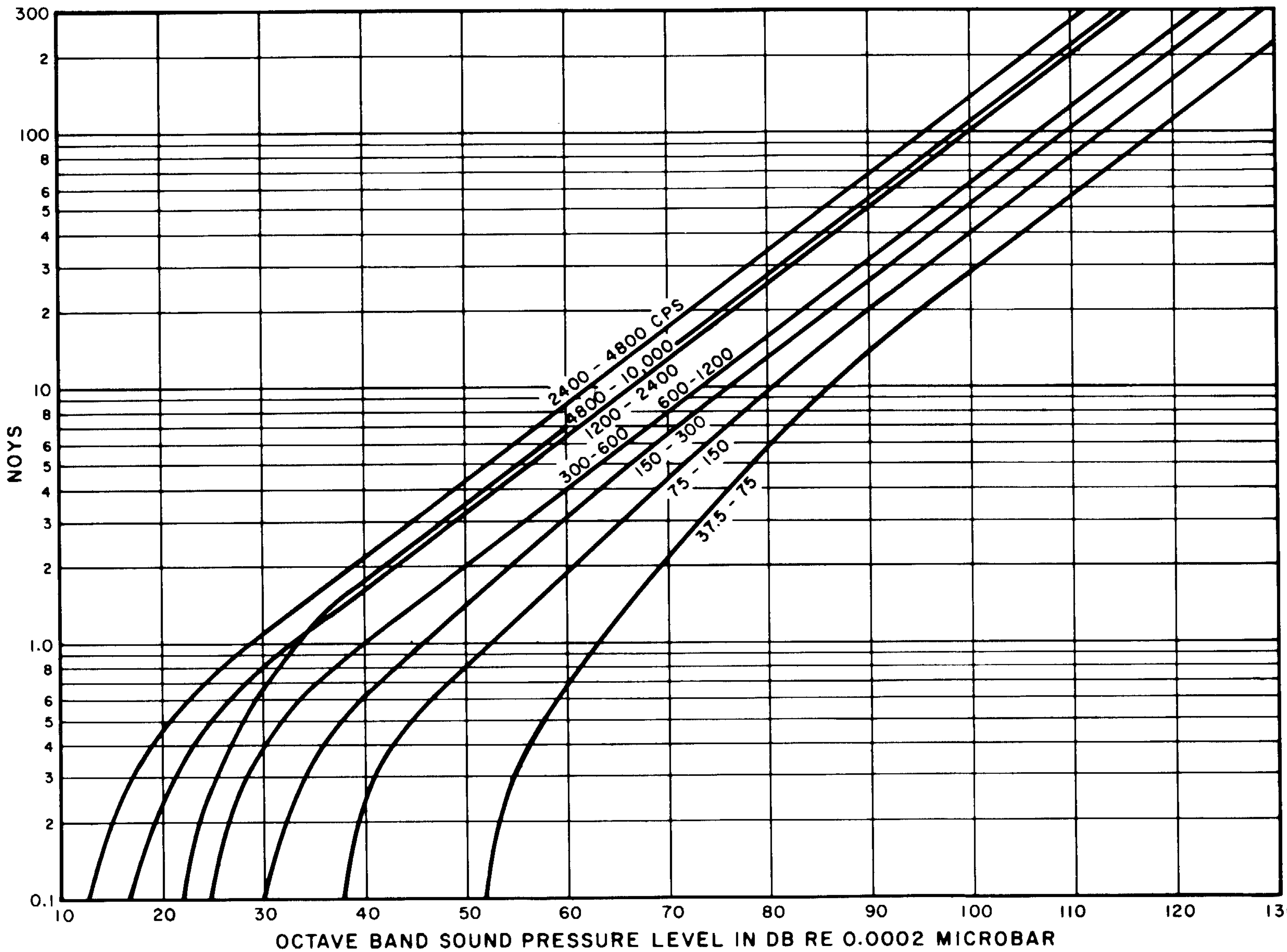

FIG. 6 NOISINESS OF SOUNDS IN OCTAVE BANDS

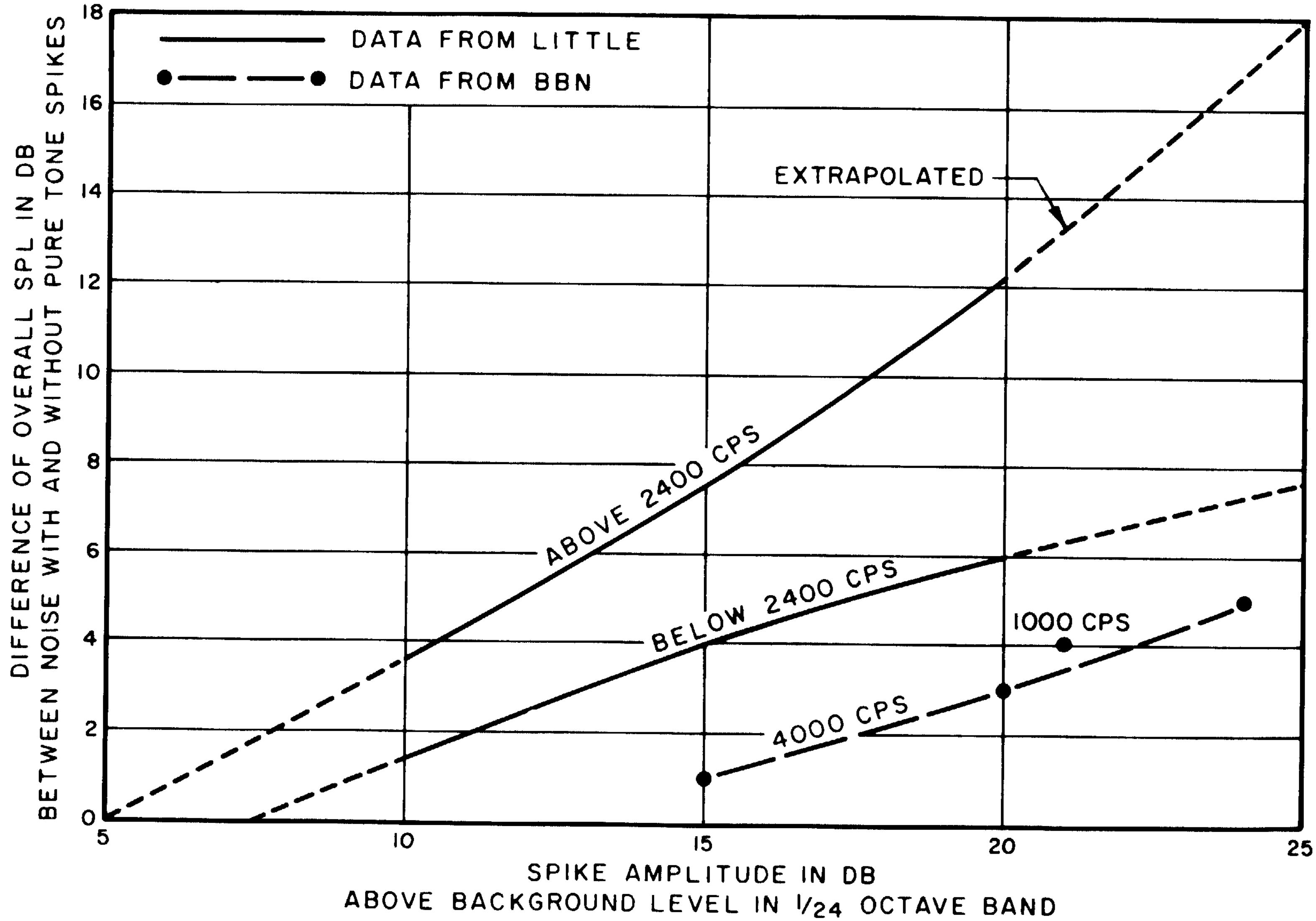

FIG. 7 COMPARISON OF LITTLE'S PURE TONE ANNOYANCE DATA WITH THAT OBTAINED BY BBN

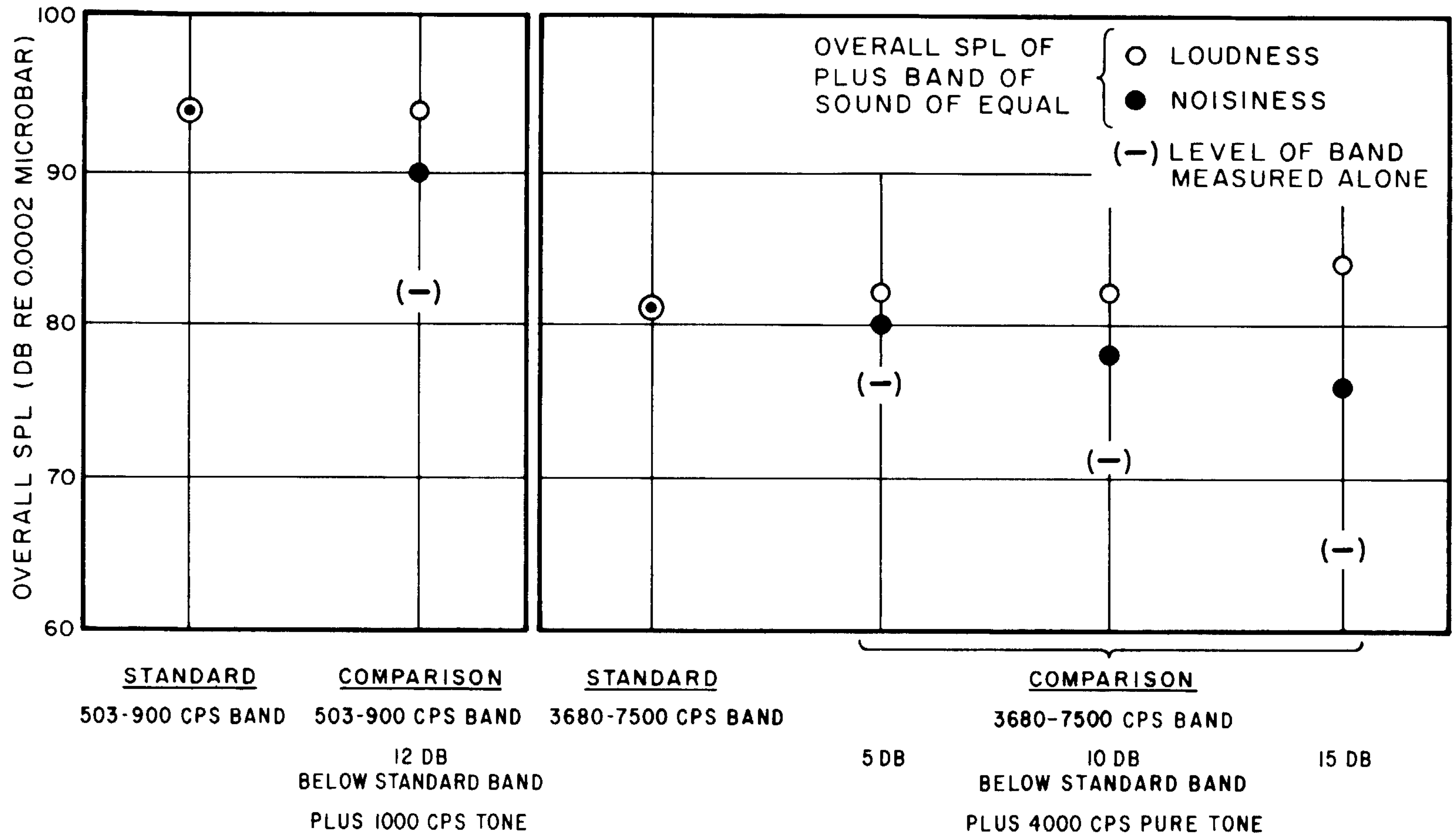

FIG. 8 LOUDNESS AND NOISINESS JUDGMENTS

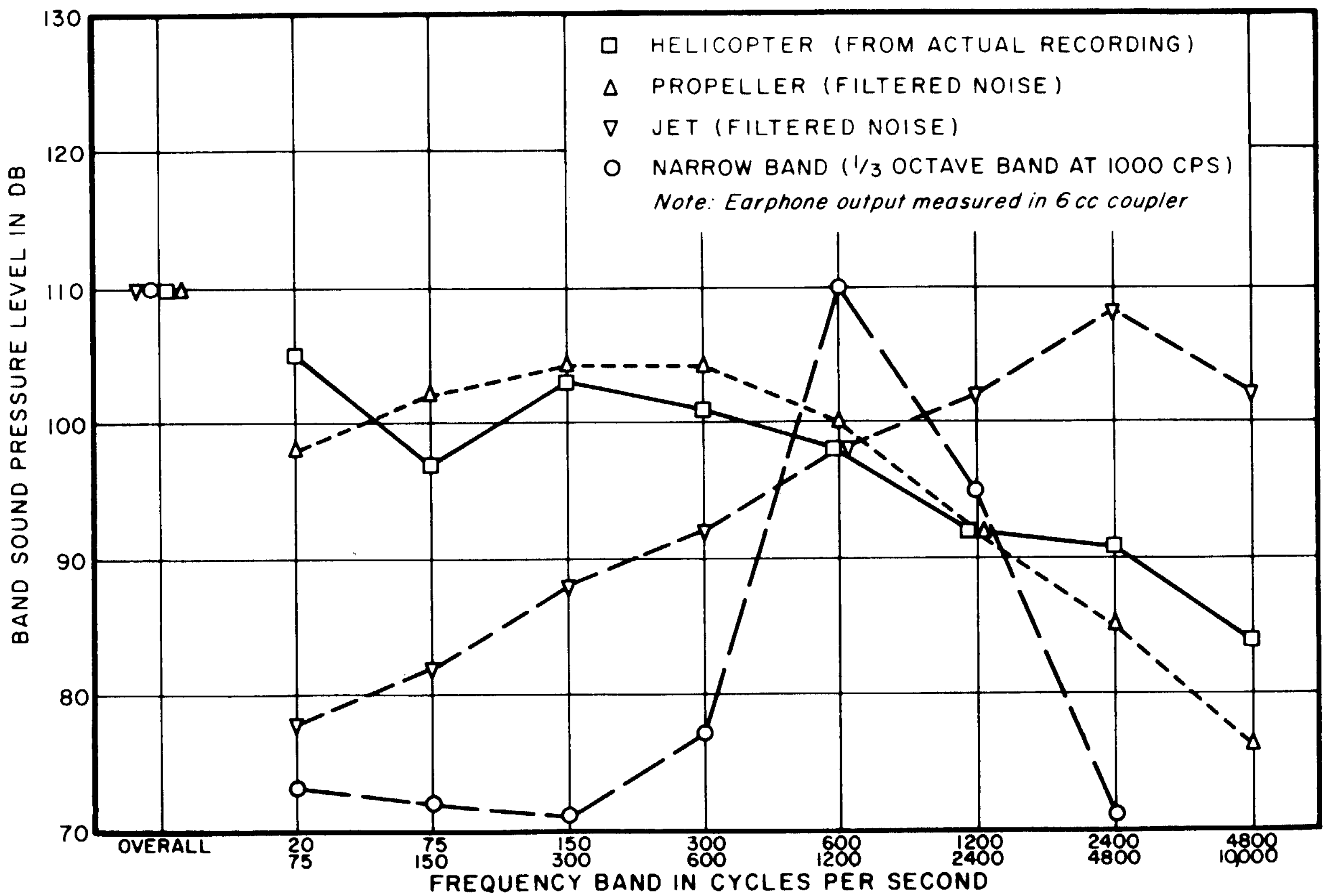

FIG. 9 SPECTRA OF NOISES FOR RISE-TIME AND DURATION TESTS

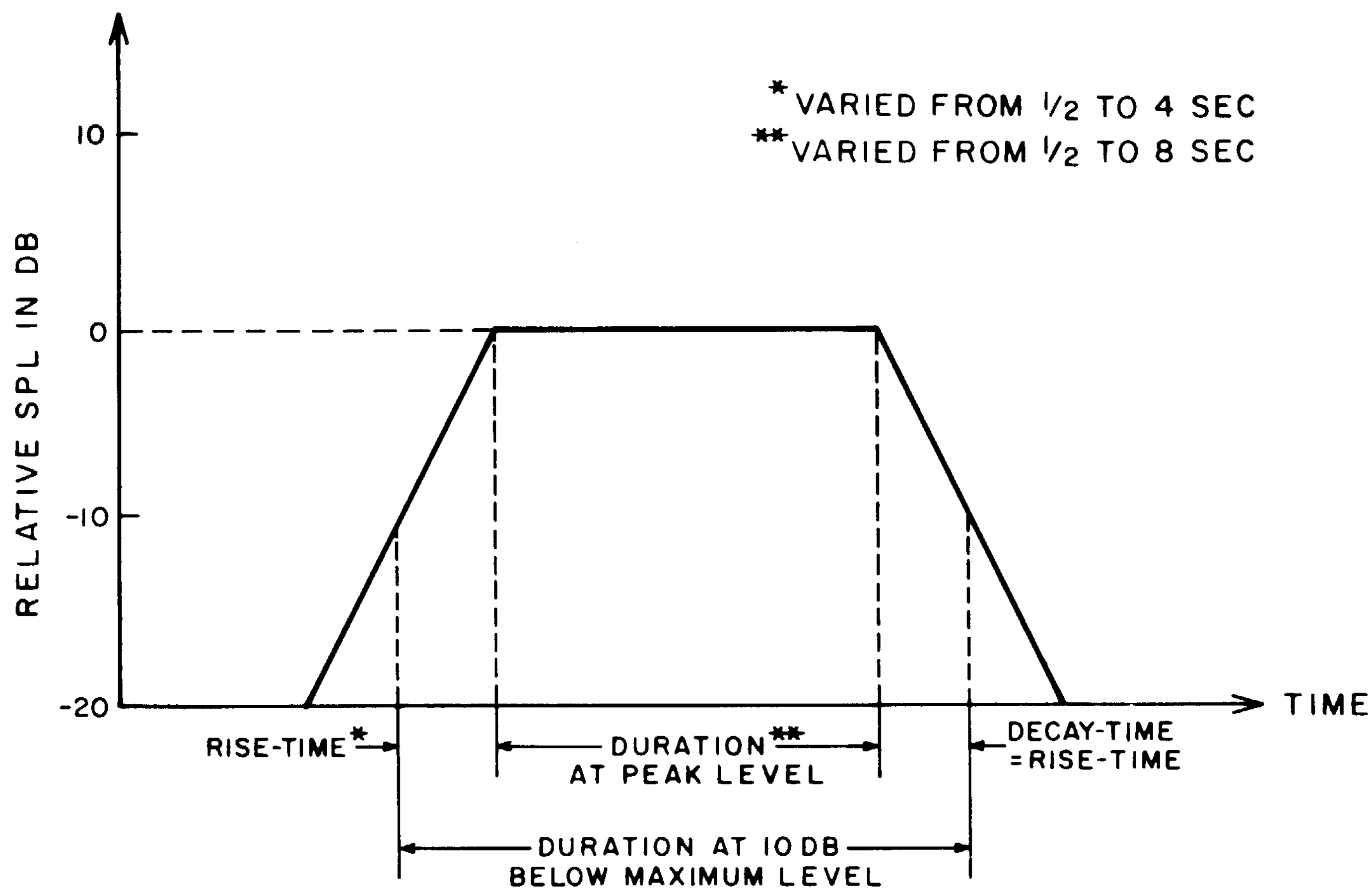

FIG. 10 ENVELOPE OF NOISE FOR RISE-TIME AND DURATION TESTS

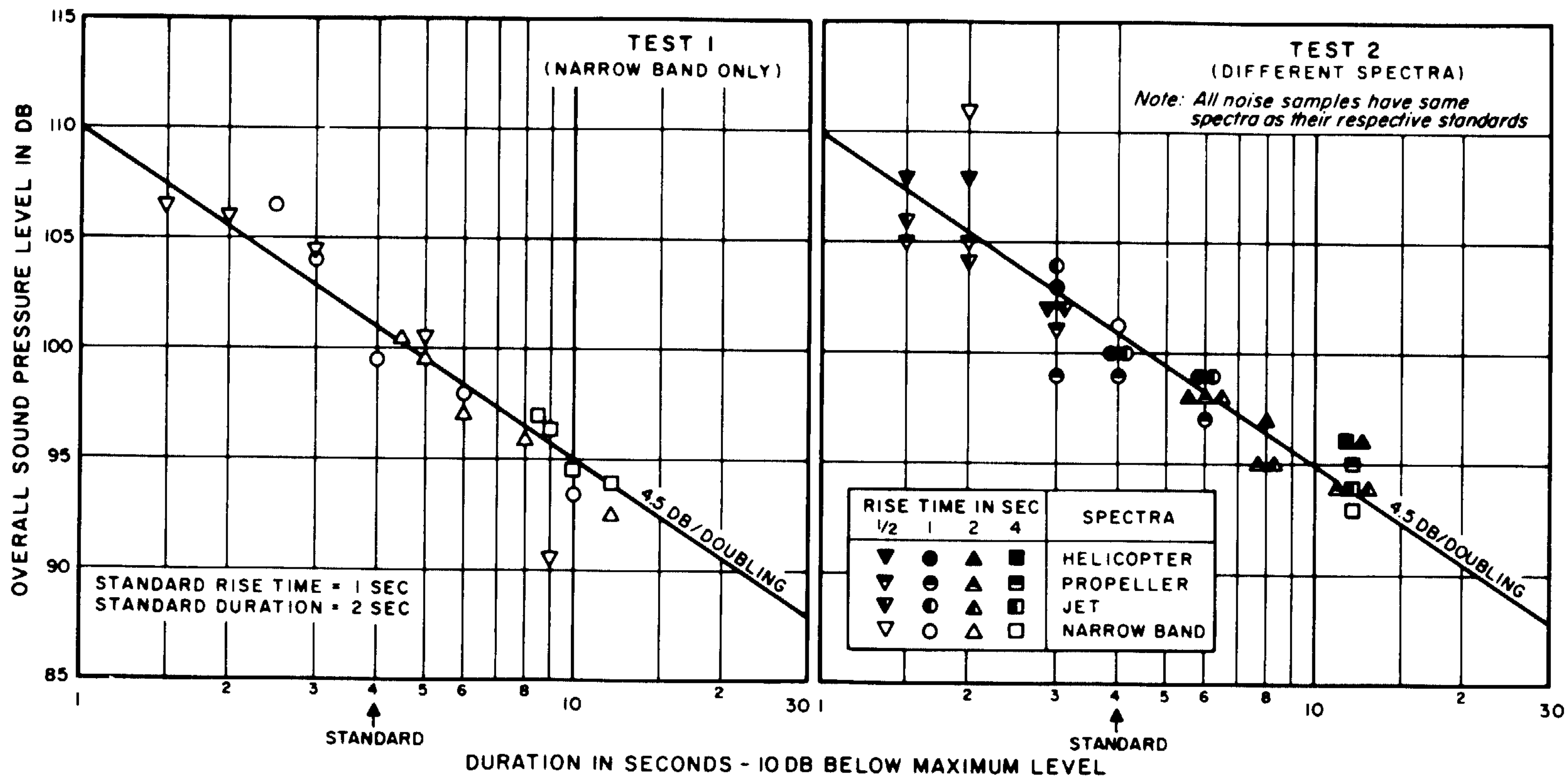

FIG. 11 EQUALLY ACCEPTABLE NOISES OF VARIOUS RISE-TIMES AND DURATIONS

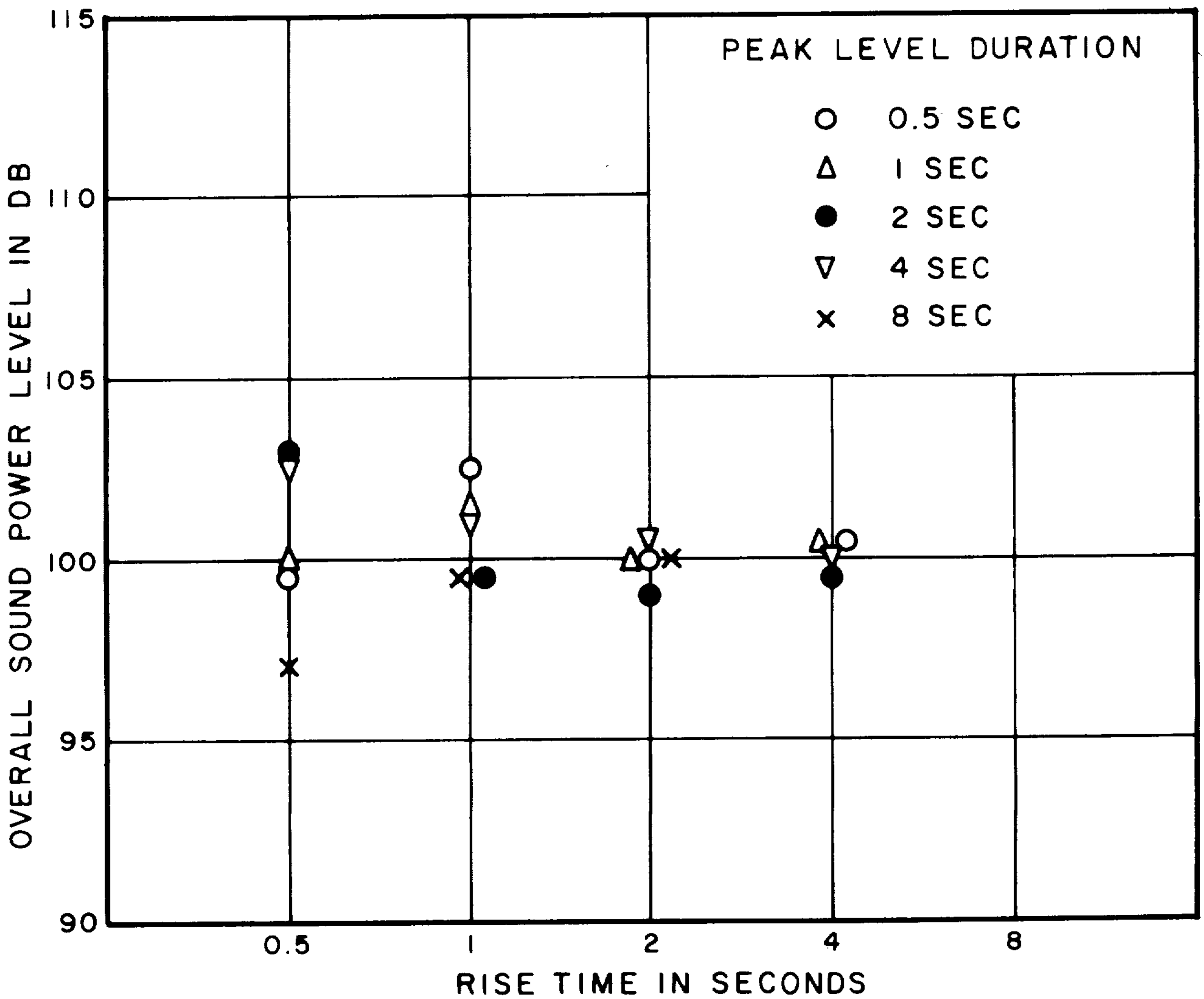

FIG. 12 EQUALLY ACCEPTABLE NOISES CORRECTED FOR DIFFERENCE IN ENERGY RELATIVE TO STANDARD, (1 SEC RISE-DECAY TIME, 2 SEC PEAK LEVEL DURATION), ACCORDING TO RELATIONSHIP INDICATED IN FIG. 11

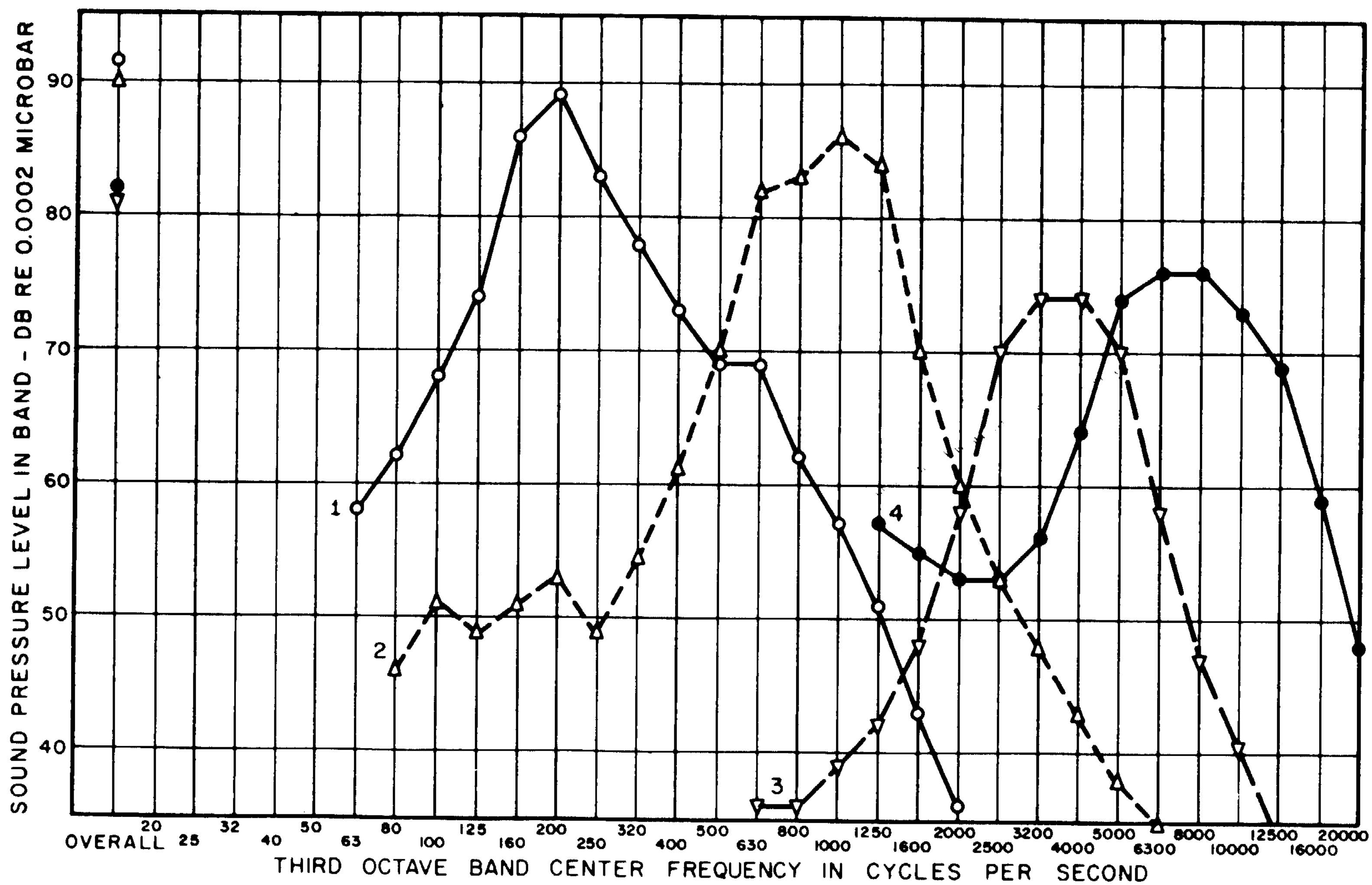

FIG. 13 SPECTRA OF NOISES USED IN JUDGEMENT TESTS

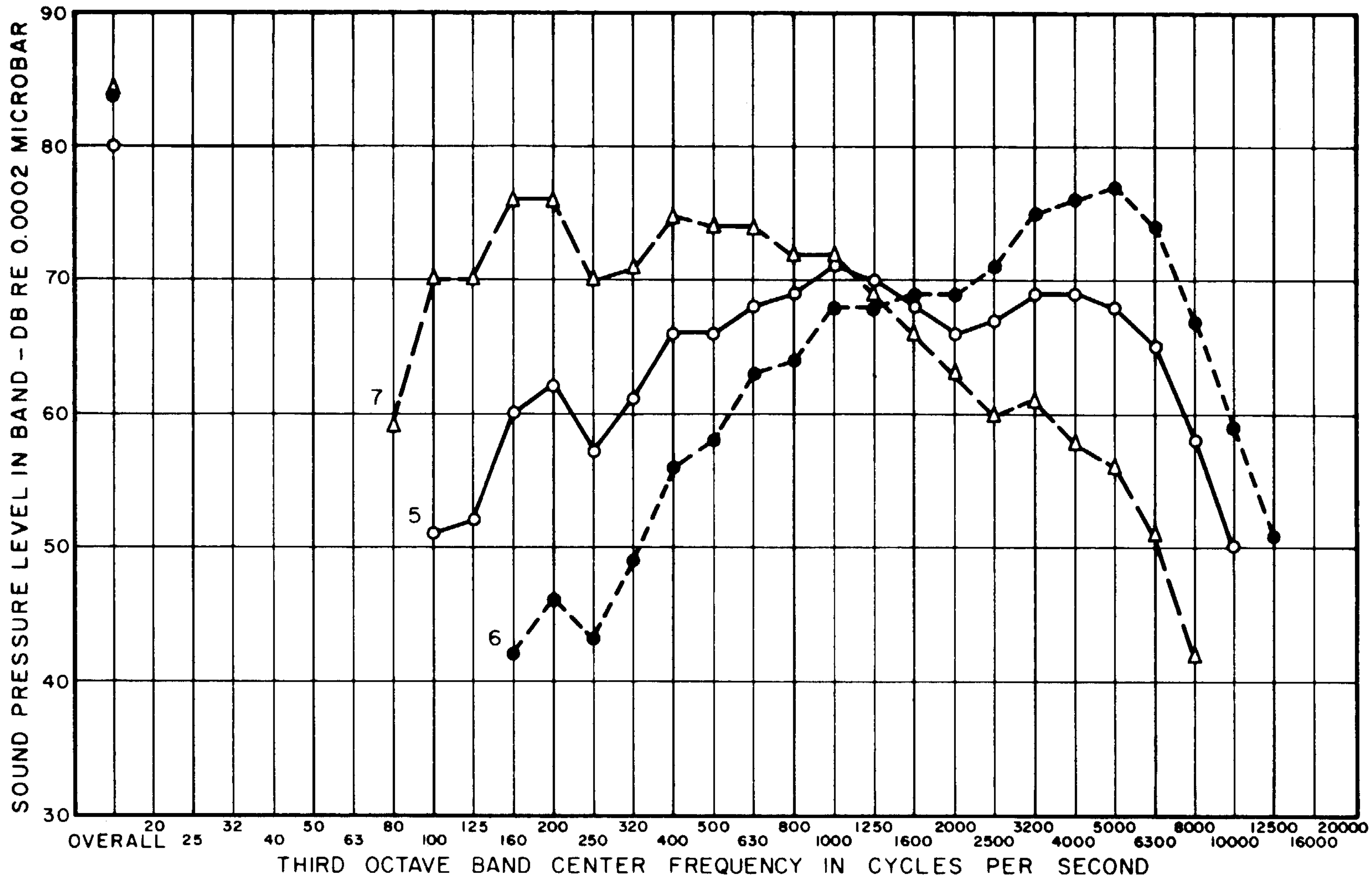

FIG. 14 SPECTRA OF NOISES USED IN JUDGEMENT TESTS

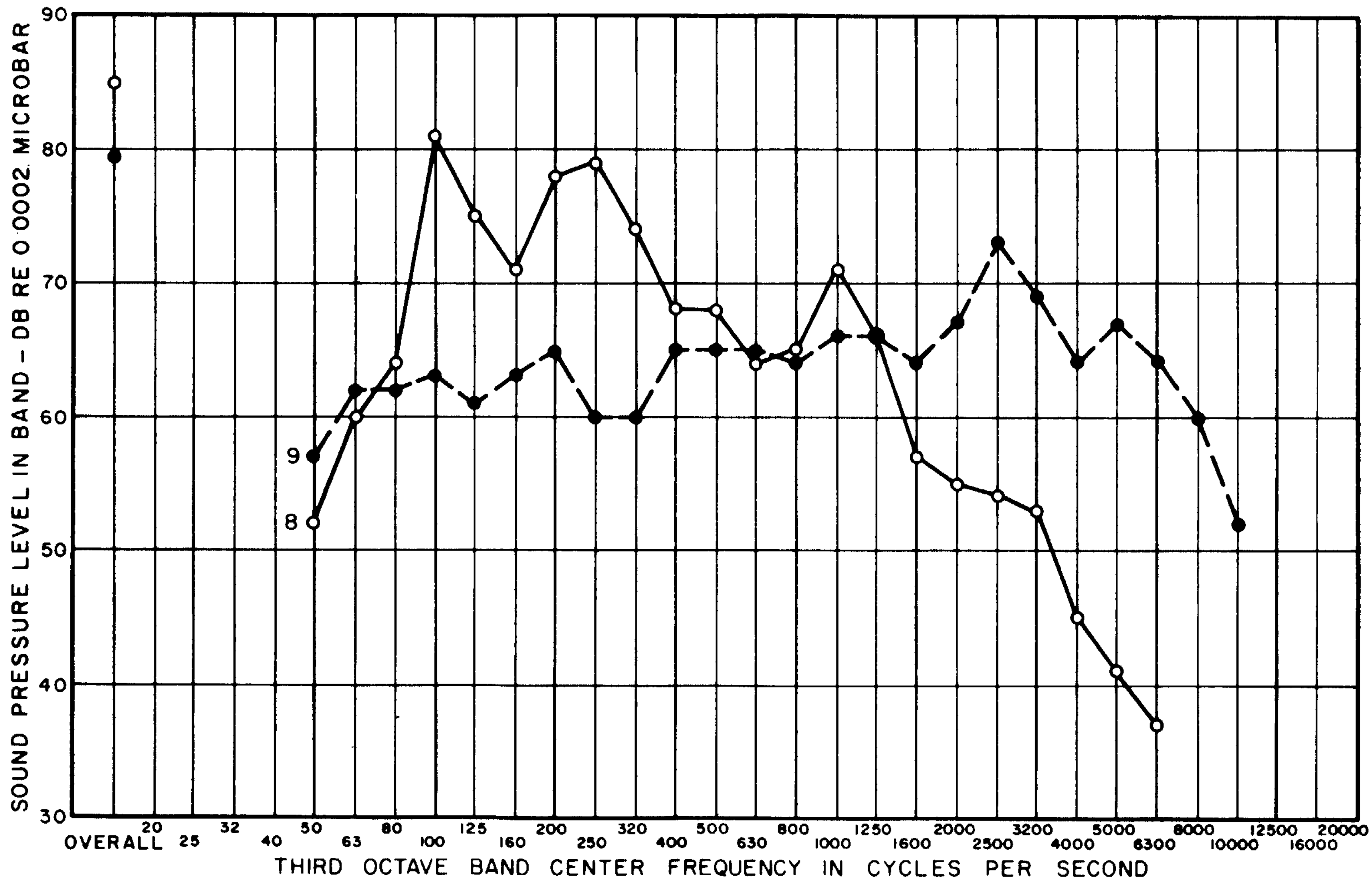

FIG. 15 SPECTRA OF NOISES USED IN JUDGEMENT TESTS

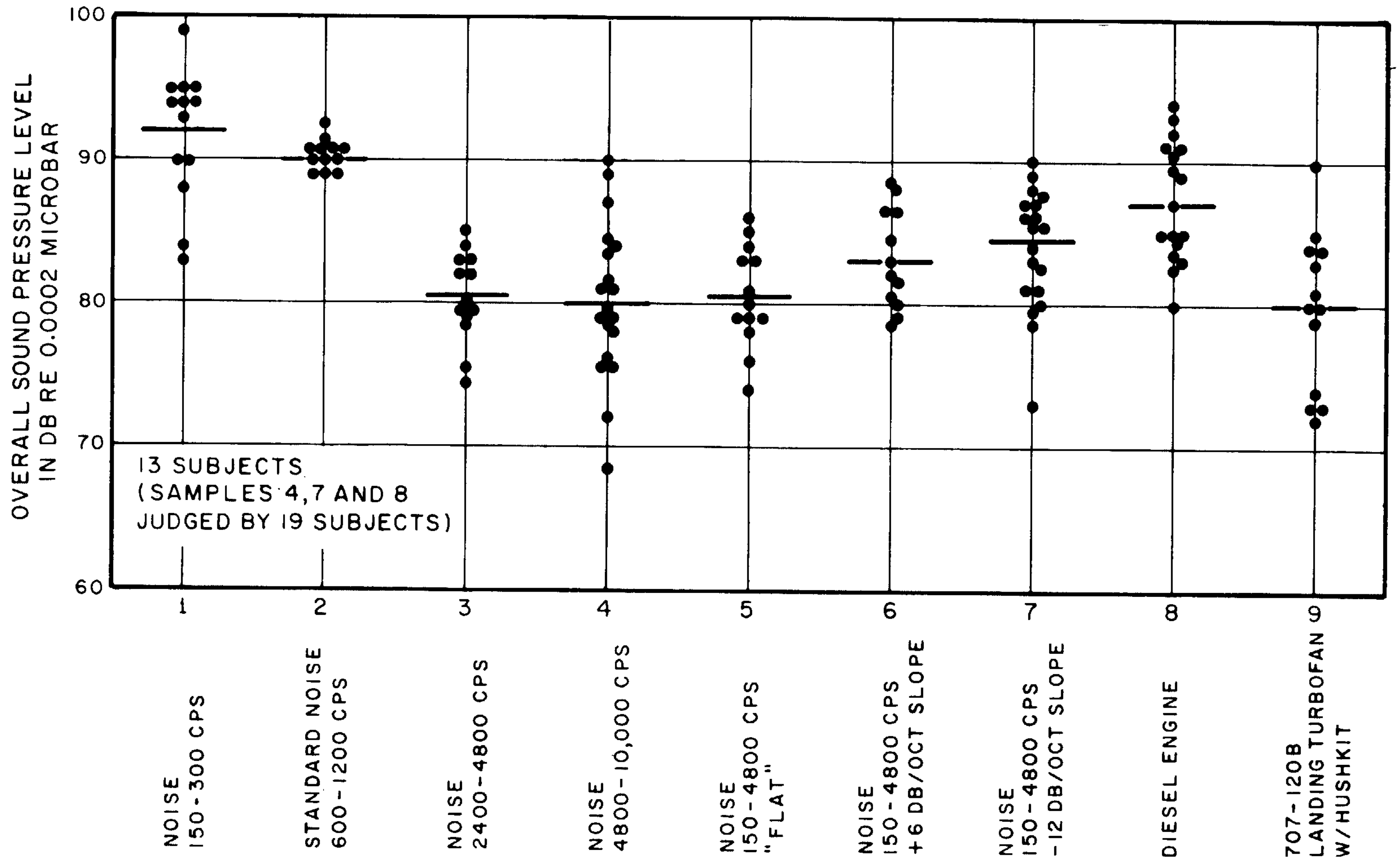

FIG. 16 SOUND PRESSURE LEVEL OF SOUNDS JUDGED EQUALLY ACCEPTABLE