36. ASSESSMENT OF THE VALIDITY OF PURE TONE CORRECTIONS TO PERCEIVED NOISE LEVEL

By Karl S. Pearsons

Bolt Beranek and Newman, Inc.

SUMMARY

Judgment tests were conducted to determine the validity of pure tone corrections to perceived noise level. Stimuli for these tests included broadband noise with single tones, modulated tones, or multiple tones. These stimuli were presented at a constant duration of 4 seconds. Other stimuli included single tones in broadband noise for durations ranging from 4 to 32 seconds. The results of the judgment tests indicate that the perceived noise level with tone corrections adequately predicts the noisiness of these stimuli. In addition, for those stimuli varying in duration, a duration correction is necessary.

INTRODUCTION

The presence of pure tones or discrete frequencies in aircraft engine noise appears to be an annoyance for the listener. The magnitude of the annoyance, insofar as it affects the assessment of aircraft flyover noise, has been measured by subjective testing.

Some early subjective testing produced pure tone corrections for the perceived noise level calculation procedure to account for the additional noisiness of these discrete frequencies. The initial part of this paper describes these tone corrections. The remainder of the paper deals with the validation of these tone corrections by using various types of pure tone and broadband noise stimuli.

The stimuli used in these validation tests are listed in figure 1. These stimuli were selected to check the adequacy of proposed tone correction methods. As indicated in the figure, they include single tones in broadband noise, modulated tones in broadband noise, and multiple tones in broadband noise. All these stimuli were presented at a constant duration of 4 seconds. Other tests included single tones in broadband noise for durations approximating those of present-day aircraft flyovers (4 to 32 seconds).

Before further details of some of these subjective tests are discussed, the method usually used to describe the tones as they might appear in the presence of broadband noise is noted. Figure 2 shows two representations of some broadband noise along with a single tone at 1000 Hz. The magnitude of the tone is indicated by how much it exceeds the measurement of noise in a 1/3-octave band as shown in the upper curve. This measure is called the tone-to-noise ratio (T/N) as determined in a 1/3-octave band. In the example

36

shown it is 10 dB. The lower curve is a different representation of the same stimuli using a vertical line for the tone.

When a tone is added to noise and the perceived noise level is calculated in a manner described by Karl D. Kryter (ref. 1), the noisiness of the combination is underestimated by the perceived noise level calculation. In other words, some sort of a correction is necessary to account for the presence of the pure tone.

TONE CORRECTION

In the development of the pure tone corrections and in the subsequent judgment tests, groups of college students were employed as subjects. In general, the tests were conducted in an anechoic chamber with one to four subjects. All subjects were screened audiometrically prior to the judgment tests. For these tests the subjects were presented with 4-second octave bands of noise both with and without pure tones. By using the method of paired comparisons, the subjects were asked to judge which of two sounds was the more annoying or objectionable. The levels at which 50 percent of the subjects stated that one of the pairs was noisier or more objectionable than the other were selected as the levels of equal noisiness. For these judged levels of equality, the corrections were determined by noting the amount that the octave band of noise without the tone needed to be increased to be equal to the octave band of noise with the tone. These judgments were determined for various frequencies and tone-to-noise ratios and resulted in the set of corrections depicted in figure 3. Notice that as the tone-to-noise ratio is increased, the correction increases; likewise, as the frequency is increased to about 4000 Hz, the tone correction also increases. For a given frequency and tone-to-noise ratio, the amount of correction necessary is determined from the graph. This correction is added to the 1/3-octave band level prior to calculation of perceived noise level. In this way, if more than one tone is present, more than one correction can be added.

VALIDATION TESTS

Single Tones

As mentioned before, the development of these corrections utilized octave bands of noise. Since most aircraft flyovers produce broadband noise, it was important to determine whether the corrections did indeed work for tones in broadband noise. Therefore, additional judgment tests using the conditions and techniques described were conducted. Figure 4 shows what happens in a typical judgment test comparing broadband noise with the same broadband noise with a tone inserted. The broadband noise alone is called the standard and the broadband noise with the tone, the comparison. After a typical judgment where the subjects have stated that the two are approximately equal in noisiness, perceived noise levels (PNL) are calculated for both the standard and the comparison. Note that the perceived noise level of 95 PNdB for the standard is quite a bit higher than the 85 PNdB calculated for the comparison. The two measures may be compared by noting the difference or the level of comparison relative to the level of the standard. In this first case, for perceived noise level alone, the difference is -10 PNdB; in other words, the comparison measured 10 PNdB below the level of the standard at the judged equal noisiness point. If the measure being employed is a good one, the difference is close to zero. Then the results can be said to be in good agreement with the judgment data.

When the pure tone correction is added, the perceived noise level for the standard does not change since there is no pure tone. However, the pure tone correction for the comparison, in this case, has the net effect of adding about 10 PNdB to the perceived noise level; thus, the perceived noise level (PNL) of the comparison is made equal to that of the standard.

A summary of results in terms of comparison minus standard level is shown in figure 5. Each point represents the results for 20 subjects. A group of data taken at various tone frequencies for perceived noise level alone is shown as a measure. Compared with this measure are the results using perceived noise level with the tone correction as a measure. By looking at the median lines, it can be seen that the perceived noise level with the tone correction agrees much more closely with the judgment results (that is, the comparison minus the standard is nearer zero) than do the results with perceived noise level without the pure tone corrections. The various points on the figure indicate different spectrum shapes of broadband noise that were used in the test. The spread of the points provides an indication of the repeatability that the group had when both the same and different shapes of broadband noise are used. Standard deviations for the data at various frequencies vary from 1.5 to 2.5 PNdB. It may be concluded then that for single steady tones in broadband noise, the pure tone correction seems to work well.

Modulated Tones

However, in aircraft flyover noise the tones are not as steady and also there may be more than one of them. First look at the problems of nonsteady-state tones. For the sample shown in figure 4 of a single tone in broadband noise, the tone is amplitude modulated. This procedure was followed for a series of tests to investigate the effects of amplitude modulating a tone in broadband noise. Judgment tests were conducted in which the modulated tones in broadband noise were compared with the broadband noise alone.

Figure 6 shows the results of the tests in a manner similar to that shown in figure 5. The level of the comparison is again plotted against the level of the standard. The rate of modulation or the envelope of the sketch in the upper portion of the figure is shown on the abscissa, that is, no modulation, 5 Hz, etc. The various coded points indicated the frequency (500 or 2000 Hz) of the tone that was modulated. Again, the results are shown for perceived noise level without the pure tone corrections and also the results for pure tone with the tone corrections.

In most cases, the results with the tone corrections are in much closer agreement with the judgment data than those results without the tone corrections. The one case where the results are not in particularly good agreement is for the low-rate amplitude-modulation case. This difference may be due to the large annoying beats associated with signals of this type.

In figure 7 are the results for the frequency-modulated tones. In this case, the tone is modulated in frequency at various rates. Again, the perceived noise levels with tone corrections are in closer agreement with the judgment data than those results for perceived noise level without tone corrections.

Multiple Tones

Investigations have also been conducted for the case where more than one tone is present in the stimulus. Both harmonically and inharmonically related tones were employed. The stimuli for these tests consisted of either two- or five-tone complexes in broadband noise. Samples of some of the stimuli that were used are shown in figure 8. The two-tone complexes are shown at the top of the figure and the five-tone complexes are shown at the bottom. The frequency and range of the two-tone and five-tone stimuli are given in the following table:

Frequency of lowest tone, Hz (cps)	Range, octaves
250	1/10, 1/3, 1, 4/3, 2
500	
1000	
2000	
4000	

The range refers to the difference in frequency between the highest and lowest component in the tone complex. For the samples shown, the lowest tone was always 1000 Hz. As shown in the table, frequencies of 250, 500, 2000, and 4000 Hz were also tested. Both the harmonically related tones, that is, the 1- and 2-octave ranges and the inharmonically related, the 1/10-, 1/3-, and 4/3-octave ranges, were used to determine whether any difference existed between the two cases. Actually, there was very little difference in the judgment results for the various ranges, at least from the 1/10-octave range to the 2-octave range. Therefore, the results of the various ranges were averaged and the averages are plotted in figure 9 according to the frequency of the lowest pure tone components. Again, results are shown for perceived noise level without tone correction for both the two-tone and five-tone complexes. Also shown are the perceived noise levels with tone corrections. Again, as in previous figures the results with the tone corrections are in much closer agreement with the judgment data than are those without the tone corrections. Also, as indicated in figure 9, there does not appear to be an appreciable difference between the two-tone or the five-tone complexes.

A 16-tone complex was also tested, as shown in figures 9 and 10. This sample is somewhat similar to the so-called "buzz tones" present in high bypass ratio turbofan engines. The results of this test are shown on the right-hand side of figure 9. Again, the perceived noise levels with tone corrections are in much closer agreement with the judgment results; that is, they lie closer to the zero line than do the perceived noise levels alone. Note that for the perceived noise level alone in this case, the estimates were as much as 10 dB too low, whereas with the tone correction the estimate was only about 2 dB high.

The tests described up to this point have all been conducted at a constant duration; however, some aircraft flyovers are much longer in duration than others, and certainly are longer than the 4-second samples employed in these tests.

Since there was a possibility that the duration effect might interact with the pure tone effect, some additional tests have been conducted to see whether these tone and duration effects can be accounted for by present duration and tone correction techniques. Before the details of the tests are presented, the ideas behind the present duration correction will be discussed. Figure 11 shows two simulations of aircraft flyovers plotted with sound pressure level as a function of time. The time history on the right is twice as long as the time pattern on the left if measurements are made at the 10-dB-down points. It has been shown from subjective tests that in order for the two signals to be judged equally noisy, the level of the longer duration sound must be decreased by 3 dB. This relationship or tradeoff seems to hold up fairly well over the range from 4 seconds to 64 seconds as measured at the points 10 dB down from the maximum level.

In the tests that were used to generate this kind of relationship, both the standard and the comparison were of similar spectral shape. The only thing that was varied was the duration of the signal itself. To learn more of any possible interaction between tone and duration parameters, stimuli were employed such as those shown in figure 12. As shown in this figure, the standard was a noise alone for a given duration (12 seconds) and the comparison was a combination of tone and noise of a different duration. The other parameter that was varied was a tone-to-noise ratio or the amount that the tone exceeded the noise in a 1/3-octave band. The results of these tests are shown in figure 13. Here are shown as a function of tone-to-noise ratio and duration the judgment data determined both for perceived noise level with and without tone and duration corrections. The results for the perceived noise level alone are shown as open symbols connected by dashed lines on the figure, whereas the results for the perceived noise level with tone and duration corrections are shown as closed symbols bounded by a shaded area. Note that the shaded area is in much closer agreement with the zero line; that is, it agrees closer with the judgment results than the line connected points do. This condition is especially true for the longer durations where, without the corrections, errors of as much as 13 dB occur. Separate plots of the perceived noise level with just the duration correction and also with just the tone correction were also made but the combination of both tone and duration corrections provides the best agreement with the judgment results.

Other tests were also conducted by using stimuli with different time patterns. Both tone and noise were employed with the duration of the tone differing from the duration of the noise. Also, the time at which the tone peaked was different from the time that the noise reached its peak. Without going into the details of the results, it is sufficient to say that varying the duration of the tone provided little change in the judgment results compared with those results where the duration of the tone was comparable with the duration of the noise. Also, the time at which the tone peak occurred did not seem to affect greatly the judgment results. If tone and duration corrections are applied to PNL for all these cases, the agreement with the judgment data is better than that for PNL alone. It should be mentioned that the tone and duration corrections that have been described here are not unique. There are others available that may do as good a job. Some of these other techniques are discussed in reference 2.

CONCLUDING REMARKS

From the results of the investigations described in this paper, several conclusions can be drawn. The main conclusion is that the perceived noise level with a tone correction predicts the noisiness of broadband noise stimuli containing single, modulated, and multiple tones for the stimuli employed in the judgment tests. Also, for complex stimuli varying in both tone content and duration, a duration correction is also necessary for optimum prediction of noisiness. All the questions with regard to discrete frequency components in aircraft engine noise however have not been answered. An attempt has been made rather to provide a better understanding of the state of the art with regard to subjective testing of tones in noise. It should be mentioned that the tone and duration corrections that have been described here are not unique. There are others available that may do as good a job.

REFERENCES

1. Kryter, Karl D.: Prediction of Effects of Noise on Man. Conference on Progress of NASA Research Relating to Noise Alleviation of Large Subsonic Jet Aircraft, NASA SP-189, 1968. (Paper No. 34 herein.)
2. Kryter, Karl D.; Johnson, P. J.; and Young, J. R.: Judgment Tests of Aircraft Noise. Conference on Progress of NASA Research Relating to Noise Alleviation of Large Subsonic Jet Aircraft, NASA SP-189, 1968. (Paper No. 37 herein.)

TEST STIMULI

SINGLE TONES
MODULATED TONES — 4 SECONDS
MULTIPLE TONES

SINGLE TONES (DURATION VARIED) — 4 –32 SECONDS

Figure 1

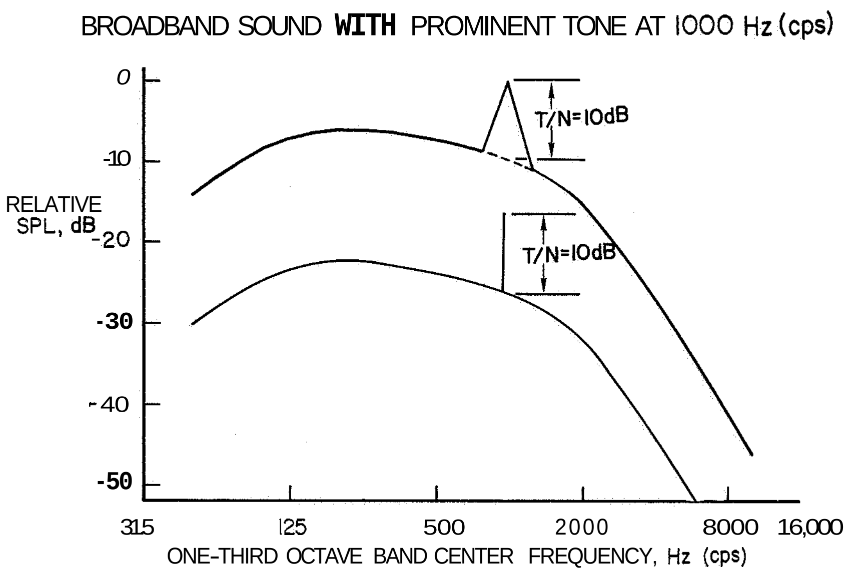

Figure 2

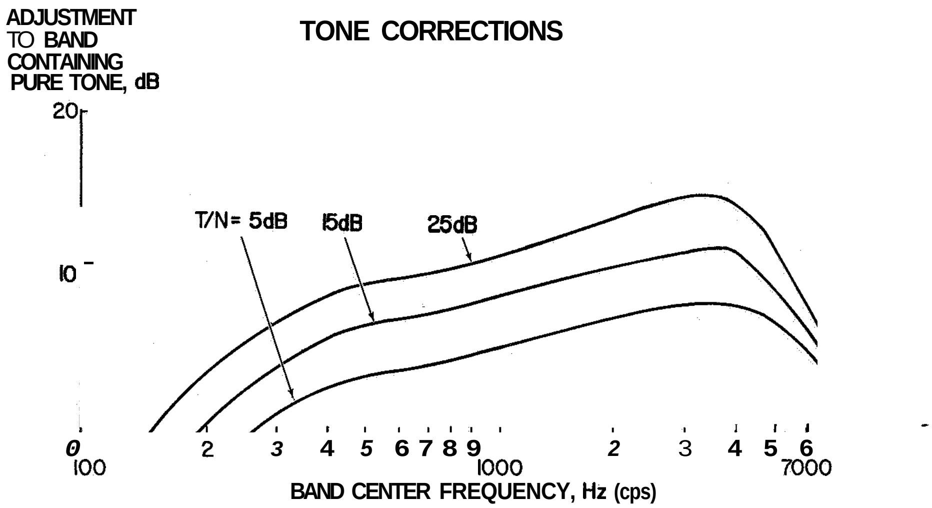

Figure 3

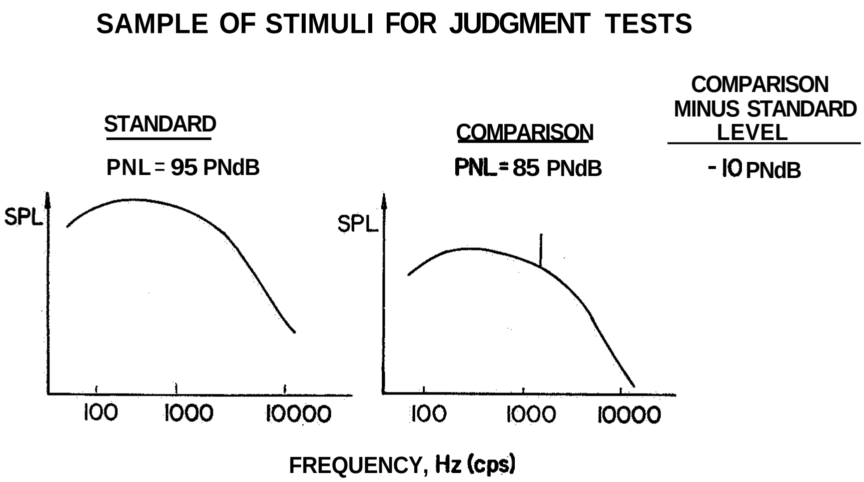

Figure 4

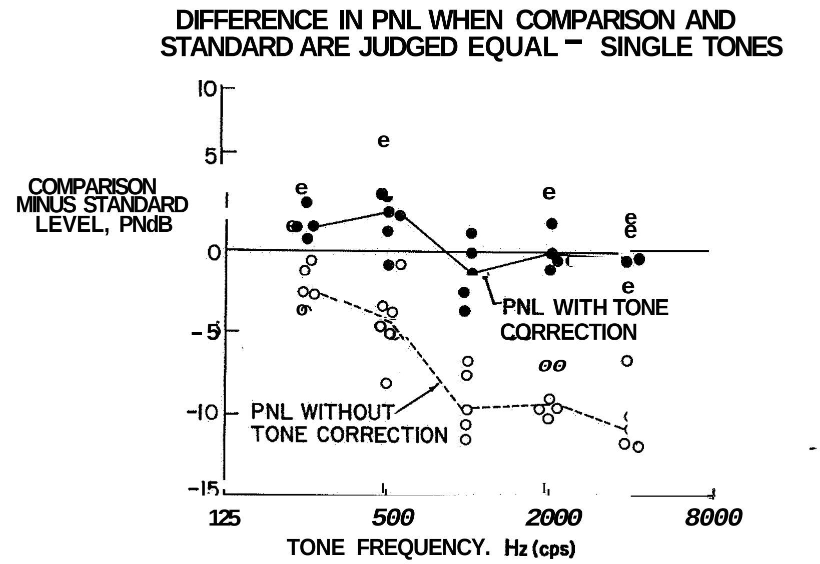

Figure 5

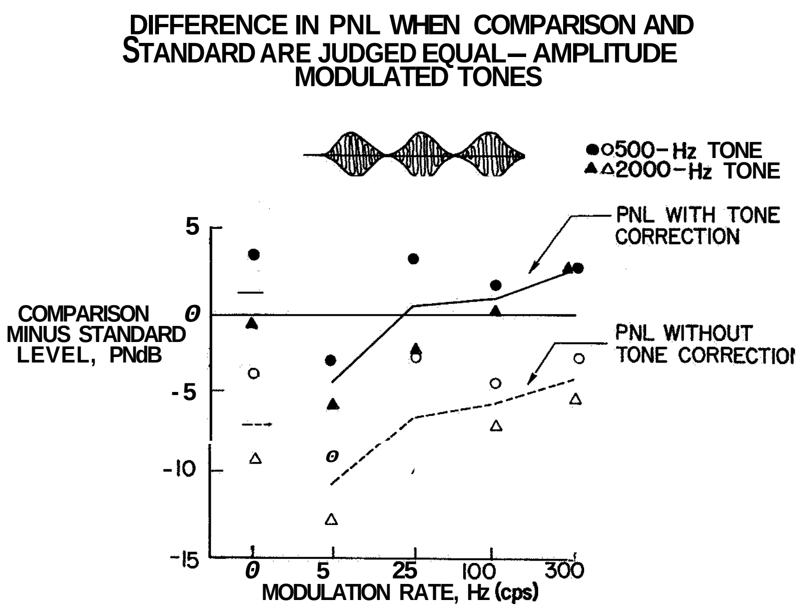

Figure 6

DIFFERENCE IN PNL WHEN COMPARISON AND STANDARD ARE JUDGED EQUAL — FREQUENCY MODULATED TONES

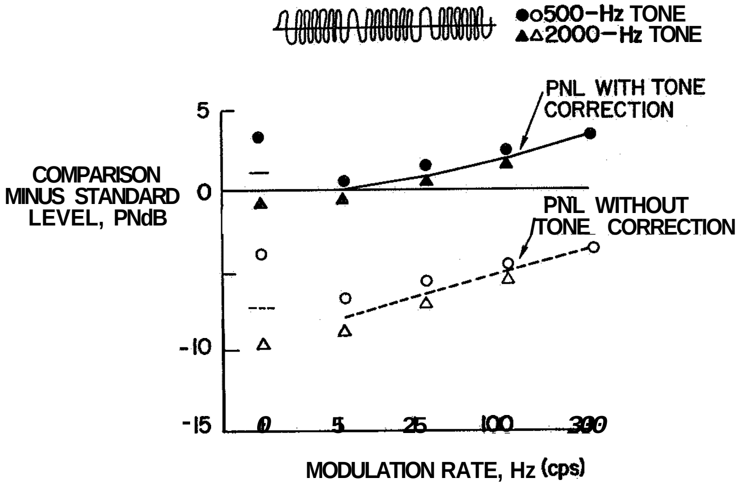

Figure 7

SAMPLE OF COMPARISON STIMULI USING 2–AND 5–TONE COMPLEXES

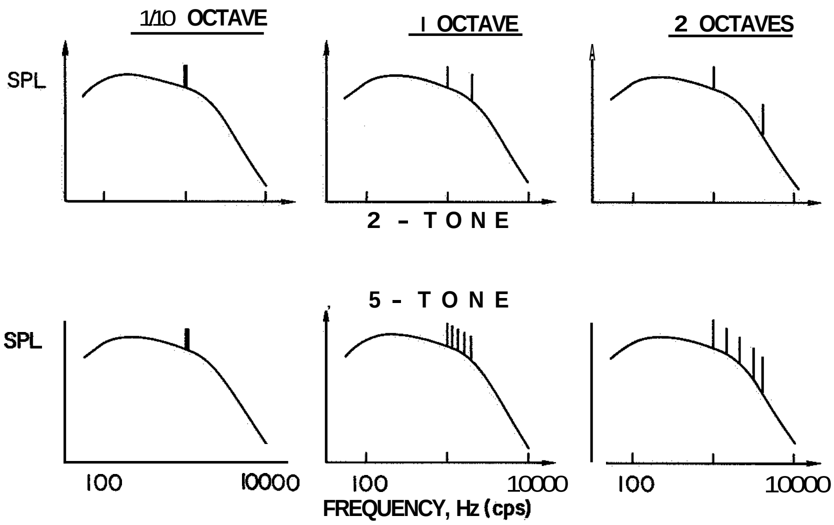

Figure 8

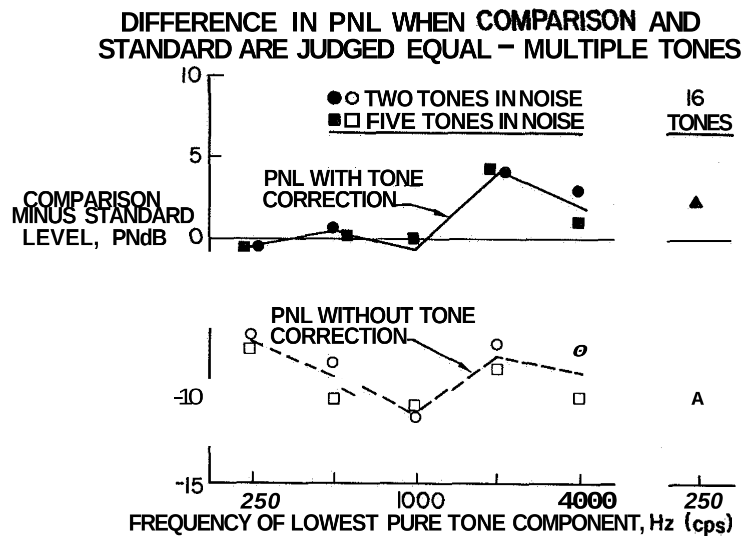

Figure 9

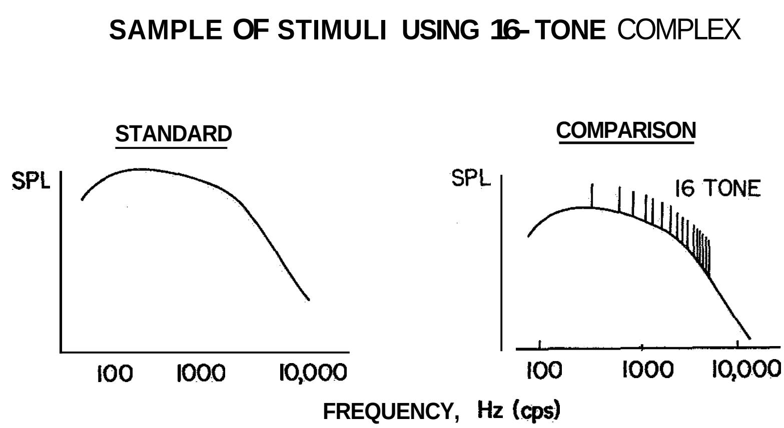

Figure 10

DURATION EFFECT

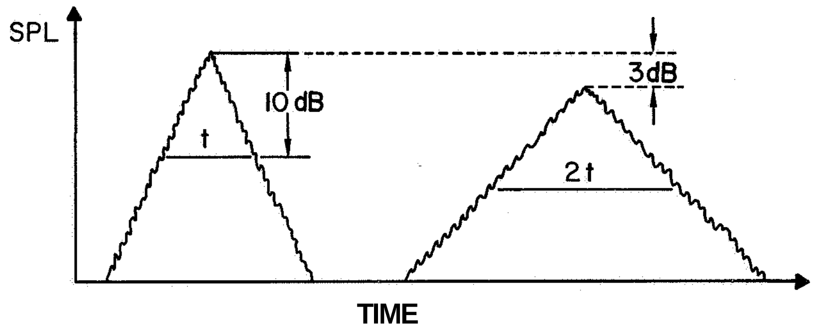

Figure 11

SAMPLE OF STIMULI FOR VARIABLE-DURATION TEST

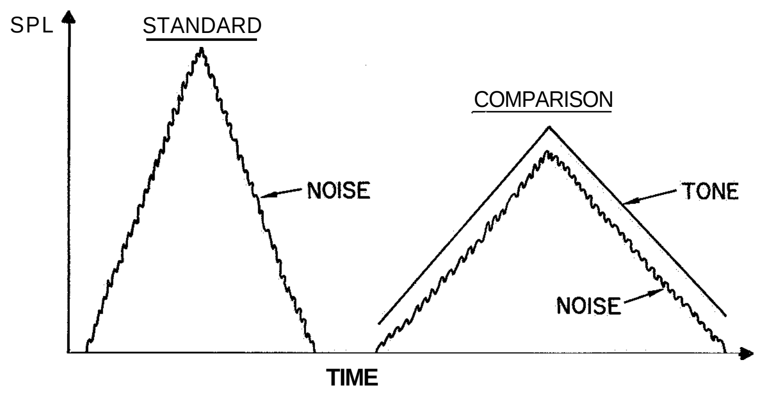

Figure 12

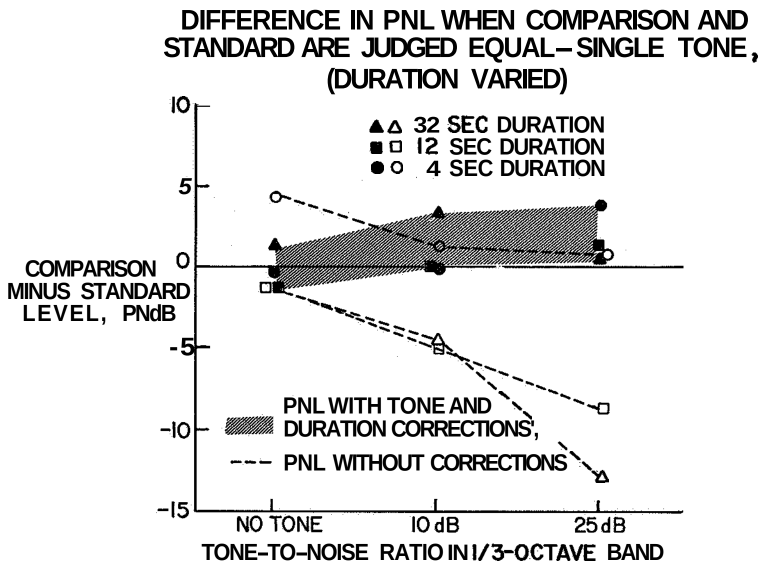
DIFFERENCE IN PNL WHEN COMPARISON AND STANDARD ARE JUDGED EQUAL – SINGLE TONE, (DURATION VARIED)
32 SEC DURATION
12 SEC DURATION
4 SEC DURATION
COMPARISON MINUS STANDARD LEVEL, PNdB
10
5
0
-5
-10
-15
PNL WITH TONE AND DURATION CORRECTIONS
PNL WITHOUT CORRECTIONS
NO TONE
10 dB
25 dB
TONE-TO-NOISE RATIO IN 1/3-OCTAVE BAND

Figure 13