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RELATIVE EFFECTIVENESS OF SEVERAL SIMULATED JET ENGINE NOISE SPECTRAL TREATMENTS IN REDUCING ANNOYANCE IN A TV-VIEWING SITUATION

By

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April 1976

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16. Abstract

An experiment was conducted in order to determine the relative effectiveness of several hypothetical jet engine noise treatments and to test the hypothesis that speech interference, at least in part, mediates annoyance in a TV-viewing situation. Twenty-four subjects watched television in a simulated living room. Recorded jet flyover noises were presented in such a way as to create the illusion that aircraft were actually flying overhead. There were 27 stimuli (nine spectra at three overall levels) presented at an average rate of approximately one flight every 2 minutes. One spectrum was that of an untreated commercial jet aircraft takeoff noise, while the other eight spectra were the same as the first but with one of two amounts of energy removed from a 1-octave band centered at 315 Hz, 800 Hz, 1.6 kHz, or 4 kHz. Subjects judged the annoyance value of individual stimuli using either a category rating method or magnitude estimation method in each of two 1-hour sessions. The spectral treatments most effective in reducing annoyance were at 1.6 kHz and 800 Hz, in that order. The degree of annoyance reduction resulting from all treatments was affected by the overall sound level of the stimuli, with the greatest reduction at the intermediate overall sound level, about 88 to 89 dB(A), peak value. The results are interpreted as supporting the hypothesis that speech interference, at least in part, mediates annoyance with aircraft noise in a TV-viewing situation.

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SUMMARY

An experiment was conducted in order to determine the relative effectiveness of several hypothetical jet engine noise treatments and to test the hypothesis that speech interference, at least in part, mediates annoyance with aircraft noise when test subjects are engaged in a TV-viewing situation. Specifically, if speech interference mediates annoyance with aircraft noise, then one might expect greater relief by energy reductions at the intermediate frequency bands (800 Hz to 2 kHz) than at higher frequency bands (2 kHz to 4 kHz) or lower frequency bands (less than 800 Hz) when the overall sound level is on the order of 89 dB. Additionally, one might expect the frequency of the most effective band reduction to increase somewhat as the overall sound level is decreased to about 83 dB.

In this experiment, twenty-four subjects watched television in a simulated living room. During this time, recorded aircraft sounds were presented in such a way as to create the illusion that aircraft were actually flying overhead. The stimuli were intense enough to cause interference with speech reception, as is experienced by many people who live near airports. The subjects judged the annoyance value of each stimulus using one of two psychophysical procedures during each of the two 1-hour sessions. The stimuli were all modifications of a recorded commercial jet aircraft takeoff noise. Some of the stimuli were produced by filtering out various amounts of acoustic energy from individual 1-octave bands centered at four specific parts of the acoustic spectrum, 315 Hz, 800 Hz, 1.6 kHz, and 4 kHz. Other stimuli were of the same spectra as these but presented at lower overall levels. Thus, there were 27 stimuli which were combinations of 9 spectra

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(one untreated and eight different treatments of the basic aircraft takeoff noise) at three distinct overall levels. The following results were obtained:

(1) The spectral treatments most effective in reducing annoyance responses were at 1.6 kHz and 800 Hz, in that order.

(2) The greatest annoyance reduction resulting from treatments was at the intermediate overall sound level (88 to 89 dB(A), peak value) with less reduction at both higher and lower levels.

(3) The category rating procedure was relatively insensitive to annoyance reductions resulting from spectral treatments such as those used in this experiment, whereas the magnitude estimation procedure proved to be quite sensitive.

The results of this study are interpreted as supporting the hypothesis that speech interference, at least in part, mediates annoyance with aircraft noise in a TV-viewing situation.

INTRODUCTION

Interference with speech communications, primarily television viewing, is the major aircraft-related problem (ref. 1 and 2). Williams, et al. (ref. 3), used an 11-point rating scale to obtain judgments of the acceptability of individual aircraft flyover noises while subjects watched television. These ratings were nearly identical to those made without the presence of television and showed the typical linear relationship between sound level in dB(A), PNdB, or SIL and rating. In experiments conducted by Langdon, et al. (ref. 4), subjects watched videotaped television programs and, at the end of each session, rated the acceptability of the total noise exposure during that period. The authors concluded that their data were best described by a model which combines the intensity prediction of Williams, et al. (ref. 3) with a "masking prediction." This combination predicts relatively small effects above or below the masking threshold with a dramatic effect at the masking point. A more comprehensive model of human response to aircraft noise was proposed by Gunn, et al., (ref. 5). This stress-reduction model hypothesizes, in part, that annoyance response to aircraft noise is mediated by three primary factors; the inherent unpleasant characteristics of the noise, per se; aversive meanings associated with the noise source; and interference with ongoing activities. In order to test the hypothesis that interference with various ongoing activities differentially affects annoyance responses to recorded aircraft noises, Gunn, et al. (ref. 6) performed a large-scale laboratory study in which 324 subjects, in groups of six, were engaged in TV-viewing, telephone listening, or reverie (no activity) for a 1/2-hour session. During this period, they were exposed to a series of recorded aircraft noises which were presented at the rate of one flight every 2 minutes. At the end of the test session, subjects recorded their responses to the aircraft noises, using an 11-point bipolar rating scale which covered the range from "very pleasant" to extremely annoying." The responses were found to be differentially affected by the particular activity in which the subjects were engaged. Subjects engaged in the telephone listening task were significantly more sensitive to changes in peak flyover level than those engaged in either TV-viewing or reverie. Additionally, the annoyance value of the overflights in the TV-viewing task was found to be significantly greater than that during reverie, at all levels. The differences in the three psychophysical functions suggest a possible different basis for the annoyance response in each situation. The authors suggest that distraction, as well as speech masking, may be involved in annoyance response to aircraft noise in a TV-viewing situation.

Given that interference with TV-viewing is a major aircraft noise related problem (ref. 1 and 2), and that different psychophysical functions relating aircraft noise exposure and annoyance responses have been found for subjects engaged in different activities (ref. 6), it would seem desirable to obtain information about the relative effectiveness of jet engine noise treatments while subjects are engaged in various realistic activities.

There are many possible ways to reduce jet engine noise. Overall level reductions are possible as are discrete noise reductions at specific parts of the acoustic spectrum. The question is, which is the most cost-effective? That is, which approach provides the greatest annoyance reduction for the least expense? The experiment to be described in this paper deals directly with the question of relative effectiveness of various hypothetical jet engine noise reduction treatments.

Support for the hypothesis that speech interference, at least in part, mediates annoyance with aircraft noise in a TV-viewing situation might be obtained by comparison of the results of this study with predictions based on speech masking considerations. For instance, Miller (ref. 7) presents data which show that at 89 dB, the most effective speech masking bands are in the frequency region of 800 Hz to 2 kHz. As the level of the masking decreases, the frequency of the most effective masking band increases and the differences in the masking effectiveness of individual bands decrease. With respect to the effectiveness of noise treatments in which energy is removed from specific frequency bands of the spectrum of a jet engine noise, speech masking considerations would then suggest that the greatest annoyance reduction will be obtained by noise treatments in the frequency region between 800 Hz and 2 kHz, when the overall sound level is on the order of 89 dB. As the overall sound level is decreased, the amount of annoyance reduction from each treatment will decrease and differences in the effectiveness of the treatments will disappear.

METHOD

Subjects

Twenty-four subjects ranging in age from 19 to 50 participated in the experiment. Eighteen were women and six were men. Only those whose hearing level was found to be within 20 dB of normal (ISO, 1964) were allowed to participate.

Stimuli

Twenty-seven stimuli were presented in each test session. Stimulus 1 was a recorded commercial jet aircraft takeoff noise. All other stimuli were simply electronically modified versions of stimulus 1. A description of the technique used for synthesis of the stimuli and examples of peak spectra are contained in Appendix A.

Table 1 shows that the 27 stimuli are combinations of nine spectra presented at three overall levels. Stimuli 4 through 27 have the same basic spectrum as stimuli 1, 2, and 3, except that in each case, energy has been removed from a specific 1-octave band. There are two degrees of treatment which are designated D1 (the lesser treatment) and D2 (the greater treatment). Thus, there are nine treatment conditions; the first is an untreated spectrum, designated T1. The other eight are combinations of the two degrees of treatment (D1 and D2) at each of the four treatment bands which are centered at 315, 800, 1.6 k, and 4 kHz. These are designated T2 through T9. Table 1 also shows the peak levels of the stimuli in dB(A), dB(D), and PNdB, as well as the overall level category, L1, L2, and L3.

Apparatus

The test was conducted in a simulated living room, complete with TV receiver and contemporary furnishings. Figure 1 shows a floor diagram of the test room. Four speakers, positioned over the test room, were used to present the stimuli. Two channels of a multichannel tape recorder were connected to four power amplifiers via an electronic switch and a noise elimination system. Each of the tape recorder channels drove two of the power amplifiers, which were connected in parallel. In this way, using the specially altered tapes (described in Appendix A), it was possible to create the illusion that the aircraft were actually flying overhead with distinct directional characteristics.

Procedure

Test subjects, in groups of either two or four at a time, were taken to a briefing room where they were given copies of the General Instructions, which are contained in Appendix B. The General Instructions were then read to the subjects as they followed along on their own copies. Next, a Voluntary Consent Form (contained in Appendix C) was distributed, signed by the subjects, and collected. Finally, an Audiovisual Monitoring Consent Form (contained in Appendix D) was distributed, signed by the subjects, and collected. The subjects were then escorted to the simulated living room (see fig. 1) where they participated in two 1-hour sessions which were separated by a 5-minute break.

In one session, they judged the annoyance value of the 27 stimuli (shown in table 1) using a nine-point category rating scale. The instructions to subjects and a sample data sheet for the category rating method are contained in Appendix E. In the other session, subjects judged the annoyance value of the same 27 stimuli, using a magnitude estimation method. The instructions to subjects and a sample data sheet for the magnitude estimation method are contained in Appendix F. In this session, the modulus (stimulus 2=100) was presented twice, before any judgments were made by the subjects, and again every tenth flyover to serve as a reminder. For these stimuli, no subject response was required as the space on the data sheet was already filled in with the number 100. Stimulus 2 was additionally presented and judged along with the other 26 stimuli, which were presented in a random sequence to each group.

Half of the subjects (S1 through S12) used the magnitude estimation method in the first session and the category rating method in the second session. The other half of the subjects (S13 through S24) received the reverse order for the method of judgment in each session.

The test subjects viewed various television programs during each session. The volume control was set by the experimenter to a level which was found to be comfortable by all subjects. This level was generally in the range of 45 to 51 dB(A) and was not altered during the remainder of the session. Most groups watched movies, talk shows, and quiz shows and appeared to be fairly interested in the proceedings, as was indicated by smiles of amusement and moderately frequent outbursts of laughter.

At the end of the first session, subjects were allowed a 5-minute rest break outside the test room. After the rest break, they were returned to the test room and given the instructions for the second session. The order of stimulus presentation was randomized for each group to control temporal or order effects. The interstimulus interval varied from trial to trial but averaged approximately one flight every 2 minutes, similar to flyover rates at a busy airport. After the second session, the subjects were thanked for their participation and released.

RESULTS

Analysis of Variance of Category Rating Data

Tables 2 and 3 show the analysis of variance for the category rating data. Since category ratings are essentially noninterval data, a nonparametric analysis (Friedman Two-Way Analysis of Variance) was used. The analysis shows that the effect of spectral treatment was not significant. Only the effect of overall level reached significance. Inspection of the data shows that the effect of level was similar for all treatments. The results indicate that the category rating method is relatively insensitive to spectral treatments such as those used in this experiment. Hence, no further analysis of category rating data will be presented in this report.

Analysis of Variance of Magnitude Estimation Data

Table 4 shows the analysis of variance for the magnitude estimation data. The analysis shows significant effects of spectral treatment, overall sound level, and their interaction. This result indicates that the magnitude estimation procedure used in this experiment is sensitive to the effects of spectral treatments such as those used in this study as well as to the effect of differences in overall level. Furthermore, the analysis indicates that the amount of annoyance change resulting from each spectral treatment depends on the overall level of the treated aircraft sound, as indicated by the significant interaction of treatment with level.

Comparison of Individual Treatment Effects

Table 5 summarizes the means of the judgments for the 24 subjects for magnitude estimation of the annoyance value of the 27 different stimuli. These data are shown graphically in figure 2. Table 6 shows the mean annoyance reduction (relative to the judgments for the untreated spectrum at the same overall level category) caused by each spectral treatment, as well as the significance of these reductions, as determined by two-tailed t tests. Note that at level L1, only stimuli 12 and 18 (the D1 level of treatment at 800 and 1,600 Hz octave bands) result in significant annoyance reductions, whereas at level L2 almost all treatments result in significant decreases in annoyance. At level L3, the lowest overall level, only stimulus 15 (the D2 level of treatment at the 800 Hz band) causes significant annoyance reduction. At level L1, the D1 treatment at 800 Hz provides significantly greater annoyance reduction than the D1 treatments at 315 Hz ($t = 2.52$, $p < 0.05$, two-tailed test) and 4 kHz ($t = 2.12$, $p < 0.05$, two-tailed test). Also at L1, the D2 treatment at 1,600 Hz provides significantly greater annoyance reduction than the D2 treatment at 4 kHz ($t = 2.28$, $p < 0.05$, two-tailed test). At level L2, the D2 treatment at 1,600 Hz provides greater annoyance reduction than the D2 treatments at 315 Hz ($t = 3.02$, $p < 0.01$, two-tailed test) and 4 kHz ($t = 2.10$, $p < 0.05$, two-tailed test). At level L3, the D1 treatment at 1,600 Hz provides greater annoyance reduction than the D1 treatment at 4 kHz ($t = 2.44$, $p < 0.05$, two-tailed test).

Figure 3 shows the relative effectiveness of each of the spectral treatments. A direct comparison can be made of the annoyance reduction resulting from treatment of the spectrum in each of the four octave bands for treatments in the range of 6 to 7 dB, where there is sufficient overlap of band reduction. Table 7 shows the significance of the differences in the effectiveness of the four spectral treatments. Clearly, the treatments at 1,600 Hz and 800 Hz, in that order, are more effective than the treatments at 315 Hz and 4 kHz.

Figures 4, 5, and 6 show annoyance as a function of peak sound level, expressed in terms of dB(A), dB(D), and PNdB, respectively. Inspection of these plots does not indicate that dB(D) or PNdB is superior to dB(A) in predicting annoyance to the stimuli used in this experiment. All of the above weighting scales were equally poor in such predictive ability. For instance, stimulus 20 which had a peak level of 101.5 PNdB was rated at a mean annoyance value of 84.2 while stimulus 8, which had a peak level of 101.0 PNdB was judged at a mean annoyance value of 105.8.

Annoyance was significantly reduced ($t = 2.86$, $p < 0.01$, $df = 23$, two-tailed test) by the D1 treatment at the octave band centered at 800 Hz at the highest overall level, L1. In addition, this annoyance reduction did not differ ($t = 0.22$) from the annoyance reduction caused by the overall level reduction of the untreated sound from level L1 to level L2. The annoyance of the untreated sound is significantly less ($t = 2.41$, $p < 0.05$) at L2 than L1. A similar annoyance reduction effect of spectral treatment can be seen at the octave band centered at 1,600 Hz in that the annoyance is significantly reduced ($t = 2.16$, $p < 0.05$) by the D1 treatment at this octave band, and this annoyance reduction did not differ ($t = 0.44$) from the reduction caused by reducing the overall level of the untreated sound from L1 to L2. This indicates that removing 5.0 dB from the octave band centered at 800 Hz or 5.2 dB from the octave band centered at 1.6 kHz is the equivalent (in terms of annoyance reduction) of a 2.7 dB overall sound reduction of the untreated spectrum. These and other similar trading relationships between specific spectral treatments and overall level reductions can be seen from the data shown in figure 2.

Effect of Overall Sound Level on the Effectiveness of Treatments

Differences in annoyance responses between levels for each degree of treatment (D1 and D2) of each treatment band were significant in all cases (see table 8). Also, the annoyance reduction was greater at L2 than L1 ($t = 5.43$, $df = 7$, $p < 0.001$, two-tailed test) or at L3 ($t = 9.84$, $p < 0.001$). Additionally, the annoyance reduction was greater at L1 than at L3 ($t = 3.91$, $p < 0.01$), regardless of treatment band or degree of treatment. This indicates that the spectral treatment is most effective in reducing annoyance when the overall sound level is within the range of 88 to 89 dB(A), peak value, and less effective at higher and lower levels.

Comparison of Individual Judgments and Overall Session Judgments

The mean of the 24 overall session responses was 101.29, while that of the annoyance responses to the 27 individual stimuli was 102.11, not significantly different ($t = 1.66$, $df = 23$).

DISCUSSION

The results of the present experiment lend support to the hypothesis that speech interference, at least in part, mediates annoyance responses to aircraft noise in a TV-viewing situation. Support derives from a comparison of the present results with predictions based on previous speech masking data (ref. 7). That is, the present results show that spectral treatments in the intermediate frequency range (800 Hz to 2 kHz) were more effective in reducing annoyance responses than the treatments at either the higher (4 kHz) or lower (315 Hz) frequency bands. Although the prediction that the frequency of the most effective treatment band would increase with a decrease in overall sound level was not confirmed by the data of the present study, the differences in effectiveness of treatment bands did decrease with decreases in overall sound level. Also, as predicted, the effectiveness of all treatment bands was decreased at the lowest overall sound level (83.9 to 85.2 dB(A)) where the speech masking would be expected to be the least.

The finding that the spectral treatments had less effect at relatively high (L1) and relatively low (L3) overall sound levels than at the intermediate level (L2) may have important implications for the relief to be expected by people who live at various distances from busy airports from noise treatments such as those used in the present study. The results suggest that noise treatments, such as the ones used in the present experiment, may provide the greatest relief at some intermediate distance from the airport and less relief closer in or further away.

This experiment demonstrates the viability of the approach used in this study in providing information regarding the relative effectiveness of various hypothetical jet engine noise treatments. That is, "notching" the spectrum in various specific parts to simulate possible real engine treatments and then presenting these sounds at several overall levels should allow future researchers to make valuable comparisons and establish trading relationships between overall level reductions and discrete reductions at specific parts of the noise spectrum.

Finally, the finding that noise level, expressed in terms of dB(A), dB(D), and PNdB were all similarly poor in ability to predict annoyance responses to aircraft noise in a TV-viewing situation suggests the need for further studies, using other aircraft types and different subject activities, with the aim of developing improved predictors of annoyance.

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Table 1. Noise Stimuli

Stimulus No.	Center Frequency of Treatment Band (Hz)	Band Reduction in dB	Treatment Designator	Degree of Treatment Designator	Overall Level Category	Peak Level		
						dB(A)	dB(D)	PNdB
1	Un-treated	--	T1	--	L1	91.8	99.5	10[illegible].0
2		--	T1	--	L2	89.1	96.6	102.0
3		--	T1	--	L3	85.3	92.8	98.1
4	315	5.5	T2	D1	L3	84.1	92.1	97.0
5		5.3	T2	D1	L2	88.5	96.4	101.5
6		5.7	T2	D1	L1	91.5	99.6	104.9
7		8.5	T3	D2	L1	91.5	99.5	104.6
8		8.3	T3	D2	L2	88.0	96.0	101.0
9		7.8	T3	D2	L3	83.9	92.0	96.8
10	800	6.3	T4	D1	L3	84.7	92.6	97.6
11		5.5	T4	D1	L2	88.9	96.7	101.8
12		5.0	T4	D1	L1	91.6	99.5	104.7
13		9.0	T5	D2	L1	91.5	99.4	104.6
14		10.0	T5	D2	L2	88.4	96.3	101.4
15		10.7	T5	D2	L3	84.6	92.4	97.3
16	1600	8.0	T6	D1	L3	84.8	92.4	97.6
17		7.7	T6	D1	L2	88.7	96.3	101.6
18		5.2	T6	D1	L1	91.7	99.5	104.7
19		7.2	T7	D2	L1	91.7	99.5	104.6
20		9.5	T7	D2	L2	88.7	96.3	101.5
21		9.0	T7	D2	L3	85.2	92.8	97.8
22	4000	5.2	T8	D1	L3	85.1	92.7	97.9
23		5.2	T8	D1	L2	88.9	96.6	101.8
24		3.8	T8	D1	L1	91.8	99.5	104.8
25		5.5	T9	D2	L1	91.8	99.5	104.8
26		7.0	T9	D2	L2	88.8	96.3	101.7
27		7.0	T9	D2	L3	84.9	92.5	97.7

TABLE 2. FRIEDMAN TWO-WAY ANALYSIS OF VARIANCE FOR CATEGORY RATINGS OF ANNOYANCE: TREATMENT EFFECTS.

OVERALL SOUND LEVEL	RANK SUMS OF EACH TREATMENT (R_j)									χ_r^2	P<
	T1	T2	T3	T4	T5	T6	T7	T8	T9		
L1	128.5	117.5	120.0	113.5	107.5	113.0	125.0	123.0	132.0	2.80	.95
L2	146.0	109.0	134.5	120.0	108.0	122.0	132.5	122.0	84.0	11.84	.20
L3	132.0	124.0	130.0	131.0	103.5	114.0	124.5	116.5	108.0	7.10	.70
COMBINED	406.5	350.5	384.5	364.5	319.0	349.0	382.0	361.5	322.0	10.25	.30

df=8

1. MEAN RANKS AF ANNOYANCE SCORES OBTAINED BY CATEGORY RATING FOR NINE TREATMENT CONDITIONS DO NOT DIFFER SIGNIFICANTLY.
2. APPROPRIATE ASSUMPTIONS CANNOT BE MADE ABOUT ADDITIVITY OF ORDINAL SCALE SCORES OR RANKS, HENCE, THERE ARE NO NONPARAMETRIC METHODS FOR TESTING INTERACTIONS.
3. T1 THROUGH T9 REFER TO THE SPECTRAL TREATMENTS SHOWN IN TABLE 1.

TABLE 3. FRIEDMAN TWO-WAY ANALYSIS OF VARIANCE FOR CATEGORY RATINGS OF ANNOYANCE: LEVEL EFFECTS.

SPECTRAL TREATMENT	RANK SUMS OF EACH OVERALL SOUND LEVEL (R_j)			χ_r^2	P<
	L 1	L 2	L 3		
T 1	64.5	49.5	29.5	23.70	0.001
T 2	64.5	48.5	31.0	23.40	0.001
T 3	65.0	49.5	30.0	27.64	0.001
T 4	62.5	47.5	34.0	16.94	0.001
T 5	66.0	47.5	30.5	26.28	0.001
T 6	65.0	48.0	31.0	24.0	0.001
T 7	65.0	50.0	29.0	27.25	0.001
T 8	69.0	45.5	27.5	28.15	0.001
T 9	70.0	39.5	34.5	30.77	0.001
COMBINED	591.5	425.5	277.0	221.20	0.001

df=2

1. MEAN RANKS OF ANNOYANCE SCORES OBTAINED BY CATEGORY RATINGS FOR THREE OVERALL SOUND LEVELS DIFFER SIGNIFICANTLY.

TABLE 4. Analysis of variance of scores for magnitude estimation of annoyance to untreated and various treated aircraft sounds.

Source of variation	df	SS	MS	F
Spectral treatment (T)	8	40909.51	5113.69	3.58***
Overall sound level (L)	2	553864.82	276932.41	193.92***
T x L	16	57940.07	3621.25	2.54**
Within-subgroups (w)	620	885390.00	1428.05	
Total	647	1538104.40		

**p < 0.01 ***p < 0.001

TABLE 5. Mean annoyance score for each stimulus condition (N=24)

Stimulus No.	Mean annoyance score
1	156.38
2	128.13
3	73.83
4	73.58
5	99.58
6	151.67
7	143.67
8	105.83
9	72.21
10	77.50
11	96.04
12	125.46
13	145.04
14	103.54
15	61.50
16	65.04
17	91.67
18	133.13
19	132.21
20	84.17
21	66.00
22	83.04
23	107.08
24	147.50
25	152.00
26	100.63
27	73.33

TABLE 6. Annoyance reduction(as measured by magnitude estimation) caused by two degrees of spectral treatment at four frequency bands with overall sound level as a parameter

Overall sound level	Spectral treatment		Annoyance reduction[1]	t
	Center frequency of treatment band (in Hz)	Degree of treatment (in dB)		
L_1	315	D_1	4.71	0.64
		D_2	12.71	0.54
	800	D_1	30.92	2.86**
		D_2	11.34	1.11
	1600	D_1	23.25	2.16*
		D_2	24.17	2.00
	4000	D_1	8.88	0.79
		D_2	4.38	0.47
L_2	315	D_1	28.55	3.09**
		D_2	22.30	1.92
	800	D_1	32.09	3.22**
		D_2	24.59	2.91**
	1600	D_1	36.46	4.58***
		D_2	43.96	7.57***
	4000	D_1	21.05	2.13*
		D_2	27.50	3.12**
L_3	315	D_1	0.25	0.55
		D_2	1.62	0.26
	800	D_1	-3.67	1.71
		D_2	12.33	2.24*
	1600	D_1	8.79	0.90
		D_2	7.83	1.26
	4000	D_1	-10.79	1.01
		D_2	0.50	0.11

1. Amount of annoyance reduction as indicated by a decrease in scores for magnitude estimation of annoyance to treated aircraft sounds, from the annoyance score for the untreated aircraft sound at that overall sound level. (Negative figure indicates annoyance increase.)

t test gives significance of difference between any given treatment condition and the baseline (untreated condition).

$*p < 0.05$ $**p < 0.01$ $***p < 0.001$

df=23 Two-tailed tests.

TABLE 7. Relative effectiveness in reducing annoyance by noise reduction treatments at four frequency bands.

Comparison between frequency bands[1] A : B	Difference in annoyance reduction[2]	t
1600 : 800	6.14	1.41
1600 : 315	12.39	4.83**
1600 : 4000	15.23	8.64***
800 : 315	6.24	1.39
800 : 4000	9.08	2.70*
315 : 4000	2.84	1.07

1. Comparison between frequency bands (in Hz), without regard to degree of spectral treatment and overall sound level.
2. Mean difference in amount of annoyance reduction, caused by spectral treatment, between frequency bands.

   Each figure indicates greater annoyance reduction at A than at B.

*p 0.05 **p 0.01 ***p 0.001

df=5 Two-tailed tests.

TABLE 8. Difference in annoyance level between overall sound levels at each degree of treatment and at each frequency band of spectral treatment (Summary of results of two-tailed t tests)

Treatment conditions (in Hz)		Comparison between overall sound levels A : B	Annoyance difference[1]	t
Untreated		$L_1 : L_2$	28.25	2.41*
		$L_1 : L_3$	82.55	8.16***
		$L_2 : L_3$	54.30	5.88***
315	D_1	$L_1 : L_2$	52.09	4.77***
		$L_1 : L_3$	78.09	8.24***
		$L_2 : L_3$	26.00	3.22**
	D_2	$L_1 : L_2$	37.84	3.43**
		$L_1 : L_3$	71.46	6.59***
		$L_2 : L_3$	33.62	3.82***
800	D_1	$L_1 : L_2$	29.42	4.72***
		$L_1 : L_3$	47.96	3.03**
		$L_2 : L_3$	18.54	3.02**
	D_2	$L_1 : L_2$	41.50	5.90***
		$L_1 : L_3$	83.54	7.35***
		$L_2 : L_3$	42.04	5.99***
1600	D_1	$L_1 : L_2$	41.46	3.91***
		$L_1 : L_3$	68.09	9.11***
		$L_2 : L_3$	26.63	3.41**
	D_2	$L_1 : L_2$	48.04	4.64***
		$L_1 : L_3$	66.21	7.32***
		$L_2 : L_3$	18.17	3.35**
4000	D_1	$L_1 : L_2$	40.42	4.12***
		$L_1 : L_3$	64.46	5.56***
		$L_2 : L_3$	24.04	2.39*
	D_2	$L_1 : L_2$	51.37	4.44***
		$L_1 : L_3$	78.67	7.27***
		$L_2 : L_3$	27.30	3.63**

1. Mean difference in annoyance level. Each figure indicates that the annoyance level is less under B than A.

df=23   *$p < 0.05$ **$p < 0.01$ ***$p < 0.001$

SIMULATED LIVING ROOM

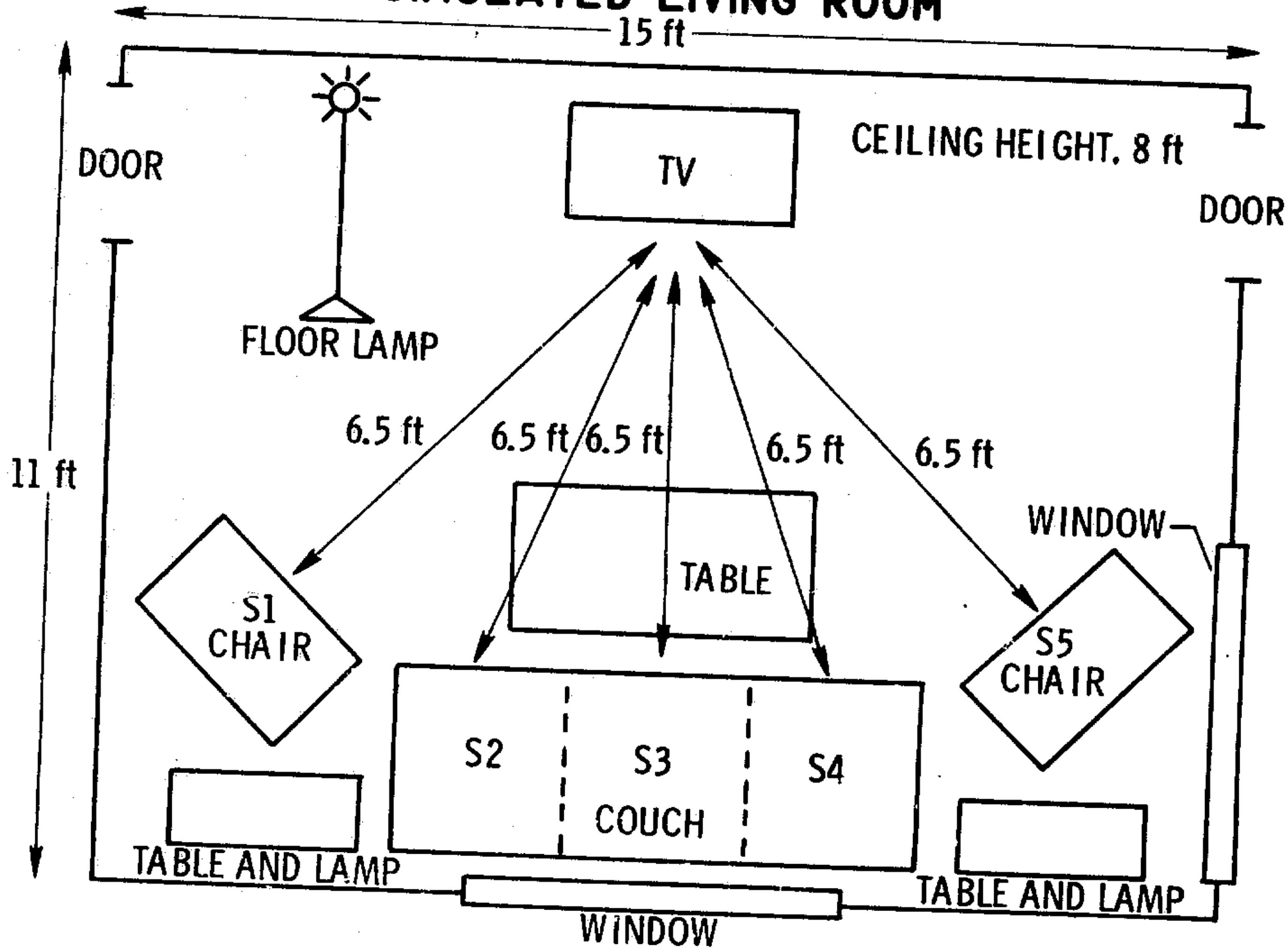


Figure 1

SYSTEM USED FOR SPECTRUM MODIFICATICATION

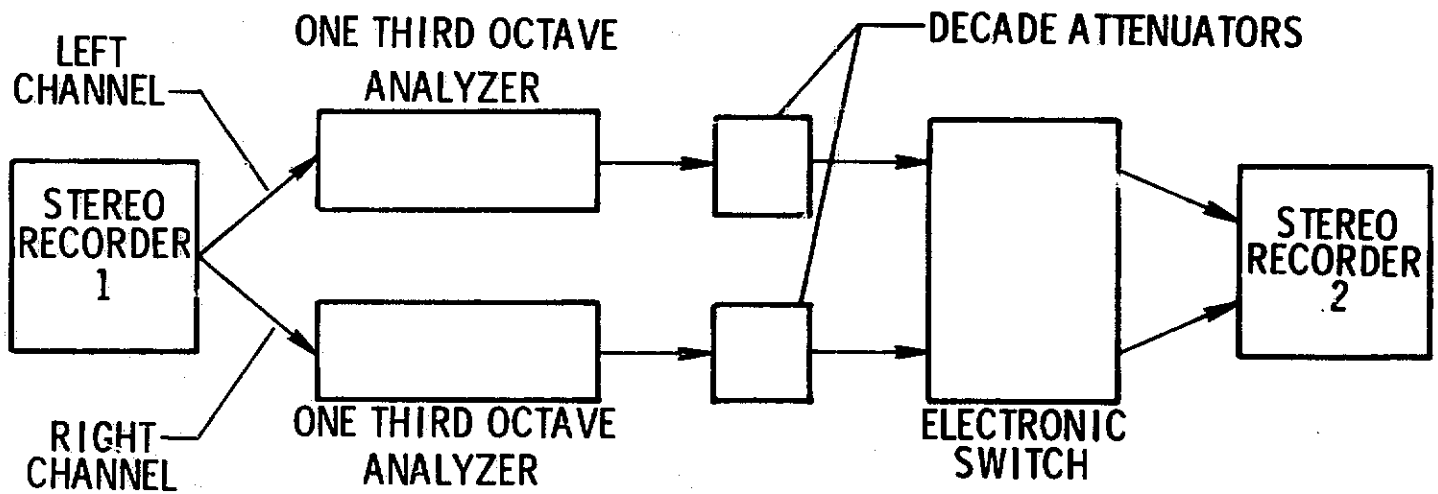


Figure 1(a)

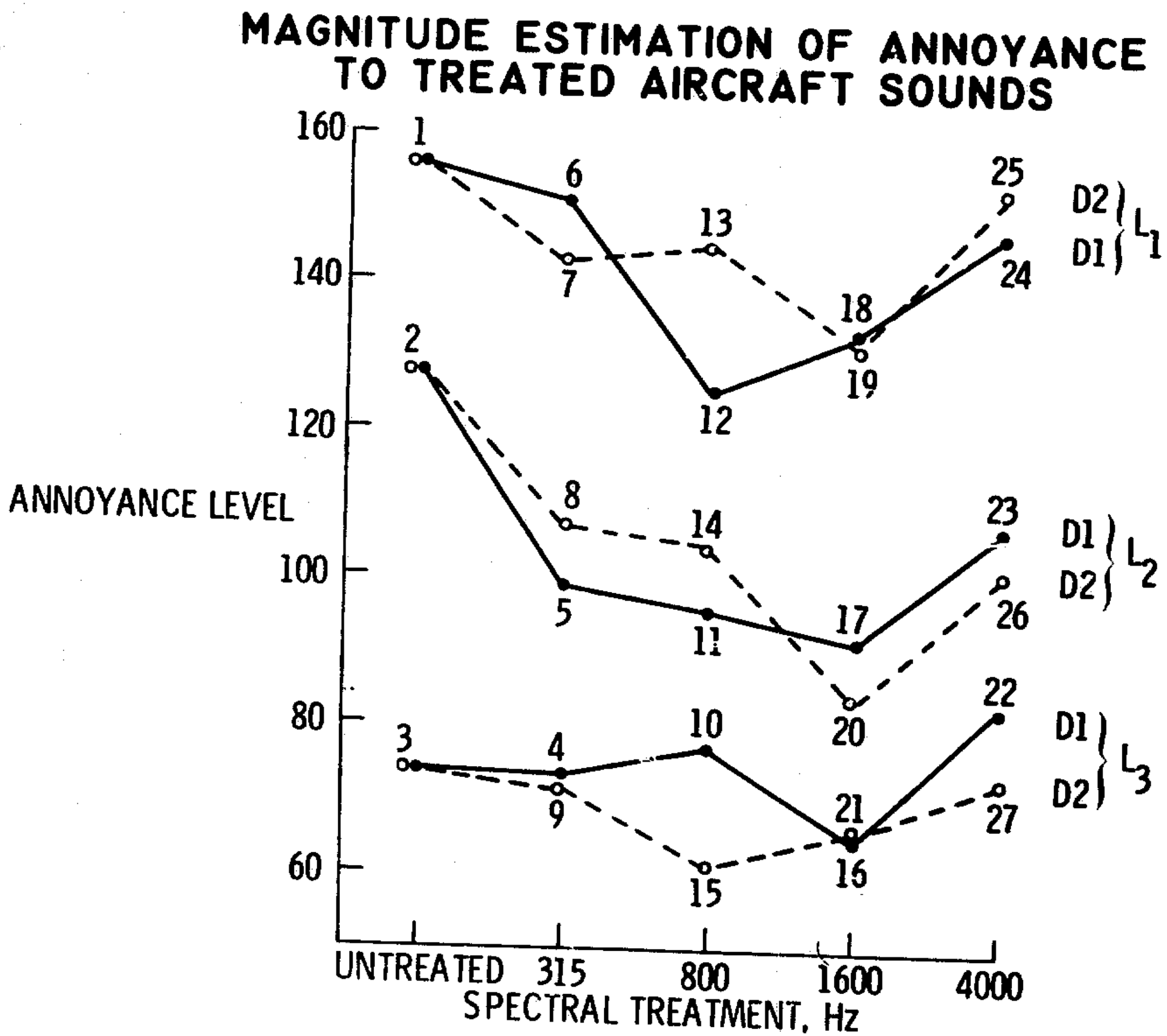

MAGNITUDE ESTIMATION OF ANNOYANCE TO TREATED AIRCRAFT SOUNDS
ANNOYANCE LEVEL
160
140
120
100
80
60
UNTREATED
315
800
1600
4000
SPECTRAL TREATMENT, Hz
D2
D1
L_1
D1
D2
L_2
D1
D2
L_3

Figure 2

ACOUSTIC SPECTRA FOR STIMULI 1, 2, AND 3

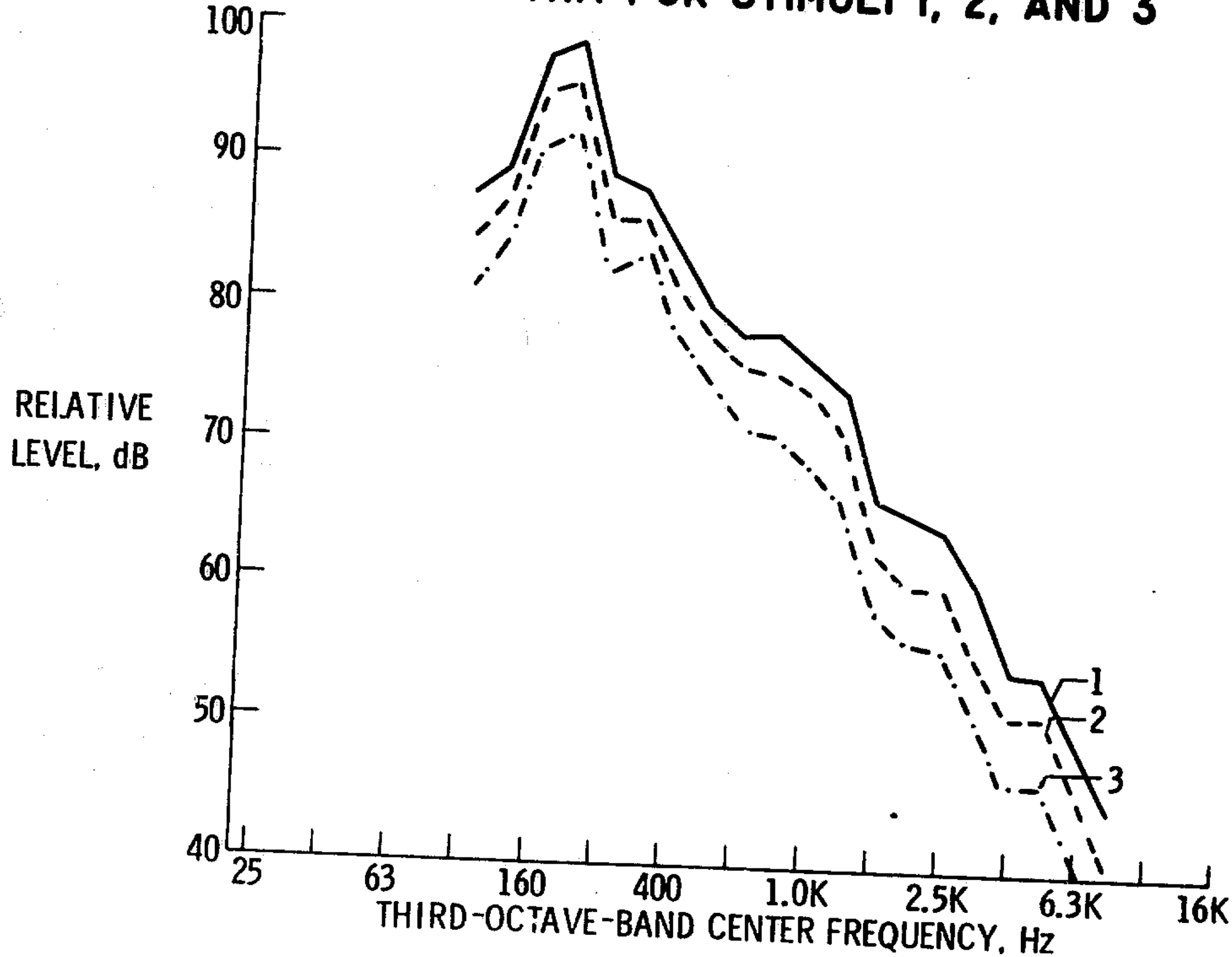


Figure 2(a)

SPECTRAL TREATMENT — ANNOYANCE REDUCTION RELATIONSHIP

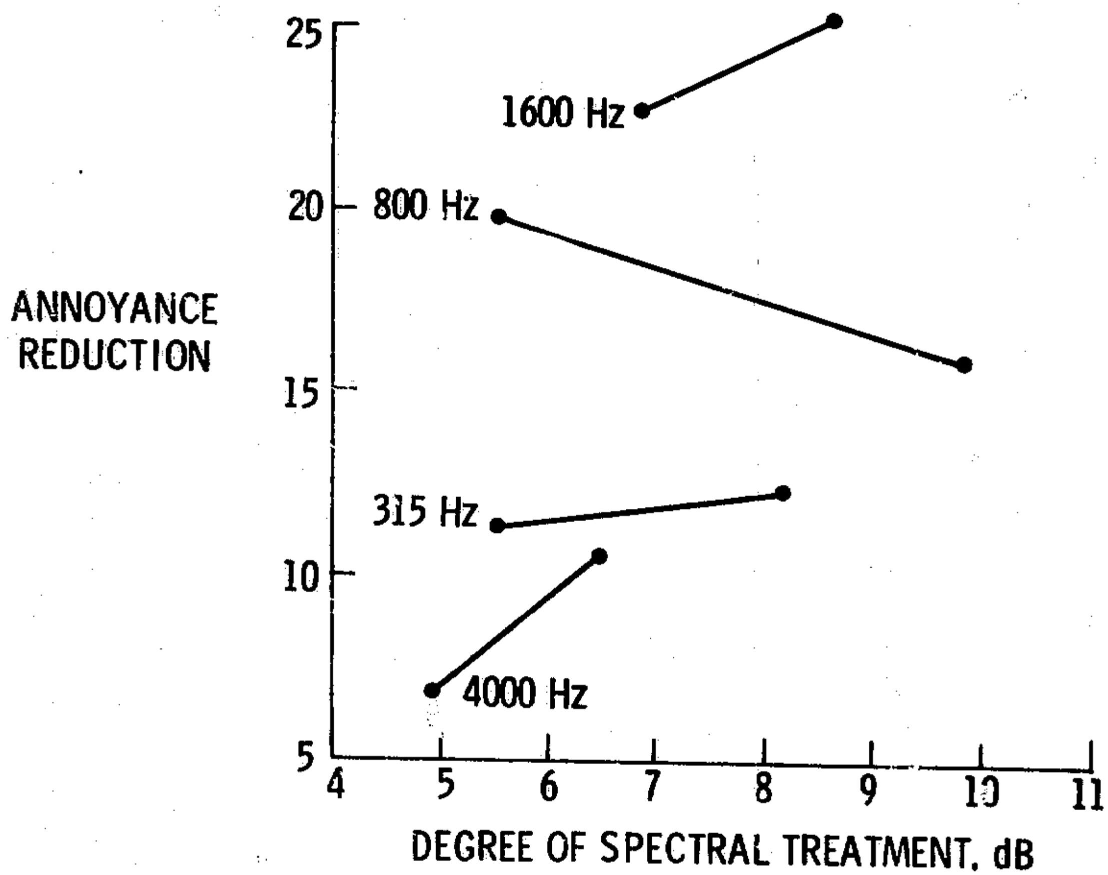
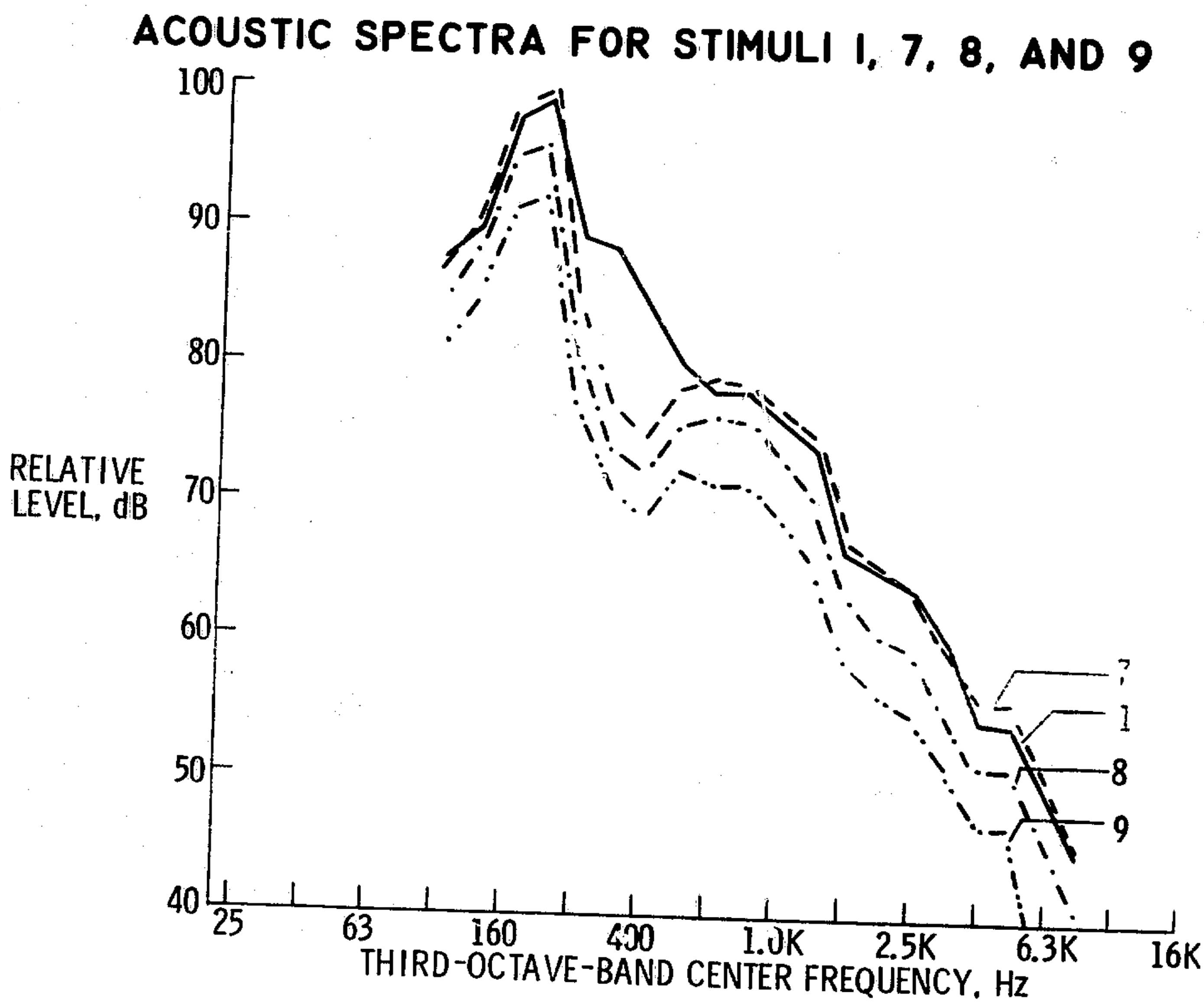


Figure 3



ACOUSTIC SPECTRA FOR STIMULI I, 7, 8, AND 9
RELATIVE LEVEL, dB
100
90
80
70
60
50
40
25
63
160
400
1.0K
2.5K
6.3K
16K
THIRD-OCTAVE-BAND CENTER FREQUENCY, Hz
7
1
8
9

Figure 3(a)

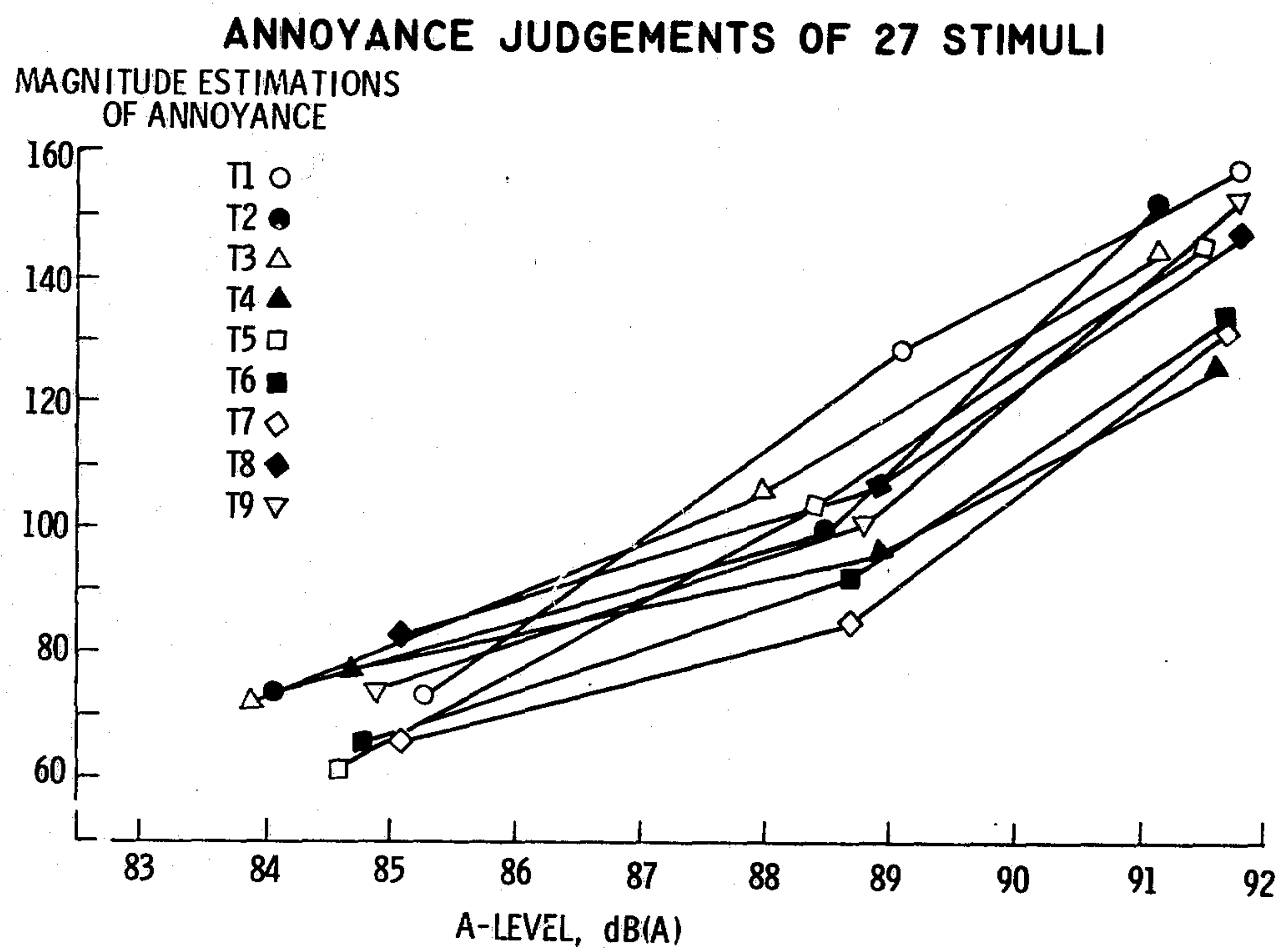

ANNOYANCE JUDGEMENTS OF 27 STIMULI
MAGNITUDE ESTIMATIONS
OF ANNOYANCE
160
140
120
100
80
60
T1
T2
T3
T4
T5
T6
T7
T8
T9
83
84
85
86
87
88
89
90
91
92
A-LEVEL, dB(A)

Figure 4

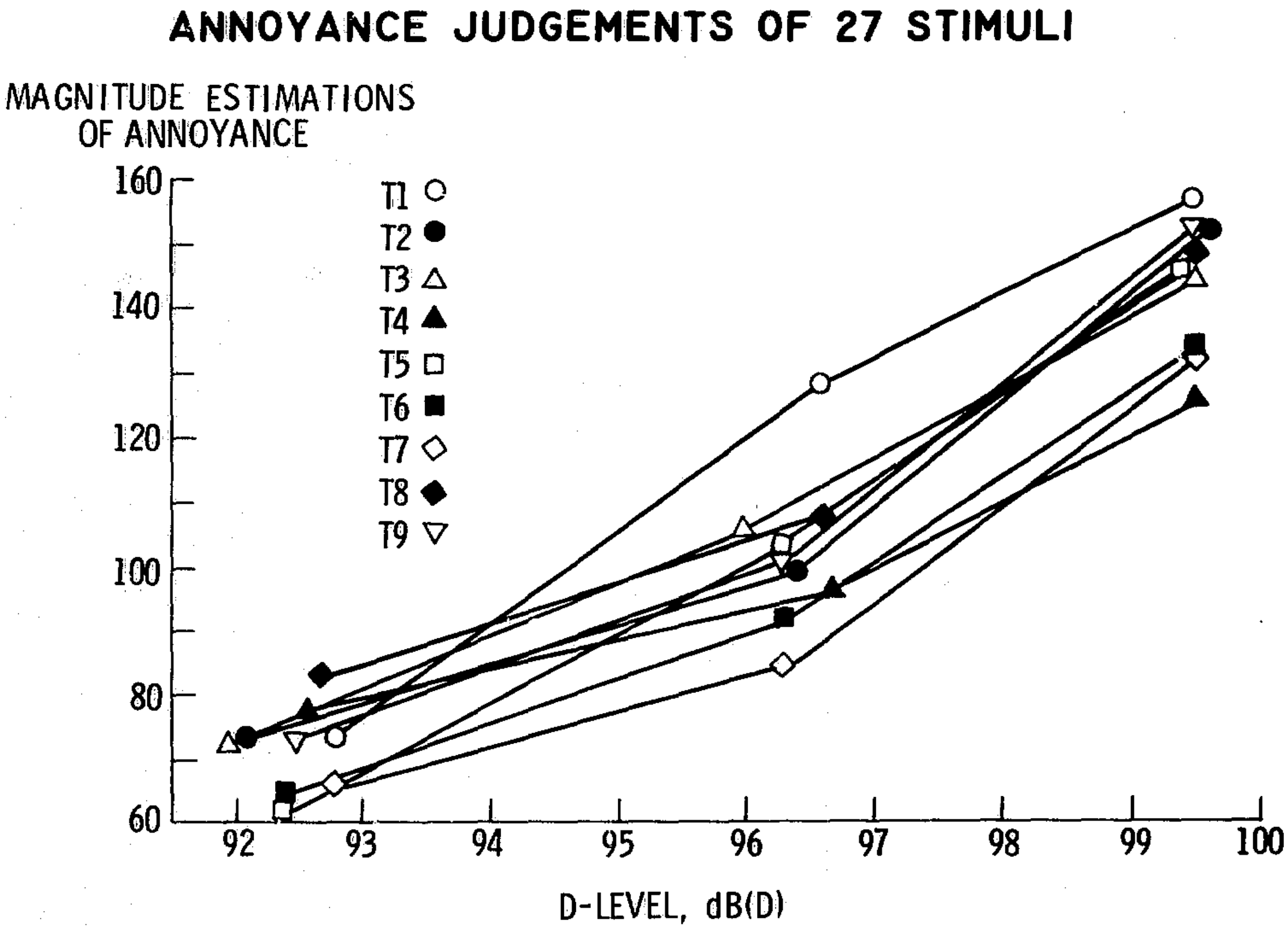

ANNOYANCE JUDGEMENTS OF 27 STIMULI
MAGNITUDE ESTIMATIONS OF ANNOYANCE
160
140
120
100
80
60
T1
T2
T3
T4
T5
T6
T7
T8
T9
92
93
94
95
96
97
98
99
100
D-LEVEL, dB(D)

Figure 5

ANNOYANCE JUDGEMENTS OF 27 STIMULI

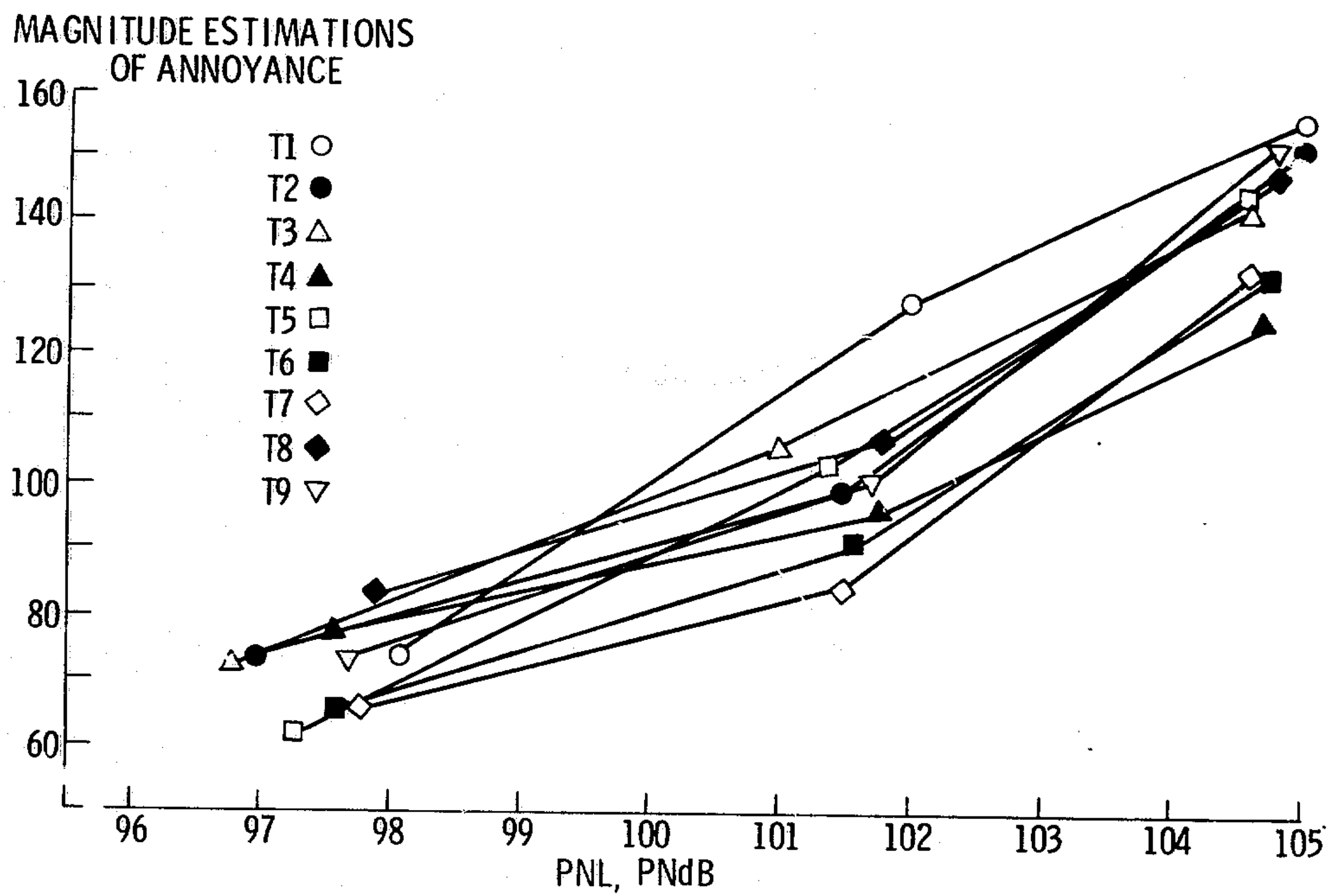


Figure 6

APPENDIX A

Synthesis of Aircraft Flyover Tapes

The objective in synthesizing the tapes used in this experiment was to create the illusion that aircraft with various hypothetical engine treatments were actually flying overhead. The technique used to create the illusion of overhead movement was an adaptation of a procedure originally proposed by Gunn in 1971 (ref. A-1). Basically, the movement effect can be achieved by controlling the relative levels of the right and left channels of a stereo audio system. First, a high quality monophonic audio recording of an aircraft flyover is made. The monophonic recorder is then connected, through a signal splitter, to the left and right channels of a stereo recorder. The recording level controls of the stereo recorder are adjusted such that the VU meters peak at about -3 dB when the monophonic recording is played. The level controls are then marked so that this setting can be easily reset. With the left channel level control set at zero and the right channel level control set at the mark for -3 dB maximum, the monophonic recording is started. As the right channel VU meter approaches -3 dB, the left channel level control is slowly turned to the mark corresponding to -3 dB. As soon as the peak has passed, the right channel level control is slowly turned to zero and the remainder of the flight finishes on the left channel. The stereo recording is then played back to insure a smooth and realistic transfer from one channel to the other. Several tries usually result in an acceptable simulation of movement. The process has been described as "ear-balling" and is probably more accurately termed as "art" than a "science." Perhaps more sophisticated computer controlled techniques will improve the procedure sometime in the near future. Now that the movement effect has been achieved, the next step is to simulate various hypothetical engine treatments.

Figure A-1 shows the system used for spectrum modification. Stereo recorder 1 plays its left and right channel outputs into separate 1/3-octave band analyzers. The output of each analyzer connects to the input of a decade attenuator. The output of each attenuator is connected to the input of a two channel electronic switch, whose outputs are, in turn, connected to the left and right input channels of tape recorder 2. Stimulus 1 was recorded as follows:

Output level controls on both tape recorders and on both spectrum shapers are set for -3 VU when the aircraft noise is at its peak. The controls on the spectrum shapers are set for flat response up to 6.3 kHz. All controls for higher frequencies are set for -40 dB. The electronic switch is set to the "A off" position and the rise/decay time control is set for 250 ms. The attenuators are set for zero attenuation. With initial conditions as stated, tape recorder 2 is started, followed by tape recorder 1 and finally the electronic switch is turned to the "A on" position. The untreated aircraft sound (with hiss suppression) has now been recorded. Stimuli 2 and 3 were recorded in similar fashion, only with the attenuators set to give the appropriate overall level attenuation. Stimuli 4, 5, and 6 were recorded in the same way only with the spectrum shapers adjusted to remove energy from the octave band centered at 315 Hz. Each time a stimulus is recorded, the electronic switch is turned to "A off" so that when tape recorder 1 is stopped, rewound, and restarted there will be no clicks recorded on the master tape on recorder 2, which is left running. The electronic switch has a rise/decay time of 250 ms so that it does not cause clicks when it is switched on and off.

Figure A-2 shows acoustic spectra for stimuli 1, 2, and 3 which represent the untreated commercial jet aircraft noise at three overall sound levels. Figure A-3 shows acoustic spectra for stimuli 7, 8, and 9 which represent the aircraft noise with spectral treatment at the octave band centered at 315 Hz. For comparison, the spectrum for stimulus 1 is also shown. These peak levels were recorded at subject position 3 within the test room.

REFERENCES

Gunn, W. J.: The Sound Comes From Up. dB, The Sound Engineering Magazine, vol. 5, no. 2, 1971, pp. 30-31.

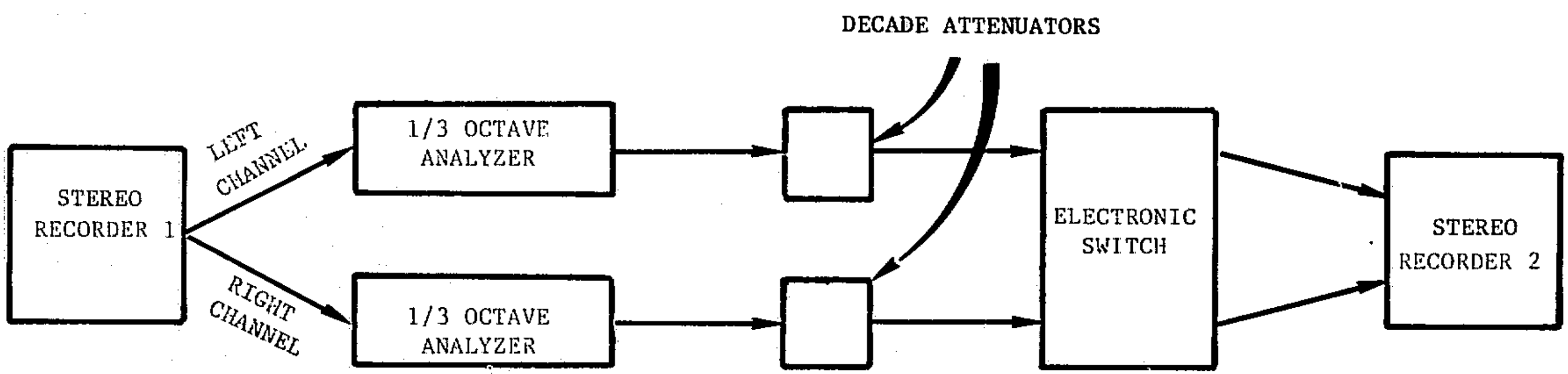


Figure **A-1**.- System used for spectrum modification

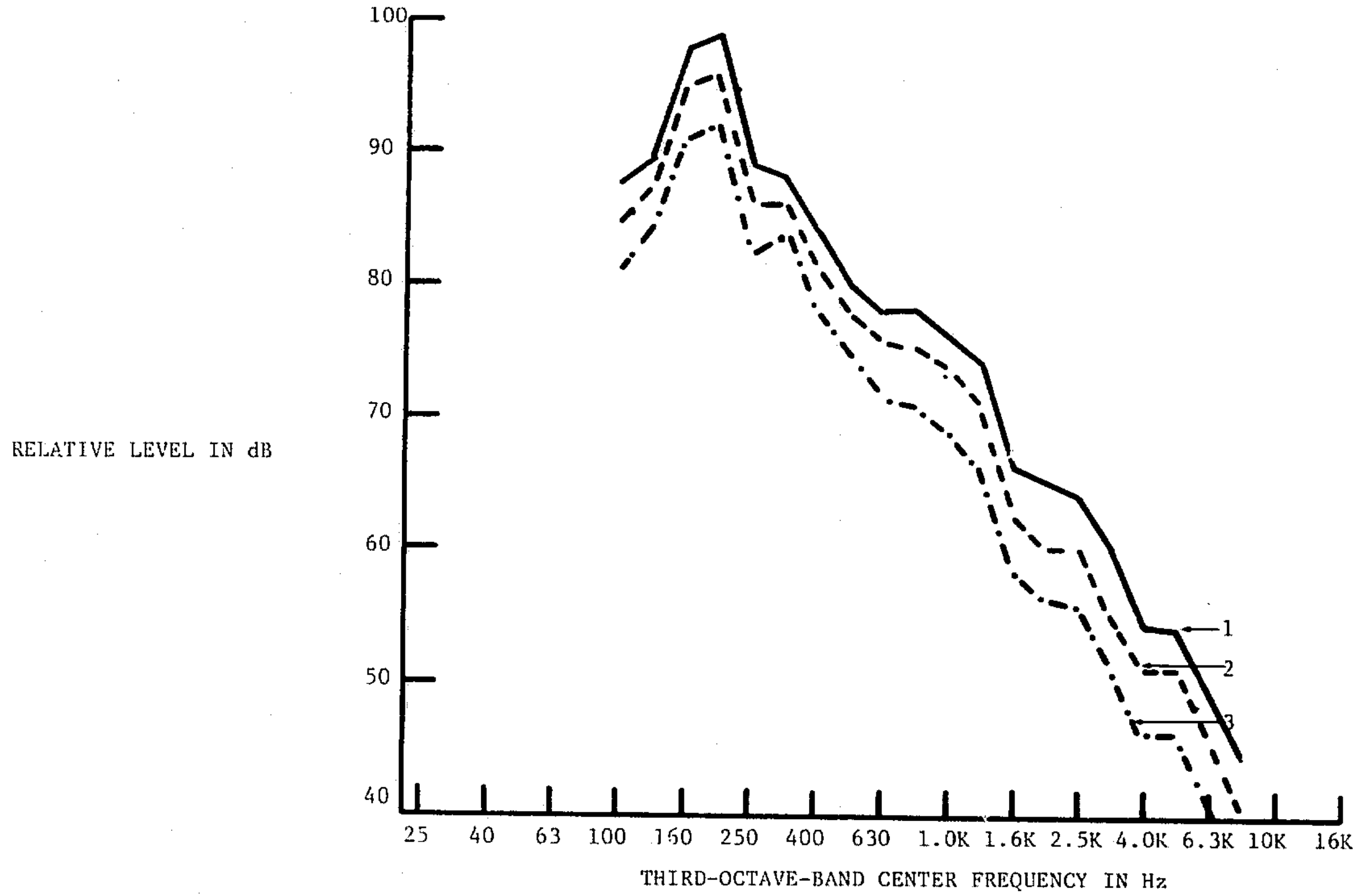


Figure **A-2.** Acoustic spectra for stimuli 1, 2, and 3.

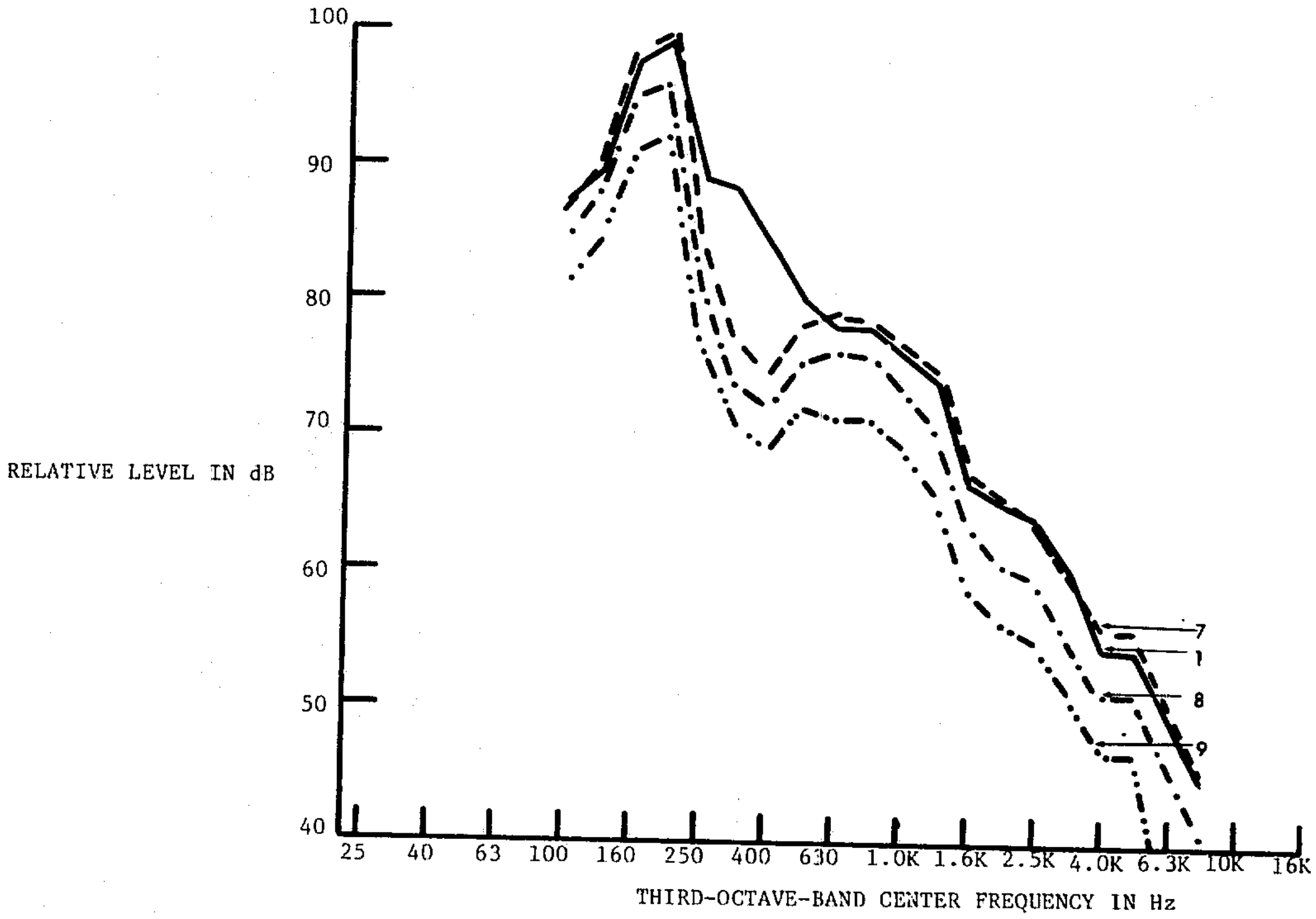


Figure **A-3**. Acoustic spectra for stimuli 1, 7, 8, and 9.

APPENDIX B

General Instructions

You are being asked to participate in an experiment which is concerned with how people feel about airplane noise. The purpose of this experiment is to obtain information about the relative effectiveness of various hypothetical noise reduction treatments of aircraft engine noises. Additionally, we hope to develop information regarding the extent to which we can generalize the results of our laboratory studies, performed with local residents, to other populations living in distant large city areas, such as New York.

The sounds which you will hear are no louder than those experienced on a daily basis by many people who live near large airports, and no undue physical or psychological stress is expected. If, however, you feel you would like to terminate your participation in the experiment, you may do so by simply leaving the test room.

If you would kindly sign the attached voluntary consent forms, it will signify that you understand the purpose for the research and the techniques to be used.

APPENDIX C

Voluntary Consent Form for Subjects for Human Response to Aircraft Noise

I understand the purpose of the research and the technique to be used, including my participation in the research, as explained to me by the Principal Investigator (or qualified designee).

I do voluntarily consent to participate as a subject in the human response to aircraft noise experiment to be conducted at NASA Langley Research Center on ______________________________.

(Date)

I understand that I may at any time withdraw from the experiment and that I am under no obligation to give reasons for withdrawal or to attend again for experimentation.

I undertake to obey the regulations of the laboratory and instructions of the Principal Investigator regarding my safety, subject only to my right to withdraw declared above.

I affirm that, to my knowledge, my state of health has not changed since the time at which I completed and signed the medical report form required for my participation as a test subject.

____

(Signature of Subject)

APPENDIX D

Voluntary Consent Form for Recording of Subjects' Responses to Aircraft Noise

I understand that AUDIO/VIDEO recordings are to be made of my response to the AIRCRAFT NOISE experiment to be conducted at NASA Langley Research Center on ______________________________, and that these recordings are to
(Date)

be held in strictest confidence.

I have been informed of the purpose of such recordings and do voluntarily consent to their use.

I further understand that I may withdraw my approval of such recordings at any time before or during the actual recording.

____
(Signature of Subject)

APPENDIX E

Instructions for Category Rating

We are trying to assess how people respond to the sound of aircraft. They do not bother some people at all, while other people find the sounds of aircraft annoying.

I am going to play you a series of aircraft sounds and I want you to rate the annoyance of each one on a scale of numbers from 1 to 9, where the number 1 represents the minimum annoyance and the number 9 represents the maximum annoyance.

(The experimenter distributes data sheets)

Please print your name, date, and time on the top of the sheet. Record your response to each aircraft sound on the data sheet and remember that we want your response independent of what the other person may indicate on his or her response sheet. In order to supply some context to this experiment, I will turn on the television for you to watch.

(The experimenter turns on the television and adjusts the audio to a level which the subjects agree to be comfortable (within 45 to 51 dB(A). The channel was selected by the experimenter.)

Here are some of the extremes you will hear during the session.

(The experimenter plays aircraft sounds 1 and 3)

There are no right or wrong answers. We just want your opinion about these sounds. In order to help you keep track of the sounds, I will announce over the intercom the number of every fifth sound. In this way, you can get back in step if you have missed a response. Are there any questions?

(The experimenter leaves the test room and the series of aircraft sounds is begun. After all 27 sounds have been presented, the experimenter reenters the test room and announces ...).

This completes this series of aircraft sounds. How annoying, on the whole, has this series been? Please assign a number to the annoyance of this series as a whole, using the same scale from 1 to 9.

APPENDIX E

DATA SHEET

FOR

CATEGORY RATING

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	26	27

OVERALL SESSION

9	Maximum Annoyance
8	
7	
6	
5	
4	
3	
2	
1	Minimum Annoyance

APPENDIX F

Instructions for Magnitude Estimation

In this experiment, I will be asking you to make certain numerical judgments. First, for practice, I will show you how it is that I want you to make these judgments. I will show you pieces of string of varying lengths. I want you to call the length of the first string 100. That will be your standard. If the second string looks to be twice as long as the first, call it 200. If it looks to be a third as long, call it 33 or 35. If it looks 10 times as long, call it 1,000. Do you have any questions? (The experimenter then presents the standard string to the subjects.)

This first piece of string is your standard. This is the one you call 100. Here is the next one. What number do you call it? (The subjects respond.) Very good.

(The experimenter continues with as many stimuli as he feels are needed to insure that the subjects understand the procedure.)

Now we are going to turn to our real problem. We are trying to assess how people respond to the sound of aircraft. They do not bother some people at all, while other people find the sounds of aircraft annoying. I am going to play a series of aircraft sounds and I want you to make judgments about how annoying they are using the same kind of scale you used to judge how long the strings were. The first plane you hear will be given the arbitrary annoyance rating of 100. That will be your standard. In order to supply some context to this experiment, I will turn on the TV for you to watch.

(The experimenter turns on the television and adjusts the audio to a level which the subjects agree to be comfortable; in the range of 45 to 51 dB(A). The channel is selected by the experimenter.)

Here is the first plane.

(The experimenter plays stimulus number 2.)

Remember, that flight is your standard. It has an annoyance rating of 100. I am going to play it again. Here it is.

(The experimenter plays stimulus number 2.)

Again, that sound has a rating of 100. If the next sound is more annoying, give it a bigger number. If it is less annoying, give it a smaller number. Just be sure to make the numbers proportional to the annoyance.

(The experimenter distributes the data sheets.)

There will be 30 flyovers. Please indicate, on the data sheet, how annoying you think the airplane noises are and remember that we want your response independent of what the other person may indicate on his or her response sheet. There are no right or wrong answers. We only want your opinion about the airplane sounds. Notice on your data sheet that we are repeating the standard sound on the 10th, 20th, and 30th trials and that the annoyance rating of 100 is already filled in. Therefore, it will not be necessary for you to write anything down on those trials. In order to help you keep track of the sounds, I will announce over the intercom the number of every 5th flight. Are there any questions?

(The experimenter leaves the test room and the series of 30 aircraft sounds is begun. After all 30 sounds have been played, the experimenter reenters the test room.)

This completes this series of aircraft sounds. How annoying, on the whole, has this series been, relative to the standard sound which was 100? Please assign a number to the annoyance of this series as a whole.

APPENDIX F

DATA SHEET FOR MAGNITUDE ESTIMATION

STANDARD IS 100

Flight	Rating
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	Std. = 100

Flight	Rating
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	Std. = 100

Flight	Rating
21	
22	
23	
24	
25	
26	
27	
28	
29	
30	Std. = 100

Overall annoyance rating of session