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SUMMARY

A laboratory experiment was conducted to determine the effects of variations in the rate and magnitude of sound level fluctuations on the annoyance caused by aircraft-flyover noise. The effects of tonal content, noise duration, and sound pressure level on annoyance were also studied. The basic test stimuli consisted of 32 synthesized aircraft-flyover noise stimuli representing the factorial combinations of 2 tone conditions, 2 noise durations, 2 sound pressure levels, 2 level fluctuation rates, and 2 level fluctuation magnitudes. Each noise was presented twice for a total of 64 test stimuli. The 32 unique stimuli were based on 4 synthesized aircraft noises in which tonal content and noise duration were individually controlled by the use of a newly developed aircraft-noise synthesis system. The appropriate sound level fluctuations were introduced into the four synthesized noises by using a fluctuation apparatus consisting of a random noise generator and a signal multiplier. Thirty-two test subjects made annoyance judgments of the test stimuli in a subjective listening test facility simulating an outdoor acoustic environment.

Statistical analyses of the subjective judgments were used to determine the effects of level fluctuation rate, level fluctuation magnitude, and the other noise characteristics on annoyance. The impact of the addition of tone corrections and noise duration corrections to several noise rating scales was also assessed.

Variations in the rate and magnitude of level fluctuations were found to have little, if any, effect on annoyance. Tonal content, noise duration, sound pressure level, and the interaction of tonal content with sound pressure level were found to affect the judged annoyance significantly. The addition of tone corrections and/or duration corrections significantly improved the annoyance prediction ability of noise rating scales.

INTRODUCTION

In recent years, much attention has been directed toward determining the effects of various aircraft noise characteristics on annoyance (e.g., refs. 1 to 5). A primary objective of such research is the development of a procedure to quantify the important noise characteristics that need to be incorporated into a noise rating scale. The primary noise characteristics that have been investigated include sound pressure level, frequency content, noise duration, and Doppler shift. A noise characteristic for which no systematic, subjective information is available, and one which may need to be incorporated into noise rating scales, is sound level fluctuations within the aircraft noise. The term "level fluctuations" is best explained by the illustrations in figure 1. Figure 1(a) is a theoretical aircraft-flyover noise time history in which no level fluctuations occur. The sound pressure level increases with an always positive slope until the peak value is reached; it then decreases with an always negative slope. The time history in figure 1(b) is a more realistic case; the slope of the sound pressure level curve alternates from positive to negative for short durations, while over the long term, the sound pressure level still increases to a peak value before decreasing to the ambient level. These audible fluctuations in level occur in varying degrees in almost all aircraft-flyover noises.

The purpose of this study was to determine the effects of variations in the rate and magnitude of these level fluctuations on the annoyance caused by aircraft-flyover noise. In order to maximize the application of the results to various types of aircraft noise, level fluctuations were studied using aircraft noises having different tonal content, noise durations, and sound pressure levels. To insure that the effects on annoyance of different noise characteristics could be separated, a newly developed aircraft-noise synthesis system, capable of individuallly controlling spectral content, noise duration, aircraft velocity, and sound pressure level, was used to generate the test stimuli.

SYMBOLS AND ABBREVIATIONS

The following rating scales have been used in the acoustical analysis of the aircraft noises used in this study. Additional descriptive information concerning frequency weightings and computational procedures can be found in reference 6.

L_A A-weighted sound pressure level, based on 1/3-octave bands from 50 Hz to 10 kHz, dB

L_D D-weighted sound pressure level, based on 1/3-octave bands from 50 Hz to 10 kHz, dB

PL perceived level, according to Stevens Mark VII procedure, PLdB

PNL perceived noise level, PNdB

The addition of the capital letter "T" at the end of the abbreviations of the rating scales (e.g., L_DT and PNLT) denotes the addition of a tone correction to the calculation procedure. The tone correction used is the same as that incorporated in the effective perceived noise level calculation (FAR 36 procedure, ref. 7) and is based on the tonal frequency and the amount that the tone exceeds the noise in the adjacent 1/3-octave bands. The use of the capital letter "I" preceding the abbreviations of the rating scales (e.g., IL_AT and IPL) denotes the addition of a noise duration correction to the calculation procedure. This correction procedure is the same as that incorporated in the effective perceived noise level calculation and has a magnitude of 3 dB per doubling of effective duration. Effective duration is defined as the duration of a continuous-level signal with energy equal to the energy contained in the flyover-noise signal. The energy contained in the flyover signal is based on the numerical integration of energy between the first and last points at which the flyover signal is 10 dB down from the maximum sound level.

Other abbreviations and symbols used herein are as follows:

FAR Federal Aviation Regulation

r_L low-level fluctuation rate

r_H high-level fluctuation rate

m_L low-level fluctuation magnitude

m_H high-level fluctuation magnitude

SPL sound pressure level, dB

EXPERIMENTAL METHOD

Test Facility

The exterior effects room of the Langley aircraft noise reduction laboratory (see fig. 2) was used as the test facility in the experiment. This room has a volume of approximately 340 m^3 and a reverberation time of approximately 0.5 sec at 1000 Hz. The subjects pictured in figure 2 occupy the seats used during testing by each group of four subjects. The monophonic recordings of the aircraft-noise stimuli were played on a studio-quality tape recorder and presented to the subjects by means of four overhead loudspeakers. A commercially available noise reduction system which provided a nominal 30-dB increase in signal-to-noise ratio was used to reduce tape hiss to inaudible levels.

Test Subjects

Thirty-two subjects were randomly selected from a pool of local residents with a wide range of socioeconomic backgrounds and were paid to participate in the experiment. All subjects had previously participated in experiments related to aircraft noise. However, none of the subjects had participated in a previous study (ref. 5) which used aircraft-noise stimuli similar to those used in this study. All test subjects were given audiograms prior to the experiment to verify normal hearing with 20 dB (ref. 8). Table I gives the sex and age data for the subjects.

Subjective Evaluations

A unipolar, 10-point (from 0 to 9) continuous-type category scale was used by the subjects to record their subjective responses to the test stimuli. The end points of the scale were labeled "Not at all Annoying" and "Extremely Annoying." The term "ANNOYING" was defined in the subject instructions as "UNWANTED, OBJECTIONABLE, DISTURBING, or UNPLEASANT." To prevent instruction bias, a short tone or beep audio cue was placed at the end of each test stimulus and the subjects were instructed to wait until they heard the audio cue before making their annoyance judgments. No mention of any noise characteristic was made in the instructions given the subjects. The purpose of this method was to insure that the subjects' judgments were based on the entire stimulus noise but were not biased by the mention of any specific noise characteristic such as noise duration or level fluctuation. The exact subject instructions are reproduced in the appendix.

Noise Stimuli

The noise stimuli used in this study consisted of loudspeaker-reproduced tape recordings of 32 aircraft-flyover noises representing the factorial combinations of 2 tone conditions, 2 noise durations, 2 sound pressure levels, 2 level fluctuation rates, and 2 level fluctuation magnitudes. The stimuli were based on synthesized aircraft noises in which the noise characteristics were individually controlled through the use of a newly developed aircraft-noise synthesis system (ref. 5). In generating aircraft noises, the synthesis system takes into account the time-varying aircraft position, specified broadband and narrowband frequency components, Doppler shift, directivity, and atmospheric effects. Hence, independent variation of tonal content and noise duration is possible while holding the broadband spectral content constant.

In order to prepare the noise stimuli for this study, the synthesis system was used to generate four synthesized aircraft noises, one for each of the factorial combinations of two tone conditions and two noise durations. The broadband spectral content of all four of the synthesized noises was similar to that of a 727 airplane departure. One of the two tone conditions consisted of the broadband noise with no tonal components. The other tone condition consisted of the broadband noise with the addition of strong tonal components centered at 1100 Hz and 2200 Hz. The aircraft velocity was set at a constant 80 m/sec while the altitude was varied to obtain the two desired noise durations. These combinations of velocity and altitude resulted in two Doppler shift patterns, one for each noise duration. However, as reference 5 indicates, this difference in Doppler shift has no significant effect on annoyance. Based on the A-weighted sound pressure level, the 10-dB down noise durations were 10 and 20 sec. The 1/3-octave-band spectra and the time histories of the four synthesized noises having the different combinations of these tone and duration conditions are shown in figures 3 and 4, respectively. The time histories of these noises were fairly smooth curves with few fluctuations.

The desired level fluctuations were introduced into the time histories using the apparatus shown in figure 5. A repeatable random-noise signal having the appropriate fluctuation magnitude and rate was multiplied with the synthesized flyover-noise signal to obtain a flyover-noise stimulus with fluctuating level. The factorial combinations of two level fluctuation rates r_L and r_H and two level fluctuation magnitudes m_L and m_H resulted in the introduction of four different fluctuation patterns into each of the four synthesized noises. The four fluctuation patterns, as applied to pink noise, are presented in figure 6. The time histories of the 16 noises representing the factorial combinations of 2 tone conditions, 2 noise durations, 2 level fluctuation rates, and 2 level fluctuation magnitudes are shown in figure 7. Replication of these 16 noises at each of 2 sound pressure levels comprised the set of 32 unique noise stimuli.

Noise Presentation Order

Four tape recordings of 16 stimuli each were prepared for presentation to the subjects. Tapes III and IV contained the same stimuli as tapes I and II, but in reverse order. The order of the stimuli on each tape is given in table II. The particular order of the noise stimuli on each tape was based on random selection from the 32 noises with 2 constraints providing some measure of balance. The first constraint was that each of the two tone conditions, two noise durations, two sound pressure levels, two level fluctuation rates, and two level fluctuation magnitudes should occur an equal number of times on each tape. The second constraint was that none of these conditions should occur three times in a row on a tape. A period of 6 sec was provided between stimuli for the subjects to make and record their judgments.

All four tapes were presented to each of the eight groups of four subjects so that each subject judged each unique noise stimulus twice. As shown in table III, the four tapes were presented to each subject group in a different order. Each tape required approximately 15 min for playback and served as a test session for the subjects.

Procedure

Upon arrival at the laboratory, the subject groups were seated in a conference room and given a set of instruction sheets, a consent form, a practice scoring sheet, and a set of scoring sheets. Copies of these items are shown in the appendix. After reading the instructions and completing the consent form, the subjects were given a brief verbal explanation of the scoring sheets and were asked if they had any questions about the test. The subjects were then taken into the test facility and randomly assigned seat locations. Three practice stimuli, listed in table II, were presented to the subjects while the test conductor remained in the test facility. In order for the subjects to gain experience in scoring the sounds, they were instructed to make and record judgments of the practice stimuli. After asking again for any questions about the test, the test conductor left the facility and the first of four test sessions began. After the conclusion of each 15-min session, the test conductor reentered the test facility and issued new scoring sheets for the next session. Between the second and third sessions, the subjects were given a 15-min rest period outside the test facility.

Acoustic Data Reduction

The stimuli were measured, with no subjects present, at the average head position of the subject pictured in figure 2 in the first row to the reader's right. A 1/3-octave-band analysis of the measurements (analog filtering with digital sampling, root-mean-square detection, and integration) was used to provide time histories for computations required by the rating scales. The frequency range of the analysis was 50 Hz to 10 kHz; the rating scale values were calculated from the measured 1/3-octave-band levels.

Maximum levels, duration-corrected levels, tone-corrected levels, and duration- and tone-corrected levels were obtained for each of the 64 noises (32 unique stimuli presented to each subject twice) for each rating scale. Table IV lists the average value, over both occurrences, of the levels of the stimuli. The levels were calculated as specified in "Symbols and Abbreviations."

RESULTS AND DISCUSSION

Reliability of Subjective Judgments

An initial consideration in subjective response studies is the reliability of the subjective judgments given by the test subjects. Because in this study the last 32 stimuli judged by each subject were a repetition of the first 32 stimuli in reverse order, it was possible to obtain a measure of the reliability of the subjective judgments. Regression analyses were performed on these repeated judgments in two ways. The first was a regression of each individual subject's second judgment (dependent variable) on his first judgment (independent variable) for each stimulus. The second was a regression of the mean (over subjects) of the second judgments on the mean of the first judgments for each of the 32 stimuli. The Pearson product-moment correlation coefficients for the two regression analyses were 0.773 and 0.990, respectively. These results indicate that the subjective judgments were highly reliable.

Effects of Noise Characteristics

Analysis of variance.- In order to determine which noise characteristics affected the subjective annoyance responses significantly, an analysis of variance was computed. The analysis of variance was a mixed model (ref. 9) in which tonal content, noise duration, sound pressure level, fluctuation rate, and fluctuation magnitude were considered fixed, and subjects and replications were considered random. There were 64 judgments for each of the 32 unique stimuli. The results of the analysis of variance are given in table V. These results indicate that of the five fixed main parameters, four were significant (0.05 level): tonal content, noise duration, sound pressure level, and fluctuation magnitude. Fluctuation rate was not significant. Only four of the interactions between the fixed effects were significant: (1) the interaction of tonal content and level; (2) the interaction of tonal content, fluctuation rate, and fluctuation magnitude; (3) the interaction of tonal content, noise duration, fluctuation rate, and fluctuation magnitude; and (4) the interaction of tonal content, level, fluctuation rate, and fluctuation magnitude. The random effects of replications and subjects were both significant.

To obtain a measure of the relative importance of the significant main effects and interactions, the variance (expected-mean-square method, ref. 9) for each main effect and interaction was calculated and expressed as a percentage of the total variance. The percentages for each main effect and for the interactions of interest are given in table VI. The only noise characteristics which accounted for more than 1 percent of the total variance were the main effects of sound pressure level (86.45 percent), noise duration (3.54 percent), and tonal content (2.57 percent) and the interaction of tonal content with level (1.13 percent). Fluctuation magnitude and fluctuation rate each accounted for less than 0.1 percent of the total variance. Each of the three- and four-way interactions, indicated as significant by the analysis of variance, accounted for less than 0.4 percent of the total variance. The effects of these noise characteristics are discussed separately in the following paragraphs.

Fluctuation rate and fluctuation magnitude.- The effects of fluctuation rate and fluctuation magnitude on annoyance are shown in figure 8. The figure illustrates the relationship between the mean annoyance rating and the fluctuation rate for each of the fluctuation magnitude conditions. Mean annoyance rating is the average of the subjective annoyance judgments of all the stimuli having the combination of parameters specified. In this case, it is the average across tonal content, noise duration, level, and replications. Figure 8 indicates that fluctuation rate has no effect on annoyance and that the high-fluctuation-magnitude condition is only slightly more annoying than the low-fluctuation-magnitude condition. These trends and the associated low values of explained variance from table VI show that neither fluctuation rate nor fluctuation magnitude has a major impact on subjective annoyance response to aircraft noise. Consequently, there is no indication of a need to include these parameters in a noise rating scale.

Tonal content and sound pressure level.- The effects of tonal content and sound pressure level on annoyance are shown in figure 9. The figure illustrates the relationship between the mean annoyance rating and L_A for stimuli without tones and stimuli with tones. Consistent with previous research (e.g., refs. 1, 2, and 5), the noises with tones are more annoying than the noises without tones, and annoyance increases as the sound pressure level increases. This trend and the associated high value of explained variance from table VI clearly indicate the need for the inclusion of tone corrections in noise rating scales. An additional result that is of interest is the significant interaction of tonal content with sound pressure level. The difference in annoyance between stimuli with tones and stimuli without tones decreased as the level of the stimuli increased. This finding is consistent with results reported in a previous study (ref. 5). However, since both studies used the same basic stimuli and since both had a limited number of test conditions, further study of this interaction is needed to verify its existence and to determine its importance as a parameter in noise-rating-scale calculations.

Noise duration and sound pressure level.- Figure 10 illustrates the effects of noise duration and sound pressure level on annoyance. The figure shows the relationship between the mean annoyance rating and L_A for both duration conditions. As the figure indicates, increased noise duration causes increased annoyance, and increased sound pressure level causes increased annoyance. No significant interaction of duration with any of the parameters in the experiment design was found. These results agree with the duration findings reported in reference 5. The trends in figure 10 and the associated high value of explained variance from table VI clearly indicate the need for the inclusion of noise duration corrections in noise rating scales.

Three- and four-factor interactions. Three additional interactions were found to be significant by the analysis of variance: (1) the interaction of tonal content, fluctuation rate, and fluctuation magnitude; (2) the interaction of tonal content, noise duration, fluctuation rate, and fluctuation magnitude; and (3) the interaction of tonal content, level, fluctuation rate, and fluctuation magnitude. Each of these interactions contributed less than 0.4 percent of the total variance. None of the interactions had a large overall effect on annoyance, nor were any consistent interaction trends apparent in the data. Therefore, on the basis of these results and consideration of the limited number of test conditions, it is not possible to say with certainty that these interactions have real effects on annoyance. Consequently, there is no indication of a need to include these interactions in a noise rating scale.

Rating Scale Corrections

The need for the addition of tone and duration corrections to the noise rating scales is clearly indicated by the results discussed in the previous sections. Regression analyses were used to determine the effect of these corrections on the predictive ability of the rating scales. Linear regressions of the mean subjective judgments on the uncorrected levels, tone-corrected levels, duration-corrected levels, and tone- and duration-corrected levels of each of the rating scale calculation procedures, L_A, L_D, PNL, and PL, were performed. The mean subjective judgments are the average of individual subjective responses across subjects for each of the 64 noises presented. Table VII presents the results of these regressions for each of the calculation procedures. The four correlation coefficients based on a given calculation procedure were compared by using a two-tailed t-test for the significance of difference (0.01 level) between correlation coefficients when samples are not independent (ref. 10). The results of these analyses showed the same trends for each calculation procedure and can be illustrated using the L_A calculation procedure as a representative example.

Comparison of the correlation coefficient of the tone-corrected scale L_AT (0.962) to the correlation coefficient of the uncorrected scale L_A (0.920) shows a significant improvement in predictive ability resulting from the addition of the tone correction. The correlation coefficient of the duration-corrected scale IL_A (0.959) is also significantly higher than the uncorrected scale coefficient. The addition of both a tone correction and a duration correction results in a further significant improvement in predictive ability. The correlation coefficient of the scale with both corrections IL_AT (0.983), is significantly higher than either of the scales with only one correction. These comparisons clearly indicate that the addition of noise duration and/or tone corrections significantly improves the annoyance prediction ability of the L_A calculation procedure. The results for the other three rating scale calculation procedures showed similar significant improvements in predictive ability.

CONCLUSIONS

A laboratory experiment was performed to investigate the effects of variations in the rate and magnitude of sound level fluctuations on the annoyance caused by aircraft-flyover noise. The effects of tonal content, noise duration, and sound pressure level on annoyance were also studied. The following conclusions were noted:

1. The rate and magnitude of level fluctuations have little, if any, effect on the annoyance caused by aircraft-flyover noise.

2. The duration and tonal content of an aircraft-flyover noise significantly affect annoyance and should be taken into account in the quantification of annoyance caused by aircraft noise.

3. Tone-corrected and duration-corrected rating scales were found to predict annoyance significantly better than scales with no corrections.

4. The interaction of tonal content with sound pressure level was found to affect annoyance significantly. Further study of this interaction may result in improved prediction of overall annoyance response.

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APPENDIX

INSTRUCTIONS, CONSENT FORM, AND SCORING SHEETS

Copies of the instructions, consent form, and scoring sheets used in the experiment are presented in this appendix.

APPENDIX

Instructions

The experiment in which you are participating will help us understand the characteristics of aircraft sounds which can cause annoyance in airport communities. We would like you to judge how ANNOYING some of these aircraft sounds are. By ANNOYING we mean - UNWANTED, OBJECTIONABLE, DISTURBING, or UNPLEASANT.

The experiment consists of four 15-minute sessions. During each session 16 aircraft sounds will be presented for you to judge. Before each session you will be given a rating sheet with 16 scales like the one below.

Not at all Annoying	0	1	2	3	4	5	6	7	8	9	Extremely Annoying

After listening to each sound, please indicate how annoying you judge the sound to be by placing a mark across the scale. If you judge a sound to be only slightly annoying, then place your mark close to the "NOT ANNOYING AT ALL" end of the scale. Similarly, if you judge a sound to be very annoying then place your mark closer to the "EXTREMELY ANNOYING" end of the scale. A moderately annoying judgment should be marked in the middle portion of the scale. A mark may be placed anywhere along the scale, not just the numbered locations. Each aircraft sound will be followed by a beep or short tone. Please do not make your judgments until after the beep. You will have about five seconds after the beep to make and record your judgment. There are no right or wrong answers; we are only interested in your judgment of each sound.

Before the first session begins you will be given a practice rating sheet and three sounds will be presented to familiarize you with making and recording judgments. I will remain in the testing room with you during the practice time to answer any questions you may have.

Thank you for your help in conducting the experiment.

APPENDIX

Voluntary Consent Form for Subjects for Human Response to Aircraft Noise and Vibration

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 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

Practice Rating Sheet

Subject No. __________ Group __________

Practice Sound		Judgment	
I	Not at all Annoying	0 1 2 3 4 5 6 7 8 9	Extremely Annoying
II	Not at all Annoying	0 1 2 3 4 5 6 7 8 9	Extremely Annoying
III	Not at all Annoying	0 1 2 3 4 5 6 7 8 9	Extremely Annoying

APPENDIX

Rating Sheet

Page 1

Subject No. __________ Group __________ Session __________ Tape __________

Sound

Sound												
1	Not at all Annoying	0	1	2	3	4	5	6	7	8	9	Extremely Annoying
2	Not at all Annoying	0	1	2	3	4	5	6	7	8	9	Extremely Annoying
3	Not at all Annoying	0	1	2	3	4	5	6	7	8	9	Extremely Annoying
4	Not at all Annoying	0	1	2	3	4	5	6	7	8	9	Extremely Annoying
5	Not at all Annoying	0	1	2	3	4	5	6	7	8	9	Extremely Annoying
6	Not at all Annoying	0	1	2	3	4	5	6	7	8	9	Extremely Annoying
7	Not at all Annoying	0	1	2	3	4	5	6	7	8	9	Extremely Annoying
8	Not at all Annoying	0	1	2	3	4	5	6	7	8	9	Extremely Annoying

APPENDIX

Rating Sheet

Page 2

Subject No. ________ Group ________ Session ________ Tape ________

Sound													
9	Not at all Annoying	0	1	2	3	4	5	6	7	8	9	Extremely Annoying
10	Not at all Annoying	0	1	2	3	4	5	6	7	8	9	Extremely Annoying
11	Not at all Annoying	0	1	2	3	4	5	6	7	8	9	Extremely Annoying
12	Not at all Annoying	0	1	2	3	4	5	6	7	8	9	Extremely Annoying
13	Not at all Annoying	0	1	2	3	4	5	6	7	8	9	Extremely Annoying
14	Not at all Annoying	0	1	2	3	4	5	6	7	8	9	Extremely Annoying
15	Not at all Annoying	0	1	2	3	4	5	6	7	8	9	Extremely Annoying
16	Not at all Annoying	0	1	2	3	4	5	6	7	8	9	Extremely Annoying

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TABLE I.- TEST SUBJECTS

Sex	Number of participants	Mean age	Median age	Age range
Male	10	29	25	18 to 56
Female	22	33	33	21 to 54
All subjects	32	32	31	18 to 56

TABLE II.- PRESENTATION ORDER OF STIMULI ON TAPES

Practice tape	Tape I	Tape II	Tape III	Tape IV
12221	11212	22121	12222	21111
22122	21121	12212	12121	11222
11211	12112	21221	21211	22211
	21222	12122	22122	11112
	22111	11211	12211	21122
	11122	22112	21112	12221
	22221	22222	11221	21212
	11111	11121	22212	12111
	22212	12111	11111	11121
	11221	21212	22221	22222
	21112	12221	11122	22112
	12211	21122	22111	11211
	22122	11112	21222	12122
	21211	22211	12112	21221
	12121	11222	21121	12212
	12222	21111	11212	22121

Stimuli key				
A	B	C	D	E
Tonal content	Duration, sec (a)	Nominal L_A, dB	Fluctuation rate	Fluctuation magnitude
1 = No tones	1 = 10	1 = 70	1 = r_L	1 = m_L
2 = Strong tones	2 = 20	2 = 85	2 = r_H	2 = m_H

[a]Time between the first and last points at which the noise signal is 10 dB down from the maximum sound level.

TABLE III.- ORDER OF TAPES PRESENTED

TO TEST SUBJECTS

Test-subject group	Tape presented during session -			
	1	2	3	4
1	I	II	IV	III
2	II	III	I	IV
3	III	IV	II	I
4	IV	I	III	II
5	I	IV	II	III
6	II	I	III	IV
7	III	II	IV	I
8	IV	III	I	II

TABLE IV.- AVERAGE MEASURED LEVELS OF NOISE STIMULI

Stimuli	L_A	IL_A	L_AT	IL_AT	L_D	IL_D	L_DT	IL_DT	PNL	IPNL	PNLT	IPNLT	PL	IPL	PLT	IPLT
11111	71.8	67.5	73.0	68.1	79.1	75.1	80.3	75.8	83.9	79.8	85.0	80.5	75.0	71.9	76.3	72.4
11112	72.0	66.7	73.1	67.5	79.3	74.3	80.3	75.0	83.7	78.9	84.8	79.5	75.1	70.9	76.0	71.6
11121	71.4	67.5	72.7	68.2	78.7	75.2	79.8	75.8	83.2	79.9	84.2	80.4	74.7	71.9	76.0	72.5
11122	72.0	67.8	73.6	68.5	79.2	75.4	80.8	76.2	83.7	80.1	85.3	80.7	75.3	72.1	76.9	72.5
11211	87.1	82.6	88.4	83.5	94.4	90.3	95.7	91.1	99.4	95.5	100.9	96.3	90.1	86.3	91.6	87.0
11212	87.0	81.8	88.4	82.7	94.0	89.4	95.4	90.2	98.9	94.7	100.3	95.4	89.8	85.4	91.1	86.2
11221	86.7	82.8	88.3	83.6	94.0	90.5	95.6	91.2	98.8	95.6	100.4	96.3	89.8	86.3	91.4	87.1
11222	86.8	83.2	88.3	84.1	93.9	91.0	95.6	91.7	99.4	96.0	100.9	96.8	90.0	86.8	91.5	87.6
12111	70.8	70.7	71.9	71.3	78.2	78.5	79.1	79.0	82.8	83.1	83.8	83.7	74.2	75.1	75.3	75.6
12112	71.6	70.6	72.9	71.2	79.3	78.2	80.5	78.8	83.5	82.9	84.8	83.4	75.0	75.0	76.3	75.4
12121	72.2	71.3	73.6	72.0	79.8	78.9	81.1	79.5	84.3	83.6	85.5	84.3	75.6	75.6	77.0	76.1
12122	72.5	70.6	74.1	71.3	80.1	78.4	81.7	79.0	84.5	83.0	86.1	83.6	75.7	75.1	77.3	75.6
12211	86.2	86.1	87.4	86.8	93.6	93.8	94.8	94.4	98.4	99.1	99.5	99.7	89.3	89.8	90.4	90.4
12212	86.6	86.0	87.9	86.7	94.2	93.6	95.5	94.2	98.9	98.8	100.3	99.4	89.7	89.5	91.1	90.1
12221	87.5	86.7	89.1	87.4	94.8	94.3	96.5	95.0	99.3	99.7	100.9	100.3	90.4	90.3	92.0	90.9
12222	87.3	86.2	88.7	86.8	94.7	93.9	96.1	94.5	99.5	99.0	100.9	99.8	90.3	89.8	91.7	90.5
21111	68.4	66.0	73.9	69.4	75.4	73.7	80.7	76.9	80.5	78.8	85.6	81.9	72.5	71.1	77.8	74.0
21112	70.3	67.1	75.6	70.8	77.1	74.8	82.2	78.1	82.2	79.8	87.5	83.1	73.9	71.9	79.2	75.1
21121	69.6	66.6	75.3	70.5	76.6	74.3	82.1	78.0	81.7	79.3	87.3	83.1	73.4	71.6	79.0	75.0
21122	70.0	66.6	75.2	70.4	76.8	74.2	81.9	77.8	82.2	79.2	87.4	82.9	73.7	71.4	78.9	74.8
21211	84.7	82.1	90.5	85.8	91.3	89.8	97.2	93.2	96.9	95.6	102.8	98.8	87.6	86.1	93.5	89.3
21212	85.2	82.2	91.3	86.2	92.3	89.9	97.8	93.5	97.7	95.6	103.8	99.1	88.3	86.2	94.5	89.8
21221	85.2	81.9	91.0	85.8	92.2	89.5	97.8	93.1	97.6	95.1	103.3	98.8	88.4	85.6	94.0	89.3
21222	85.2	81.7	91.1	85.6	91.7	89.3	97.9	93.0	97.6	95.0	103.7	98.8	88.3	85.6	94.4	89.3
22111	69.0	70.0	74.7	74.1	76.7	77.6	82.5	81.3	81.4	82.6	87.2	86.4	73.1	74.9	79.0	78.6
22112	69.2	69.1	74.9	73.2	76.5	76.7	81.9	80.4	81.5	81.6	87.1	85.5	73.1	74.1	78.8	77.7
22121	70.9	70.8	76.6	74.8	78.1	78.4	84.0	82.1	83.3	83.4	89.1	87.2	74.7	75.4	80.6	79.1
22122	70.1	69.7	75.4	73.7	77.3	77.4	82.7	80.9	82.4	82.4	87.8	86.0	73.9	74.7	79.4	78.1
22211	84.7	85.3	90.5	89.5	91.8	93.0	97.6	96.8	97.3	98.7	103.1	102.5	87.6	89.3	93.5	93.0
22212	84.5	84.3	90.2	88.3	91.5	91.9	97.2	95.6	97.3	97.6	103.1	101.2	87.5	88.2	93.2	91.7
22221	85.7	86.1	91.4	90.4	92.9	93.8	98.7	97.6	98.6	99.4	104.2	103.3	89.0	89.9	94.7	93.8
22222	84.8	84.9	90.5	89.1	92.0	92.5	97.6	96.3	97.6	98.2	103.5	102.0	88.2	88.8	94.2	92.5

Stimuli key				
A	B	C	D	E
Tonal content	Duration, sec (a)	Nominal L_A, dB	Fluctuation rate	Fluctuation magnitude
1 = No tones	1 = 10	1 = 70	1 = r_L	1 = m_L
2 = Strong tones	2 = 20	2 = 85	2 = r_H	2 = m_H

[a] Time between the first and last points at which the noise signal is 10 dB down from the maximum sound level.

TABLE V.- ANALYSIS OF VARIANCE

[T, tonal content; D, duration; L, level; R, fluctuation rate; M, fluctuation magnitude; S, subjects]

Source of variance	Sum of squares	Degrees of freedom	Mean square	F-ratio (a)
T	168.87774	1	168.87774	30.51974*
T × S	171.53523	31	5.53339	
D	226.11340	1	226.11340	225.16325*
D × S	31.13082	31	1.00422	
L	5520.70618	1	5520.70618	272.04327*
L × S	629.09804	31	20.29349	
R	0.08379	1	0.08379	0.05903ns
R × S	44.00730	31	1.41959	
M	5.81192	1	5.81192	5.53190*
M × S	32.56917	31	1.05062	
T × D	0.00532	1	0.00532	0.00410ns
T × D × S	40.18453	31	1.29628	
T × L	38.30860	1	38.30860	16.00009*
T × L × S	74.22250	31	2.39427	
T × R	8.31555	1	8.31555	3.26943ns
T × R × S	78.84617	31	2.54342	
T × M	0.84094	1	0.84094	1.24893ns
T × M × S	20.87328	31	0.67333	
D × L	3.67036	1	3.67036	2.72288ns
D × L × S	41.78699	31	1.34797	
D × R	1.65961	1	1.65961	1.54061ns
D × R × S	33.39460	31	1.07725	
D × M	2.01879	1	2.01879	1.82255ns
D × M × S	34.33792	31	1.10767	
L × R	1.85883	1	1.85883	1.67193ns
L × R × S	34.46539	31	1.11179	
L × M	0.61536	1	0.61536	0.64245ns
L × M × S	29.69261	31	0.95783	
R × M	0.49067	1	0.49067	0.52473ns
R × M × S	28.98792	31	0.93509	
T × D × L	3.94629	1	3.94629	3.98870ns
T × D × L × S	30.67042	31	0.98937	
T × D × R	3.22739	1	3.22739	3.16036ns
T × D × R × S	31.65746	31	1.02121	
T × D × M	0.38555	1	0.38555	0.44478ns
T × D × M × S	26.87179	31	0.86683	
T × L × R	1.36641	1	1.36641	1.51161ns
T × L × R × S	28.02218	31	0.90394	
T × L × M	0.02325	1	0.02325	0.03024ns
T × L × M × S	23.83160	31	0.76876	
T × R × M	6.94946	1	6.94946	9.45411*
T × R × M × S	22.78726	31	0.73507	
D × L × R	2.82774	1	2.82774	3.10181ns
D × L × R × S	28.26085	31	0.91164	
D × L × M	0.74649	1	0.74649	0.41074ns
D × L × M × S	56.34085	31	1.81745	
D × R × M	1.58086	1	1.58086	1.20722ns
D × R × M × S	40.59460	31	1.30950	
L × R × M	2.38575	1	2.38575	2.19422ns
L × R × M × S	33.70597	31	1.08729	
T × D × L × R	1.31524	1	1.31524	1.27383ns
T × D × L × R × S	32.00773	31	1.03251	
T × D × L × M	0.09165	1	0.09165	0.08839ns
T × D × L × M × S	32.14007	31	1.03678	
T × D × R × M	3.61973	1	3.61973	5.56637*
T × D × R × M × S	20.15886	31	0.65029	
T × L × R × M	3.53614	1	3.53614	6.18713*
T × L × R × M × S	17.71746	31	0.57153	
D × L × R × M	0.61536	1	0.61536	0.79502ns
D × L × R × M × S	23.99449	31	0.77402	
T × D × L × R × M	0.92395	1	0.92395	0.55770ns
T × D × L × R × M × S . . .	51.35777	31	1.65670	
Replications	22.09047	1	22.09047	5.41816*
Replications × S	126.39062	31	4.07712	
Subjects	2787.73925	31	89.92707	72.06272*
Residual	1237.91389	992	1.24790	
Total	12 012.30438	2047	5.86825	

[a]ns indicates not significant at 0.05 level; * indicates significant at 0.05 level.

TABLE VI.- BREAKDOWN OF TOTAL VARIANCE FOR MAIN EFFECTS AND SELECTED INTERACTIONS

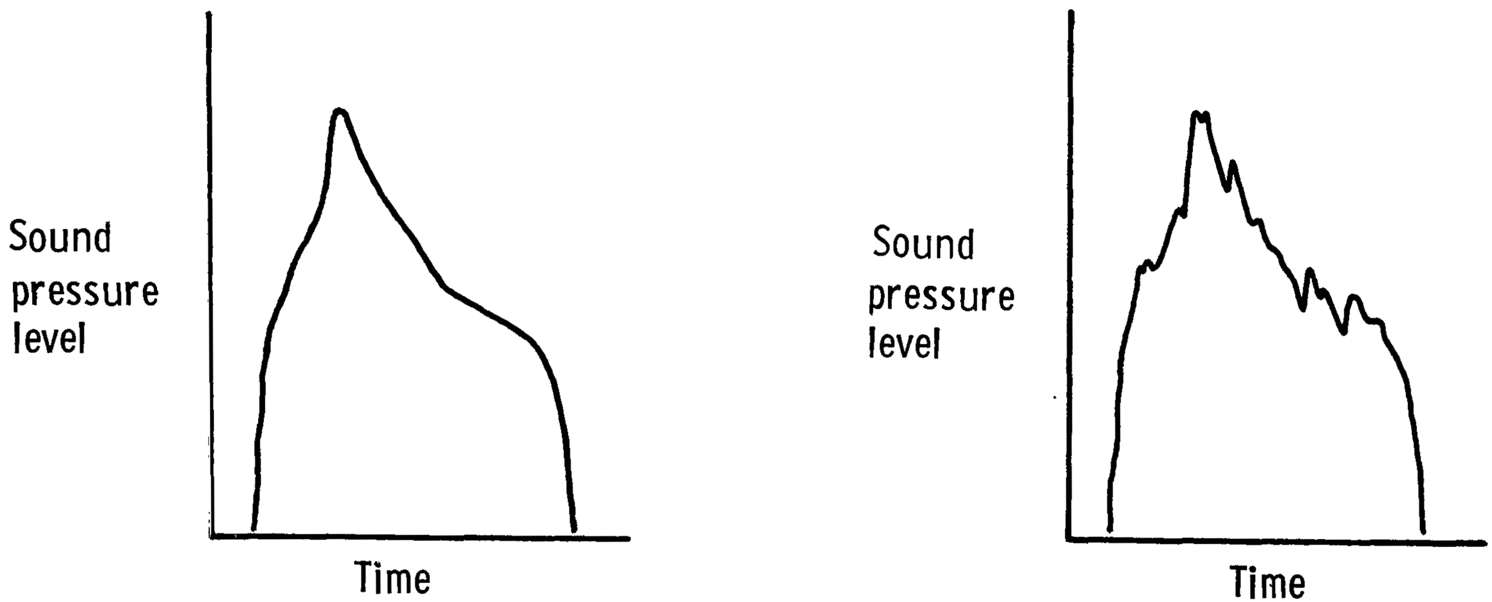
Source	Variance	Percentage of total variance
Level, L	85.94395	86.45207
Duration, D	3.51733	3.53813
Tonal content, T	2.55226	2.56734
Subjects, S	1.34140	1.34934
Error	1.24790	1.25528
Tonal content and level . . .	1.12232	1.12896
Subjects and level	0.59517	0.59869
T × R × M	0.38840	0.39070
T × D × R × M	0.37118	0.37337
T × L × R × M	0.37058	0.37277
Replications	0.28146	0.28312
Fluctuation magnitude, M . . .	0.07440	0.07484
Fluctuation rate, R	<0.00001	<0.00001
Other interactions	1.53333	1.54239
Total	99.41225	100

TABLE VII.- RESULTS OF LINEAR REGRESSIONS OF

MEAN SUBJECTIVE JUDGMENTS ON

RATING SCALES

Scale	Correlation coefficient	Slope	Intercept
L_A	0.920	0.2061	-12.262
L_AT	.962	.2124	-13.507
IL_A	.959	.2102	-12.159
IL_AT	.983	.2114	-12.752
L_D	0.918	0.2069	-13.820
L_DT	.966	.2145	-15.213
IL_D	.960	.2101	-13.768
IL_DT	.983	.2123	-14.403
PL	0.927	0.2155	-13.720
PLT	.966	.2186	-14.741
IPL	.965	.2238	-14.137
IPLT	.984	.2223	-14.474
PNL	0.928	0.2042	-14.611
PNLT	.965	.2066	-15.555
IPNL	.965	.2036	-14.267
IPNLT	.984	.2044	-14.779



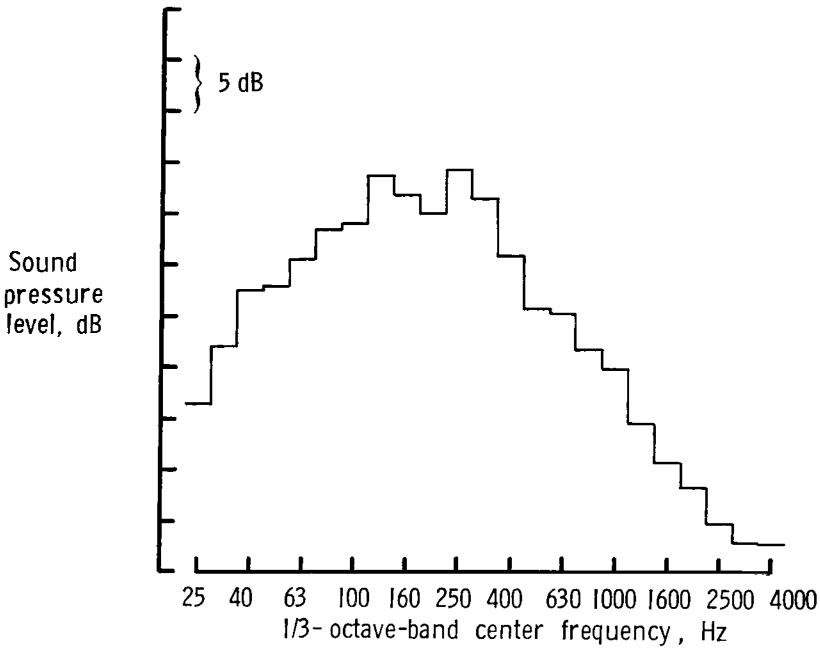
(a) Time history without level fluctuations.

(b) Time history with level fluctuations.

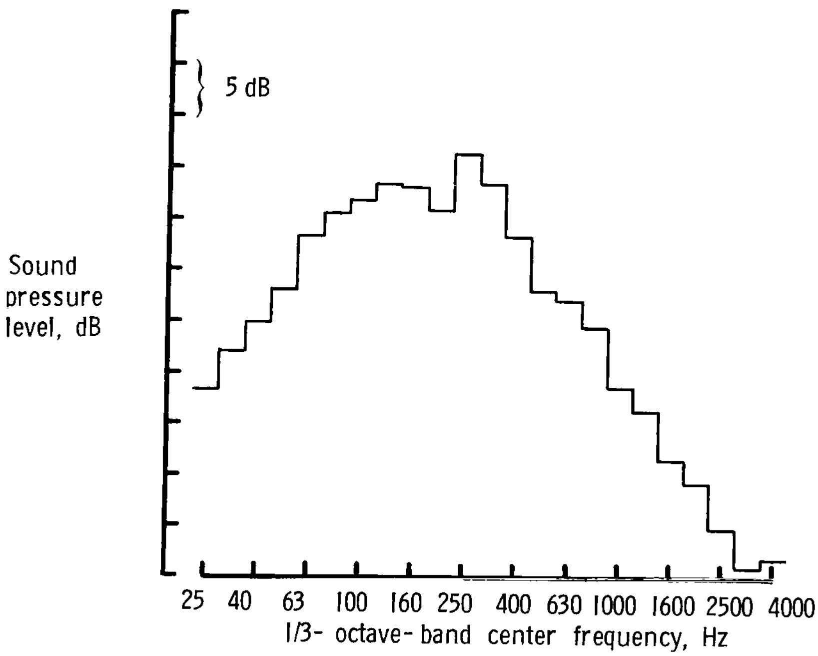
Figure 1.- Comparison of aircraft-flyover noise time history without level fluctuations and aircraft-flyover noise time history with level fluctuations.

L-79-121

Figure 2.- Subjects in exterior effects room of the Langley aircraft noise reduction laboratory.

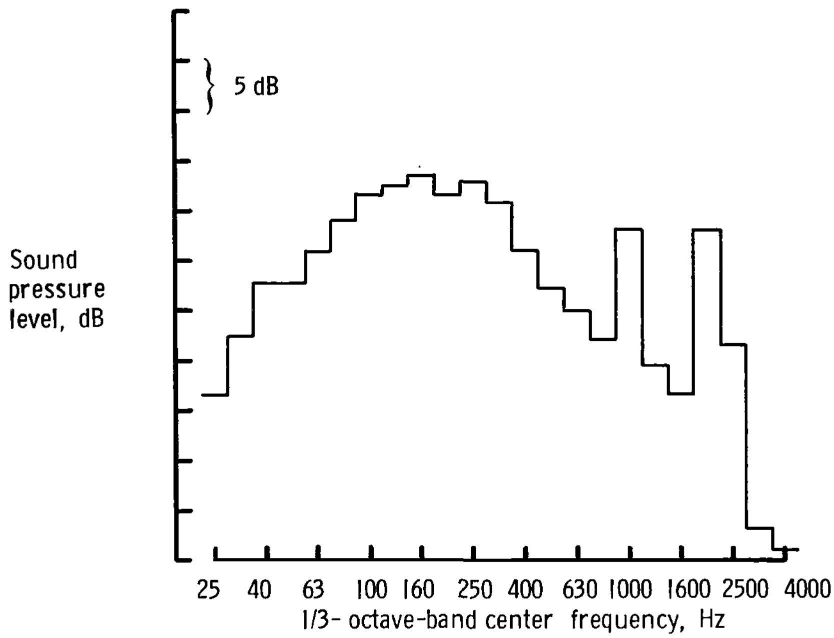


(a) Synthesized noise with no tonal components; short duration.

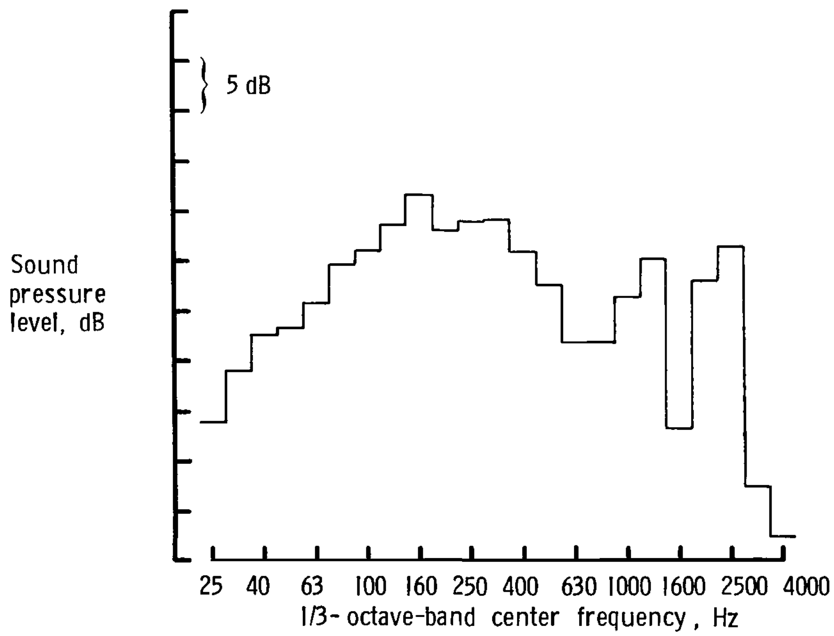


(b) Synthesized noise with no tonal components; long duration.

Figure 3.- One-third-octave-band spectra of four synthesized noises at maximum A-weighted sound pressure level.

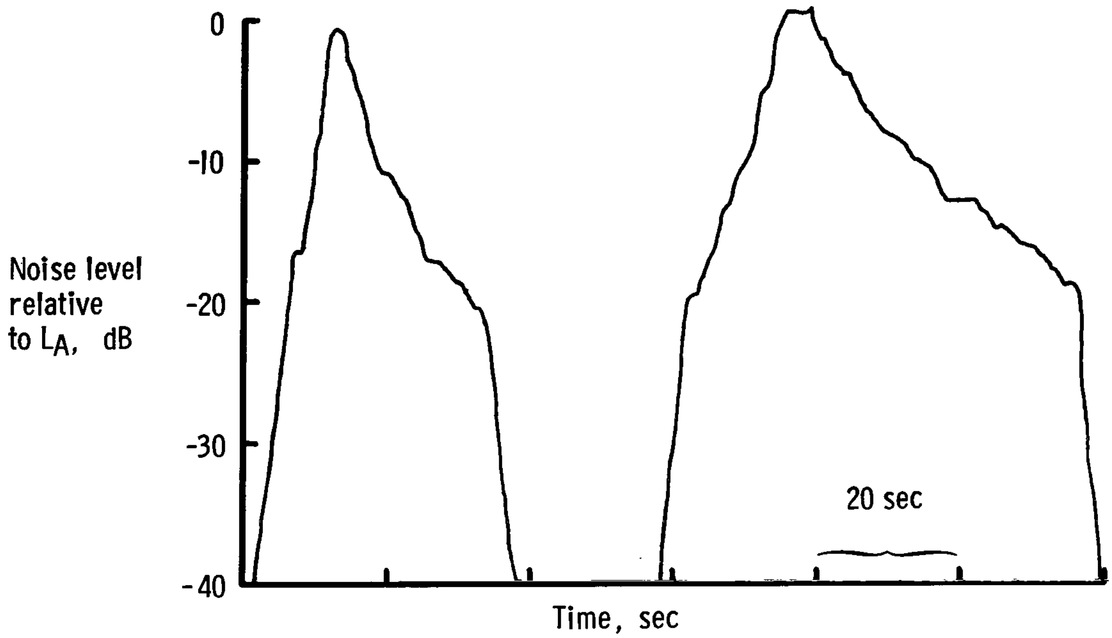


(c) Synthesized noise with strong tonal components; short duration.

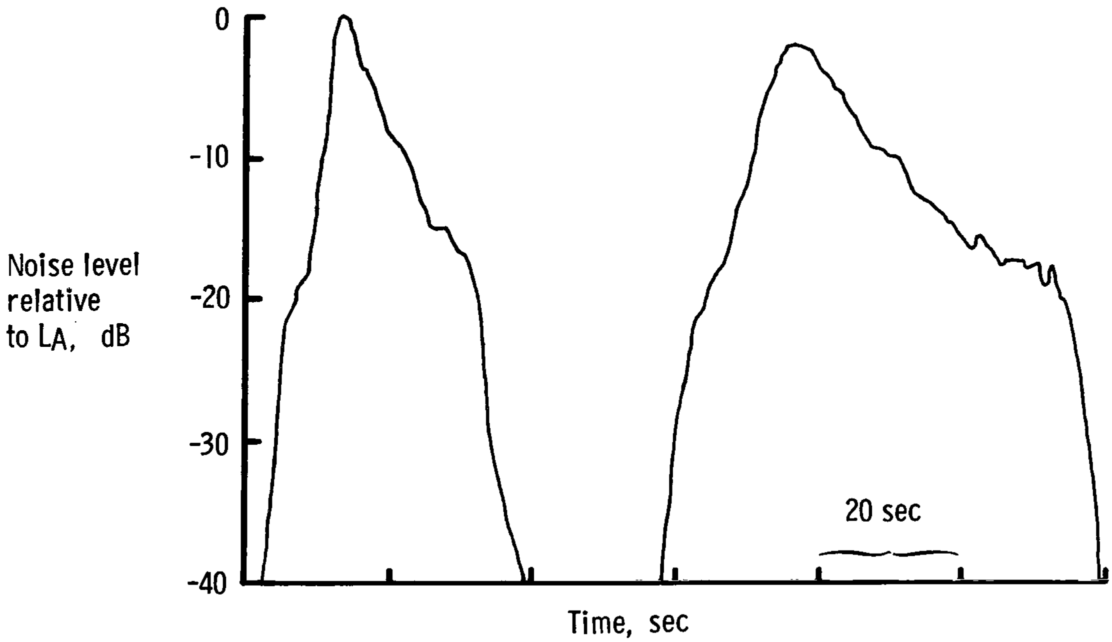


(d) Synthesized noise with strong tonal components; long duration.

Figure 3.- Concluded.



(a) Synthesized noises with no tones.



(b) Synthesized noises with strong tones.

Figure 4.- Time histories of four synthesized noises.

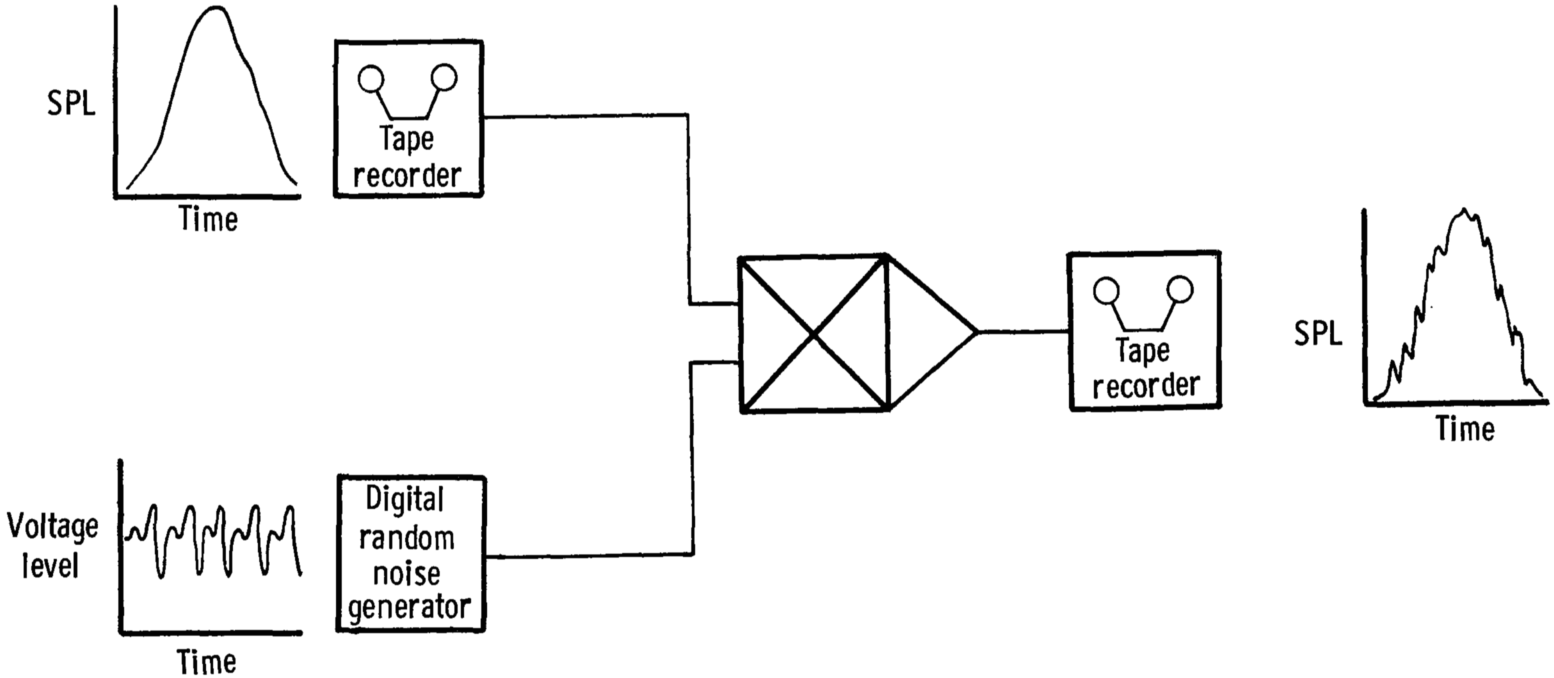
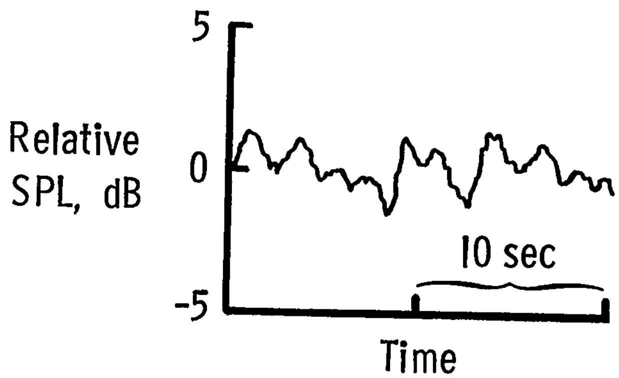
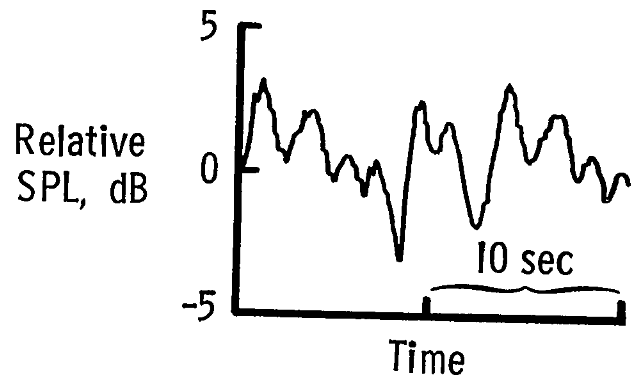


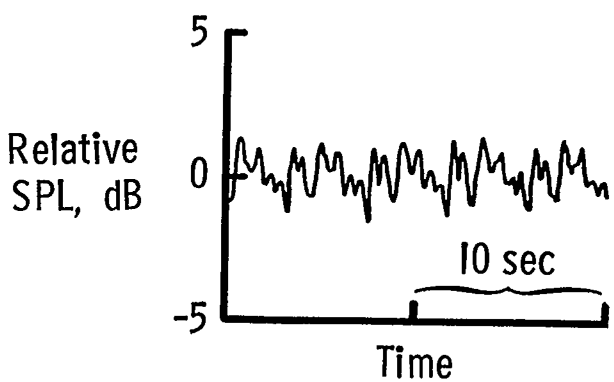
Figure 5.- Diagram of level fluctuation apparatus.



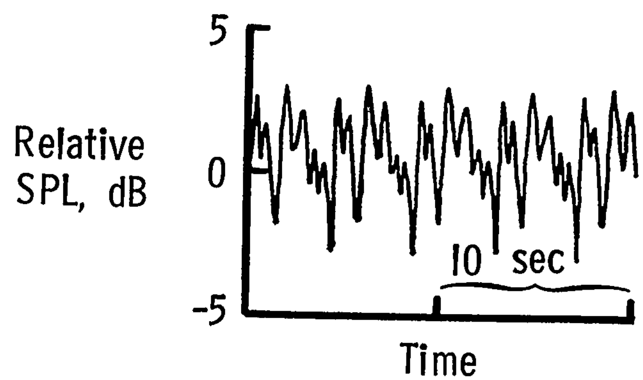
(a) Low rate; low magnitude.



(b) Low rate; high magnitude.

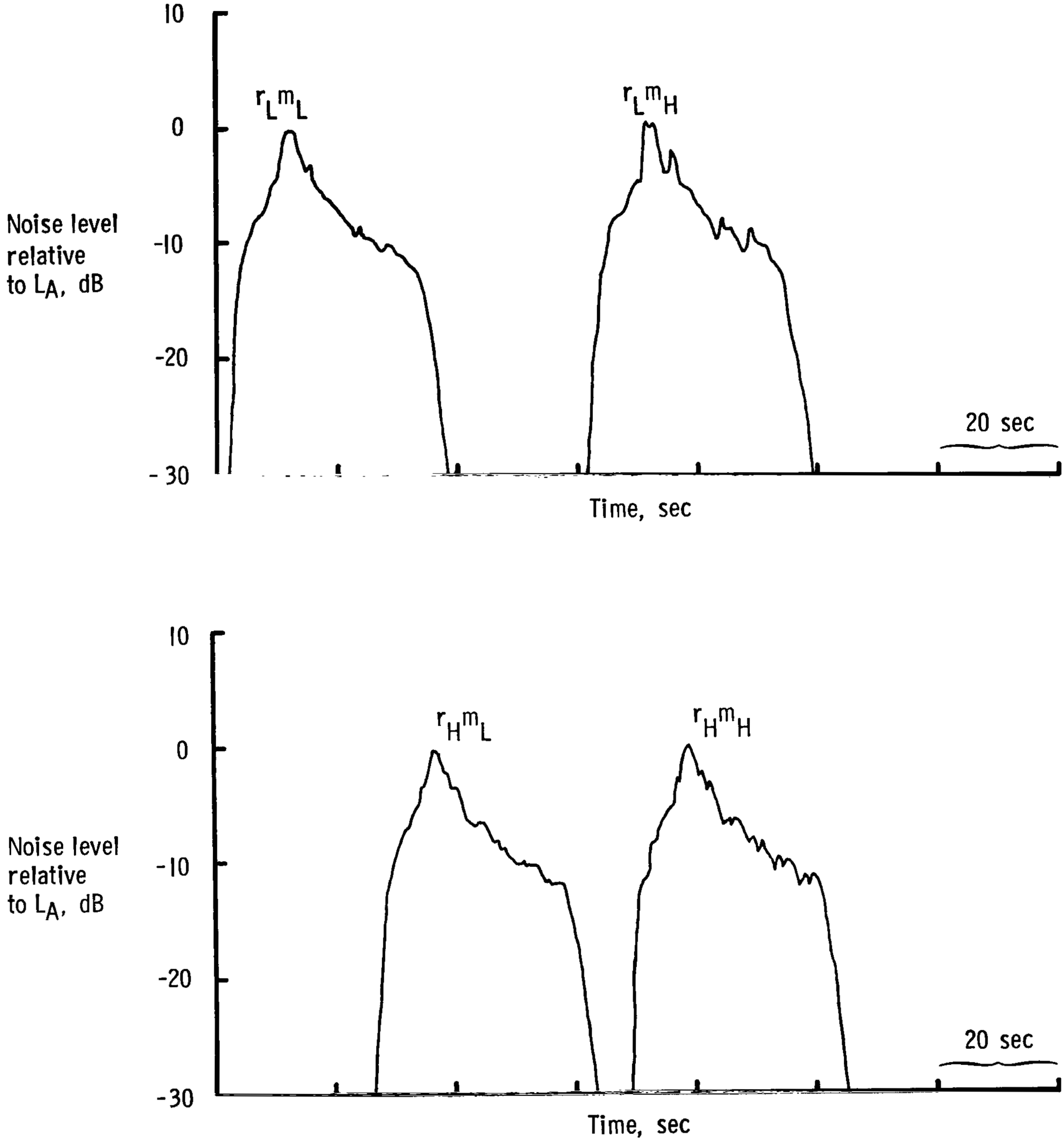


(c) High rate; low magnitude.



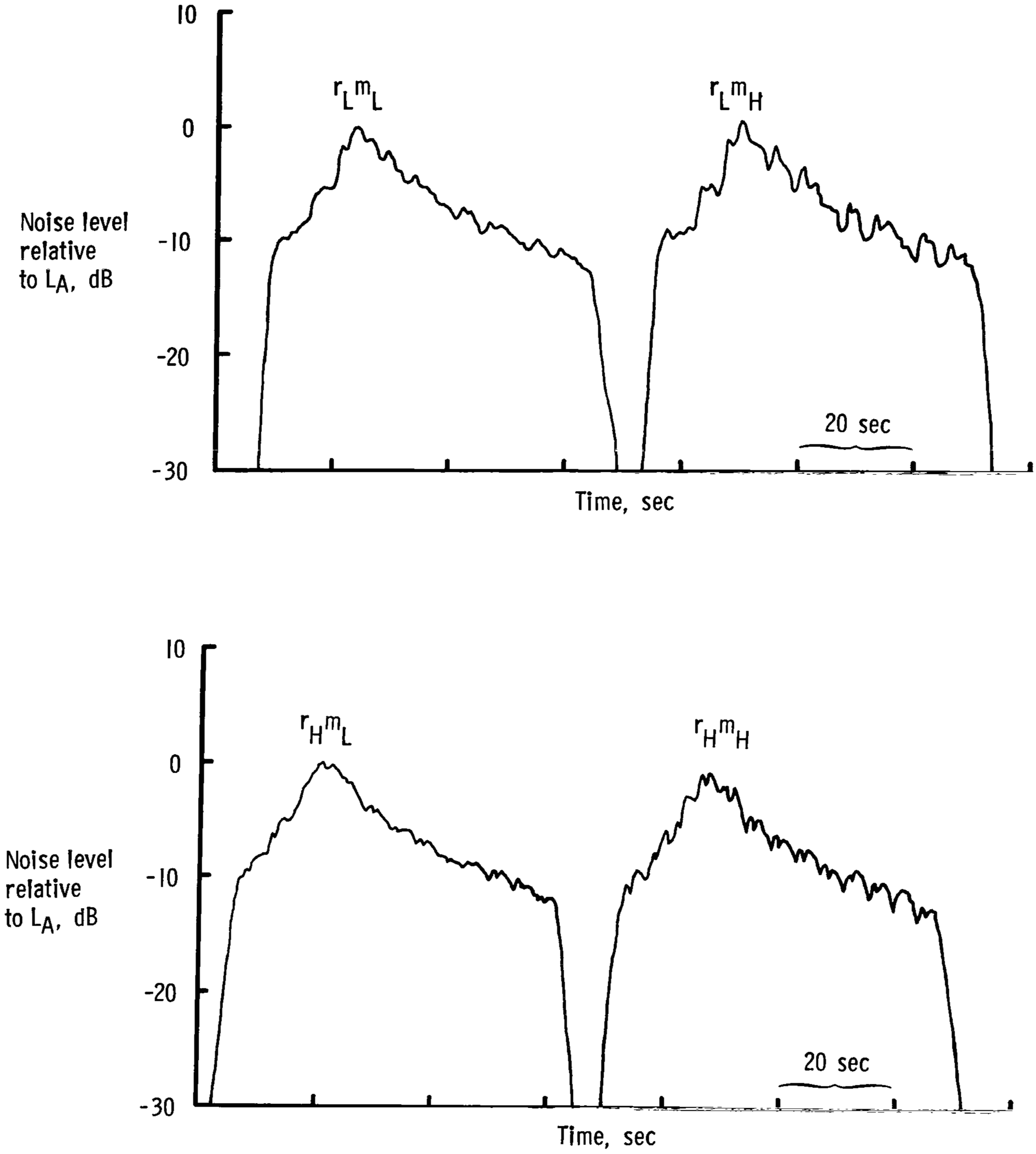
(d) High rate; high magnitude.

Figure 6.- Four fluctuation patterns (as applied to pink noise).



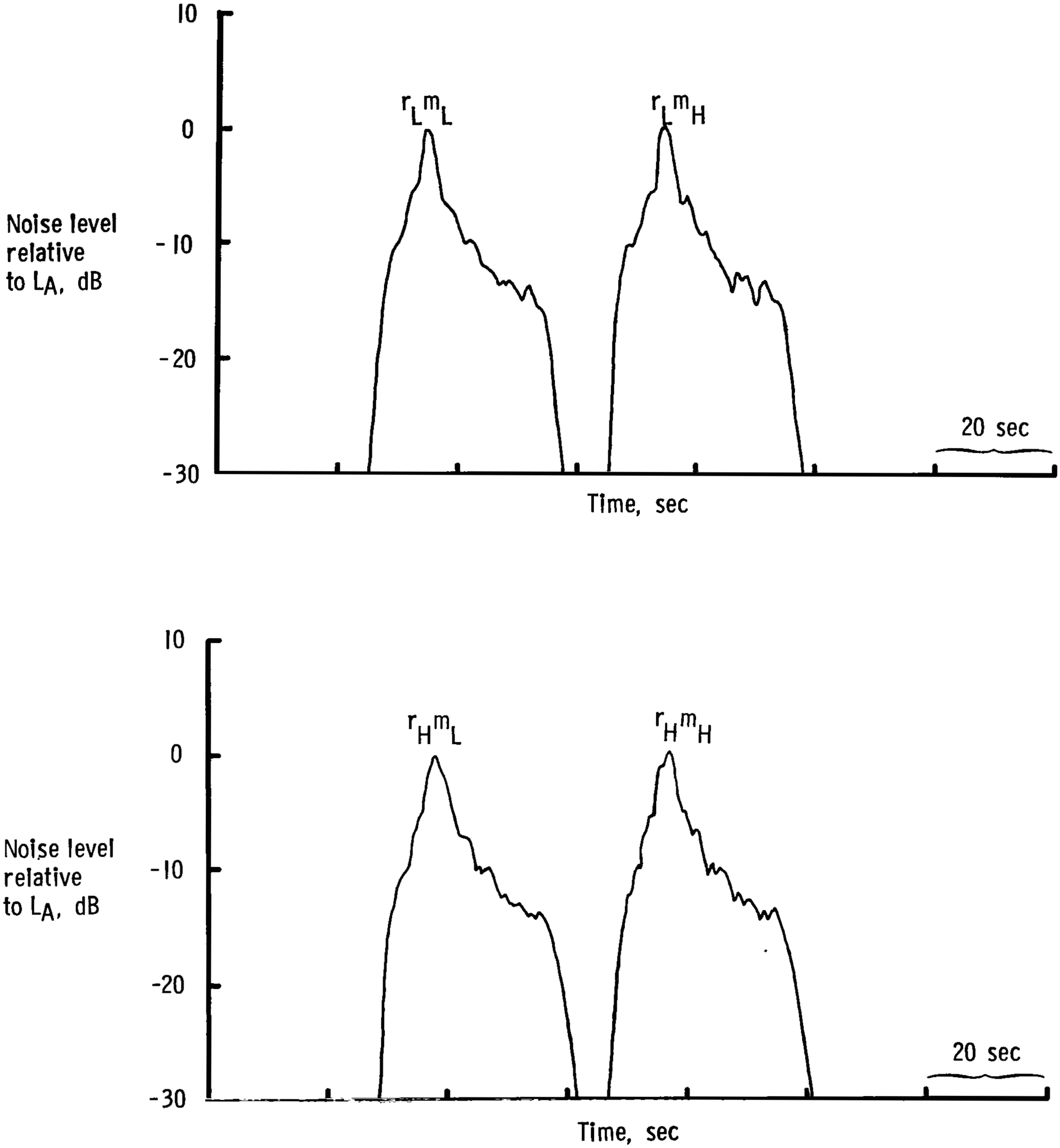
(a) No tones; short duration.

Figure 7.- Stimuli time histories for each combination of tone condition, noise duration, level fluctuation rate, and level fluctuation magnitude.



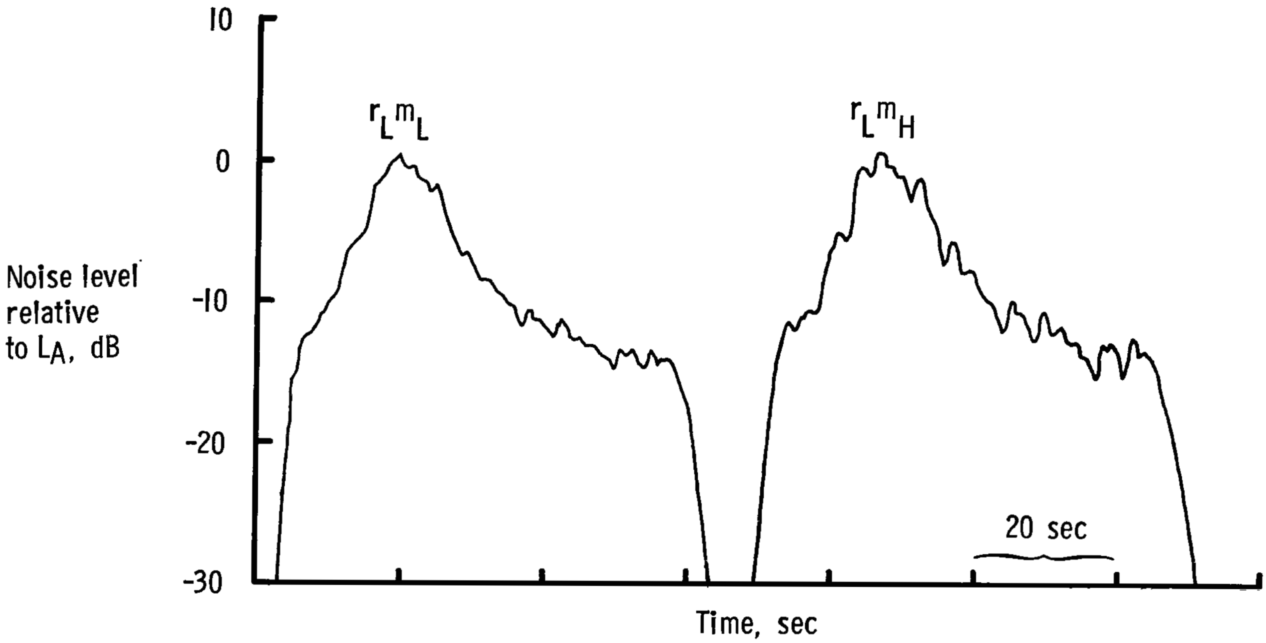
(b) No tones; long duration.

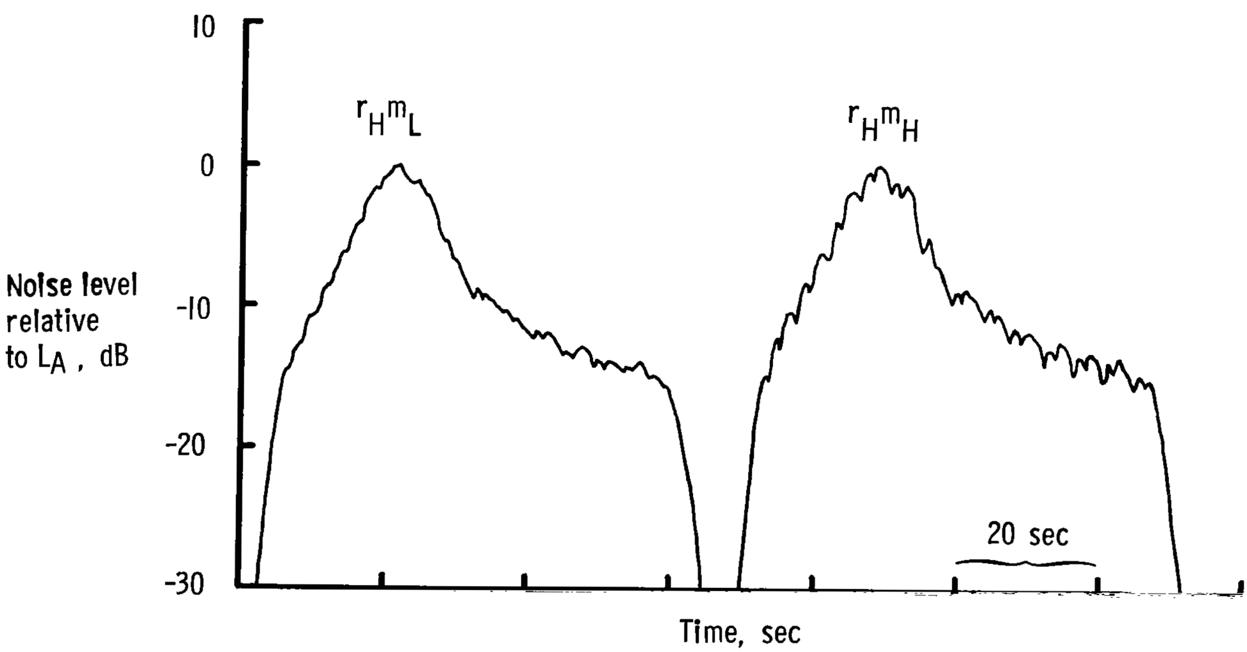
Figure 7.- Continued.



(c) Strong tones; short duration.

Figure 7.- Continued.





(d) Strong tones; long duration.

Figure 7.- Concluded.

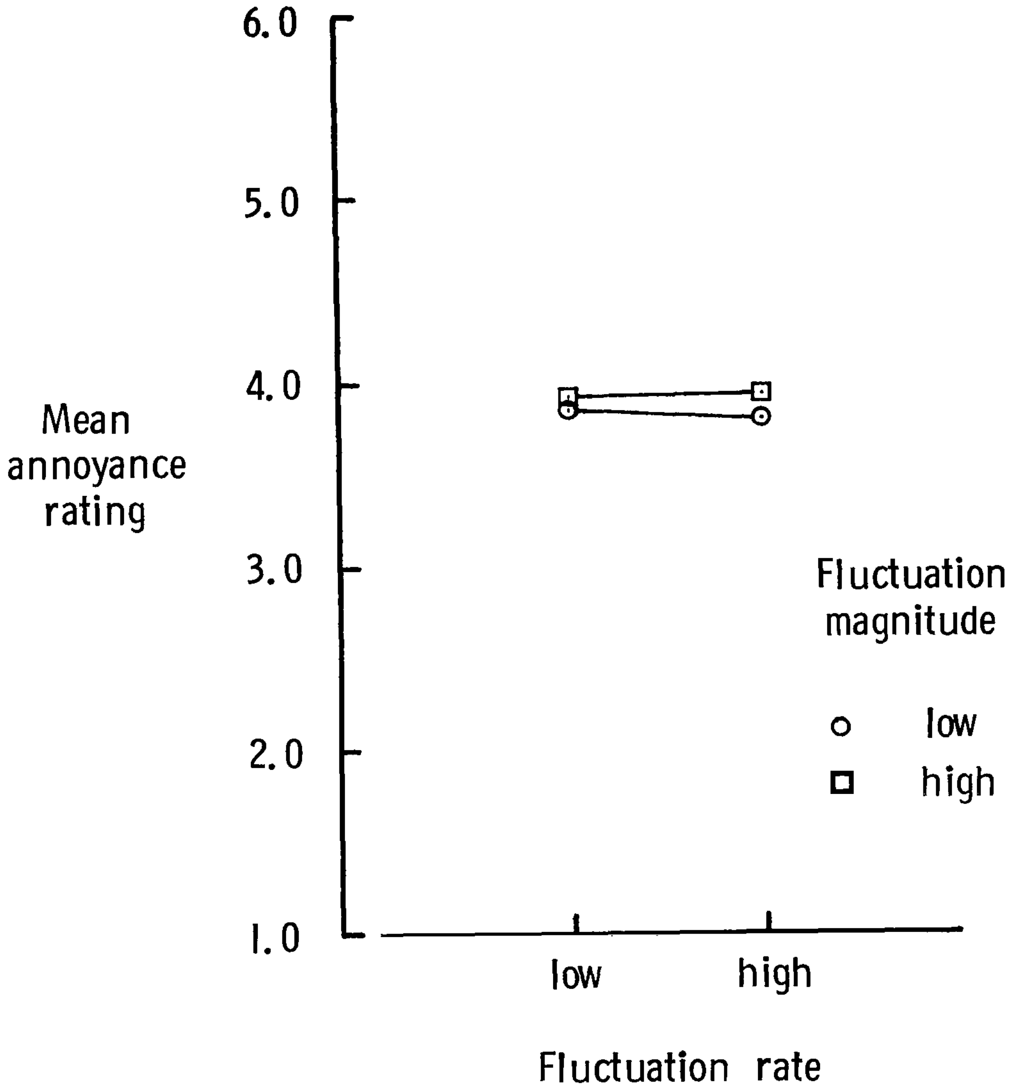


Figure 8.- Effects of level fluctuation rate and level fluctuation magnitude on annoyance.

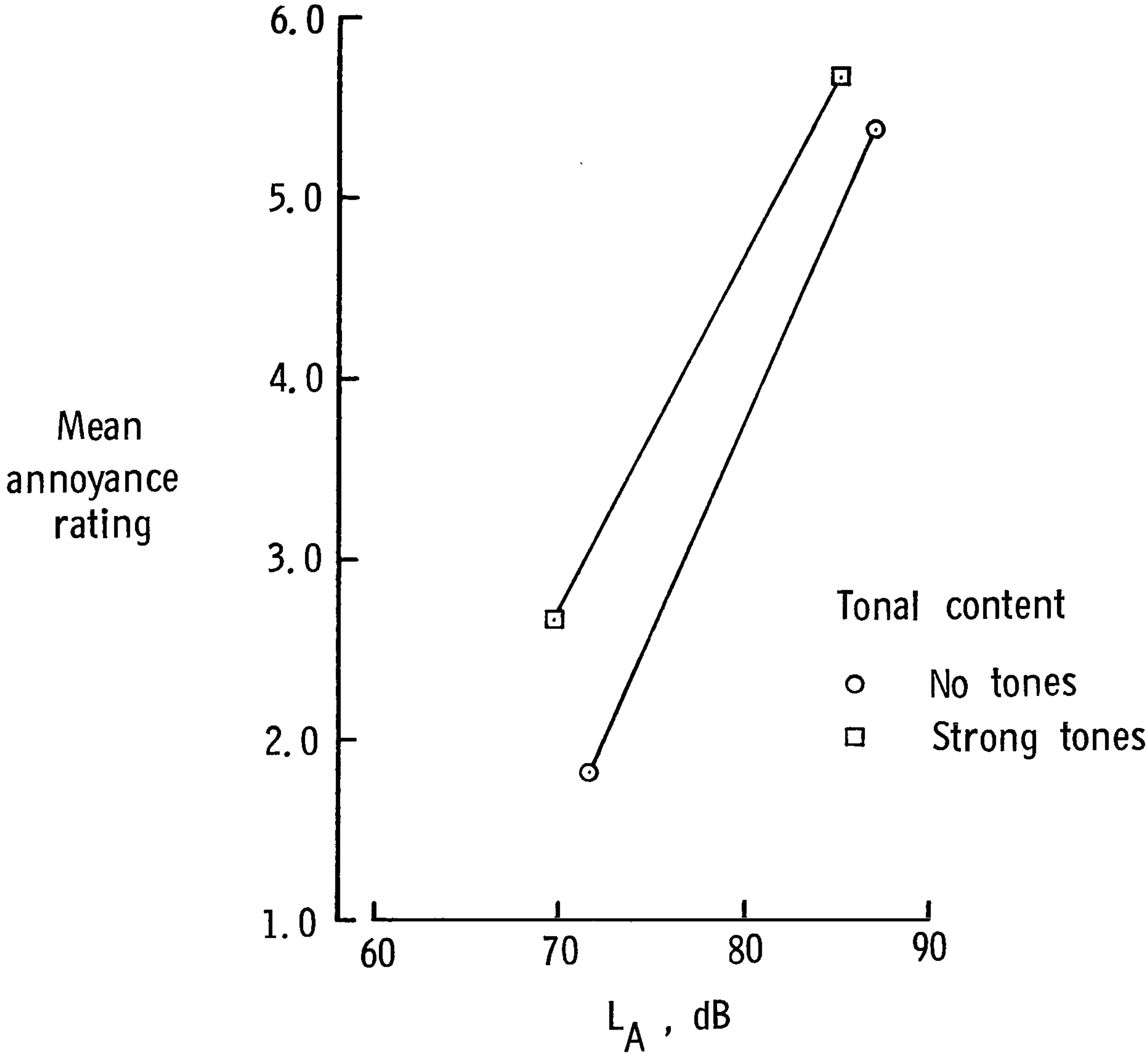


Figure 9.- Effects of tonal content and sound pressure level on annoyance.

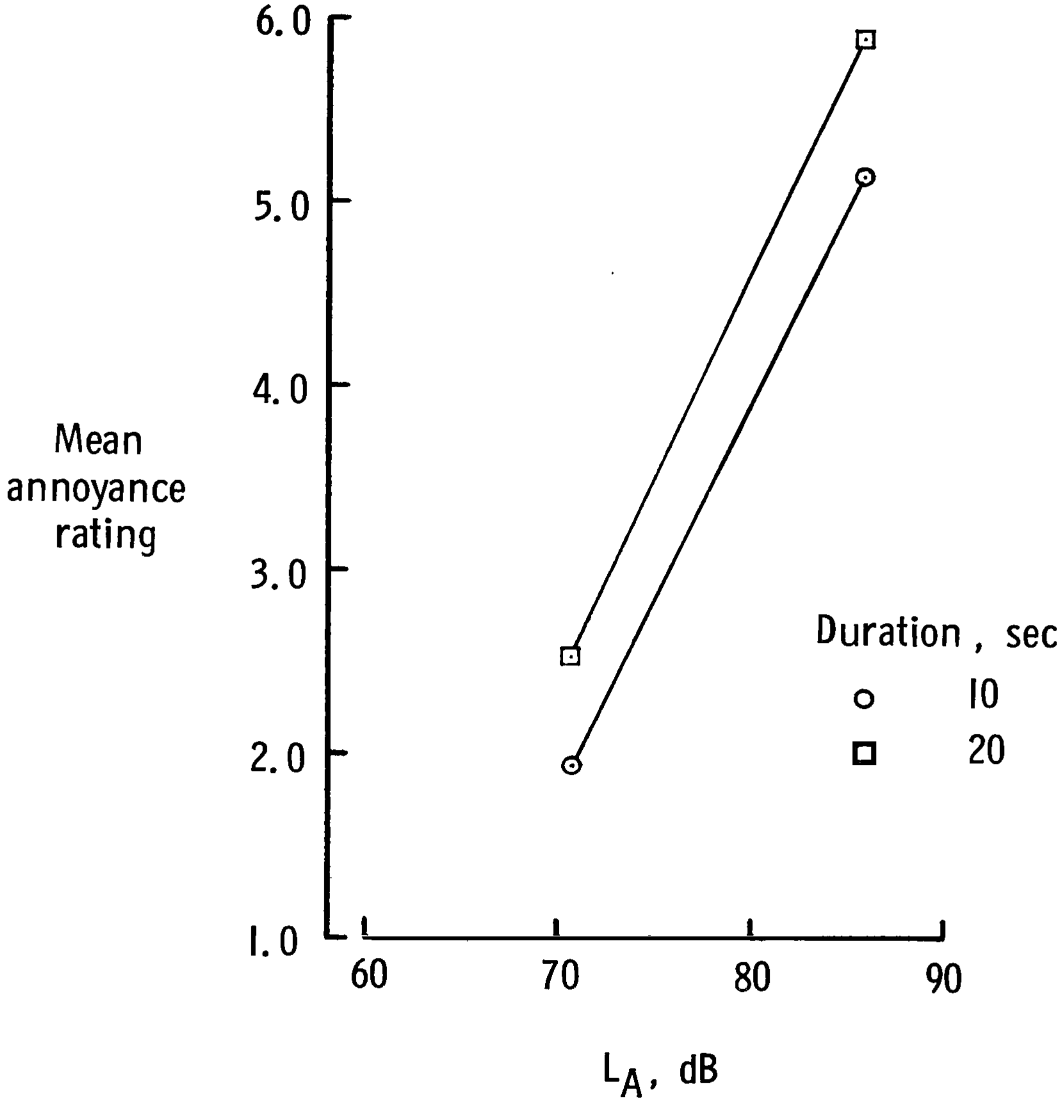


Figure 10.- Effects of duration and sound pressure level on annoyance.

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16. Abstract

A laboratory experiment was conducted to determine the effects of variations in the rate and magnitude of sound level fluctuations on the annoyance caused by aircraft-flyover noise. The effects of tonal content, noise duration, and sound pressure level on annoyance were also studied. A newly developed aircraft-noise synthesis system was used to synthesize 32 aircraft-flyover noise stimuli representing the factorial combinations of 2 tone conditions, 2 noise durations, 2 sound pressure levels, 2 level fluctuation rates, and 2 level fluctuation magnitudes. Thirty-two test subjects made annoyance judgements on a total of 64 stimuli in a subjective listening test facility simulating an outdoor acoustic environment. Variations in the rate and magnitude of level functuations were found to have little, if any, effect on annoyance. Tonal content, noise duration, sound pressure level, and the interaction of tonal content with sound pressure level were found to affect the judged annoyance significantly. The addition of tone corrections and/or duration corrections significantly improved the annoyance prediction ability of noise rating scales.

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