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RELATIVE ANNOYANCE AND LOUDNESS JUDGMENTS OF VARIOUS SIMULATED SONIC BOOM WAVEFORMS

by L. J. Shepherd and W. W. Sutherland

Prepared by
STANFORD RESEARCH INSTITUTE
Menlo Park, Calif.
for Langley Research Center

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ABSTRACT

A series of investigations were initiated in an effort to assess the effect of sonic boom signature modification on human subjective response, using Lockheed's sonic boom simulation facility. Subjective response was found to be influenced by changes in several signature parameters, including rise time, interpeak duration, and the addition of short duration transients to the signature "bow" wave. Detailed descriptions and the results of this series of experiments, completed under subcontract B-87017-US with the Stanford Research Institute, are described in the following report.

RELATIVE ANNOYANCE AND LOUDNESS JUDGMENTS OF VARIOUS SIMULATED SONIC BOOM WAVEFORMS

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Introduction and Background:

As an aircraft travels through the atmosphere at velocities greater than Mach 1, a pressure wave is generated which propagates away from the aircraft and upon intersecting with the ground, produces an explosive sensation in the auditory mechanisms of humans and animals located along the flight path.

The continued operation of aircraft at supersonic speeds with the consequent generation of this sonic boom pnenomena, has sparked controversy concerned with the nature of the boom phenomena, primarily as related to possible damage effects to humans or structures exposed to the short duration transients. Numerous damage claims filed by private citizens alleging personal injury or property damage have led to the initiation of a series of research programs conducted by both the government and private industry concerned with detailed examination of the phenomena. Since 1950, at least 21 studies have been sponsored by the NASA, FAA, and USAF dealing with the subjective responses of humans, and the effects of sonic booms on structures located beneath the supersonic flight path. These investigations have formed the core of an intensive research effort and have served to illuminate the problem by providing a broad understanding of the generation and propagation of the sonic boom pressure wave, while providing useful knowledge concerning structural and community response.

The first investigations concerned with the specification of human response were implemented with extensive flight test programs and yielded a large amount of useful data. Attempts to accurately define the nature of the pressure stimulus affecting large numbers of individuals was soon identified as an important problem area. The problems of variability in flight and atmospheric conditions were compounded by the problem of providing extensive arrays of instrumentation and the all important cost of providing enough supersonic flyovers for statistical reliability. Active confrontation with these problems lead to attempts to simulate the boom phenomenon in the controlled environment of the laboratory.

In order to implement tests of subjective reactions under laboratory conditions it is necessary to replicate as closely as possible the specific sonic boom pressure signatures. Zeppler and Harel (1965), enclosed only the ear in a headset-earmuff configuration and drove the reproducers with appropriate electrical waveforms. Kryter and Pearsons (1965), experimented with a 100 ft^3 chamber with large loudspeakers mounted in the walls acting as pressure reproducers, and of the different techniques tried, the pressure chamber concept has provided the most accurate pressure time history sonic boom simulation.

In the summer of 1965, the Bioacoustics Laboratory at Lockheed developed a chamber similar to that described by Kryter and Pearsons, but differing in that the system utilized direct current amplifiers and servo system techniques to produce the required low frequency response.

Following the successful implementation of this facility, a series of test programs were designed and executed, in the interest of establishing the ameliorative effects of modifications in sonic boom parameters on human subjective response judgments. These studies were designed with a series of independent variables, including signature overpressure, duration, gross waveshape changes, and rise time. The results of these early Lockheed studies were reported at the June 1966 meeting of the Acoustical Society of America. The results indicated the existence of several important relationships between changes in the physical parameters of the sonic boom waveform and subjective human response, most notable signature rise time and overpressure were seen as response modifiers, parameters which had been thought to be important based on previous subjective studies and theoretical predictions. Several other interesting effects were noted, including an apparent effect on subjective loudness appearing as a function of selective modification of the bow wave of the boom pressure signature. In addition, systematic examination using a number of differing experimental methods indicated possible differences to exist between loudness and annoyance as subjective judgment criteria.

The various topic areas listed here were seen as important problems in the overall goal of human sonic boom response definition. A detailed research program was designed jointly by personnel from the Life Sciences Department of the Lockheed-California Company and the Sensory Sciences Research Center at the Stanford Research Institute. The program was conceived in the interest of examining a series of sonic boom effects and relationships in depth utilizing personnel and facilities located at Lockheed's Rye Canyon Research Laboratory. This program executed by Lockheed under subcontract B-87017-US with the Stanford Research Institute is described in the following sections of this report.

Description of the Program:

1) Experimental Design

The research effort was divided into three main sections as shown in Table 1. Each section was composed of a series of subjective comparisons designed to examine possible boom parameter-human response relationships using a paired comparison technique. In all tests the waveforms to be compared were presented to human subjects seated singly in the pressure chamber of the sonic boom simulator. Each pair of booms was presented at 4 second intervals, with a duration of 2 seconds between each boom of the pair. The first boom of the pair was designated the standard with the second boom transient being compared relative to the subjective judgment of the standard. The subject was required to state whether the second boom was louder, equal to, or softer, in the tests using loudness as a criterion, or more, equally, or less annoying in the case of the subjects basing their judgments on annoyance. Perceived stimulus equality was determined through a technique utilizing the method of limits in which the experimenter varied the amplitude of the comparison stimulus systematically in discreet increments of 2.0 dB. Presentation order effects were compensated for using AB and BA stimulus presentation order. A total of 67 subjects, all Lockheed employees stationed at Rye Canyon Research Laboratory, participated in the three part test series. Both male and female subjects participated in the test series. Subjects ranged in age from 20 to 57 years with the mean age at 34.2 years. Tests were performed with the experimenter recording the subjects responses.

Sample instruction sheets are shown in Appendix 1. The initial testing session with each subject began with a learning period of

TABLE 1.

RESEARCH TEST PROGRAM SUMMARY

	PARAMETERS EXAMINED
SERIES I:	RISE TIME: 1, 3, 10 MSec. DURATION: 100, 350, 500 MSec. REFERENCE LEVELS: 0.8, 1.6, 2.4 PSF SUBJECTIVE CRITERIA: Loudness, annoyance SIGNATURES USED: Idealized N-Waves APPROX. TESTING HOURS: 180
SERIES II:	SIGNATURES USED: 1/2 N-Waves at standard reference level of 1.6 PSF with peaks of 2.2 and 3.3 PSF added to bow wave of test waveforms. DURATION: 180 MSec. CRITERION: Loudness APPROX. SUBJECT TESTING HOURS: 10
SERIES III:	SIGNATURES USED: 1/2 N-Wave "Sawtooth" waves with variable interpeak spacing. A & B configurations INTERPEAK DURATIONS: 2, 4, 8, 16, 32, 64 MSec. DURATION: 150 MSec REF. LEVEL: 1.6 PSF CRITERION: Loudness APPROX. TESTING HOURS: 44

approximately ten minutes during which the experimenter explained the instructions and allowed the subject to make a practice test run under actual testing conditions. Each individual subject was tested for approximately 50 minutes; attempts at longer sessions tried during pretesting periods had resulted in fatigue and inconsistent judgments. Within the course of an individual session, the chamber was opened after every three test trials (approx. 15 min.) to allow fresh air to circulate in the airtight testing chamber and to give the subject a brief rest period. Each test subject returned for testing at intervals of approximately 4 days. An attempt was made to maintain this 4 day interval throughout the test series in the interest of controlling for any possible intertrial learning (extinction) effects.

The complete test program is shown in Tables 2 and 3. The Series I tests comprised the majority of the total program effort, involving approximately 180 subject testing hours. The tests in Series I were designed to attempt to specify the relationships between sonic boom signature duration, rise time and human subjective response, at three different standard intensity levels. Standard intensity levels were 0.8, 1.6, and 2.4 PSF, with the reference signature at each of these levels consisting of an N-wave of 350 ms duration, having a rise time of 3 ms. Both AB and BA presentation orders were used in the interest of correcting for possible stimulus order effects. The subjects in Series I were divided into two groups of 20 persons each, Group A using loudness as a judgment criterion, and Group B making their judgments using annoyance as a basis for comparison. Reference to Table 1 will indicate the details of each individual waveform comparison. As indicated previously, three standard reference levels were used, with both groups of 20 subjects making 9 waveform comparisons at each level, (using AB and BA orders) for a total of 54 Series I trials for each test subject. Idealized N-waves, free from any simulated atmospheric distortion were used for all test signatures in this series.

Series II was the shortest test series of the program, involving approximately 10 subject testing hours. This series of comparison trials was designed to assess the modifying effects on subjective loudness of the addition of a short duration peak on the "bow" part of 1/2 N-wave transients. 1/2 N-waves were used in the interest of eliminating any potential subjective "averaging" effects occurring with the presence of a complete signature. The reference signature, as shown in Table 3, consisted of a 1/2 N-wave, presented at 1.6 PSF with a duration of 180 ms and a rise time of 1 ms. The two test signatures consisted of the basic reference 1/2 N-wave with short duration peaks of 2.2 and 3.3 PSF total amplitude added to the bow wave. As before, both AB and BA stimulus presentation orders were used.

Series III was an investigation of the modifying effects of inter-peak spacing of "sawtooth" 1/2 N-waves on subjective loudness. Table 3 indicates the content of this phase. Approximately 44 subject testing hours were used to evaluate the differences between the 1.6 PSF 1/2 N-wave of 150 ms duration reference signature and the type 1 and 2 "sawtooth" waveforms having different interpeak durations. Six interpeak durations, 2, 4, 8, 16, 32 and 64 ms, were chosen for examination on the basis of data obtained prior to beginning the present reported program. For each type "sawtooth" wave of a particular interpeak spacing, trials were run using AB and BA stimulus presentation order, resulting in a total of 24 subjective comparisons for each of the 20 test subjects. In both Series II and III, the rise time filter network in the simulator was adjusted to produce transients having rise times of 1. ms.

TABLE 2

SERIES I

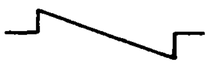
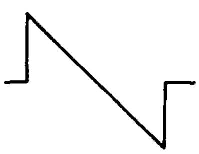
STANDARD				COMPARISON				
TYPE	PSF	DUR.	R.T.	TYPE	PSF@=	DUR.	R. T.	N
N-WAVE	.8	350	3	N-WAVE	0.8	100	1	20L, 20A
					0.8	100	3	20L, 20A
					0.8	100	10	20L, 20A
				N-WAVE	0.8	350	1	20L, 20A
					0.8	350	3	20L, 20A
					0.8	350	10	20L, 20A
				N-WAVE	0.8	500	1	20L, 20A
					0.8	500	3	20L, 20A
					0.8	500	10	20L, 20A
N-WAVE	1.6	350	3	N-WAVE	1.6	100	1	20L, 20A
					1.6	100	3	20L, 20A
					1.6	100	10	20L, 20A
				N-WAVE	1.6	350	1	20L, 20A
					1.6	350	3	20L, 20A
					1.6	350	10	20L, 20A
				N-WAVE	1.6	500	1	20L, 20A
					1.6	500	3	20L, 20A
					1.6	500	10	20L, 20A
N-WAVE	2.4	350	3	N-WAVE	3.3	100	1	20L, 20A
					3.3	100	3	20L, 20A
					3.3	100	10	20L, 20A
				N-WAVE	3.3	350	1	20L, 20A
					3.3	350	3	20L, 20A
					3.3	350	10	20L, 20A
				N-WAVE	3.3	500	1	20L, 20A
					3.3	500	3	20L, 20A
					3.3	500	10	20L, 20A

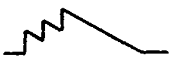
TABLE 3

SERIES II

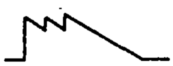
STANDARD				COMPARISON				
TYPE	PSF	DUR.	R.T.	TYPE	PSF@=	DUR.	R.T.	N
1/2 N-WAVE	1.6	180	1	1/2 N-WAVE	1.6	180	1	20L
				1/2N + PK	2.2 PK	180	1	20L
				1/2N + PK	3.3 PK	180	1	20L

SERIES III

STANDARD				COMPARISON					
TYPE	PSF	DUR.	R.T.	TYPE	PSF	DUR.	R.T.	SHK SP.	N
1/2 N	1.6	150	1	1	1.6	150	1	64	20L
				1	1.6	150	1	32	20L
				1	1.6	150	1	16	20L
				1	1.6	150	1	8	20L
				1	1.6	150	1	4	20L
				1	1.6	150	1	2	20L
				2	1.6	150	1	64	20L
				2	1.6	150	1	32	20L
				2	1.6	150	1	16	20L
				2	1.6	150	1	8	20L
				2	1.6	150	1	4	20L
				2	1.6	150	1	2	20L



TYPE 1



2

2) Simulation System

The basic pressure chamber simulation system concept consists of recording an appropriate electrical analog of the pressure signature on magnetic tape, delivering this signal to high power direct current amplifiers, and driving loudspeakers coupled to an airtight chamber. This system makes possible a faithful reproduction of a variety of sonic boom transients within the limits of the 0.3 to 500 cps passband of the system. Linear operation of the system allows overpressures of 4.5 PSF to be achieved with rise times of approximately 10 ms. Rise times of 1 ms duration may be reproduced at more conservative levels (2-3 PSF) and the system features circuitry specialized for the accurate control of this parameter through a variable range of 1 to 10 ms. Overpressure level is variable in 1 dB steps over the effective linear range. A unique noise squelch circuit is employed to effectively reduce undesired amplifier input signals and is controlled by an electrical command signal recorded on a separate track of the boom signal tape. The pressure chamber was 70 cubic feet in volume, and measured approximately 4 ft. x 3-1/2 ft. x 5 ft. in size. Access to the chamber interior was obtained through a hinged wall arrangement. The chamber interior was fitted with a wall mounted intercom system, a small light for interior illumination and a chair for the subject. The pressure field in the chamber was monitored continuously during testing sessions with a Photocon Model 464 capacitor microphone using a Photocon Model DG 605D Dynagage system with Tektronix Model 564 Storage and Model 502 Dual Beam Oscilloscopes. In addition, a Honeywell Model 906 recording oscillograph was available to permantently record system performance at the weekly performance calibration checks conducted throughout the testing phases of the research program. The chamber and control room facility were located adjacent to each other in an open area beneath the main laboratory complex, as shown in Figures 1 and 2. Oscillographic recordings of system performance using sample signatures from each test series are shown in Figures 3, 4, 5 and 6.

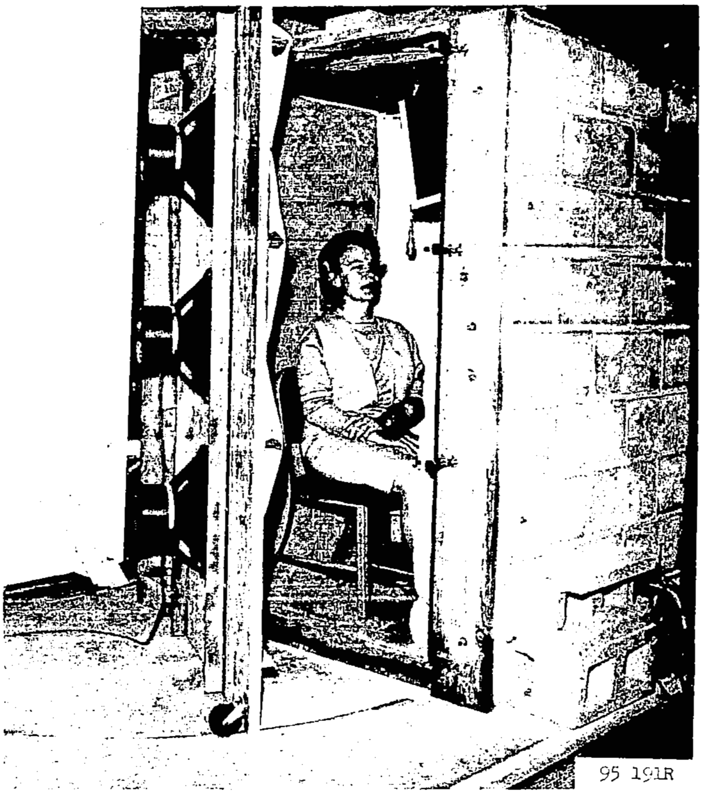


Figure 1. Sonic Boom Simulation Chamber - Note Hinged Wall Access.

Figure 2. Simulator Control Room Adjacent to Airtight Test Chamber, Subject and Experimenter at Testing Stations.

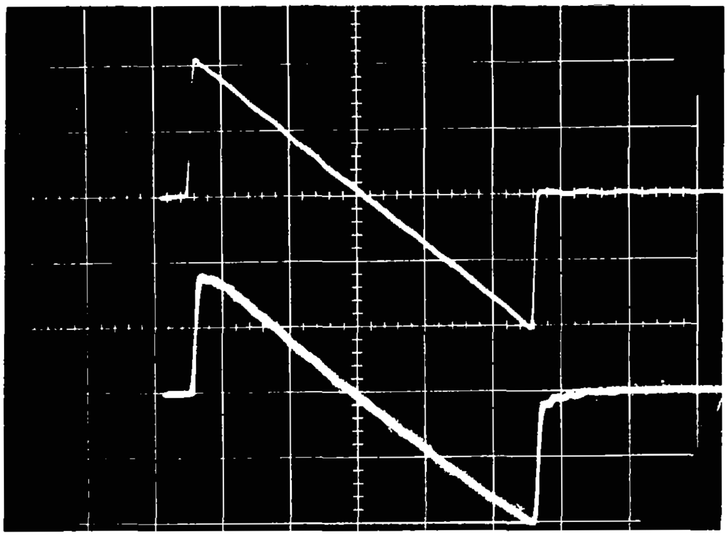


Figure 3. Typical Simulation System Performance
Top: Input Command Signal
Bottom: Chamber Pressure Time History
Series I N-Wave, 500 ms. Duration, 10 ms. Rise Time, 1.6 PSF. - Sweep = 100 ms/cm.

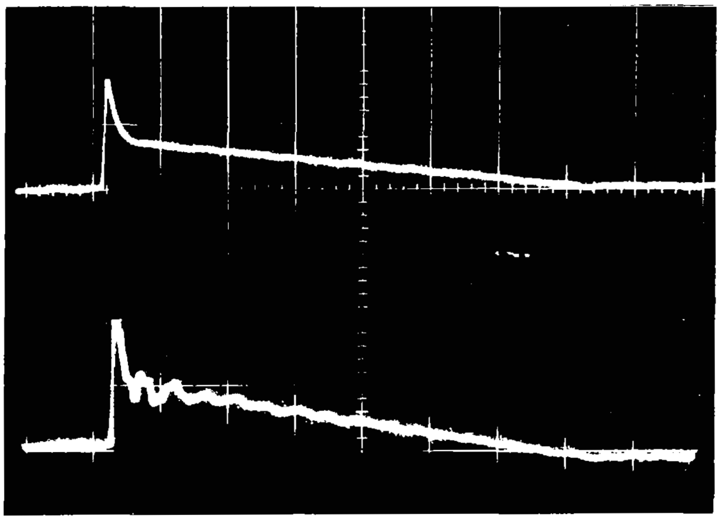


Figure 4. Typical Simulation System Performance
Top: Input Command Signal
Bottom: Chamber Pressure Time History
Series II 1/2 N-Wave, 150 ms. Duration, 1 ms. Rise Time, 3.3 PSF. (Peak), Sweep = 25 ms/cm.

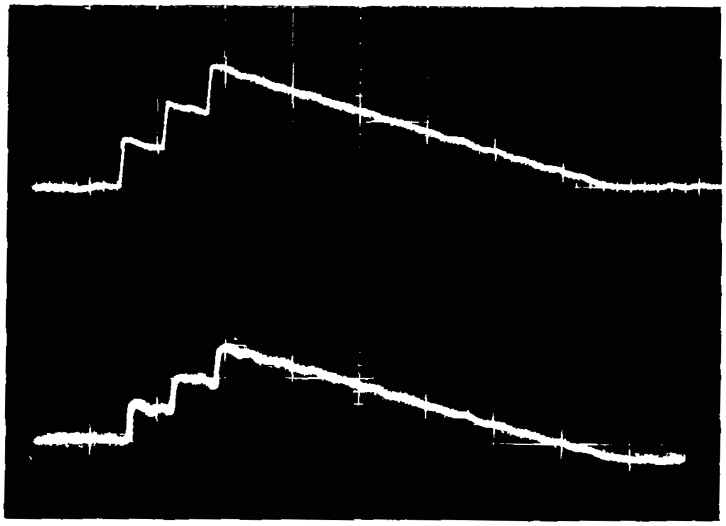


Figure 5. Typical Simulation System Performance
Top: Input Command Signal
Bottom: Chamber Pressure Time History
Series III Type 1 1/2 N-Sawtooth Wave with 16 ms.
Interpeak Spacing @ 1.6 PSF. - Sweep: 25 ms/cm.

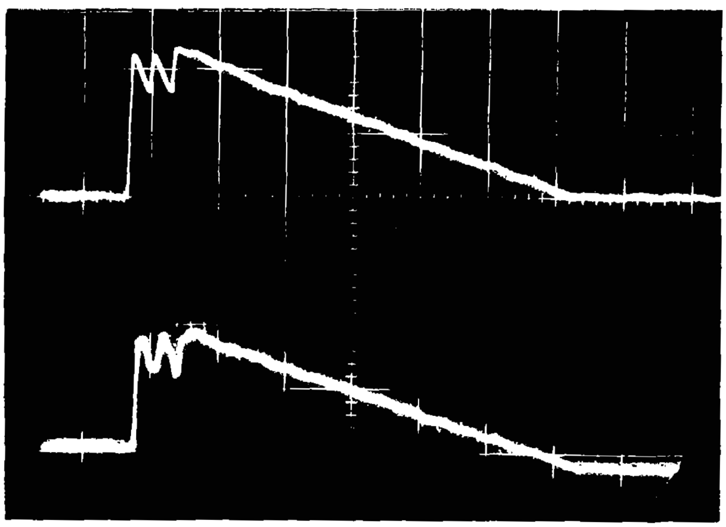


Figure 6. Typical Simulation System Performance
Top: Input Command Signal
Bottom: Chamber Pressure Time History
Series III Type 2 1/2 N-Sawtooth Wave with 16 ms.
Interpeak Spacing @ 1.6 PSF. - Sweep: 25 ms/cm.

Spectral Analysis of Boom Test Signatures:

A series of spectral energy analyses were made using selected test waveforms from each of the three test series. These analyses were completed in the interest of establishing objective criteria which might be compared with the subjective judgments of the test subjects. The analyses provided computer tabulations (not shown in the test data), spectral energy plots (as shown in Figures 13 to 28), along with pressure time histories (not shown in the test data). Of the 25 different waveform signatures used in the test program, 16 were used for spectral analysis, along with several other signals used for system calibration and noise level checks.

Several steps were required in the implementation of the analysis. The pressure time histories of the various test signatures as reproduced in the simulator were recorded on FM magnetic tape using an appropriate low frequency microphone system (Photocon). The microphone was positioned in the chamber at approximately the ear level of a seated test subject. The magnetic tape data was then converted from analog to digital form using the EAI hybrid computer facility located at the Rye Canyon Research Laboratory. The binary tape was then transported to the computer facility at the Stanford Research Institute where an existing Fourier integral computer program specialized for analysis of these transient phenomena was used to implement plotting of the spectral energy characteristics of each signature.

The 1/2 N-wave spectra shown in Figure 18 indicates a decrease in spectrum energy level dropping at a rate of approximately 6 dB per octave, which agrees relatively closely with mathematical predictions. The high peaks and nulls in the curve follow closely the established frequency response of the testing chamber. 500 Hz low pass filters were used in the amplification system driving the chamber (to eliminate the FM tape carrier signal), consequently the spectral content of each of the waves analyzed above 500 Hz is mostly analysis system noise and should be disregarded.

Experimental Results and Discussion

Series I.

The results of the Series I tests are shown in tabular form in Table 4, and graphically in Figures 7, 8, 9, and 10. As mentioned in the program description presented in a previous section of this report, the individual waveform comparisons in this series of tests were designed to identify relationships between signature duration and rise time at three different standard overpressure levels, using loudness and annoyance as judgment criteria. The levels shown in Table 4 represent the average change in dB required in the test comparison signature for a judgment of subjective equality using the judgments of 20 test subjects for the evaluation. The standard deviation provides an indication of the variability in judgments of the subjects for each signature comparison.

The comparisons shown in Table 4 and Figure 7 indicate small differences to exist in equality judgments as the duration of the test signature is varied. Variations of typically less than 2 dB are seen at each of the three overpressure ranges examined. The rise time of these test signatures has apparently little duration effect, as shown in Table 7. Both loudness and annoyance are seen to be a function of rise time at any one particular duration. The variance is relatively constant for each of the three durations at any one rise time, which supports the finding that duration has little effect on judgments of loudness or annoyance. Spectral analysis indicates the greatest differences in the waveforms of 100, 350 and 500 ms. duration to exist at frequences generally below 10 Hz, with the fundamental frequency seen to be a function of the duration of the signature. With the ear acting essentially as a high pass filter network, these large sub-audible spectral components are of little apparent auditory significance and the potential for subjective differences becomes a function of the spectrum associated with the bow and tail waves and any summation effects thereof.

Interesting differences were noted with variations in rise time. Figures 8, 9 and 10 indicate the results of the analysis of these test comparisons conducted at 0.8, 1.6 and 2.4 PSF reference levels, respectively. Subjective loudness or annoyance is seen to decrease as the rise time is increased, with levels of about 13 dB typical of subjective differences between signatures having rise times of 1 and 10 ms. Reference to Figures 8, 9 and 10 will indicate the relationship between standard reference level and judgments of the rise time loudness or annoyance with differences between identical comparisons at different reference levels being on the order of 1 dB. Reference level would appear to have little effect on rise time loudness or annoyance comparisons, for the range of the three reference levels examined.

Previous studies conducted by Lockheed-California Company have established essentially the same increase rise time - lower loudness relationship as appears to be evident in this study. Spectral differences have been offered as possible explanation for the definite subjective changes in loudness and annoyance noted in this type of investigation. The spectral analysis performed on Series I N-waves having 1, 3 and 10 ms. rise times appears to support the subjective data. Figures 14, 15 and 16 show the spectral characteristics of the test signatures used here. The range of greatest spectral difference for the 1 ms. rise time N-wave with respect to the 3 ms. standard reference occurs between approximately 200 and 500 Hz. The average difference is seen to be on the order of 7 dB with maximum differences of about 12 dB. In the case of the 10 ms. rise time N-wave, the range of difference extends to approximately 80 Hz with a definite decrease in energy evident from this frequency up to cutoff at 500 Hz. In summary, the spectral analysis indicates the 1 ms. rise time wave to have the most energy between 20 to 500 Hz; the 3 ms. wave averages about 7 dB less from approximately 120 to 500 Hz; and the 10 ms. rise time wave averages about 16 dB less for the range 120 to 500 Hz. Testing indicates the 1 ms. wave to be loudest and most annoying, followed by the 3 and 10 ms. rise time signatures. Using an audibility criterion, the spectral analyses appear to support the subjectively determined loudness and annoyance judgments.

Much interest has been generated with regard to the topic of instructional set as applied to psychoacoustic experimentation. In the interest of examining this potential parameter, the entire Series I test schedule was run using both subjective loudness and annoyance as judgment criteria. The results will be noted with reference to Table 4 and Figures 7, 8, 9, and 10. Loudness and annoyance criteria seem to effect little difference for all of the comparisons except these involving signatures with 10 ms. rise times. A subjective difference of about 2 dB is consistently noted in the analysis of comparisons using this particular waveform parameter. For identical comparisons, the data indicate the annoyance level to be less than that subjectively determined for loudness. The standard deviations for both comparisons are large when compared with the remainder of the investigations, with the variance in judgments using a loudness criteria greater than that obtained using an annoyance basis. Many of the test subjects expressed difficulty making judgments with the 10 ms. wave, hence the possibility of learning variables operating here seems plausible. It would appear that for the purposes of comparing waves of varying rise time, as accomplished in this experimental program, the establishment of an annoyance criteria would appear more valid than loudness as a criterion, in terms of the apparent variance in subjective evaluation.

The results of an analysis of variance performed on the Series I annoyance data are as follows:

1. The variance between rise time comparisons = 655.5 (df = 3)

2. The variance within the rise time series (different durations) = 0.12 (df = 19)

3. Fisher's F ratio = 5462.5 which is highly significant (level greater than .01 level of confidence)

The experimental differences in rise time comparisons are taken, therefore to be real and not due to chance.

An analysis of variance performed on the Series I loudness data yielded the following results:

1. The variance between rise time comparisons = 1103.8 (df = 3)

2. The variance within the rise time series (different durations) = 0.16 (df = 19)

3. Fisher's F ratio = 6893.7 which indicates high significance (greater than 0.01 level of confidence)

As in the case of the data based on annoyance judgments, these rise time differences with the loudness criterion are taken to be real, and not due to chance.

<u>Series II</u>.

The effect on loudness judgments of adding a short duration "spike" transient to the bow wave of an idealized 1/2 N-wave pressure signature was examined in this short test series. Table 5 and Figure 11 indicate the results of the tests which involved 20 test subjects comparing two different "spike" waves with a standard reference idealized 1/2 N-wave. The graph in Figure 11 indicates a loudness increase of 4.35 dB when a spike totaling 2.2 PSF is added to the reference 1.6 PSF N-wave, and 7.7 dB increase when a spike totaling 3.3 PSF is added. Increasing the amplitude of an idealized 1/2 N-wave to twice its original value results in an increase of 6 dB. Thus, the 3.3 PSF peak wave should have a minimum effect of about 6 dB increase when compared with the 1.6 PSF reference, which appears to be the case here, plus some extra loudness factor due to the addition of high frequency energy as a result of the modification to the decaying portion of the 1/2 N-wave. When the spectra of these modified waves are compared with unmodified 1/2 N-waves an increase in spectral energy of about 6 dB through the range of 30 to 400 Hz is seen in the modified spectra, apparently due to the addition of the spike. The additional loudness factor amounts to + 1.7 dB for the 3.3 PSF wave and + 1.35 dB for the 2.2 PSF peak wave.

The standard deviations obtained in this experiment reflect an apparent difference in the subjects ability to make comparisons with different stimulus presentation orders. In view of the total time involved in the experiment (10 subject testing hours) it seems reasonable to assign this finding to a learning effect category.

Using a T test for significant differences between the means of correlated samples, the averaged (AB and BA orders) results from the Series II tests were analyzed with the following results:

1. For the 3.3 PSF peak vs. standard reference, T = 11.50 (df = 38)

2. For the 2.2 PSF peak vs. standard reference, T = 6.40 (df = 38)

3. In both cases the values exceed that required for significance at the .001 level of confidence. The differences between

loudness judgments for the modified waves and the standard are accepted as real and due to factors other than chance.

Series III.

The design of this experiment was first suggested as a result of investigations conducted by Lockheed during the SST program. Near field boom signatures resembling a "sawtooth" configuration had been predicted to occur at certain flight conditions and were seen as a topic for experimentation. A brief test series was run during the summer of 1966 in an attempt to identify potential relationships between the spacing between the peaks of the "sawteeth" and human judgments of loudness. The results of this cursory examination indicated a trend towards a loudness reduction with a reduction in peak spacing, but this relationship was not examined further until the present. As outlined in detail in the program description section of this report, the Series III tests compared 1/2 N-waves of two basic configurations, each at six different interpeak durations, with a standard reference 1/2 N-wave 150 ms. in duration and 1.6 PSF in amplitude. The experimental results are shown in Table 6 and Figure 12 and indicate the existence of a relationship between interpeak durations in the Type 1 waveforms and subjective loudness. Figure 12 graphically illustrates this relationship and indicates the results of the tests using the Type 2 signatures. In contrast to the decrease in loudness apparent with a decrease in Type 1 peak spacing, the Type 2 waves are judged to be relatively equal regardless of interpeak duration.

An analysis of variance was performed on the data and the results are as follows for the Type 1 signature comparisons:

1) For the Type 1 waves, the variance within interpeak trials =

1.18 (df = 19).

2) The variance between AB and BA presentation orders = 8.0 (df = 1).

3) The Fisher's F ratio = 6.77 which is significant at the .05 level of confidence.

The analysis of variance performed on the data for the Type 2 signatures yielded the following:

1) The variance within interpeak trials = 0.023 (df = 19).

2) The variance between AB and BA presentation orders = 0.96 (df = 2).

3) The Fisher's F ratio = 40.8 which is significant at the .01 level of confidence.

The data indicate statistically the operation of presentation order effects in the case of the Type 2 wave comparisons. The actual numerical variance is small however, and the results should be appraised considering this factor.

There are several possibilities which may account for the mechanisms operating in the apparent Type 1 loudness effect. Spectral differences in the waves should provide some basis for objective comparison. The spectral energy analysis performed indicate the waves of Type 1 configuration to have less energy through the range of 0 - 100 Hz than the standard reference signature. Above 100 Hz, the 64 ms. wave appears to have more energy than the balance of the test waveforms, yet still below the levels found for the standard "non-sawtooth" reference. Hence, the increased loudness evident with this 64 ms. test wave (about 1.4 dB) is most likely due to other factors, such as a perceptual summing of the loudness of each of the three individual positive pressure excursions characteristic of this type signature. The apparent decrease in loudness evident with the reduction in peak spacing of the other 5 waveforms is probably due in part to this potential summing (integration) effect and in part to a decrease in spectral energy in the 100 - 500 Hz range, as indicated in the energy analysis. Indeed, the spectra of the Type 1 wave with 2 ms. interpeak spacing appears similar to a "plain" 1/2 N-wave with a rise time of 10 ms., suggesting the possibility that creating bow waves with 2 ms. breaks having pressure increases of 1 ms. or so creates essentially the same subjective effect as might be expected with a rise time increase on the order of 7 ms. or so in a non-peaked wave. As the interpeak duration is decreased beyond 2 ms. the loudness should increase as the bow wave pressure front approaches a smooth (short rise time) increase. Technical limitations inherent in the simulation system limit the present capability to create waves with interpeak spacing less than 2 ms., hence, the relationship expressed in the preceeding sentence is hypothetical only. Evaluation of this apparent loudness effect should be appraised in light of the magnitude of the numerical difference (4 dB $\pm$) obtained in the tests. Previous experimentation conducted at Lockheed has indicated the ability of human subjects to detect changes in impact type transients to be on the order of 1-1/2 dB. Considering this variable in conjunction with the actual overpressure change associated with this 4 dB reduction (in the case of a 2 ms. spaced wave) leaves one with questions as to the practical significance of this finding. The identification of this relationship does suggest an instance however, when changing the shape of the generating aircraft could very possibly affect perception of the sonic boom.

TABLE 4

SERIES I-EXPERIMENTAL RESULTS N-WAVE COMPARISONS

STANDARD REFERENCE SIGNATURE: N-WAVE, 350 MS DURATION, 3.0 MS RISE TIME

JUDGMENT CRITERION	DUR. OF COMPAR.	LEVEL CHANGE (dB+) REQUIRED FOR JUDGED EQUALITY — AB Order (STD. 1st) 1 ms R.T. Level	1 ms R.T. S.D.	3 ms R.T. Level	3 ms R.T. S.D.	10 ms R.T. Level	10 ms R.T. S.D.	BA Order (STD. 2nd) 1 ms R.T. Level	1 ms R.T. S.D.	3 ms R.T. Level	3 ms R.T. S.D.	10 ms R.T. Level	10 ms R.T. S.D.	
Loudness	100 ms.	-4.79	1.69	+0.41	0.99	+10.05	2.48	-2.56	1.04	+1.29	1.21	+11.11	0.74	STD. LEVEL 0.8 PSF
Annoyance	100 ms.	-4.05	1.30	+0.30	1.09	+ 7.09	1.99	-2.75	1.75	+0.74	1.20	+ 8.52	2.33	
Loudness	350 ms.	-4.94	1.28	-0.69	0.61	+ 8.21	2.30	-3.20	1.61	-	-	+10.34	1.67	
Annoyance	350 ms.	-4.09	1.05	-0.64	0.87	+ 5.99	0.70	-3.40	1.06	-	-	+ 7.45	2.05	
Loudness	500 ms.	-5.09	1.41	-0.78	0.71	+ 8.00	1.91	-3.70	1.42	±0.00	0.70	+10.44	1.96	
Annoyance	500 ms.	-4.88	1.33	-0.81	0.57	+ 5.80	2.19	-4.10	1.07	-0.68	0.78	+ 6.82	1.77	
Loudness	100 ms.	-4.65	1.20	-0.02	0.90	+ 8.95	2.11	-3.00	1.30	+0.78	1.12	+10.30	2.41	STD. LEVEL 1.6 PSF
Annoyance	100 ms.	-3.68	1.00	+0.55	0.61	+ 7.19	2.06	-3.20	1.06	+0.48	1.18	+ 7.78	2.75	
Loudness	350 ms.	-4.74	1.16	-0.12	0.51	+ 7.92	2.03	-3.49	1.50	-	-	+ 9.36	1.61	
Annoyance	350 ms.	-4.40	1.12	-0.08	0.44	+ 5.89	1.35	-3.78	0.82	-	-	+ 7.65	1.60	
Loudness	500 ms.	-4.79	0.72	-0.49	0.60	+ 7.99	5.56	-4.04	1.22	-0.35	0.63	+ 8.93	5.29	
Annoyance	500 ms.	-4.36	1.34	-0.38	0.63	+ 5.43	2.01	-3.20	0.97	-0.38	0.69	+ 6.50	1.75	

TABLE 4 (Cont.)

SERIES I-EXPERIMENTAL RESULTS N-WAVE COMPARISONS

STANDARD REFERENCE SIGNATURE: N-WAVE, 350 MS DURATION, 3.0 MS RISE TIME

JUDGMENT CRITERION	DUR. OF COMPAR.	LEVEL CHANGE (dB+) REQUIRED FOR JUDGED EQUALITY: AB Order (STD. 1st) 1 ms R.T. Level	S.D.	3 ms R.T. Level	S.D.	10 ms R.T. Level	S.D.	BA Order (STD. 2nd) 1 ms R.T. Level	S.D.	3 ms R.T. Level	S.D.	10 ms R.T. Level	S.D.
Loudness	100 ms.	-4.35	1.03	+0.29	1.03	+ 7.75	1.48	-3.37	1.01	+0.44	0.72	+ 8.29	1.20
Annoyance	100 ms.	-3.40	1.14	+0.21	0.67	+ 6.10	2.20	-2.56	1.20	+0.19	0.70	+ 7.00	1.60
Loudness	350 ms.	-4.83	0.71	+0.17	0.36	+ 7.65	0.77	-4.00	0.91	-	-	+ 8.46	0.94
Annoyance	350 ms.	-3.77	0.60	-0.13	0.42	+ 5.81	1.35	-3.06	1.08	-	-	+ 6.76	1.26
Loudness	500 ms.	-4.54	0.86	-0.15	0.49	+ 7.29	0.18	-4.00	1.50	-0.27	0.70	+ 8.15	1.65
Annoyance	500 ms.	-3.87	1.45	-0.23	0.53	+ 5.31	2.22	-3.37	1.28	-0.12	0.47	+ 6.17	2.01

STD. LEVEL 2.4 PSF

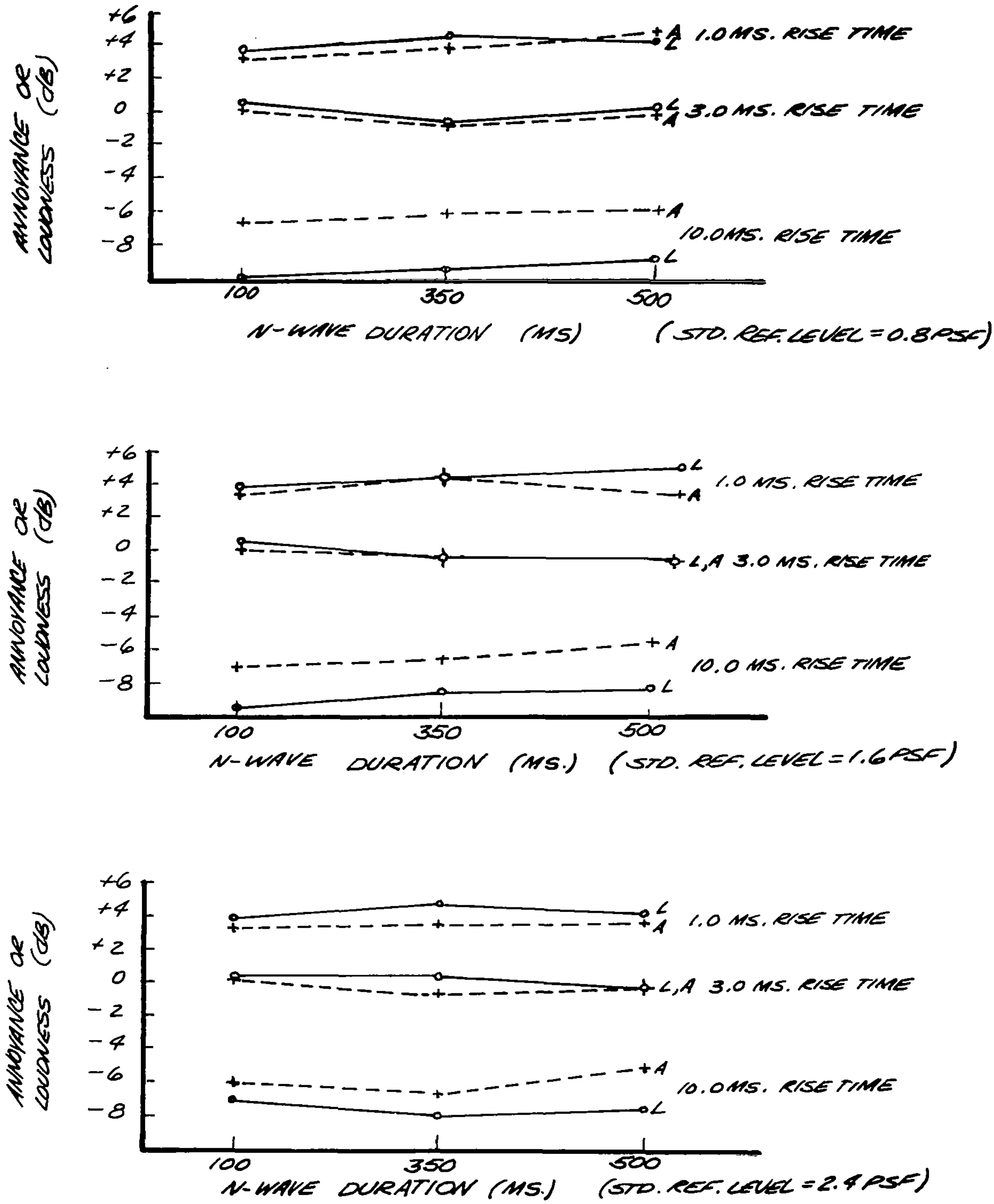


FIG. 7. RELATIVE ANNOYANCE & LOUDNESS VS. SIGNATURE DURATION — SERIES I

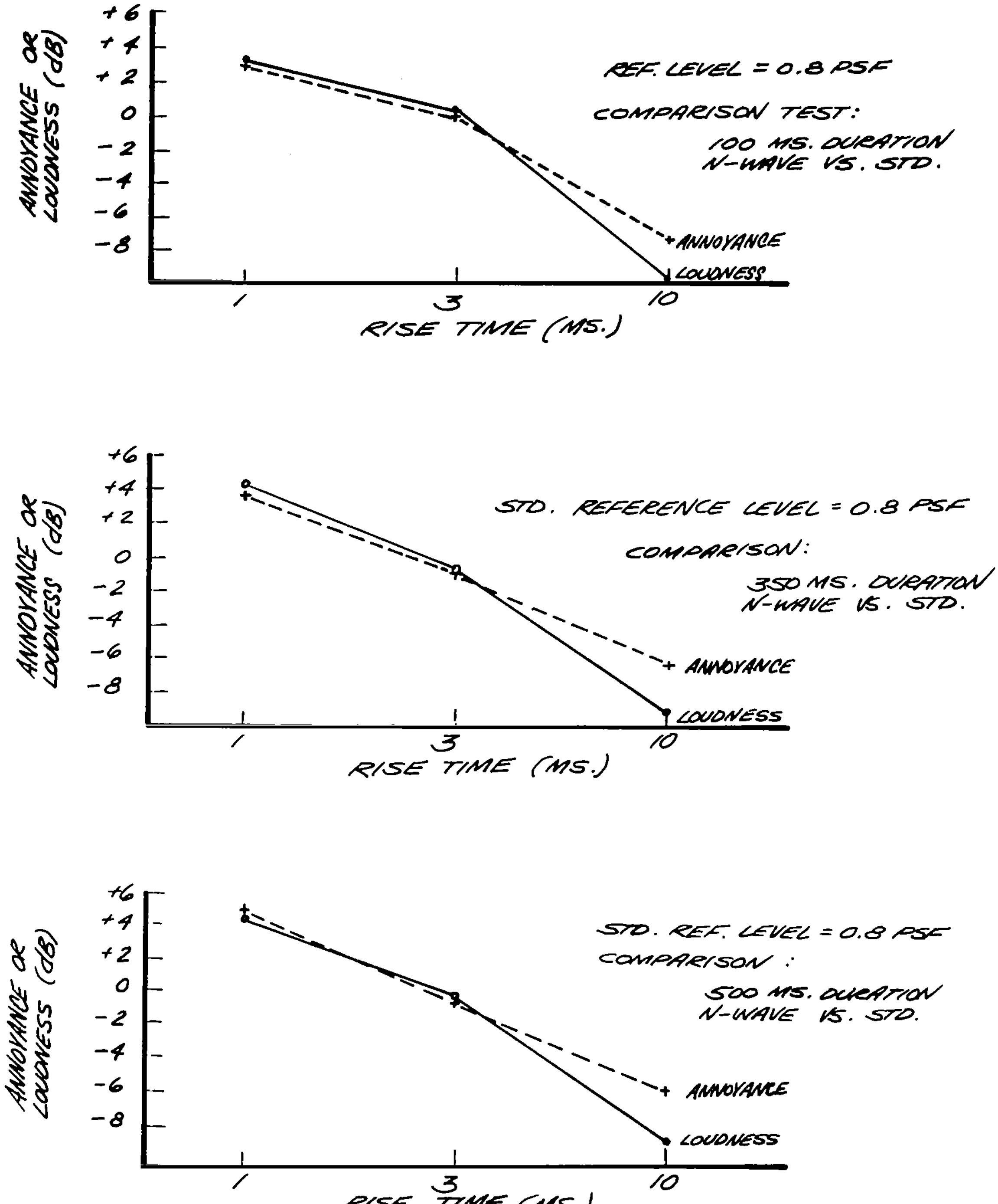


FIG. 8.
REL. LOUDNESS & ANNOYANCE VS. RISE TIME — SERIES I.

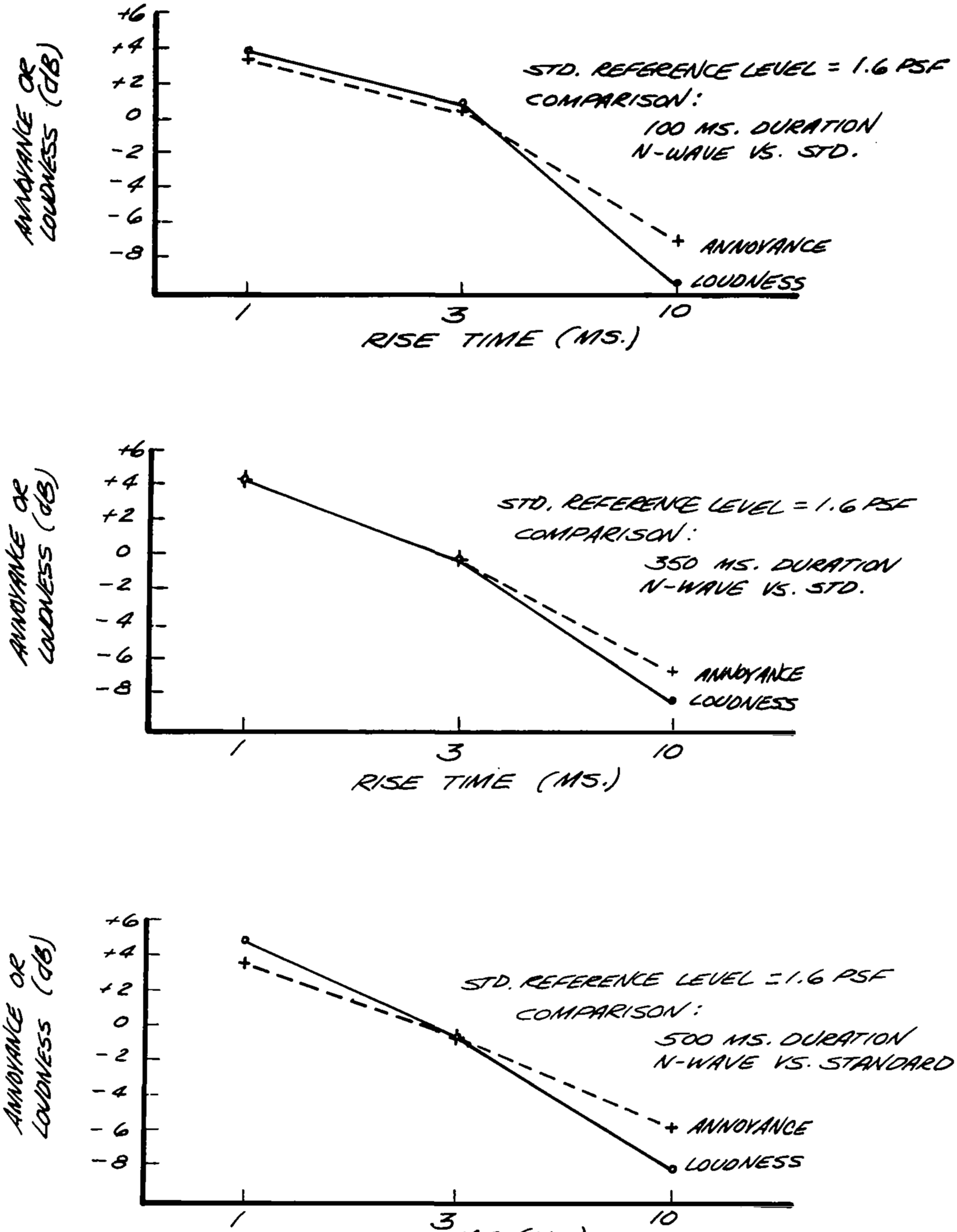


FIG. 9. RELATIVE LOUDNESS OR ANNOYANCE VS. RISE TIME
— SERIES I —

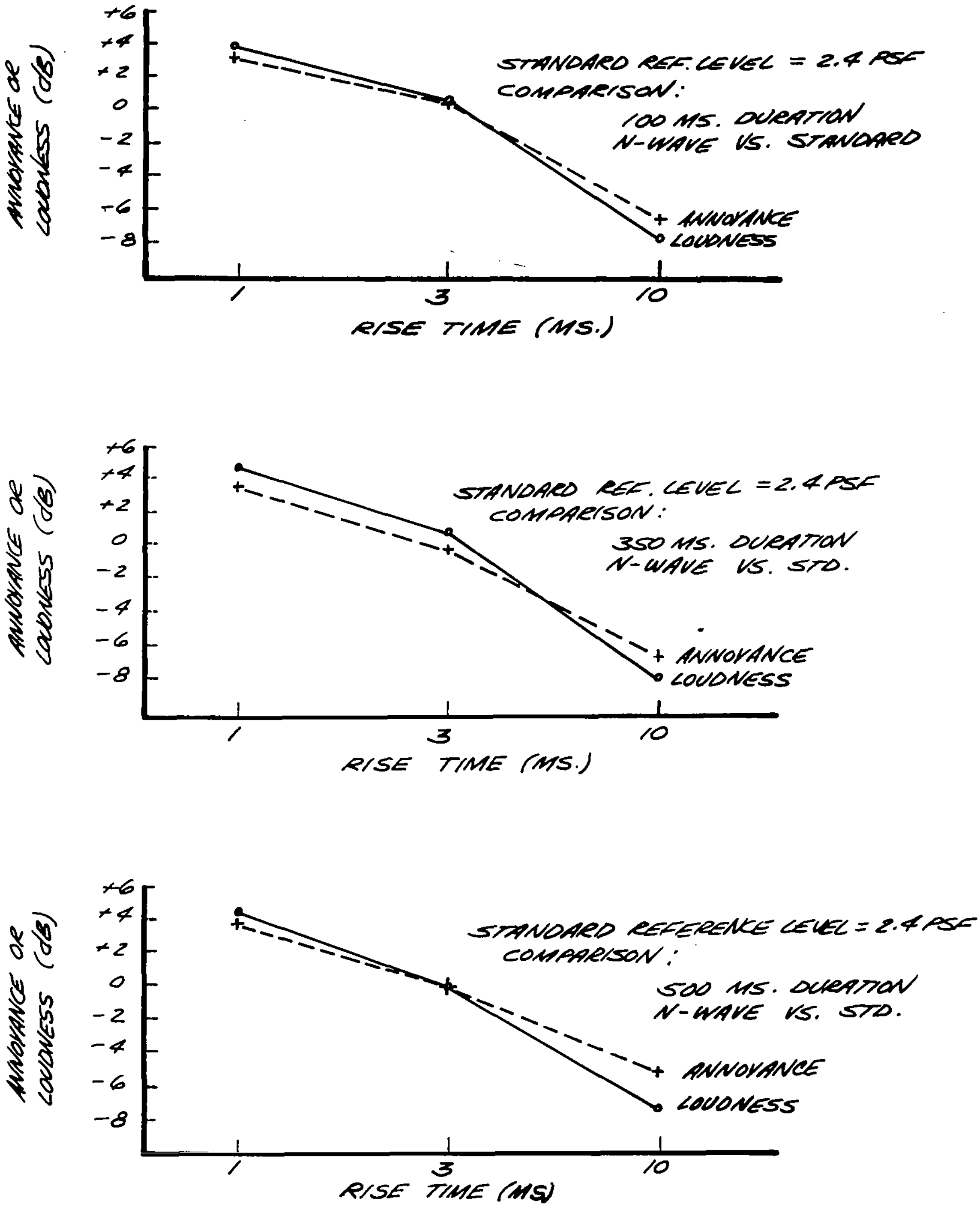


FIG. 10. RELATIVE ANNOYANCE + LOUDNESS VS. RISE TIME
— SERIES I —

TABLE 5

SERIES II EXPERIMENTAL RESULTS (1/2 N-WAVES WITH SHORT DURATION SPIKES ON BOW WAVE)

STANDARD REFERENCE SIGNATURE: Idealized 1/2 N-wave
180 ms Duration
1.6 PSF

COMPARISON SIGNATURE	LEVEL CHANGE REQUIRED FOR SUBJECTIVE EQUALITY: AB ORDER	LEVEL CHANGE REQUIRED FOR SUBJECTIVE EQUALITY: BA ORDER
3.3 PSF SPIKE	-8.15 dB STD.DEV: 1.25	-7.24 dB STD.DEV: 0.75
2.2 PSF SPIKE	-4.79 dB STD.DEV: 1.01	-3.90 dB STD.DEV: 0.72
1.6 PSF 1/2 N-WAVE (Control Comparison)	-0.56 dB STD.DEV: 0.69	

TABLE 6

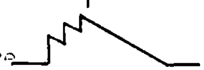
SERIES III EXPERIMENTAL RESULTS

"SAWTOOTH" 1/2 N-WAVES WITH DIFFERENT INTERPEAK DURATIONS

STANDARD REFERENCE SIGNATURE: 1/2 N-Wave
150 ms Duration
1.6 PSF

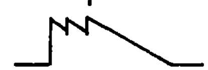
TYPE 1: Level Required For Subjective Equality (dB) & Standard Deviation

INTERPEAK DURATION (ms)	AB Level	AB S.D.	BA Level	BA S.D.
2	+3.9	1.18	+4.56	1.45
4	+3.39	1.27	+3.91	1.33
8	+2.86	1.05	+3.79	2.32
16	+2.20	1.11	+3.49	1.33
32	+0.41	1.04	+1.38	1.64
64	-1.9	1.27	-0.85	1.24

Test Signature  Type 1

TYPE 2: Level Required For Subjective Equality (dB) & Standard Deviation

INTERPEAK DURATION (ms)	AB Level	AB S.D.	BA Level	BA S.D.
2	-0.16	0.43	-0.26	0.75
4	-0.36	0.59	-0.10	0.56
8	-0.39	0.60	-0.40	0.86
16	-0.24	0.59	±0.00	1.05
32	-0.17	0.77	+0.26	1.03
64	-0.21	0.61	+0.76	1.16

Test Signature  Type 2

Order Effect (STD. vs STD) = -0.20

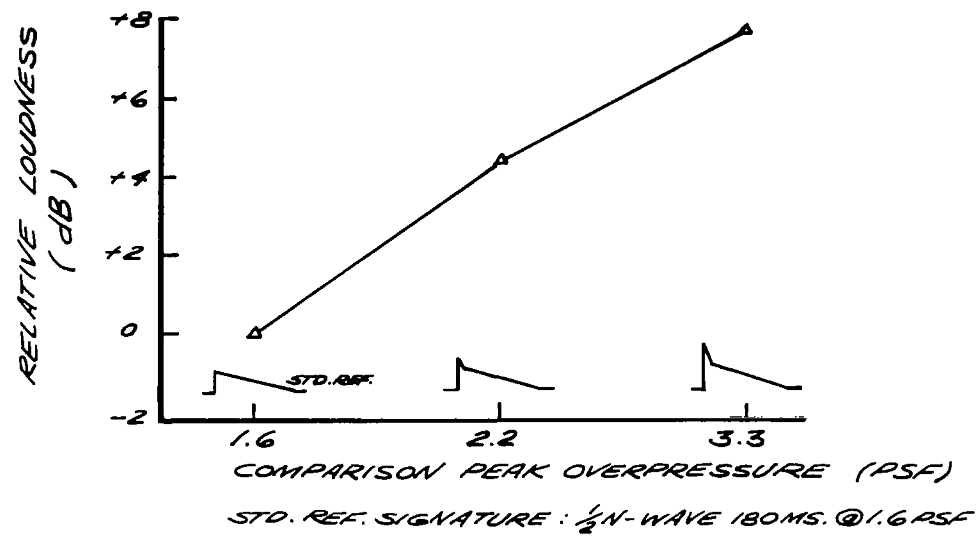


FIGURE 11. RELATIVE LOUDNESS OF ½N-WAVES WITH BOW WAVE MODIFICATION - SERIES II

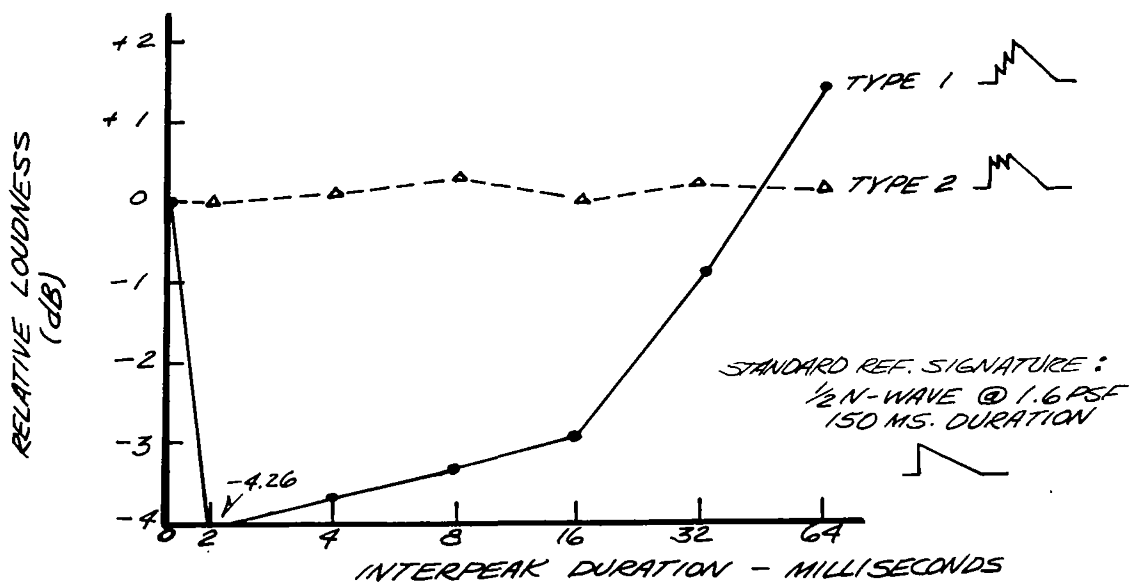


FIGURE 12. RELATIVE LOUDNESS OF ½N-WAVES (TYPES 1 & 2) WITH DIFFERENT "SAWTOOTH" SPACING — SERIES III —

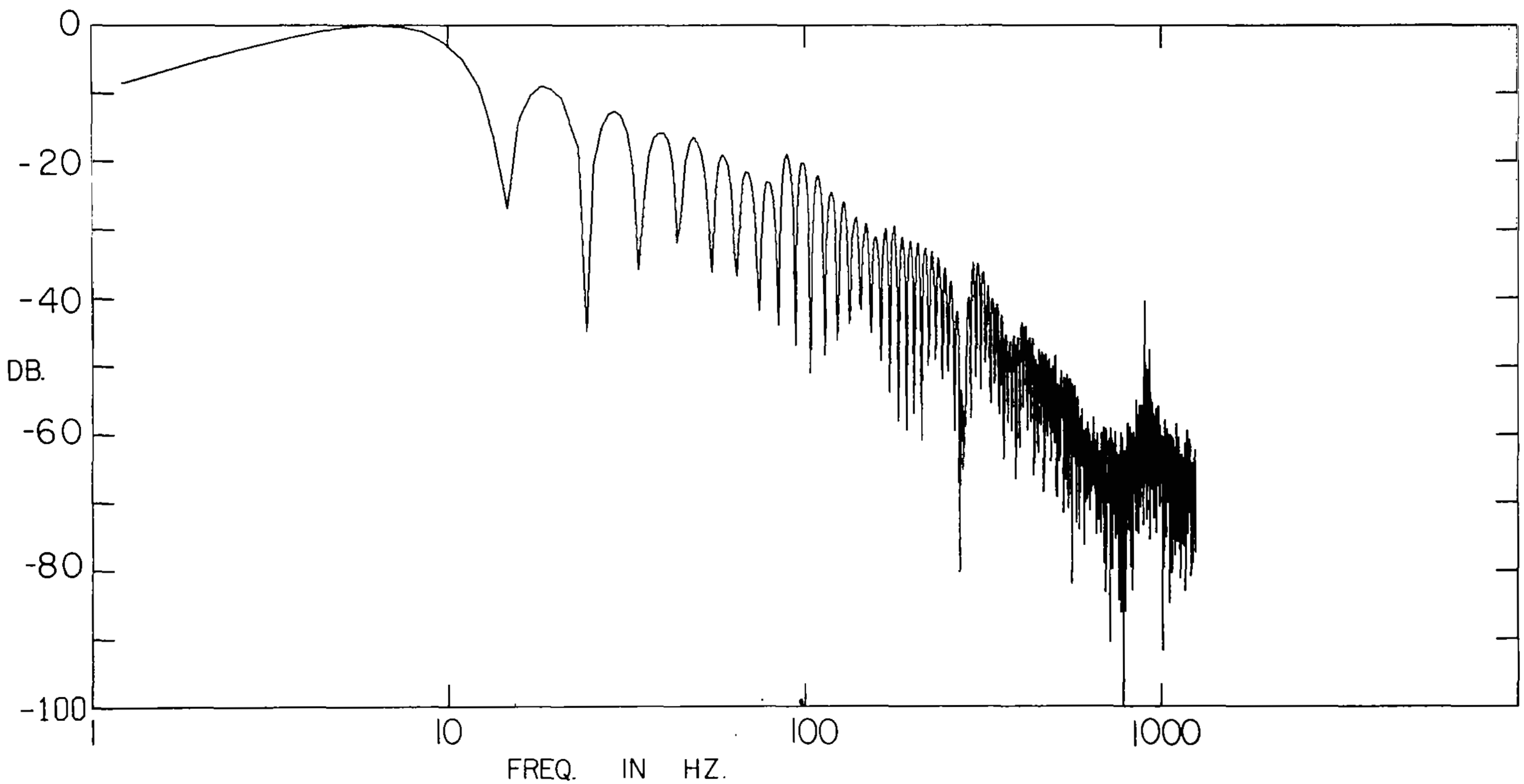


Figure 13 Spectral Energy Characteristics of Idealized 100 ms.Duration N-Wave @ Rise Time = 1 ms. as Used in Series I Tests.

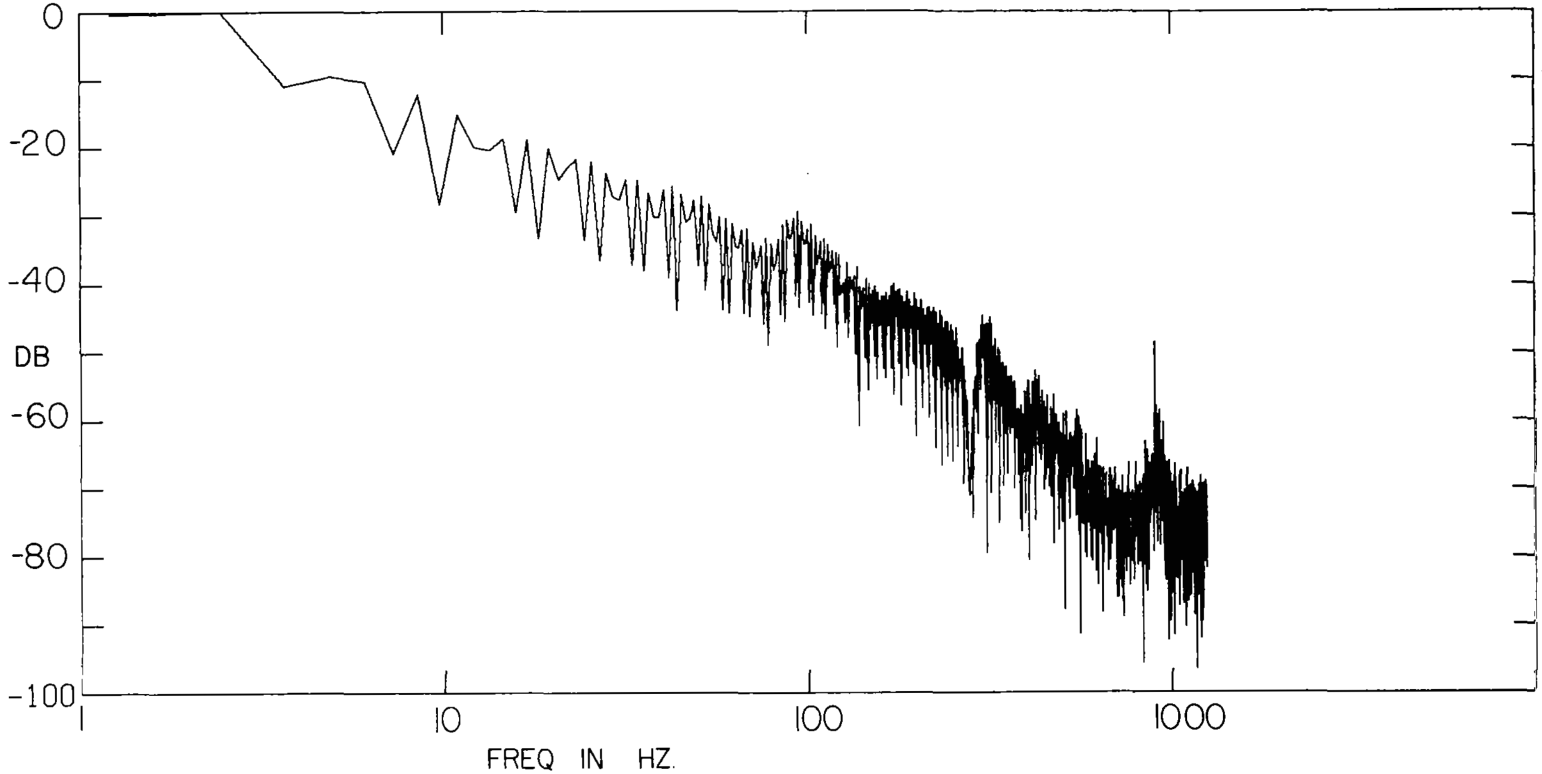


Figure 14 Spectral Energy Characteristics of Idealized 350 ms. Duration N-Wave @ Rise Time = 1 ms. as Used in Series I Tests.

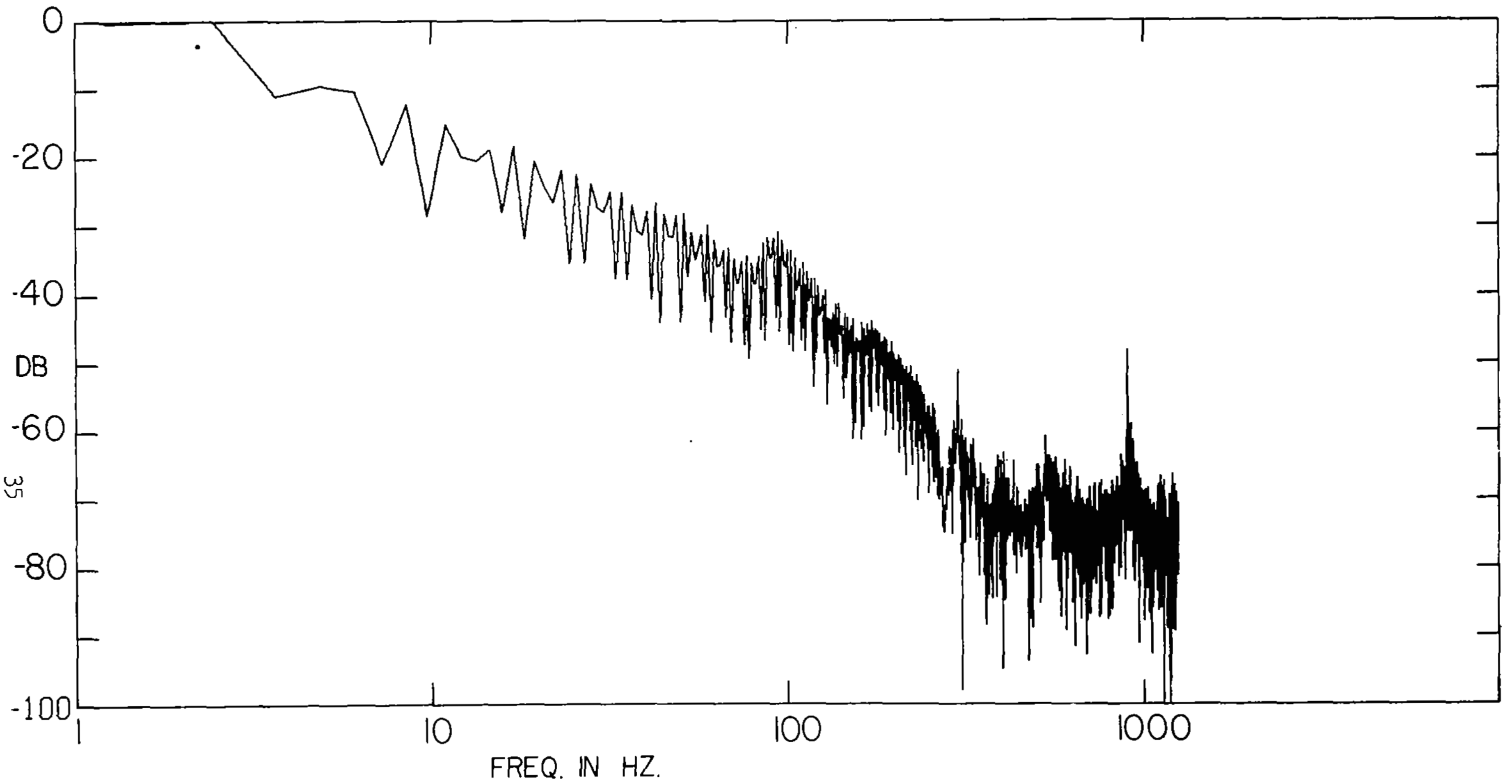


Figure 15 Spectral Energy Characteristics of Idealized 350 ms. Duration N-Wave @ Rise Time = 3 ms. as Used in Series I Tests.

35

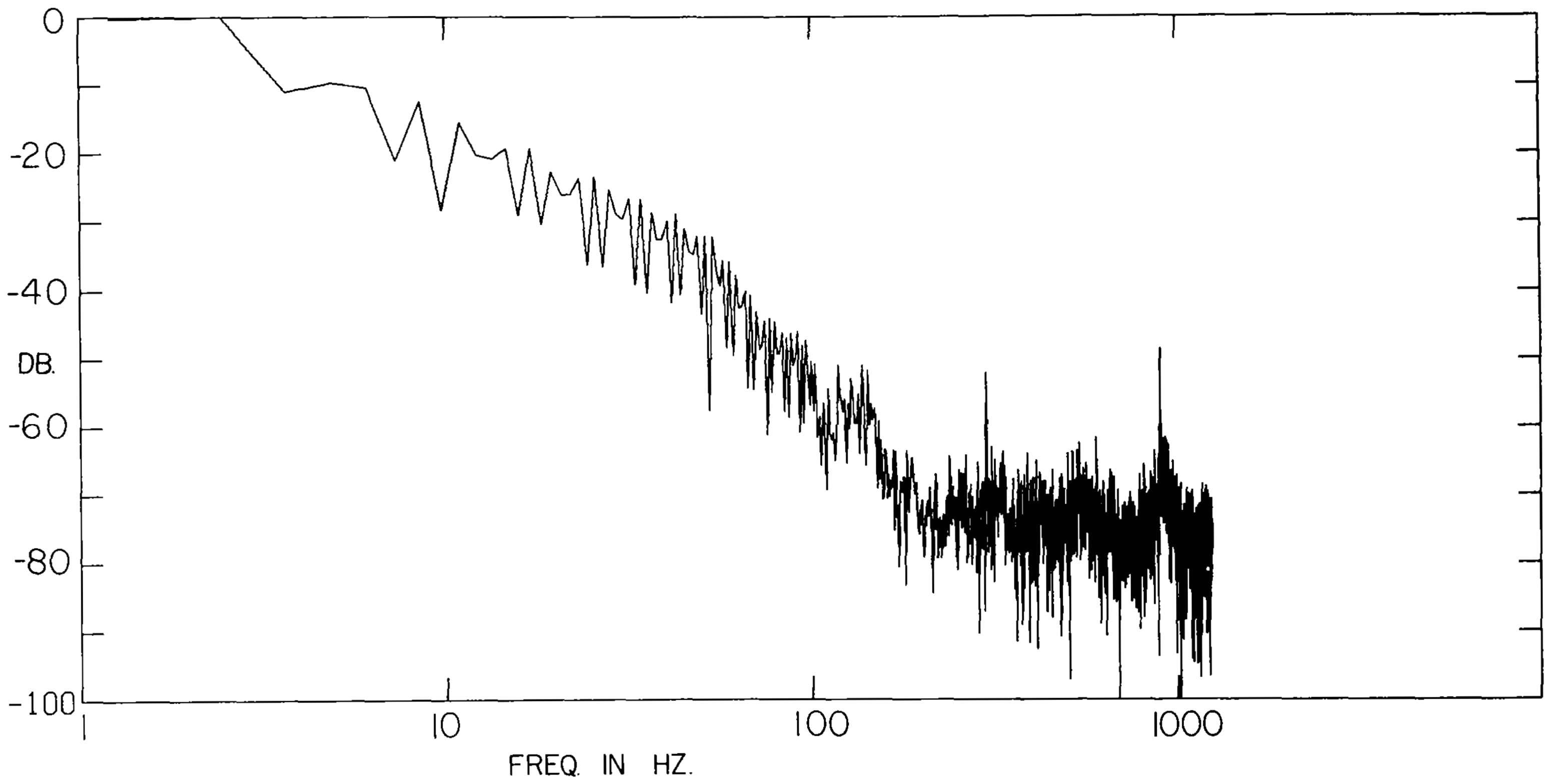


Figure 16 Spectral Energy Characteristics of Idealized 350 ms. Duration N-Wave @ Rise Time = 10 ms. as Used in Series I Tests.

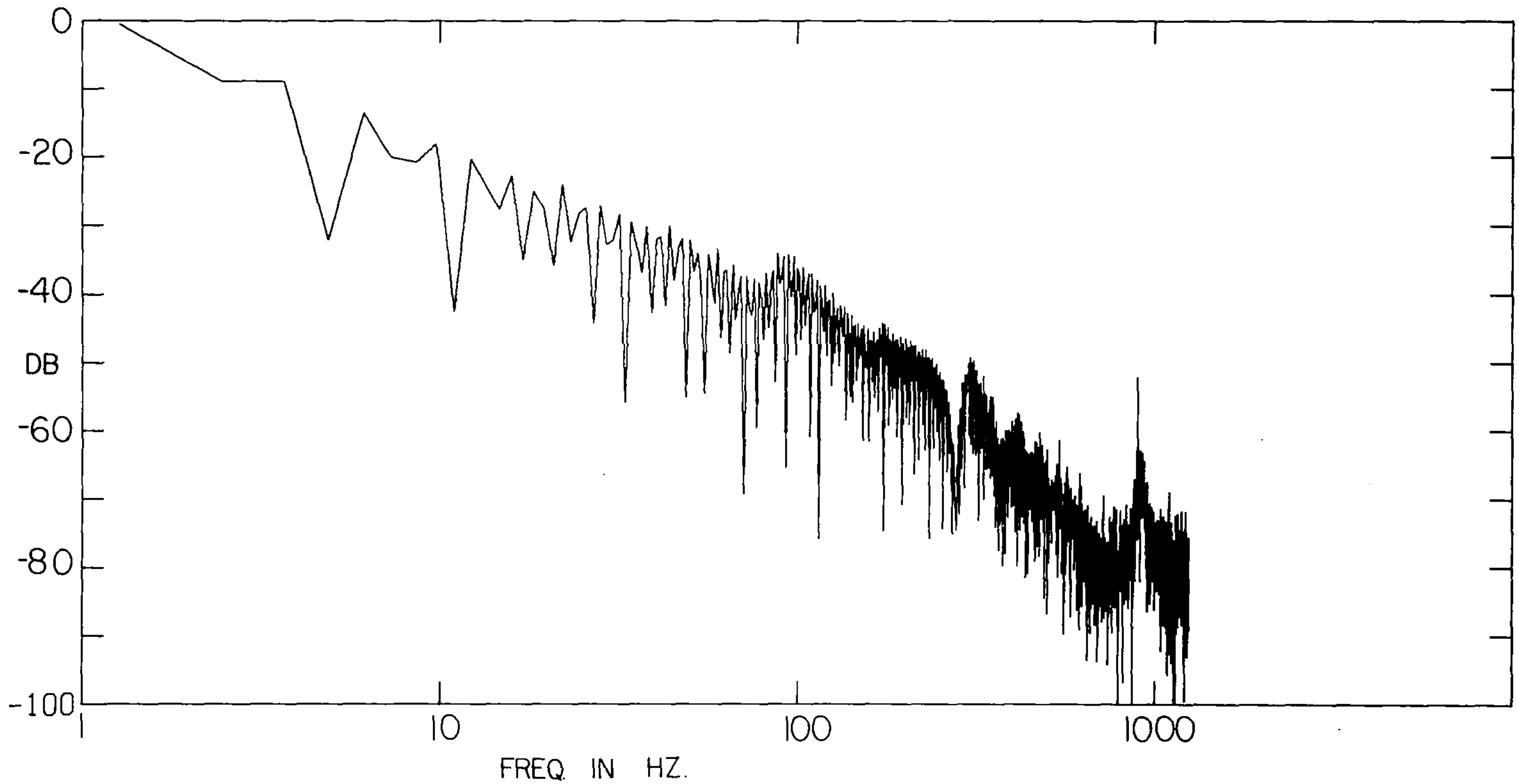


Figure 17 Spectral Energy Characteristics of Idealized 500 ms. Duration N-Wave @ Rise Time = 1 ms. as Used in Series I Tests.

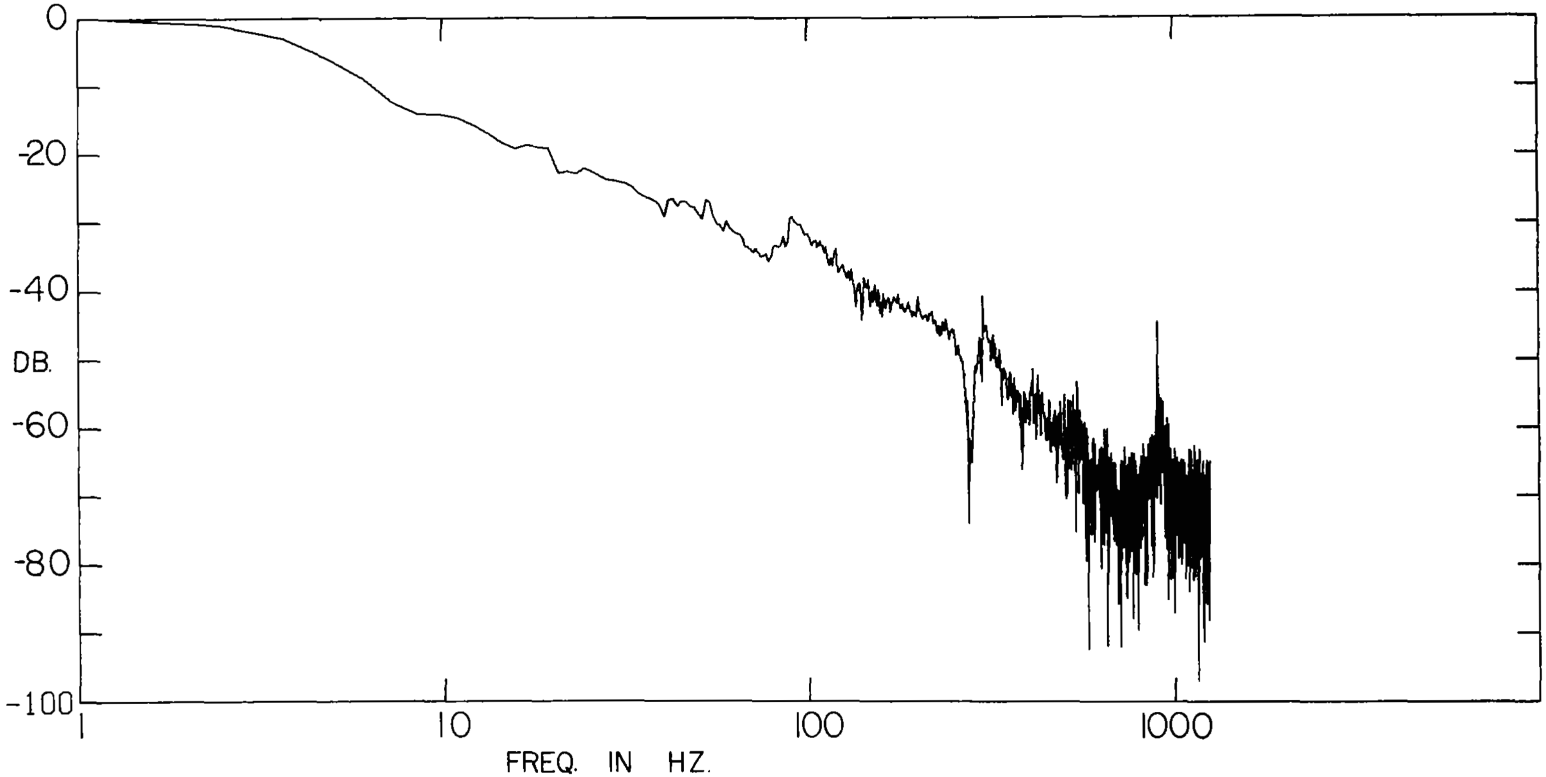


Figure 18 Spectral Energy Characteristics of Idealized 150 ms. Duration 1/2 N-Wave @ Rise Time = 1 ms. as Used in Series III Tests.

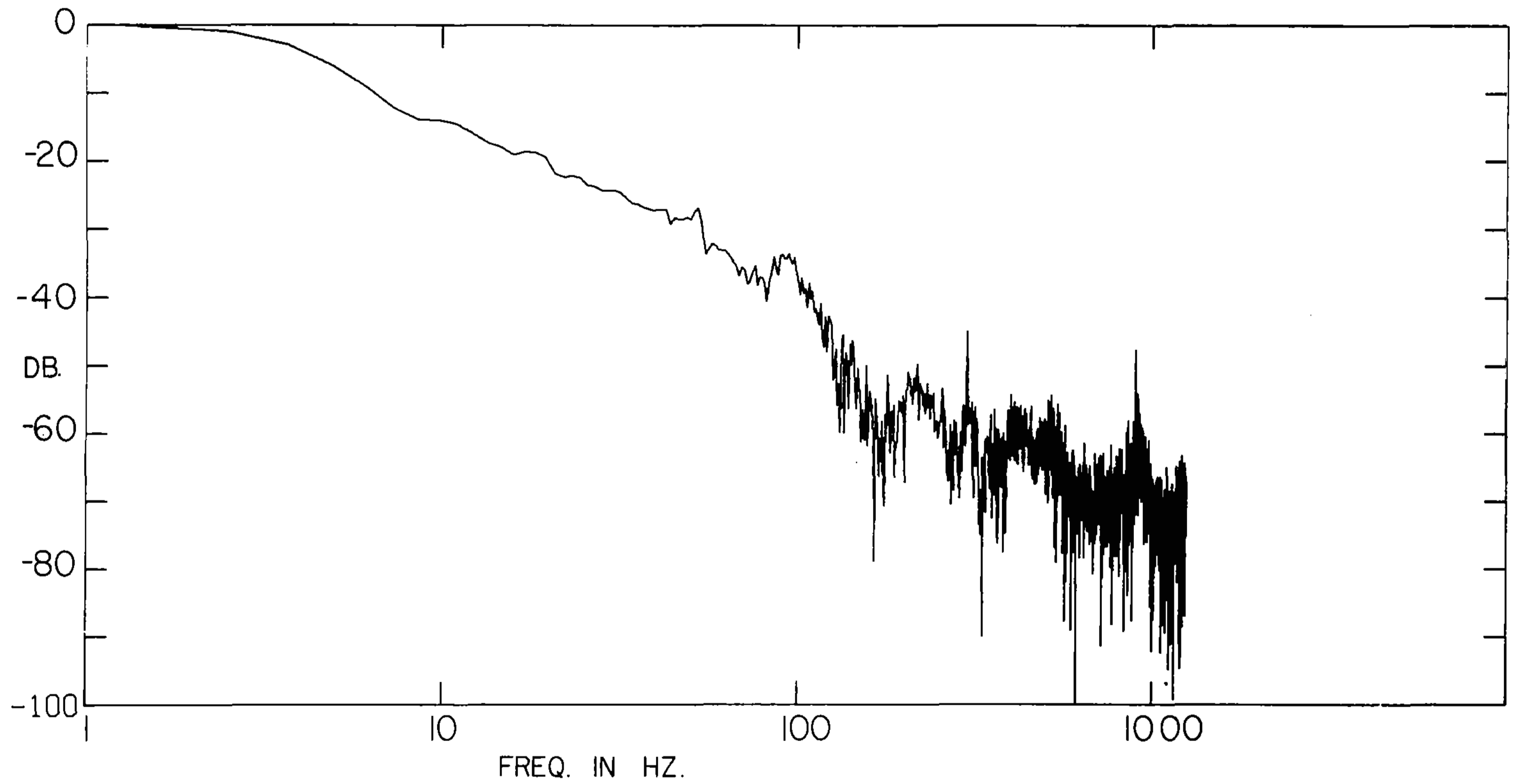


Figure 19 Spectral Energy Characteristics of Idealized 150 ms. 1/2 N-"Sawtooth" Wave @ Rise Time of 1 ms. With Interpeak Duration of 2 ms. as Used in the Series III Tests. (Type 1)

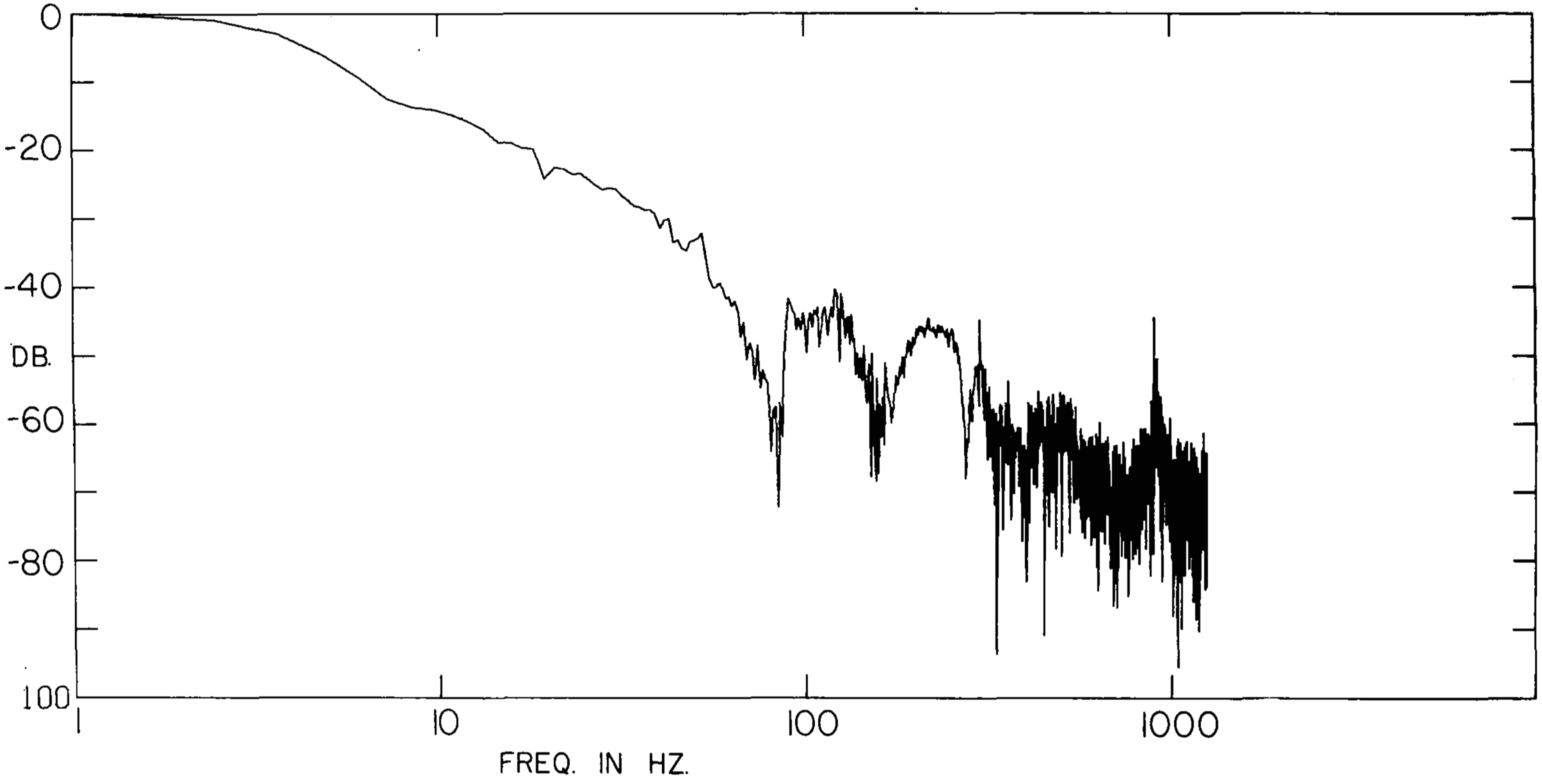


Figure 20 Spectral Energy Characteristics of Idealized 150 ms. 1/2 N-"Sawtooth" Wave @ Rise Time of 1 ms. With Interpeak Duration of 4 ms. as Used in Series III Tests. (Type 1)

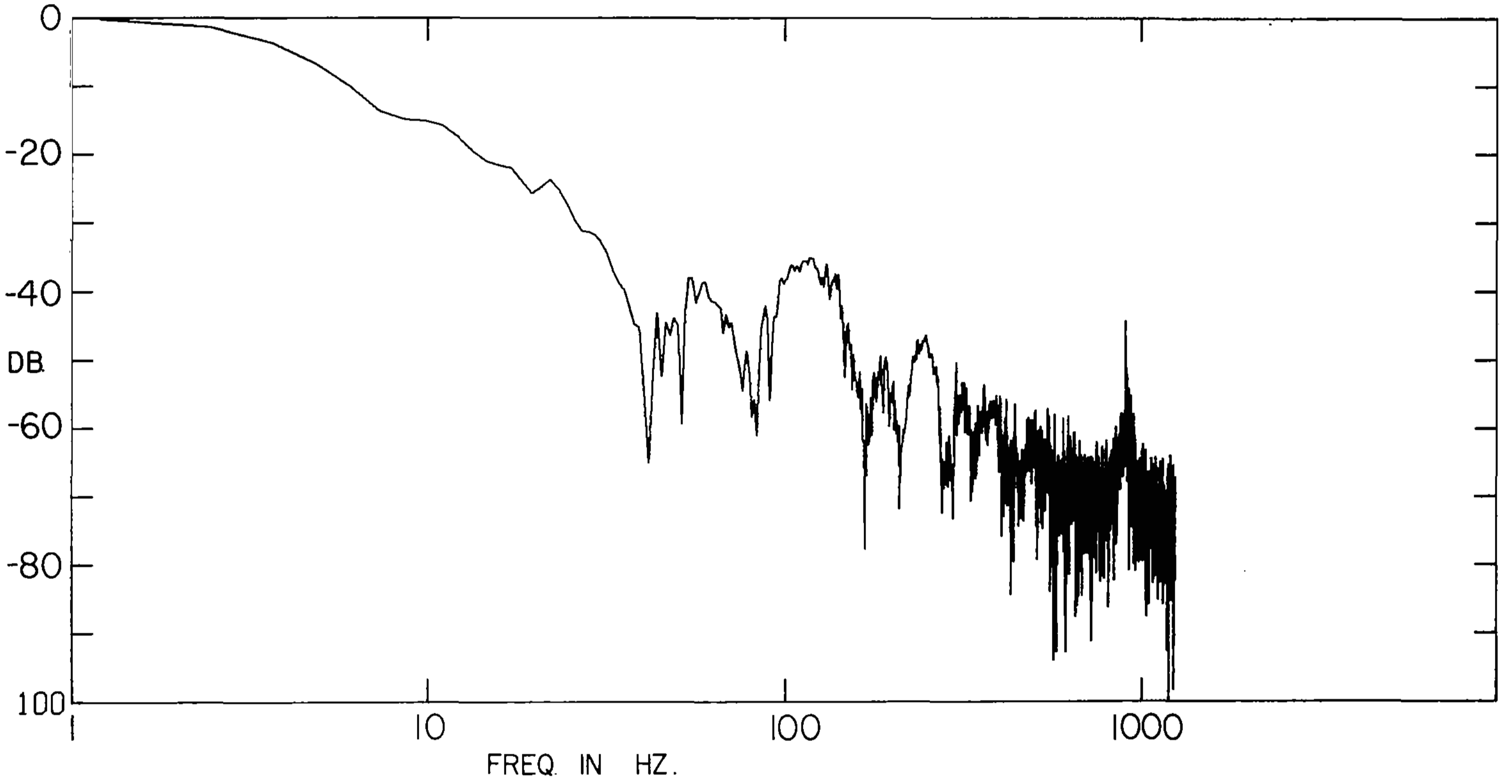


Figure 21 Spectral Energy Characteristics of Idealized 150 ms. 1/2 N-"Sawtooth" Wave @ Rise Time of 1 ms. With Interpeak Duration of 8 ms. as Used in Series III Tests. (Type 1)

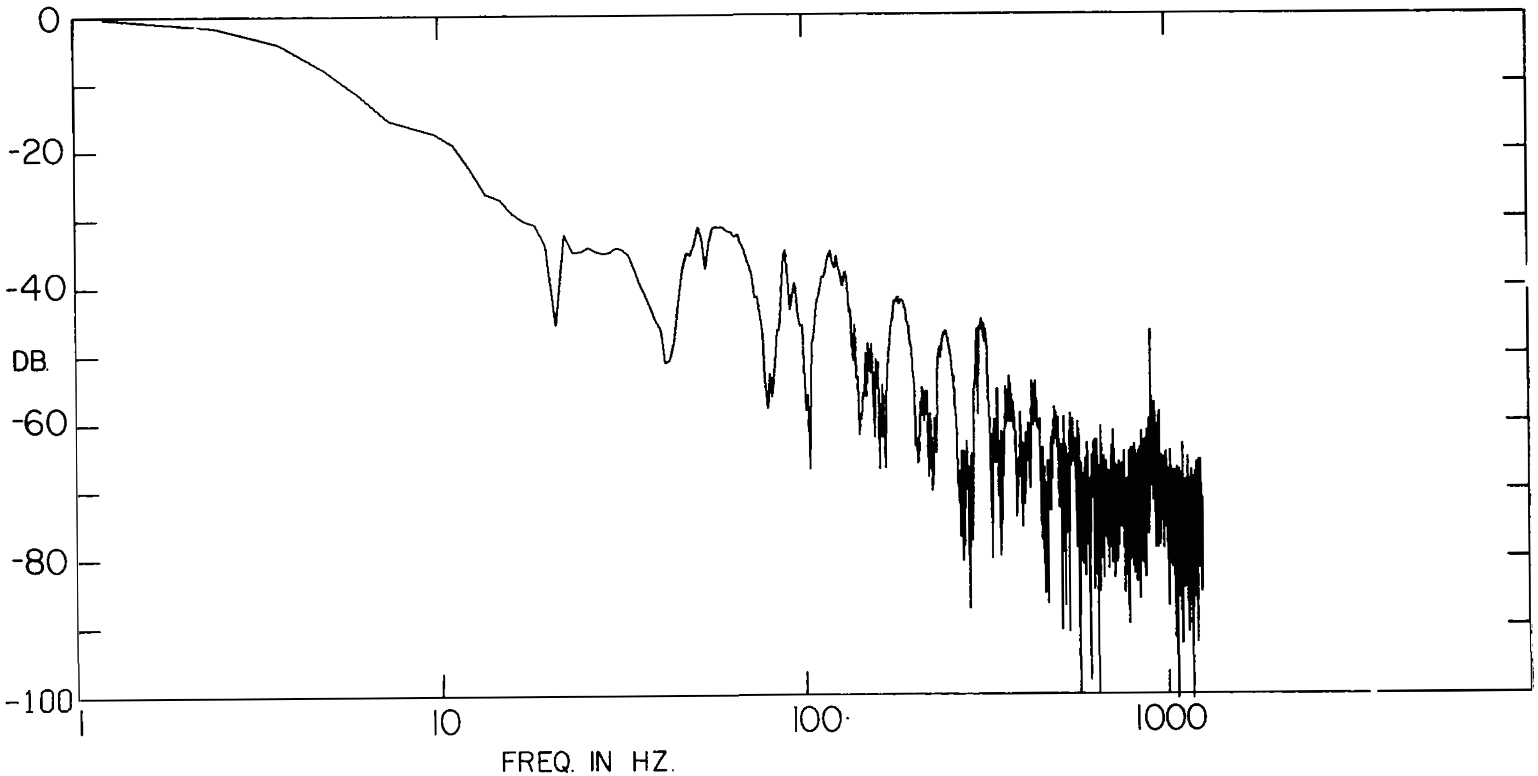


Figure 22 Spectral Energy Characteristics of Idealized 150 ms. Duration 1/2 N-"Sawtooth" Wave @ Rise Time = 1 ms. With Interpeak Duration of 16 ms. as Used in Series III Tests. (Type 1)

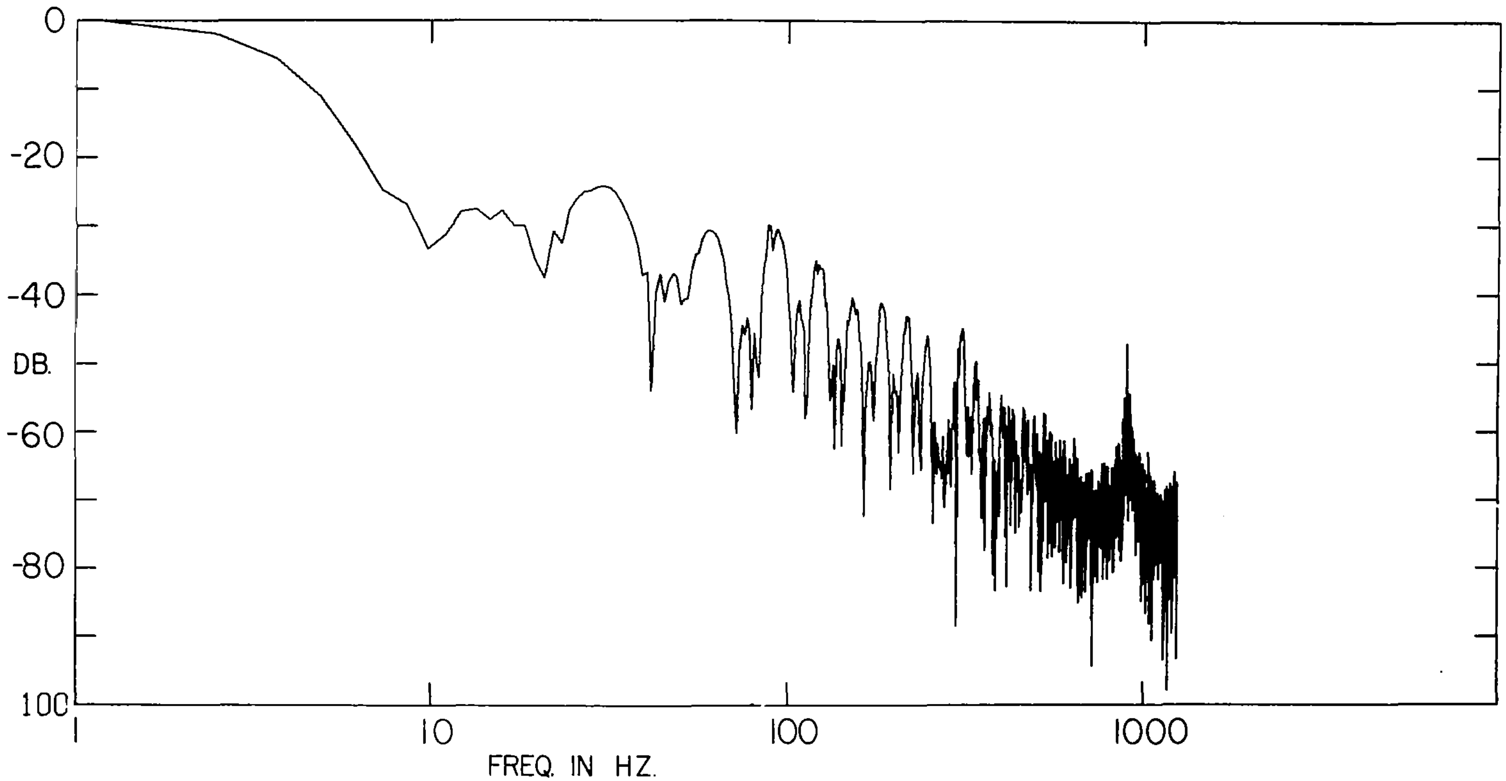


Figure 23 Spectral Energy Characteristics of Idealized 150 ms. Duration 1/2 N-"Sawtooth" Wave @ Rise Time = 1 ms. With Interpeak Duration = 32 ms. as Used in Series III Tests (Type 1)

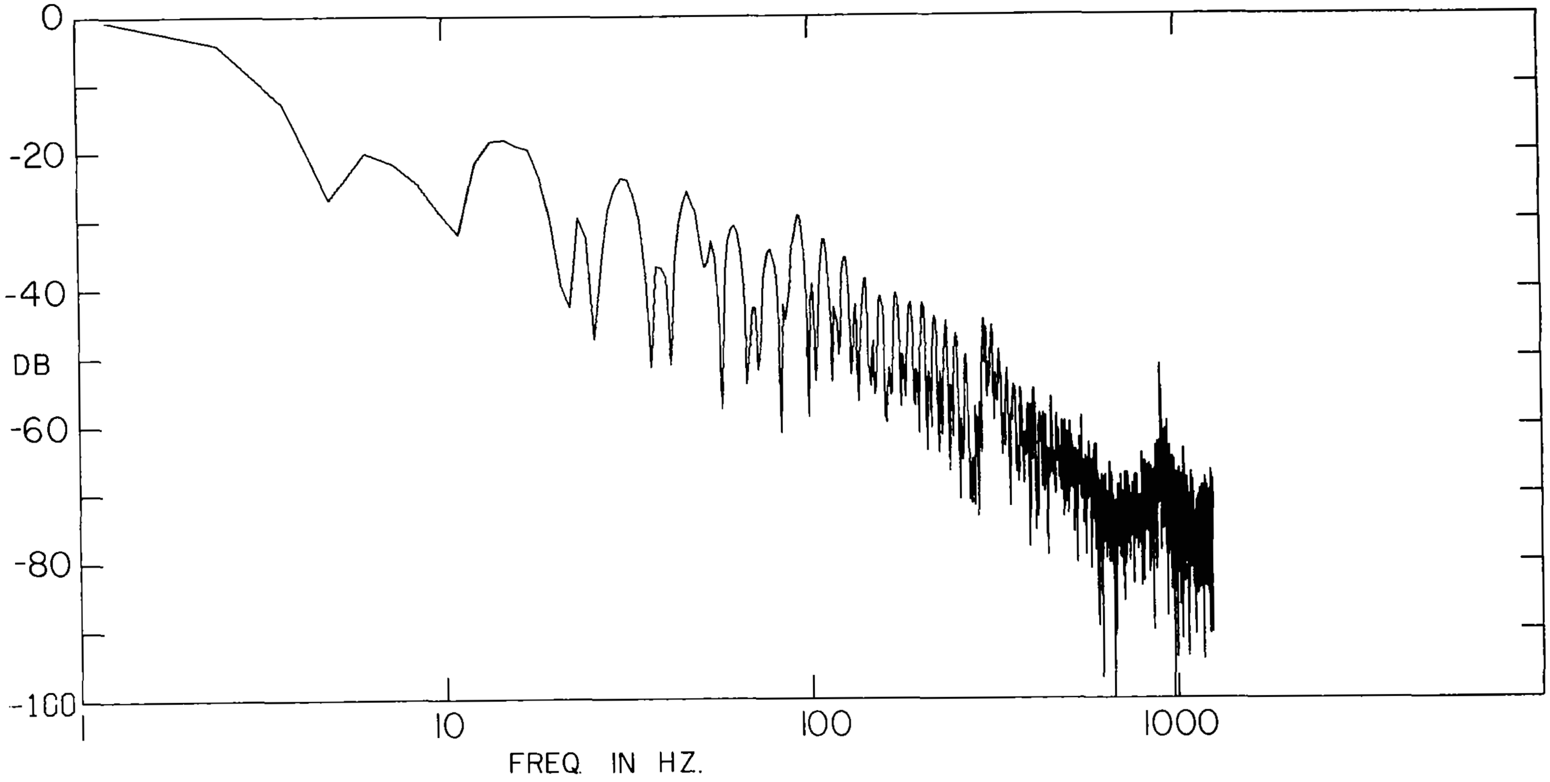


Figure 24. Spectral Energy Characteristics of Idealized 150 ms. Duration 1/2 N-"Sawtooth" Wave @ Rise Time of 1 ms. With Interpeak Duration of 64 ms. as Used in Series III Tests. (Type 1)

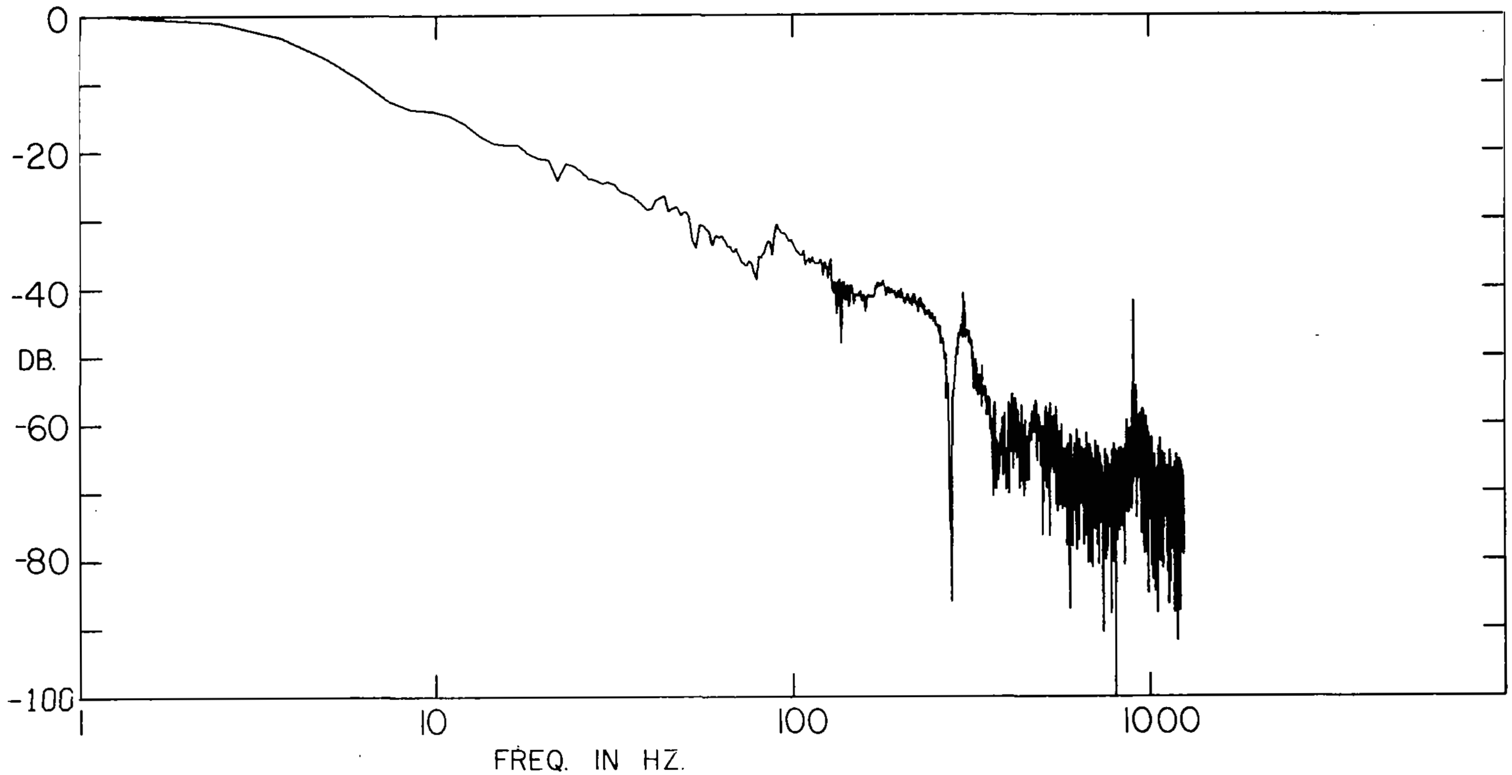


Figure 25 Spectral Energy Characteristics of Idealized 150 ms. Duration 1/2 N-"Sawtooth" Wave @ Rise Time of 1 ms. With Interpeak Duration = 2 ms. as Used in Series III Tests. (Type 2)

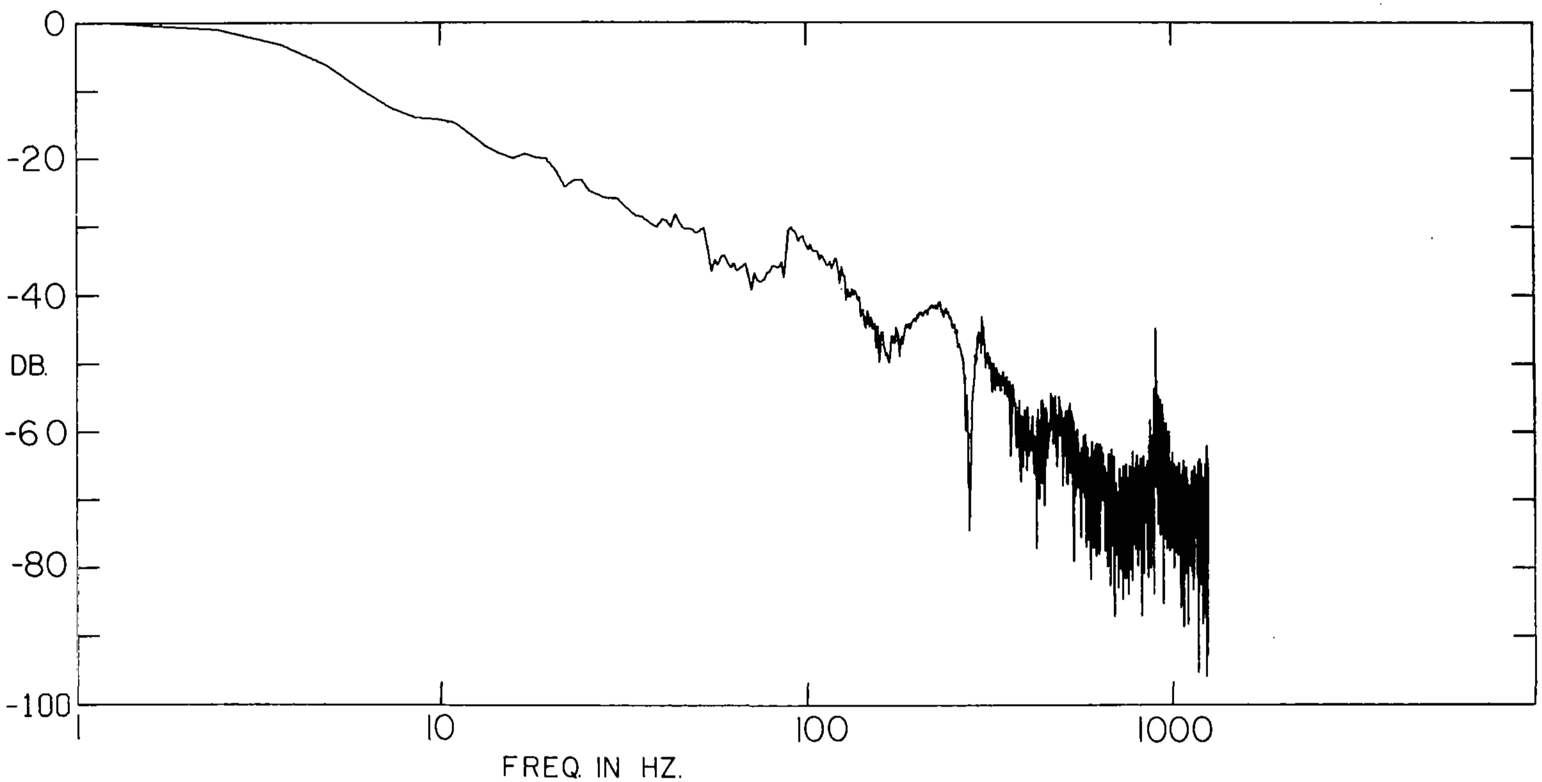


Figure 26 Spectral Energy Characteristics of Idealized 150 ms. Duration 1/2 N-"Sawthooth" Wave @ Rise Time = 1 ms. With Interpeak Duration = 4 ms. as Used in Series III Tests. (Type 2)

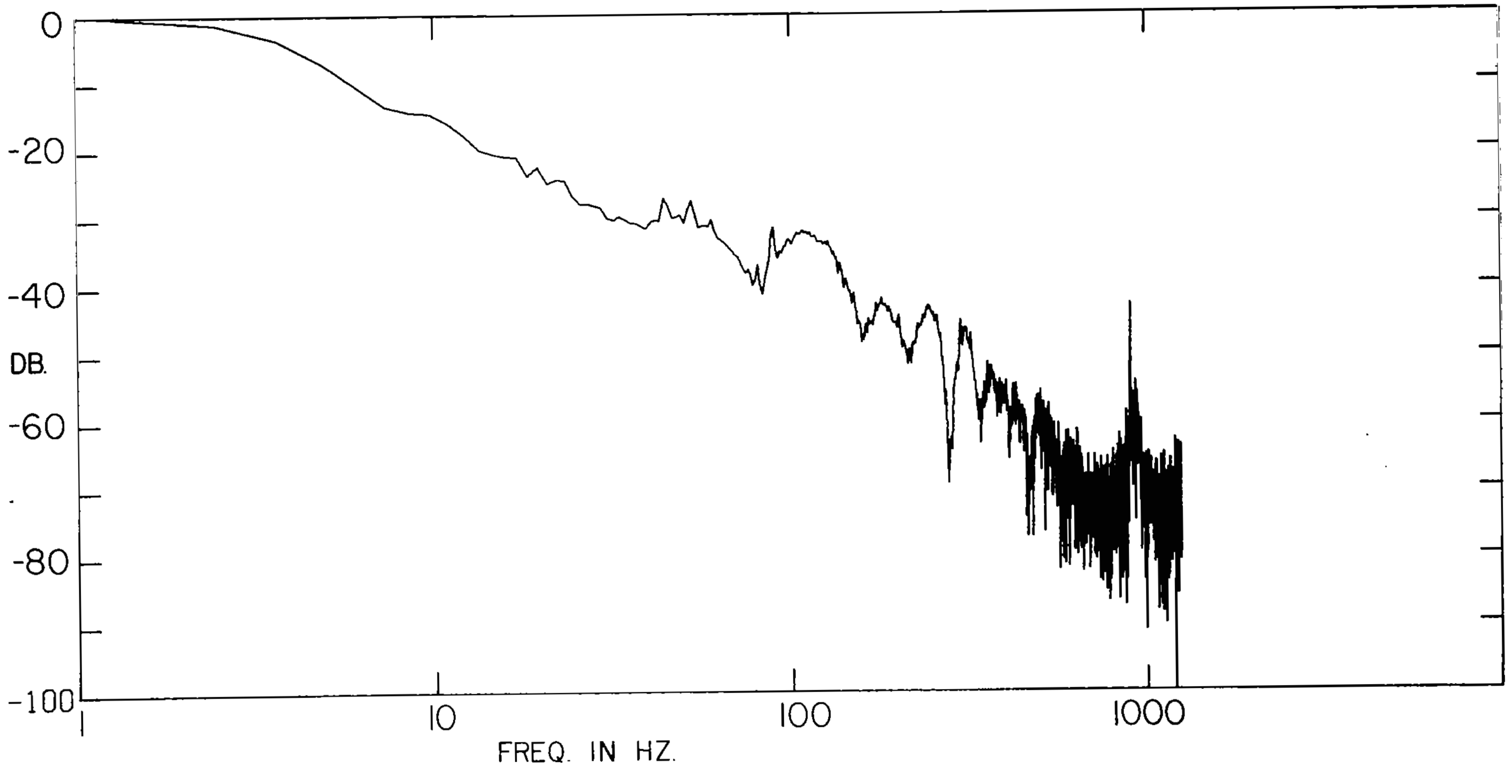


Figure 27 Spectral Energy Characteristics of Idealized 150 ms. Duration 1/2 N-"Sawtooth" Wave @ Rise Time = 1 ms. With Interpeak Duration = 8 ms. as Used in Series III Tests. (Type 2)

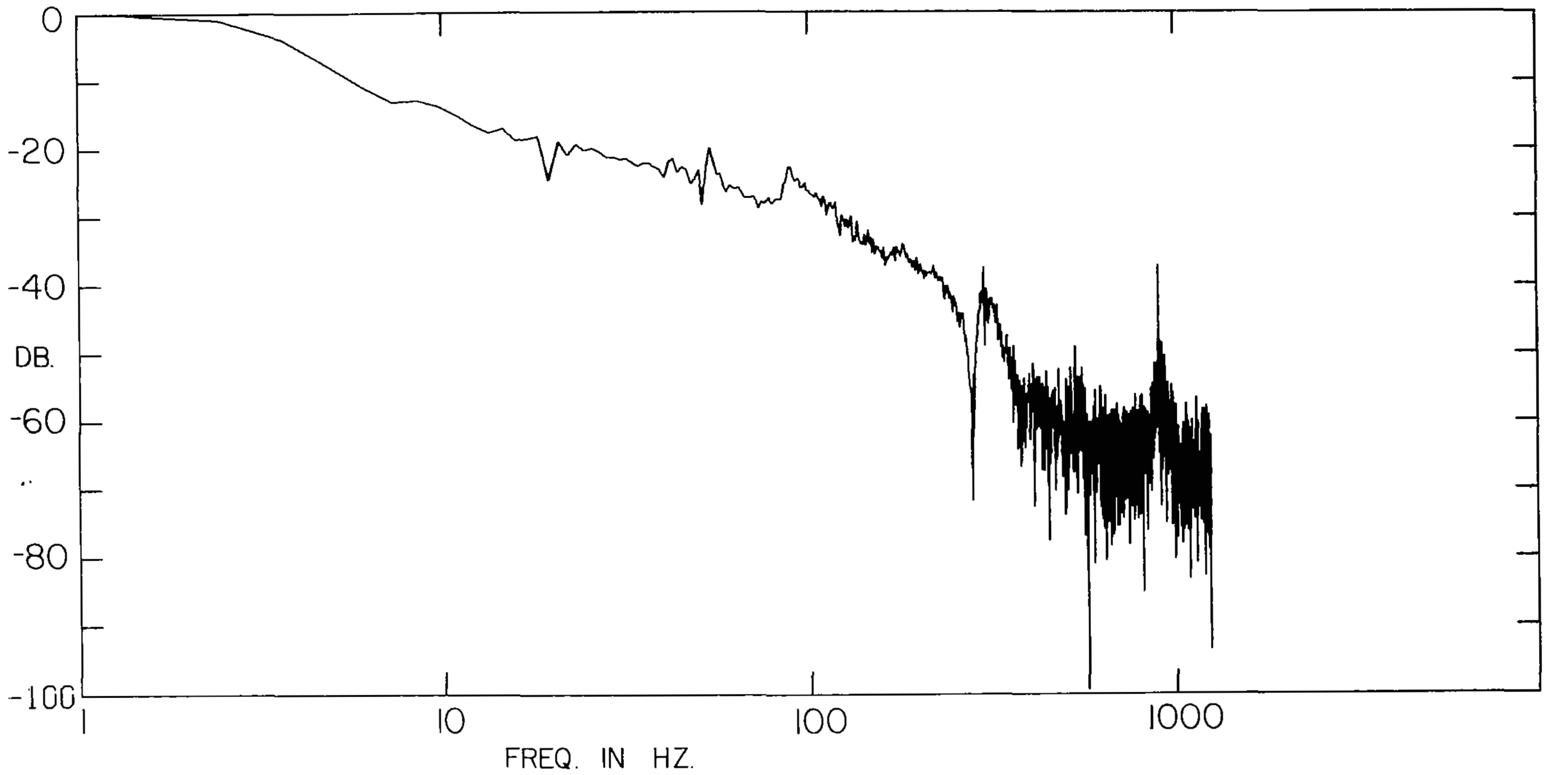


Figure 28 Spectral Energy Characteristics of Idealized 180 ms. Duration 1/2 N-Wave with Bow Wave "Spike" Modification as Used in Series II Tests.

Conclusions:

On the basis of the experiments performed as described, the following are offered as conclusions:

1. The duration of the test signatures did not affect loudness or annoyance judgments.

2. As the rise time of a test signature increases, the loudness and annoyance decrease.

3. With the exception of comparisons using waves having 10 ms. rise times, there is no difference in judgments made with a loudness criterion and those using annoyance as a basis for comparison.

4. Similar relative results for judged loudness and annoyance among the various waveforms were obtained with the standard signature set at any one of three levels, 0.8, 1.6 and 2.4 psf.

5. The addition of a "spike" bow wave modification to an idealized 1/2 N-wave results in increased subjective loudness.

6. As the interpeak spacing of Type 1 waveforms is decreased from 64 msec to 2 msec loudness decreases.

7. No apparent loudness effect is noted when the interpeak spacing of Type 2 waveforms is varied.

Acknowledgements:

The authors would like to acknowledge the helpful assistance of Drs. Walter Aron, Karl Kryter, and James Young of the Stanford Research Institute in the implementation and analysis of the impact transients used in this research program.

APPENDIX 1.

Instructions to the subjects:

1) LOUDNESS Judgments:

This is a test series designed to determine how you hear certain kinds of sonic boom type sounds. You will hear pairs of booms, and your task is to answer verbally, after the second boom of each pair, whether that second boom was louder, equal to, or softer than the first. Answer as soon as possible after hearing the second boom. The boom pairs will be repeated a number of times and you are to continue making loudness judgments until given the command "stop". Try your best to make your judgments only in terms of how loud the second boom sounds relative to the first. We will have a few practice trials before starting testing. Any questions?

2) ANNOYANCE Judgments:

This is a test series designed to determine how much certain kinds of sonic boom sounds annoy you. You will hear pairs of booms, and your task is to answer verbally, after the second boom of each pair, whether that second boom was more, equally, or less annoying than the first. Answer as soon as possible after hearing the second boom. The boom pairs will be repeated a number of times and you are to continue making annoyance judgments until given the command "stop". Try your best to make your judgments only in terms of how much the second boom annoys you, relative to the first. We will have a few practice trials before starting testing. Any questions?

References:

1. Hubbard, H, et.al.,"Symposium on Sonic Boom", J. Acous. Soc. AM. Vol. 39, No. 5, May 1966, Part 2.

2. Pearsons, K. S. and Kryter, K. D.,"Laboratory Tests of Subjective Reactions to Sonic Boom" NASA CR-187, 1965.

3. Zeppler, E. E. and Harel, J.R.P., "The Loudness of Sonic Booms and Other Impulsive Sounds", J. Sound Vib. 2, 249, 1965

4. Parnell, J. E., Sutherland, W. W., and Shepherd, L. J., "Laboratory Simulation of Sonic Boom" presented at the June 1966 Meeting of the Acoustical Society of America.

5. Zimny, G. H., Method in Experimental Psychology, Ronald Press Co., New York, 1961

6. Guilford, J. P., Fundamental Statistics in Psychology and Education, McGraw Hill, New York 1956

NASA-Langley, 1968 —— 4 CR-1192