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EFFECTS OF LOW FREQUENCY PRESSURE FLUCTUATIONS ON HUMAN SUBJECTS

by Burrell O. French, Robert O. McBrayer, W. E. Feddersen, Gerard J. Pesman, and John Billingham

Manned Spacecraft Center
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ABSTRACT

Twenty human subjects were exposed to sinusoidal pressure fluctuations which corresponded to sound pressure levels from 119 to 144 decibels at frequencies from 2 to 12 cycles per second, and their psychophysiological responses were measured. A description of the test apparatus, a piston-cylinder arrangement which produced the pressure fluctuations and a test chamber which isolated the subjects from the laboratory, is included as an appendix. Psychophysiological monitoring techniques and instrumentation consisted of audiometry, electronystagmography, electrocardiography, impedance pneumography, and performance and subjective responses. The test results show that repeated exposure to 137 to 141 decibels produced temporary threshold shifts of 10 to 22 decibels in the 3000 to 8000 cycles per second frequencies.

EFFECTS OF LOW FREQUENCY PRESSURE

FLUCTUATIONS ON HUMAN SUBJECTS

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SUMMARY

Twenty subjects were exposed to low frequency, sinusoidal pressure fluctuations, and their psychophysiological effects were measured. The subjects were monitored with audiometry, electronystagmography, electrocardiography, and impedance pneumography. Each subject reported his experience on a subjective response form which contained specific parameters. In addition, five of the test subjects were given performance tasks which would have measured a performance decrement if performance had been impaired.

The test results show that human subjects were not affected by the pressure stimulus during the first 3-minute exposure. When the stimulus was repeated, auditory effects were observed; however, vestibular and cardiopulmonary effects were not encountered nor were the subjects' performances impaired.

INTRODUCTION

As space missions become longer, payloads become larger; therefore, larger vehicles are necessary to launch the payload. The launch vehicles will produce higher noise levels, and because of the vehicles size, the noise frequencies will be lower. The noise levels measured during the Apollo boilerplate launch have a maximum acoustic energy below 100 cycles per second (cps), and predictions for future missions indicate that the frequencies will be even lower. Since low frequency noise is not readily attenuated, the spacecraft occupants will be exposed to an intense low frequency noise environment; therefore, the detrimental effects of this environment must be determined.

The literature was surveyed for data which showed the psychophysiological effects of noise, and very little data were available below 100 cps. Since the available data had been collected during pilot studies in which a specific noise spectrum was considered, the data did not satisfy present mission requirements. Furthermore, the psychophysiological effects had to be known prior to launch. Therefore, a program was initiated to thoroughly investigate the effects of noise below 100 cps and to establish acceptable levels. The first phase of the program was an exploratory study designed to demonstrate clearly the auditory and nonauditory physiological effects on, and performance decrements of, humans exposed to pressure fluctuations from 2 to 12 cps.

The purpose of this paper is to describe the test procedures, present the data collected, and consider the significant results of the study. Due to the exploratory approach and to the quantity of data, the data presentation, results, and discussion are divided into three parts - auditory, nonauditory, and performance. This division is artificial, since the nonauditory and performance data were essentially negative but are included for completeness; therefore, the topic arrangement and the treatment of each topic do not indicate their relative significance.

METHOD

Test Facility

Figure 1 depicts the test facility and pressure instrumentation which were utilized. The pressure generator produced pressure stimuli whose magnitude and frequency could be adjusted as desired. The stimuli were introduced into the test chamber through an electromagnetic diverter valve. This valve permitted the stimulus to be instantaneously applied or removed as necessary during testing and allowed the subject to abort the test if he wished.

The test chamber isolated the subjects from the ambient environment of the laboratory; therefore, the laboratory enviornment did not interfere with the subject's environment or with the data collected. The test facility is discussed in the appendix.

Description of Instrumentation

Pressure measurement. - The pressure stimulus was recorded with two differential pressure transducer assemblies and an oscillograph recorder (fig. 1). The transducer assemblies, mounted inside the chamber and referenced to the ambient pressure outside the chamber, sensed the peak-to-peak

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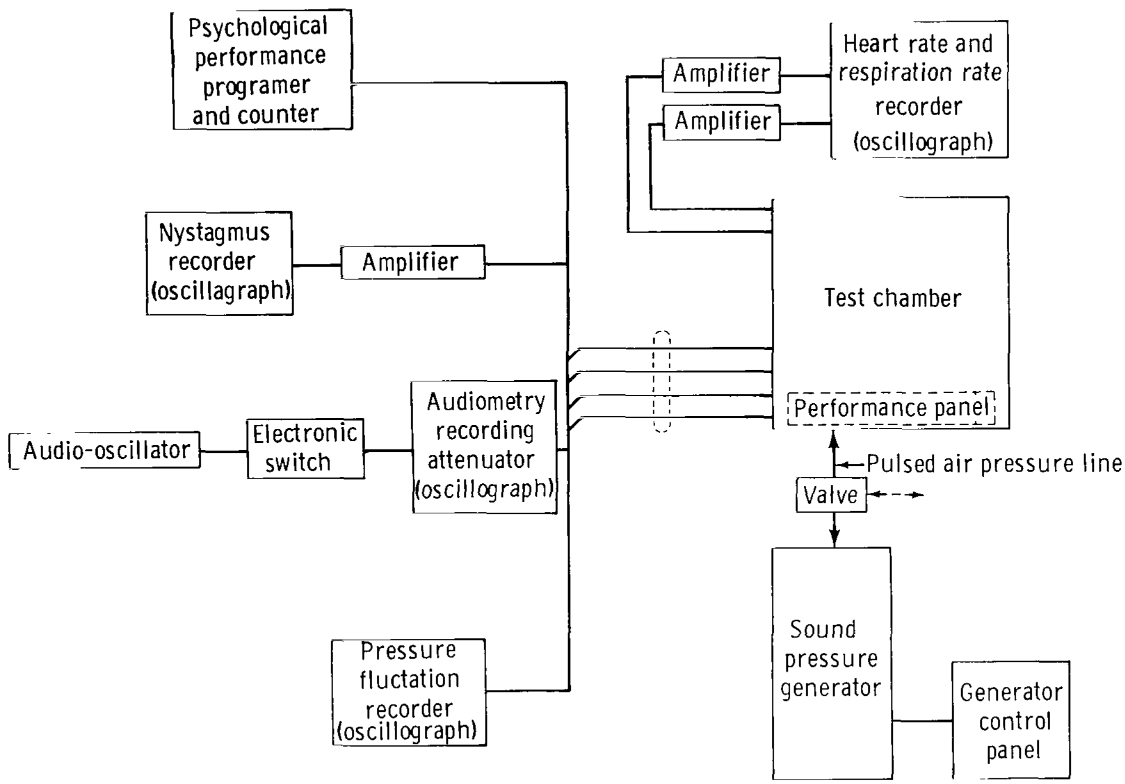

Figure 1. - Block diagram showing the arrangement of the test equipment.

pressure and converted the pressure to voltage. This voltage was recorded as a function of time, and the sound pressure level and frequency were calculated from the oscillogram.

Physiological measurements. - The auditory effects of the pressure fluctuations were determined by measuring hearing acuity. The nonauditory effects were monitored by utilizing an electronystagmograph to measure nystagmus, an electrocardiograph to measure heart rate, and an impedance pneumograph to measure respiration rate. In addition, the subject's comments were recorded by the medical monitor before and after each test run and when all test runs for each subject were completed. The subjects were also asked to complete a form that specifically included the subjective responses that are normally encountered during acoustic testing.

The test measurements given in the preceding paragraph were achieved with the instrumentation presented in figure 1. The apparatus used to track the auditory threshold consisted of a pushbutton oscillator, an electronic switch, a dynamic earphone, a hand switch, and a recording attenuator. The threshold test frequency (see Test Procedure) was produced by the oscillator, turned on or off each half second by the electronic switch, and fed to the earphones. The subject received the test frequency in the earphone and controlled the signal level at the earphone with the hand switch. The recording attenuator was motor driven at a rate of 2 dB per second. By pressing the switch when the tone became inaudible and releasing the switch when the tone was audible, the subject tracked his auditory threshold as a function of time. His tracking behavior was graphically recorded on a strip chart by an ink-writing pen coupled to the motor drive of the attenuator. Figure 2 shows a typical example of a subject's threshold record collected during the test.

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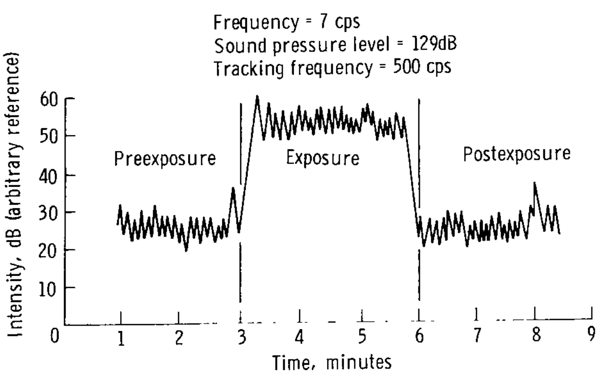

Figure 2. - Typical threshold before, during, and after exposure to 7 cps and 129 dB.

Figure 3 shows the electrode placement for the electronystagmograph, electrocardiograph, and impedance pneumograph. The electronystagmograph equipment consisted of the electrodes, amplifier, and oscillograph recorder. The electrical potential across the electrodes produced a signal current that was amplified and recorded. The current was proportional to the subject's eye movement; therefore, if the eyes had moved through a nystagmoid pattern, the characteristic nystagmus wave-form would have been recorded.

The electrocardiograph and impedance pneumograph equipment consisted of the electrodes, separate amplifiers, and a two-channel recorder. The equipment operated exactly like the electronystagmograph; however, the recorded signal was proportional to heart and respiration events and was used to calculate heart and respiration rates.

Performance measurements. - Performance in an acoustic environment has historically been a question, and the performance of the spacecraft occupants is a prime consideration during the period when launch noise is experienced; consequently, four tasks were used to measure the subject's performance during the test.

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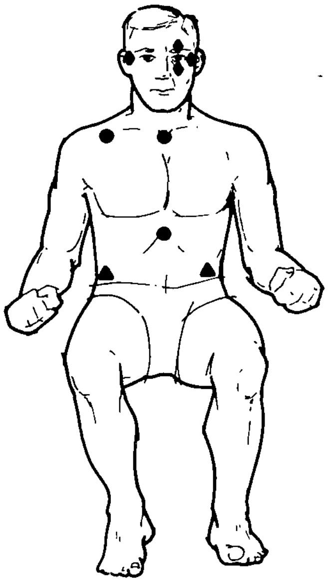

♦ Electronystagmography (ENG) electrodes
● Electrocardiogram (ECG) electrodes
▲ Impedance pneumogram electrodes

Figure 3. - Electronystagmograph, electrocardiograph, and impedance pneumograph electrode placement.

The major components of the performance equipment were the monitor's control panel and the subject's control panel. The monitor, using an array of lights, switches, counters, and relays, randomly programed three reaction-time measurements and a memory task into the subject's panel.

The subject's reaction-time was measured as he responded to a light, a meter deflection, and a simple addition problem. The light and meter, individually activated at the monitor's panel, were returned to their original condition by the subject, and the monitor recorded the subject's operating time from the visual time display. The addition task was electronically presented to the subject using four single-digit numbers. If the total of the numbers when added was equal to or less than eleven, a switch that corresponded to his solution was pressed. If the sum of the numbers was greater than eleven, the two digits of the total were then added and the switch corresponding to the subject's solution was pressed. The subject repeated this procedure until the correct switch had been pressed to extinguish the numbers and complete the task. The monitor recorded from a visual time display the operating time required by the subject to press the correct switch.

The memory task was presented to the subject with three lights. The subject was first signaled to prepare for the task. Then the lights were programed in a nonsequential pattern which changed each performance run. Upon command, the subject indicated with his control panel switches the number of times each light was illuminated. If the subject reported correctly, the command light was extinguished. If the subject had made a mistake, the error was indicated to the subject by his control lights and to the monitor by a counter. The subject then had to press a reset switch to complete the task while the monitor recorded the results.

Subjects

Twenty human males between the ages of 21 and 33 were used as test subjects. Fifteen subjects were used to assess the physiological effects of the stimulus and five subjects were used to measure performance. When the performance runs had been completed on four of the subjects, they were used to collect physiological data; consequently, relatively complete auditory and nonauditory data were collected on nineteen of the twenty subjects and performance data were collected on five of the twenty subjects. All subjects were healthy and did not have a reported history of otological disease. The subjects' auditory thresholds were measured at 100, 250, 500, 1000, 2000, 3000, 4000, 6000, and 8000 cps. By the American Standard Association (ASA) criterion that hearing is normal if a threshold does not exceed 15 dB, fourteen of the test subjects had normal hearing. Figure 4 depicts the range of hearing loss as well as the mean hearing loss for the five subjects who did not meet the "normal" criterion.

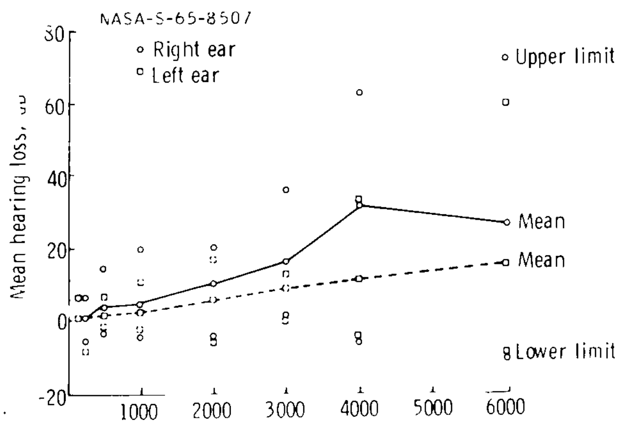

Figure 4. - Hearing loss range and mean for hearing loss subjects.

Test Procedure

Prior to being tested, each subject was given a cursory physical examination, instrumented with electrodes, and seated in the test chamber. The electrodes were connected to the monitoring equipment and the monitoring system was calibrated. Then the door of the test chamber was closed and the subject's hearing threshold recorded. Since only one ear was used to continuously monitor the subject's hearing during the test, the ear was chosen by the following criterion. If the subject had normal hearing, the ear was chosen arbitrarily; if the subject had a hearing loss, the ear with the largest loss was used.

After the ear had been chosen, the physiological data were collected in the following manner. Baseline data were recorded for 2 minutes, the sound pressure generator was started, and the stimulus was turned into the test chamber. When the subject had been exposed to the stimulus for 3 minutes, the stimulus was removed from the test chamber and the sound pressure generator was turned off; however, data were recorded for an additional 2 minutes. This procedure was repeated from 2 to 12 times for each test subject.

Testing was terminated by the medical monitor when the data indicated that a physiological change had occurred, when the subject wished to stop, or when the scheduled runs were completed.

The test procedure was modified for the performance test subjects to include the following changes. Prior to the test, the subjects were trained with the performance equipment until they were proficient at each task. Since the subjects had been previously exposed to identical stimuli where untoward effects were not encountered, they were not monitored with electronystagmograph or with continuous audiometry. When the performance tests were concluded, complete instrumentation was utilized before testing continued.

DATA PRESENTATION, RESULTS, AND DISCUSSION

Pressure Stimulus Data

The pressure stimulus data are presented in table I by subject number and by 3-minute exposures. Seven 3-minute runs were scheduled for each subject; however, subject 2 was exposed to the stimulus 12 times. For each subject the sound pressure level in dB and the frequency in cps are shown for each exposure. The sound pressure level and frequencies ranged from 119 to 144 dB and from 2 to 12 cps. Subject 21, an exception, was exposed to 14, 15.2, and 21.5 cps during runs 3, 4, and 7, respectively.

Physiological Data

Auditory. - A summary of the reduced audiometry data is presented in table II. The auditory effects were limited to temporary threshold shifts (TTS) in the 11 subjects listed. For this study a TTS was defined as a decrease in hearing acuity of 10 dB or more, relative to the pre-exposure level, that persisted for at least 2 minutes after the exposure was terminated. The data presented by subject number in table II include the magnitude of the observed TTS, the aural frequency where the TTS occurred, the ear experiencing the TTS, whether the ear was exposed to the stimulus or covered with the earphone, and the monitor's relevant comments. The hearing-loss subjects are indicated by footnote.

Employing the TTS criterion given in the preceding paragraph, some TTS's were observed in 11 of 19 subjects after 2 or more 3-minute runs. All measured TTS's were small and were limited to the 3000 to 8000 cps range. The largest, 22 dB, occurred at 3000 cps after a stimulus of 138 dB and 10.5 cps. The observed TTS's were reported for sound-pressure-level stimuli ranging from 137 to 141 dB; however, stimuli as high as 144 were tested without producing a TTS. Subject 21 experienced a TTS after a stimulus of 129 dB and 21.5 cps. However, the testing did not follow the usual procedure; the frequency was above the test range and was tested only once.

Nonauditory. - The heart and respiration data taken before, during and after each exposure were reduced, and the subject's heart rate in beats per minute and respiration in breaths per minute were analyzed. A characteristic sample is presented for each subject in table III. For these data, subjects 6 and 10 experienced a 13-beat-per-minute increase and a 14-beat-per-minute decrease, respectively. The heart rate data are representative of the more extreme heart rate variations. The respiration rate increased 8 breaths per minute for subjects 11, 12 and 15. Neither the heart nor respiration rate data, when compared to values cited in references 1 and 2, indicate that the subjects were abnormally stressed.

The subjective response forms completed by 19 of 20 subjects were analyzed and the results are presented in table IV. The subjects were directed to comment on each of the parameters listed and their negative comments were limited to "no, none, or not bothered". The positive comments have been specifically listed. In addition, the number of subjects responding in each category is included.

The subjective responses did not indicate any extraordinary auditory experiences. In fact, negative responses ranged from 47 to 90 percent for each parameter tested. Two subjects reported that the tracking tone sounded distorted and one subject reported tinnitus after the exposure was terminated. It is interesting to note that the TTS subjects were usually not aware that their hearing sensitivity had decreased.

Performance Analysis Data

The analyzed performance data are presented in table V. The data were grouped for analysis without regard to subject variation or the test stimulus. Furthermore, each of the 15 data points - 3 runs for each of 5 subjects - represents the arithmetic average of 8 separate measurements. Since each subject was used as his own control (measurement taken with and without the applied stimulus), the Wilcoxon matched pairs statistical test was used as described by Siegal (ref. 3). To test the null hypothesis that subject performance was not altered by the stimulus, the subject's response time when exposed to the stimulus was subtracted from the subject's response without the stimulus. A rank was assigned to each difference, and the level of significance for rejecting the null hypothesis (see the p-values in table V) was calculated using a one-tailed normal approximation. The p-values imply that the null hypothesis cannot be rejected.

Ideally, the order of difficulty of the reaction time performance tasks is such that the addition task is the most difficult, the meter deflection task the next most difficult, and the light task the easiest. However, the p-values indicate that the actual order of difficulty was the meter deflection, addition task, and light. This discrepancy can be explained by the fact that the control panel was not well lighted when the stimulus was applied, making it difficult for the test subjects to detect the meter deflection.

On the basis of this analysis, a performance decrement was not recorded when the subjects were exposed to the fluctuating pressure stimulus.

CONCLUSIONS

Twenty healthy human subjects were exposed to low frequency pressure pulses ranging from 119 to 144 dB and to frequencies from 2 to 12 cps. The following conclusions can be made:

a. Untoward effects were not experienced during any of the first runs.

b. Repeated exposures to stimuli in the 137 to 141 dB range produced temporary threshold shifts of up to 22 dB in the 3000 to 8000 cps frequency range.

c. Stimuli tested were not sufficient to produce vestibular effects or to cause heart or respiration rate variations that indicate the subjects were abnormally stressed.

d. Based upon the reaction time and arithmetic task, performance was not impaired by the stimulus.

e. Subjective responses to specific test parameters ranged from 47 to 90 percent negative.

Manned Spacecraft Center
National Aeronautics and Space Administration
Houston, Texas, December 2, 1965

APPENDIX

TEST CHAMBER DESCRIPTION

A test facility capable of producing stimuli of sufficient magnitude in the desired frequency range was not available. Therefore, a test facility was constructed that was adequate to conduct the exploratory study. The purpose of this appendix is to describe the test facility and discuss the environment which it produced.

TEST FACILITY

The facility - pressure generator and test chamber - is presented in figures 5 and 6 and is shown schematically in figure 7. The pressure generator chain of parts consisted of a variable speed dc motor, crankshaft, lifter arm, piston, and cylinder. As the motor turned the crankshaft, the crankshaft raised the lifter arm, and the piston moved relative to the cylinder. The relative motion produced volume variations in the 13-cubic-foot test chamber. Since the test chamber was a closed volume, the volume variations caused pressure changes in the test chamber. The rms value of the pressure corresponded to the sound pressure used during testing. The frequency corresponded directly to the speed of the motor.

The test chamber was constructed to produce a maximum sound pressure in a volume sufficient to accommodate an average human. The chamber consisted of a double wall structure with the base isolated from both walls. The door, designed as one wall, made the chamber easily accessible and retained the chamber's isolation characteristics. Absorbent wedges were installed such that the wedge surfaces were nonparallel. This construction had a tendency to decrease the magnitude of the pressure fluctuations; however, a relatively uniform sound pressure was maintained during testing. Finally, an electric shield was included in each wall to reduce electrical disturbances and facilitate instrumentation.

TEST ENVIRONMENT

To assure that the stimulus was not influenced by ambient conditions, the attenuation of the test booth and the noise levels in the surrounding laboratory

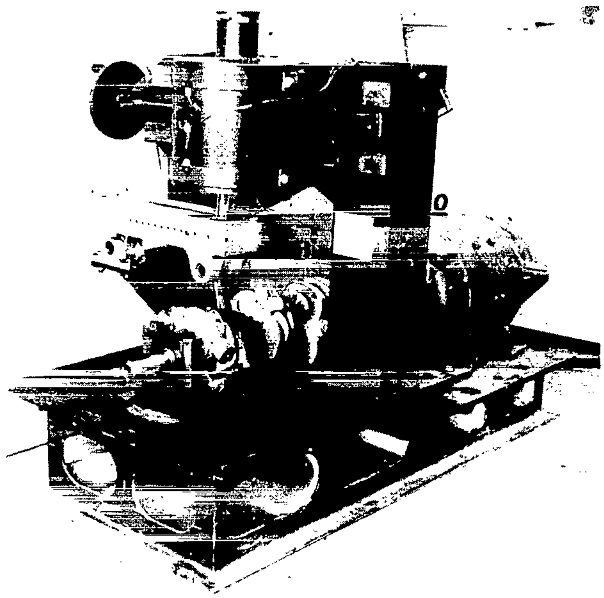

Figure 5.- Mechanical arrangement of sound pressure generator.

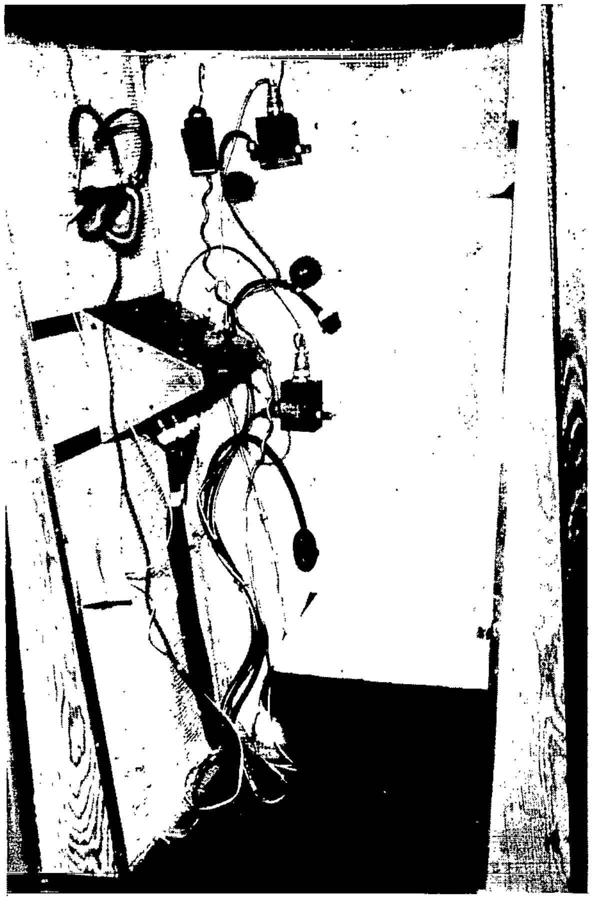

Figure 6.- Interior view of test chamber including instrumentation.

were measured. These data indicate that the observed TTS's were not a function of the operating noise produced by the pressure generator.

To measure the noise reduction of the test booth, a noise generator was placed approximately 3 feet from the test chamber. A sound level meter and octave-band analyzer were placed adjacent to the test chamber wall to record the external and internal sound pressure levels. The noise reduction was calculated and the data are presented in figure 8. The ambient noise levels were recorded at the pressure generator for several operating conditions. As figure 9 indicates, the maximum sound pressure level was 77 dB in the 300-600 octave band. This intensity was not sufficient to cause interference during testing.

HARMONIC ANALYSIS

An analysis of four test runs that included different frequency and amplitude combinations showed that the harmonic content was minimal. This analysis consisted of reading the measured amplitudes from the oscillograph

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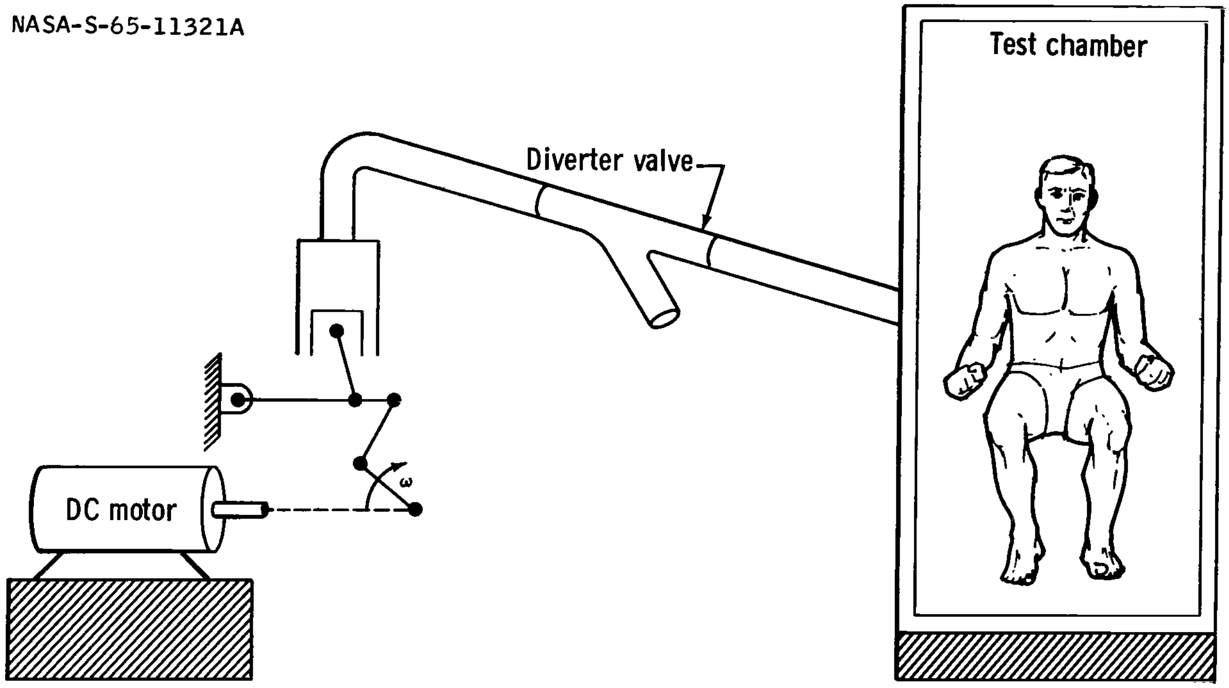

Figure 7. - Schematic of test facility showing sound pressure generator.

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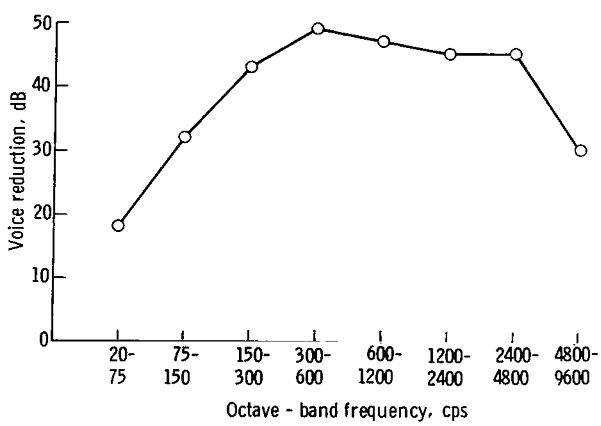

Figure 8. - Noise reduction characteristics of test chamber.

records and fitting a sine curve to the data points using a "least squares" technique. By expanding the measured curve in a Fourier series and assuming that the fitted curve is the true curve, the difference between the two curves then defines the harmonic content. The errors involved in completing this analysis (reading, round off, etc.) have been included as harmonics. Since this type of error is systemic, the case of the largest possible harmonic content has been considered.

The analysis can be illustrated as follows:

$$Y_1 = A \sin \alpha_1 t; \; Y_2 = A \sin \alpha_2 t \tag{1}$$

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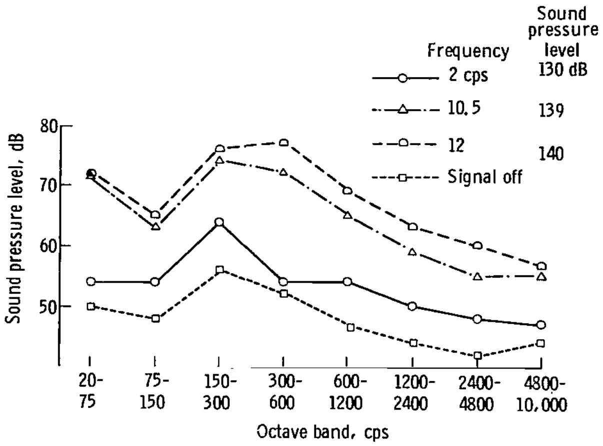


Figure 9. - Ambient room noise levels (outside test chamber) with pressure generator operating.

where Y_1 and α_1 are the measured amplitude and frequency, and Y_2 and α_2 are the fitted amplitude and frequency. The difference between the two curves is:

$$Y_1 - Y_2 = A\left(\sin \alpha_1 t - \sin \alpha_2 t\right) . \tag{2}$$

Writing $Y_1 = A \sin \alpha_1 t$ for the interval $-\pi \leq Y_1 \leq \pi$ in a Fourier series, one has:

$$\begin{aligned} A \sin \alpha_1 t &= \frac{a_0}{2} + \sum_{n=1}^{\infty} \left(a_n \cos nx + b_n \sin nx\right) \\ &= \frac{a_0}{2} + \left(a_1 \cos x + b_1 \sin x\right) \\ &\quad + \left(a_2 \cos 2x + b_2 \sin 2x\right) \\ &\quad + \left(a_3 \cos 3x + b_3 \sin 3x\right) + \dots \\ &\quad + \left(a_k \cos kx + b_k \sin kx\right) + \dots \end{aligned} \tag{3}$$

Considering the physical significance of each term,

$\frac{a_0}{2}$ describes the initial (ambient pressure) conditions,

$a_1 \cos x + b_1 \sin x$ is the fundamental frequency,

$a_2 \cos 2x + b_2 \sin 2x$ is the first harmonic,

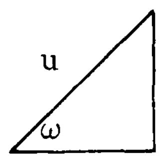
$a_3 \cos 3x + b_3 \sin 3x$ is the second harmonic,

. . . . . . , and

$a_k \cos kx + b_k \sin kx$ is the $(k-1)$ harmonic.

Rewriting the fundamental frequency term, $a_1 \cos x + b_1 \sin x$, as $u (\sin \omega \cos x + \cos \omega \sin x)$ and using the trigonometric relation shown in the diagram, then

$$a_1 \cos x + b_1 \sin x = u \sin (\omega + x).$$



$a_1 = u \sin \omega$

$b_1 = u \cos \omega$

Substituting this result into equation (3) one has:

$$A \sin \alpha_1 t - u \sin (\omega + x) = \frac{a_0}{2} + \left(a_2 \cos 2x + b_2 \sin 2x\right)$$

$$+ \left(a_3 \cos 3x + b_3 \sin 3x\right)$$

$$+ \dots$$

$$= \frac{a_0}{2} + \sum_{n=2}^{\infty} \left(a_n \cos nx + b_n \sin nx\right)$$

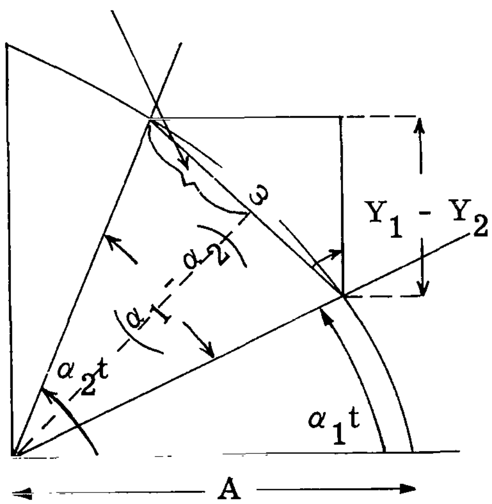
By setting $u = A$, $\omega + x = \alpha_2 t$, and $\frac{a_0}{2} = 0$, the equation becomes

$$A\left(\sin \alpha_1 t - \sin \alpha_2 t\right) = 0 + \sum_{n=2}^{\infty}\left(a_n \cos nx + b_n \sin nx\right) \tag{4}$$

The left side of equation (4) is the difference between the measured and fitted curve (equation (2)), and the right side represents all (first, second, etc.) harmonics. Hence the harmonic content, in the worst case, is equal to the difference between the two curves.

To show that this difference is small, the difference between the curves can be written in terms of α_1 and α_2 as follows:

$$A \sin\left(\frac{\alpha_1 - \alpha_2}{2}\right)t$$



$$\cos \omega = \frac{Y_2 - Y_1}{2A\left[\sin\left(\frac{\alpha_2 t - \alpha_1 t}{2}\right)\right]}$$

$$\sin\left(\frac{\alpha_2 t - \alpha_1 t}{2}\right) = \frac{Y_2 - Y_1}{2A \cos \omega}$$

$$\alpha_2 - \alpha_1 = \frac{2}{t} \sin^{-1}\left[\frac{Y_2 - Y_1}{2A \cos \omega}\right]$$

The analytical results showing the angular velocity, the variance, and the deviation in percent for the four cases are given in the following table:

Case	Angular Velocity, rad/sec	Variance, $(rad/sec)^2$	Deviation, percent
1	12.46	.320	4.5
2	26.45	.242	1.9
3	64.10	.896	1.5
4	75.21	.191	0.6

Therefore, the harmonic content of the test environment was not sufficient to cause the observed TTS's.

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TABLE I. - PRESSURE STIMULUS TIME HISTORY

Subject number	Three-minute exposures													
	Run 1		Run 2		Run 3		Run 4		Run 5		Run 6		Run 7	
	Freq, cps	SPL[a], dB	Freq, cps	SPL, dB	Freq, cps	SPL, dB	Freq, cps	SPL, dB	Freq, cps	SPL, dB	Freq, cps	SPL, dB	Freq, cps	SPL, dB
2	2.0	119	7.0	124	11.8	122	2.0	128	6.8	129	11.8	128	2.0	130
	Subject 2 (cont.)				Run 8		Run 9		Run 10		Run 11		Run 12	
					Freq	SPL	Freq	SPL	Freq	SPL	Freq	SPL	Freq	SPL
					7.0	135	11.6	136	7.0	137	12.0	137	11.9	140
	Run 1		Run 2		Run 3		Run 4		Run 5		Run 6		Run 7	
	Freq	SPL	Freq	SPL	Freq	SPL	Freq	SPL	Freq	SPL	Freq	SPL	Freq	SPL
3	2.0	130	6.3	127	11.9	128	4.0	134	12.0	142	7.2	136	12.1	140
4	2.3	131	6.8	128	11.5	128	7.0	137	11.6	136	7.1	135	11.7	139
5	2.2	132	7.3	129	11.5	128	4.1	135	11.9	136	7.3	135	11.5	[b]139
6	2.0	129	6.7	129	11.7	128	4.0	134	11.7	136	7.1	135	11.7	139
7	2.1	131	7.0	129	11.6	128	4.1	135	11.8	137	7.5	136	11.7	139
8	2.0	130	4.3	135	7.3	136	10.4	138	12.0	[b]141	-	-	-	-
9	2.5	131	4.0	135	7.0	136	10.5	[c]138	11.5	[c]140	-	-	-	-
10	10.0	135	10.3	137	10.4	138	10.5	140	10.5	140	10.5	[c]140	-	-

[a]SPL = sound pressure level = $20 \log_{10} \frac{P}{P_o}$ = decibel level $\left(P_o = 0.0002 \text{ dynes/cm}^2\right)$

[b]TTS detected postrun audiogram

[c]TTS detected

TABLE I. - PRESSURE STIMULUS TIME HISTORY - Concluded

Subject number	Three-minute exposures													
	Run 1		Run 2		Run 3		Run 4		Run 5		Run 6		Run 7	
	Freq, cps	SPL[a], dB	Freq, cps	SPL, dB	Freq, cps	SPL, dB	Freq, cps	SPL, dB	Freq, cps	SPL, dB	Freq, cps	SPL, dB	Freq, cps	SPL, dB
11	10.0	128	10.4	140	11.5	140	-	-	-	-	-	-	-	-
12	10.1	135	10.0	136	10.4	138	10.5	139	11.8	140	11.4	140	12.0	[c]140
13	10.3	139	10.3	139	10.4	139	10.5	139	11.7	140	12.5	140	12.0	140
14	2.0	136	2.0	[c]137	-	-	-	-	-	-	-	-	-	-
15	2.5	130	10.5	139	11.9	[c]140	2.0	137	2.0	139	2.0	141	2.8	142
16	2.0	129	10.5	139	11.5	140	2.0	141	2.0	141	4.4	143	-	-
17	2.0	133	2.0	140	2.0	141	4.3	141	4.0	143	10.5	139	12.3	[c]140
18	10.5	137	12.0	[c]140	2.0	141	2.0	141	4.5	143	11.9	[c]140	-	-
19	10.4	137	11.5	[c]140	2.0	141	2.0	141	4.5	142	12.0	140	10.1	138
20	2.5	141	2.4	143	4.5	142	2.7	144	4.4	144	-	-	-	-
21	11.8	140	11.5	140	14.0	142	15.2	144	8.5	137	10.3	138	21.5	[c]129

[a]SPL = sound pressure level = $20 \log_{10} \frac{P}{P_o}$ = decibel level $\left(P_o = 0.0002 \text{ dynes/cm}^2\right)$

[c]TTS detected

TABLE II. - SUMMARY OF TTS OBSERVED

[See table I for stimulus]

Subject number	TTS, dB				Ear	Comment
	3000 cps	4000 cps	6000 cps	8000 cps		
5			16		Exposed right	
8	11	15			Exposed right	
10		10			Covered right	
14		16			Exposed left	
17		10			Exposed left	Subject reported that post-exposure pure tones were distorted after last two runs.
				20	Covered right	
18			13		Exposed left	Subject reported that post-exposure pure tones were distorted after run 2. TTS of 13 dB completely recovered before testing continued.
			14		Exposed left	Subject reported tinnitus after run 6.
	11				Covered right	
21			13		Exposed left	
*9	22	15	13		Exposed left	TTS's completely recovered before testing continued.
	9				Exposed left	At 3000 cps, recovered from 22 dB TTS in 320 sec, but took 1020 sec to recover from second TTS of 9 dB.
*12				13	Covered right	
*15				11	Covered right	
*19			11		Exposed left	TTS of 11 dB at 6000 cps completely recovered before testing continued.
			11		Covered right	

*Hearing nonnormal by ASA standard.

TABLE III. - HEART RATE AND RESPIRATION RATE DURING EXPOSURE

Subject number	Run number	Heart rate, beats/min			Respiration rate, breaths/min		
		Before	During	After	Before	During	After
2	12	84	74	78	20	18	20
3	5	60	68	60	16	16	16
4	7	82	78	84	18	20	20
5	7	84	90	84	18	24	20
6	7	95	108	108	20	16	18
7	7	84	84	78	16	20	18
8	5	72	72	72	16	18	14
9	5	72	68	66	14	16	15
10	6	110	96	84	22	26	26
11	3	66	66	66	16	24	20
12	7	78	84	84	12	20	18
13	7	84	84	84	16	20	20
14	2	90	102	102	16	16	20
15	7	78	78	72	16	24	20
16	6	102	102	102	16	18	20
17	5	78	78	78	22	22	22
18	5	90	84	78	14	14	14
19	5	90	84	78	18	18	18
20	4	72	72	66	20	20	16
21	4	72	66	66	18	18	16

TABLE IV. - SUMMARY OF SUBJECTIVE RESPONSE DATA

Parameters	Subjective response		
	Negative subjects[a]	Comment	Positive subjects[a]
Body vibration	9	Slight	3
		Some	3
		Noticed, not bothered	4
Respiratory difficulties	16	Some	2
		Poor chamber air circulation	1
Disorientation	17	Vertigo	1
		Slight dizziness	1
Mental confusion or false cues	15	Occasional false cues	2
		Lack of normal sound	1
		Outside noise	1
Sensory decrement	15	Loss of ear sensitivity	1
		Cues difficult to discern	1
		Audiogram masked	1
		Odor of air hose	1
Post-testing response and fatigue	11	Boredom	2
		Dizziness on egress	1
		Acute hearing	1
		Cramped quarters	3
		Slight fatigue	1

[a]Total subjects responding

TABLE V. - PERFORMANCE DATA ANALYSIS

Number	Reaction time tasks												Memory task			
	Light				Meter				Addition							
	C	E	C-E	R	C	E	C-E	R	C	E	C-E	R	C	E	C-E	R
1	0.640	0.557	0.083	10	0.666	0.610	0.056	5.0	3.38	3.40	-0.02	1.0	2	1	1	0.33
2	.608	.422	.186	15	.596	.590	.006	1.0	2.62	3.08	-.46	-5.5	2	0	2	8.5
3	.562	.457	.105	12	.604	.477	.127	10.0	3.69	2.43	1.26	15.0	4	1	3	12.0
4	.658	.637	.025	3.0	.648	.662	-.014	-2.0	2.55	2.34	.21	2.0	3	1	2	8.5
5	.599	.532	.067	8.5	.628	.663	-.035	-3.0	2.13	2.77	-.64	-10.0	0	1	-1	-.33
6	.518	.470	.048	6.0	.582	.662	-.080	-7.0	2.57	2.03	.54	8.0	0	0	0	--
7	.513	.580	-.067	-8.5	.578	.809	-.231	-14.0	2.07	3.09	-1.02	-14.0	2	0	2	8.5
8	.558	.587	-.029	-4.0	.570	.935	-.365	-15.0	1.83	2.51	-.68	-11.0	0	1	-1	-.33

Key

C - Control R - Rank
E - Experimental

TABLE V. - PERFORMANCE DATA ANALYSIS - Concluded

Number	Reaction time tasks												Memory task			
	Light				Meter				Addition							
	C	E	C-E	R	C	E	C-E	R	C	E	C-E	R	C	E	C-E	R
9	0.526	0.490	0.036	5.0	0.542	0.745	-0.203	-12.0	3.74	4.00	- 0.26	- 3.0	1	0	1	0.33
10	.840	.710	.130	13.0	.874	.770	.104	8.0	2.87	3.77	-90	-13.0	5	0	5	13.0
11	.695	.710	- .015	- 2.0	.607	.752	- .145	-11.0	2.50	3.11	- .61	-10.0	2	0	2	8.5
12	.689	.782	- .093	-11.0	.610	.830	- .220	-13.0	3.89	3.43	.46	5.5	6	0	6	14.0
13	.735	.575	.160	14.0	.742	.680	.062	6.0	3.26	2.94	.32	4.0	2	0	2	8.5
14	.615	.677	- .062	- 7.0	.620	.730	- .110	- 9.0	3.00	3.71	- .71	-12.0	2	0	2	8.5
15	.618	.630	- .012	- 1.0	.652	.705	- .053	- 4.0	3.07	2.60	.47	7.0	0	1	-1	- .33

$N = 15.0$	$N = 15.0$	$N = 15.0$	$N = 14.0$
$T_1 = 86.5$	$T_1 = 30.0$	$T_1 = 41.5$	$T_1 = 90.6$
$T_2 = -33.5$	$T_2 = -90.0$	$T_2 = -79.5$	$T_2 = -0.99$
$p \leq 0.063$, for rejection	$p \leq 0.045$, for rejection	$p \leq 0.14$, for rejection	$p \leq .0007$, for rejection

Key

C - Control
E - Experimental

R - Rank
T_1 - Sum of positive ranks

T_2 - Sum of negative ranks

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