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A PRELIMINARY STUDY OF THE AWAKENING AND STARTLE EFFECTS OF SIMULATED SONIC BOOMS

by Jerome S. Lukas and Karl D. Kryter

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

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ABSTRACT

This report presents the results of experiments on the startling and awakening effects of sonic booms. The objectives of the study were (1) to build and test a device and associated room where one could simulate the effects of sonic booms on a room in a house, and (2) to conduct studies of the effects of the simulated indoor booms on people sleeping and performing manual tasks. The findings are based on a study of a small, homogenous group of subjects and, therefore, must be considered tentative at this time.

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I INTRODUCTION

Decisions to build the Concorde and the Boeing supersonic transports and knowledge that aircraft while flying supersonically generate sonic booms have caused concern regarding the startle and awakening effects of these noises on the population (Refs. 1,2,3,4). In response to this concern several research studies have been conducted. The most recent was conducted at Edwards Air Force Base (Ref. 5).

A significant finding of this recent study was that people who were familiar with subsonic aircraft noise and sonic booms, reported the booms to be more acceptable than did people who had infrequently experienced such noise and booms. Cited in Ref. 6 are several studies of the startle responses to impulsive stimuli such as gunshots and booms in which at least physiological adaptation was found. Some studies of the responses of sleeping individuals to pure-tone or broadband noise stimuli of relatively long durations and relatively low intensities, compared to the sonic booms, have been conducted (Refs. 6,7,8); most of these studies show differential sensitivity and some adaptation to auditory stimuli as a function of the stage of sleep the individual is in when exposed to a sound or noise.

It is, of course, to be expected that the startle and awakening effects of sonic booms would be strongly related to their audibility. Some information is available showing that perceived loudness or noisiness is dependent primarily upon the spectral content of impulsive stimuli which simulate at least some of the characteristics of the outdoor boom pressure wave (Refs. 9,10).

However, little direct quantitative information is available about the effects of sonic booms on people while performing psychomotor tasks, while sleeping, or while judging the loudness or noisiness of sonic booms having systematically different signature characteristics. This is primarily due to the unavailability in the past of adequate methods for creating in the laboratory the acoustic (including vibrational) environment that would be present either outdoors or in rooms of houses exposed to actual sonic booms.

A research contract was granted to Stanford Research Institute by the National Aeronautics and Space Administration for laboratory research on the effects of sonic booms heard indoors upon people performing psychomotor tasks and sleeping, and the effects of variations in the signature characteristics of sonic booms heard outdoors upon the judged loudness and noisiness of sonic booms.

The results of the studies on the audibility of simulated outdoor sonic booms having varying intensities, rise times, durations, and transients are reported in Ref. 11; that report was prepared by the Lockheed-California Company, under subcontract to Stanford Research Institute. For these audibility tests the Lockheed Company used a special booth in which pressure changes, similar to those from sonic booms heard outdoors, could be generated near a listener's ears.

The present report is a description of the development of the indoor sonic boom simulator at Stanford Research Institute and the results of preliminary experiments concerned with the effects of sonic booms from this simulator on sleep and startle.

The body of this report is composed of three sections: Simulator, Sleep Experiment, and Startle Experiment. Its organization reflects the amount of effort expended during the course of the project, and the relative contribution of the findings to resolution of the problem of the effects of sonic booms on people.

II SIMULATOR

A. Simulator Development

The development of the simulator was evolutionary: a prototype was built and, on the basis of the data gathered from tests of the prototype, a modified final model was built.

To simulate an indoor sonic boom with both acoustic and vibrational components, the best approach appeared to be the loading of one wall of a room with a wave of pressure similar to that from a sonic boom--the so-called N wave. An electromechanical device was designed and built to generate an N wave of pressure into a hermetically-sealed chamber. One wall of the pressure chamber was the wall of the experimental test room. The layouts of the final pressure chamber and test room are illustrated in Fig. 1.

Walls of the test room were of standard construction: drywall on 2" X 4" studs, 16" on center. In contrast, the outside walls of the pressure chamber were constructed of 3/4" plywood mounted on 2" X 4" studs, 12" on center, with horizontal cross supports joining adjacent studs about 3' from either end of the stud. Rigid construction of the outside walls was required in order to prevent bowing when the pressure in the chamber was increased, thereby decreasing the rise time and intensity of the resultant boom. For the same reason all joints in the pressure chamber were sealed with calking compound.

Given the volume of the chamber, the change in volume required to produce a two psf pressure was calculated as

$$\Delta V = \left(\frac{\Delta P}{P_o}\right)^{\frac{1}{\gamma}} V_o = \left(\frac{2}{14.7 \times 144}\right)^{\frac{1}{1.4}} V_o = .0069V_o$$

$$= 0.41 \text{ cubic feet}$$

where γ = constant, dependent upon the gas in the compartment and its compressibility

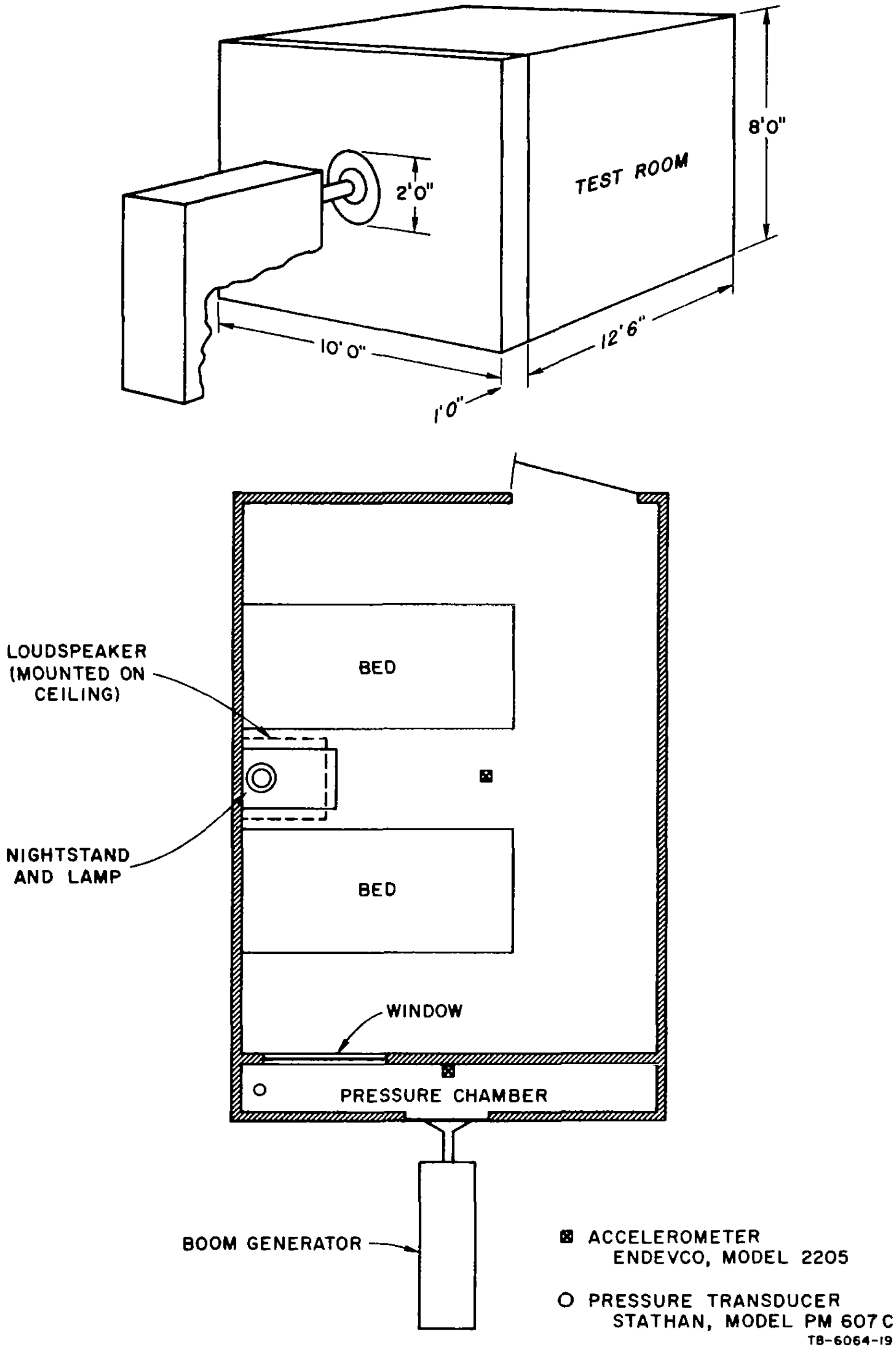

FIG. 1 SCHEMATIC OF SONIC BOOM STUDY FACILITY

ΔP = desired change in pressure

P_o = original pressure in chamber

V_o = original volume in chamber

For a plunger with a diameter of two feet, the required motion is

$$\frac{0.41}{\pi} = 0.13 \text{ feet} = 1.57 \text{ inches}$$

The boom generator operated in the following manner (see Figs. 2 and 3): In the final model of the generator the output of a DC motor was reduced through a series of belts, pulleys, and flywheels such that the result at the final drive shaft was a boom with a duration of 100 to 300 ms. The final drive shaft was attached to a "one shot" clutch, which turned through only 360^o and drove a cam. The cam (see Fig. 2) was a circle cut in half. One half was a neutral position with respect to the diaphragm. The other half had one end corresponding to the maximum forward diaphragm position and the other corresponding to the maximum back diaphragm position. Maximum and minimum chamber pressures corresponded to the forward and rearward positions of the diaphragm. The boom generator was mounted on concrete pilings separate and independent of the building in order to minimize the transmission of mechanical noise associated with operation of the generator. A quiet air-conditioning system was installed to control both acoustic and thermal environments in the test room. The noise levels of the fan and compressor of the ventilation system were approximately 55 dB re 0.0002 dyne/cm^2.

In order to permit vibration of the floor, the test room rested on eight 4" X 11" rubber vibration-isolating pads. The effectiveness of these pads is illustrated in Figs. 4, 5, and 6 which show Visicorder tracings of the output of an accelerometer mounted in the center of the floor of the test room.

Finally, to reduce the intensity of street and laboratory noises interfering with the subjects, sound-attenuating fiberboard was nailed to the outside of the wall and ceiling studs of the test room and gypsum wall boards were glued over the fiberboard.

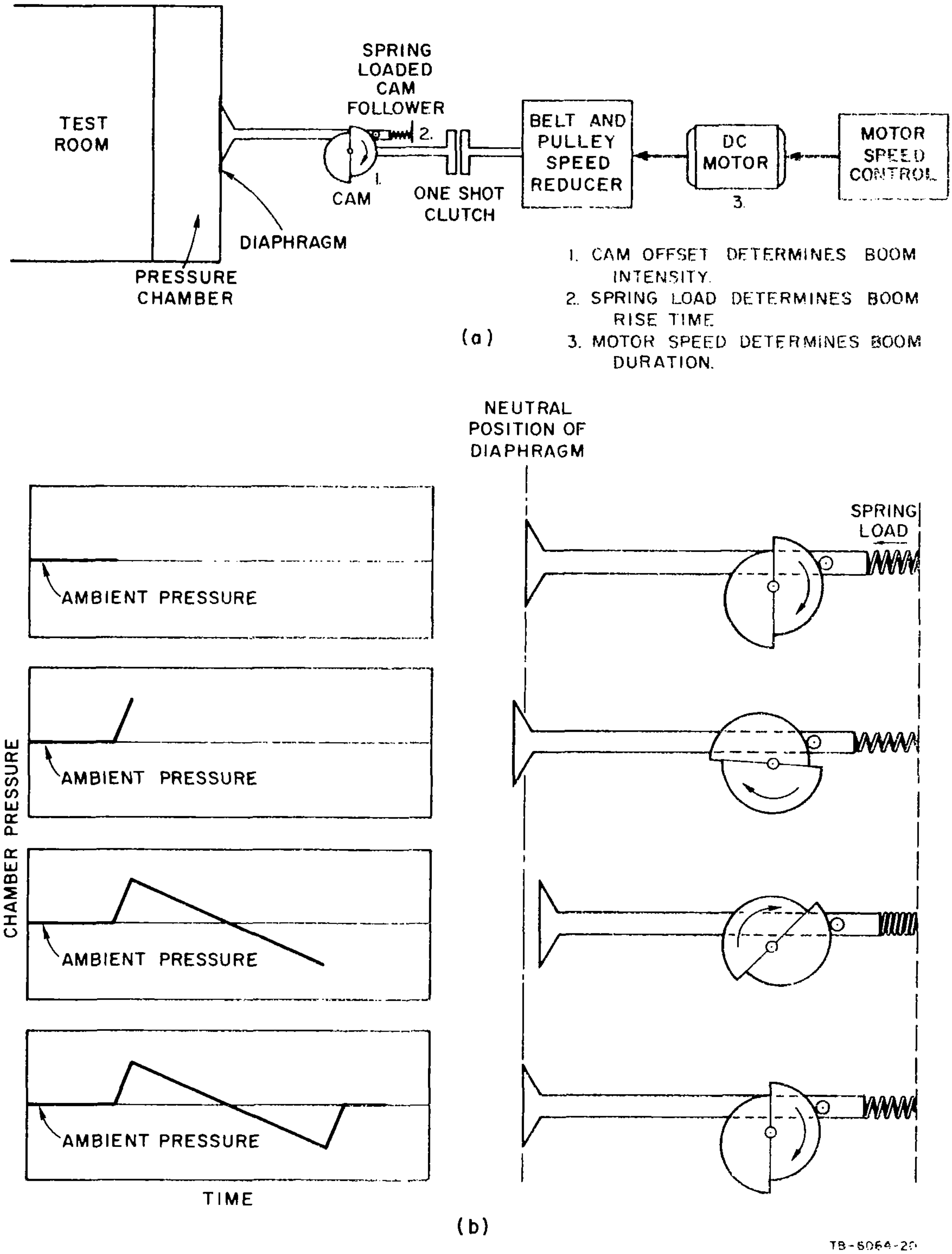

FIG. 2 SCHEMATIC OF SONIC BOOM GENERATOR OPERATION

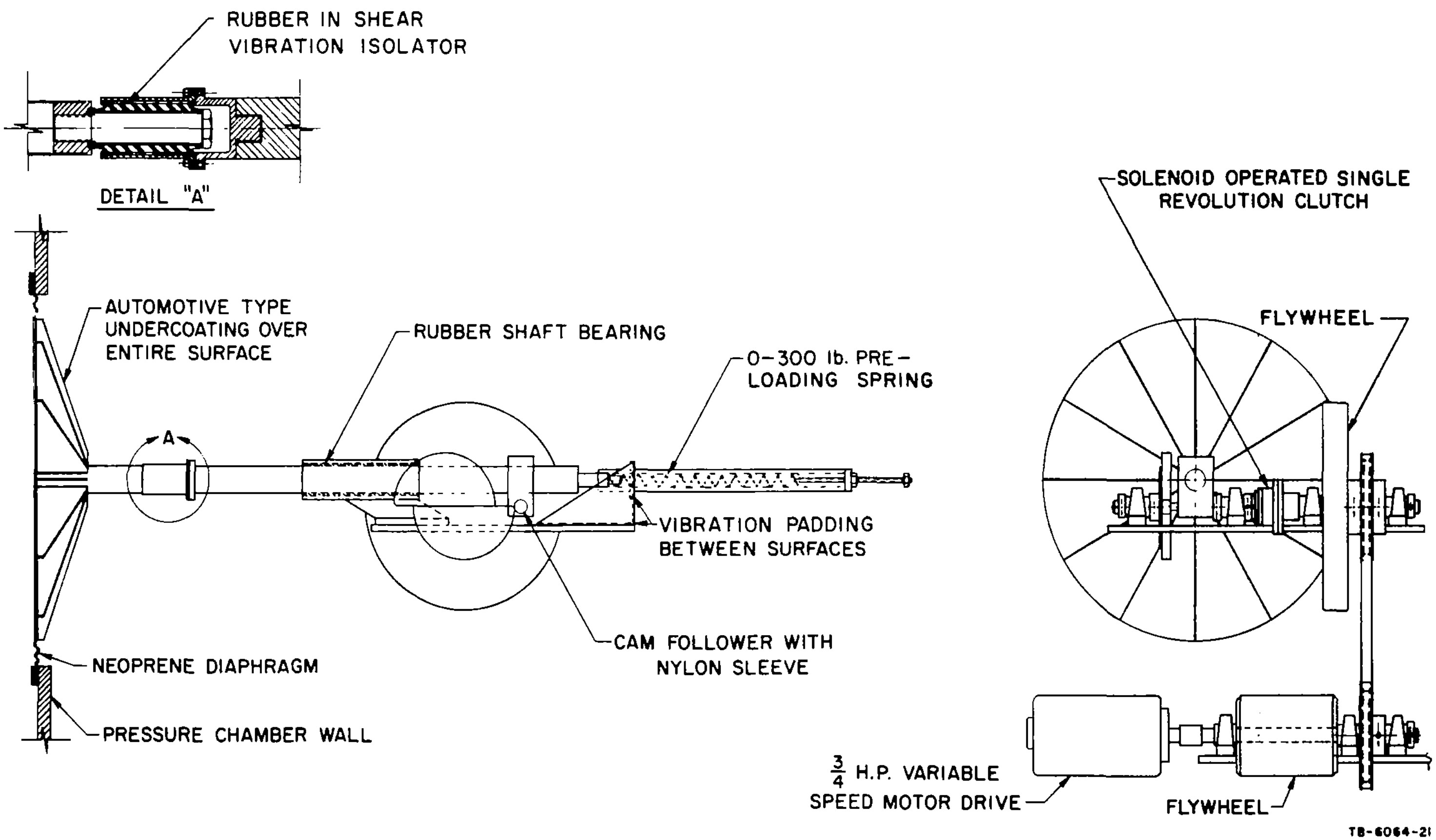

FIG. 3 SCHEMATIC OF SONIC BOOM GENERATOR

B. Simulator Performance

In Figs. 4 through 6, note the oscillations in chamber pressures. In contrast, a smoother negatively directed pressure wave is found in the case of an outdoor far-field boom. That these reverberations are transmitted throughout the room is evidenced by their coincidence with a slight lag of the oscillations recorded by the acoustic microphone and accelerometers (Figs. 4, 5, and 6). Note that the negatively directed pressure is not seen in the outputs from the accelerometers and microphones.

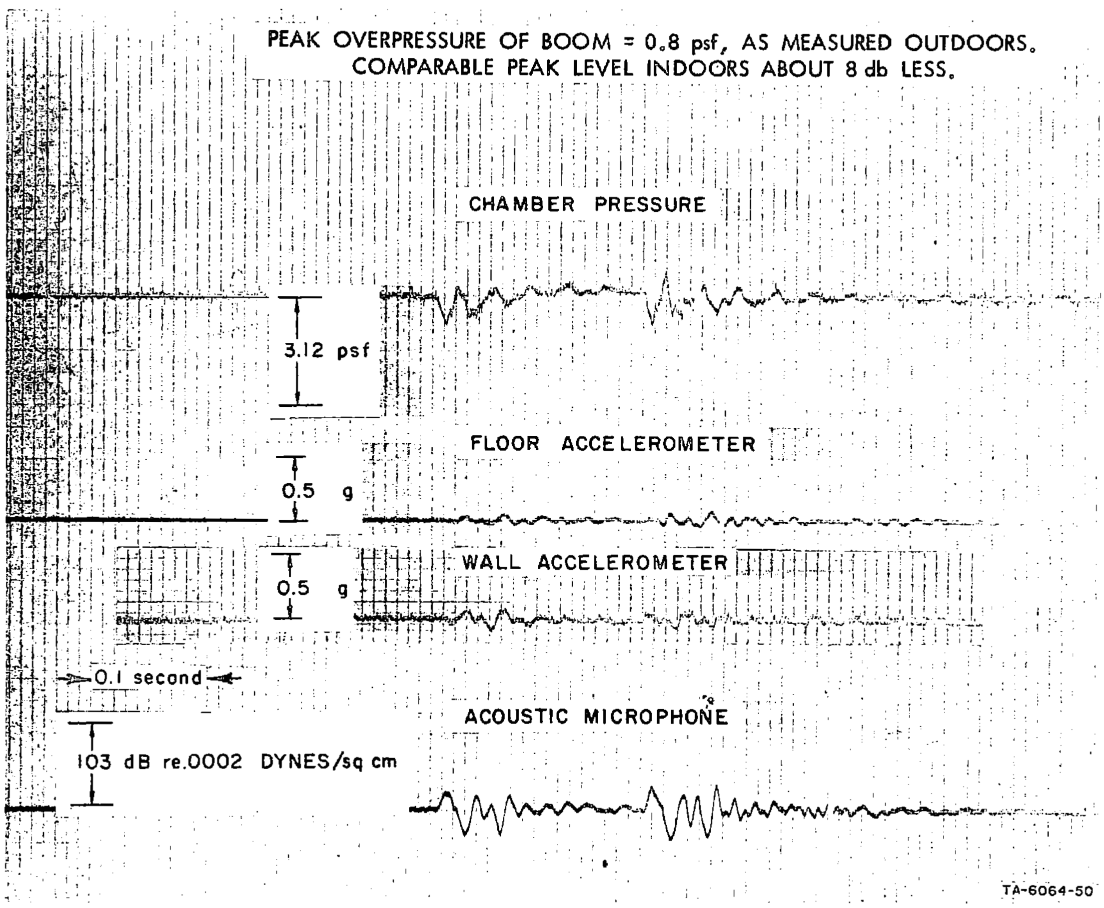

FIG. 4 CHAMBER PRESSURE (1000 Hz Low Pass Filter), ACCELEROMETER, AND INDOOR ACOUSTIC MICROPHONE TRACINGS DURING A 0.8 PSF SIMULATED SONIC BOOM

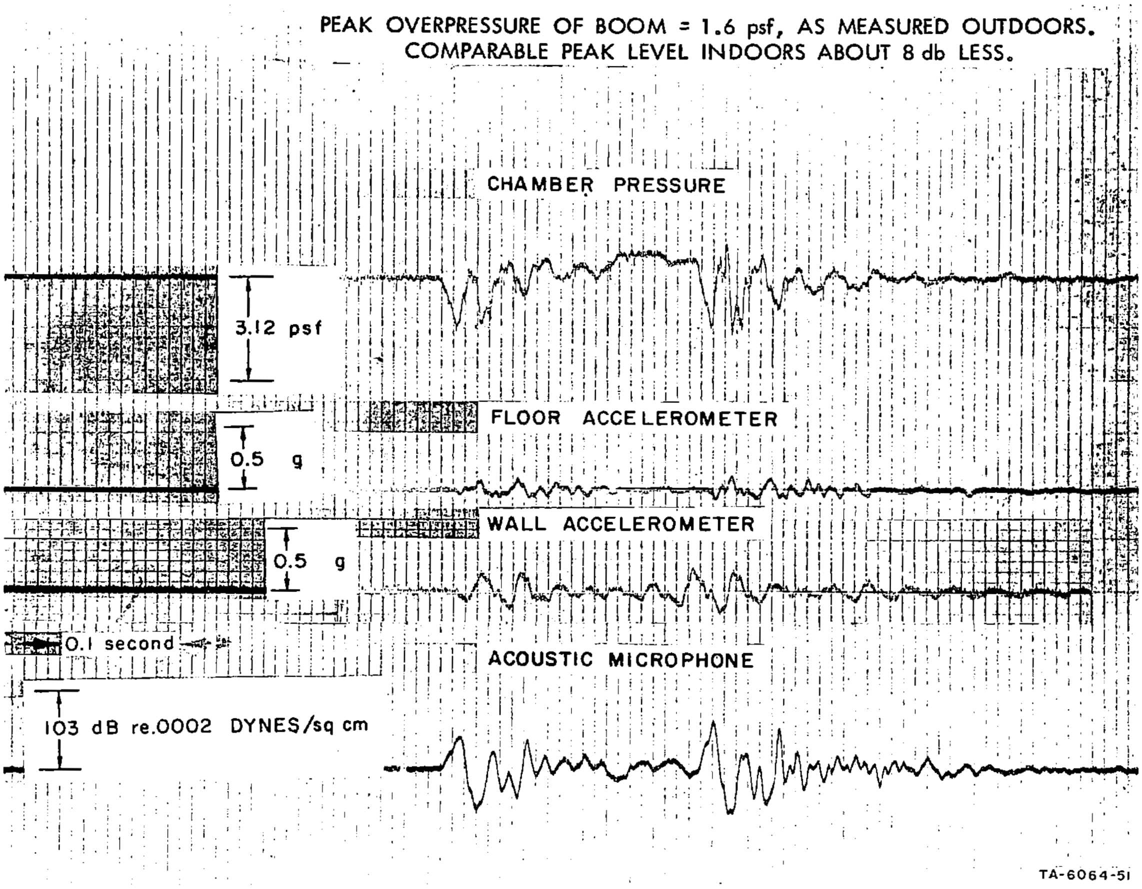

FIG. 5 CHAMBER PRESSURE (1000 Hz Low Pass Filter), ACCELEROMETER, AND INDOOR ACOUSTIC MICROPHONE TRACINGS DURING A 1.6 PSF SIMULATED SONIC BOOM

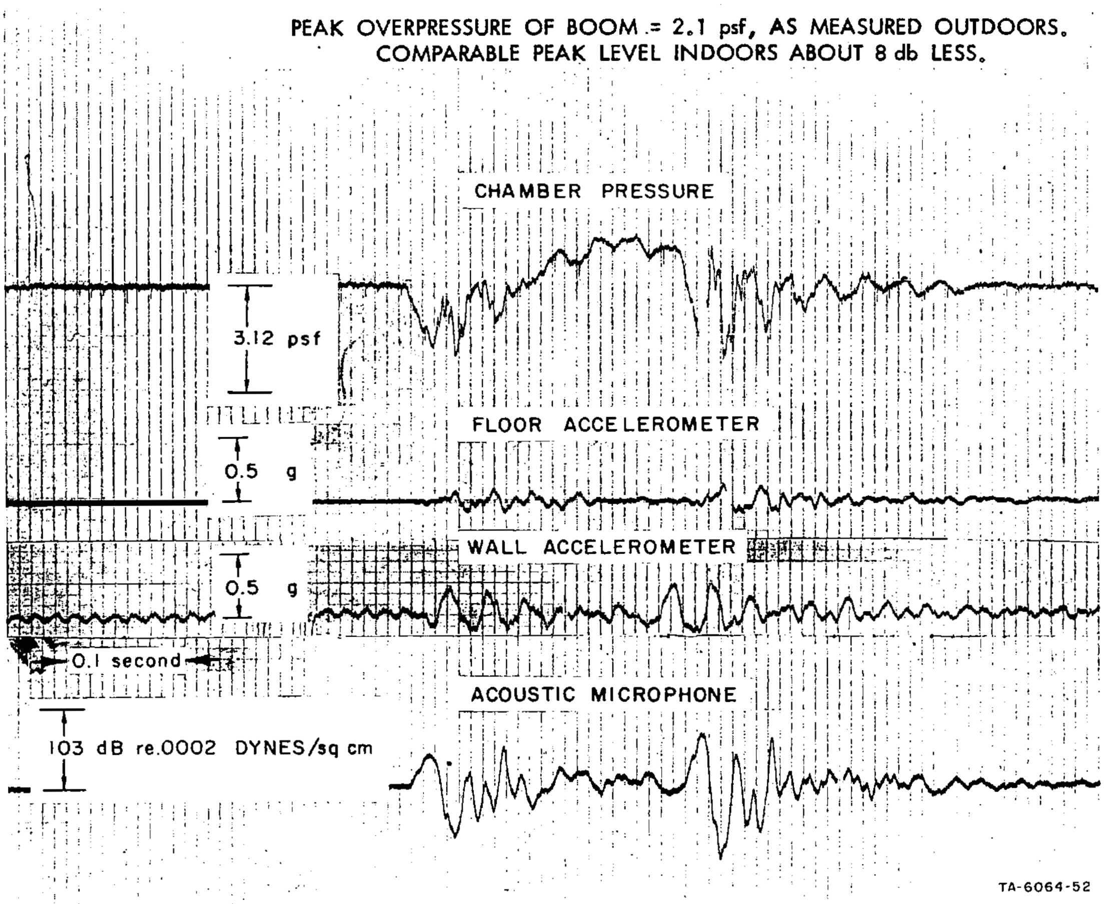

FIG. 6 CHAMBER PRESSURE (1000 Hz Low Pass Filter), ACCELEROMETER, AND INDOOR ACOUSTIC MICROPHONE TRACINGS DURING A 2.1 PSF SIMULATED SONIC BOOM

Figure 7 illustrates that the frequency response of the simulated "boom-room" remained about the same regardless of simulated boom amplitude. The extremes, 2.1 and 0.6 psf, of the simulated booms are presented for comparative purposes. The relative intensities of the frequencies comprising the spectra are essentially the same, although the overall intensities of the two booms differed by over 10 dB. The slight leftward shift of the 2.1 psf boom curve suggests that some changes were effected at lower frequencies, but their exact specification is difficult because the data fall in the insensitive region of the microphone (condenser microphone, Bruel & Kjaer, Cartridge Type 4131) response curve. Details of low frequency spectra are presented in the next section.

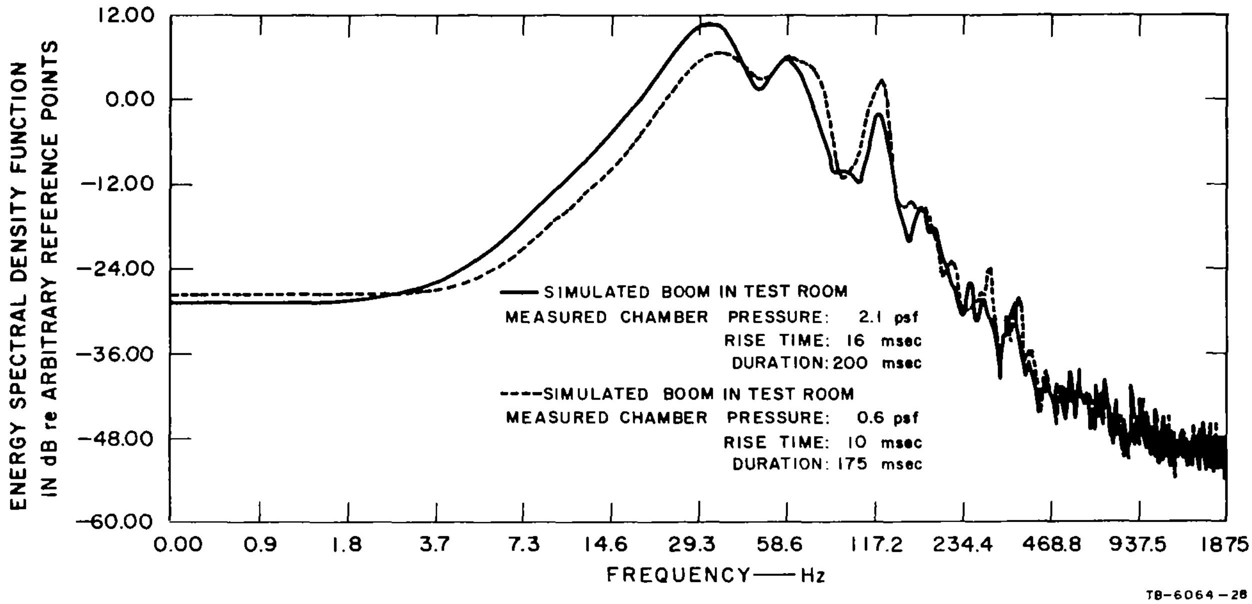

FIG. 7 INDOOR ENERGY SPECTRAL DENSITY FUNCTIONS 2.1 AND 0.6 PSF SIMULATED SONIC BOOMS

C. Comparison of Simulator with Actual Test House Performance

The vibrations felt and the sounds heard inside any given room of a house exposed to a sonic boom depend upon factors such as the construction of the house and rooms, the intensity and shape of the boom, and the characteristics of the accessories in the rooms of interest.

The acceleration patterns obtained in the test room are similar to those found in a test house studied at Edwards Air Force Base. This similarity can be seen through comparison of the accelerometer tracings of Fig. 8. (See Ref. 5, pages G-II-2 to G-II-40.) In Fig. 8, the accelerations observed in the floor (trace a) are not comparable directly with those observed in the test room floor (trace d) since at Edwards Air Force Base the floor accelerometers were mounted on 150-pound blocks of concrete which apparently acted as low pass filters. In contrast, accelerometers in the test room were coupled directly to the floor. Because booms directly affected only the north wall of the family room whose ceiling was partially sheltered from the oncoming booms by the roofs of the house and the garage, accelerations observed in the ceiling of the family room (trace b) were thought reasonably analogous to those of the test room floor (trace d). The similarity of accelerations induced in walls directly affected by booms can be seen by comparing traces c and e. Since the amplification requirements at Edwards were different from those required in the SRI test room, Fig. 8 should be used only for qualitative comparisons of the accelerations.

Of perhaps greater importance is a comparison of the acoustic stimuli generated in the test room by the simulator with those produced by actual aircraft in the bedroom of a test house at Edwards Air Force Base. Most, but not all, visitors familiar with sonic booms as heard indoors remarked that the booms of the final simulator were very similar to actual booms in terms of both acoustic and vibrational components. The general similarity of simulated and actual booms is shown in Figs. 9 and 10. The actual boom signal analyzed was the acoustic energy produced by a boom in a second-story corner bedroom of a test house at Edwards Air Force Base in which booms directly affected two walls. In contrast, the experimental room simulated a bedroom in which the boom directly affected one wall only. To expect an exact fit between actual and simulated booms would have been unreasonable. Different spectra are, in fact, likely because of the effects of room and building construction, boom characteristics, and room accessories.

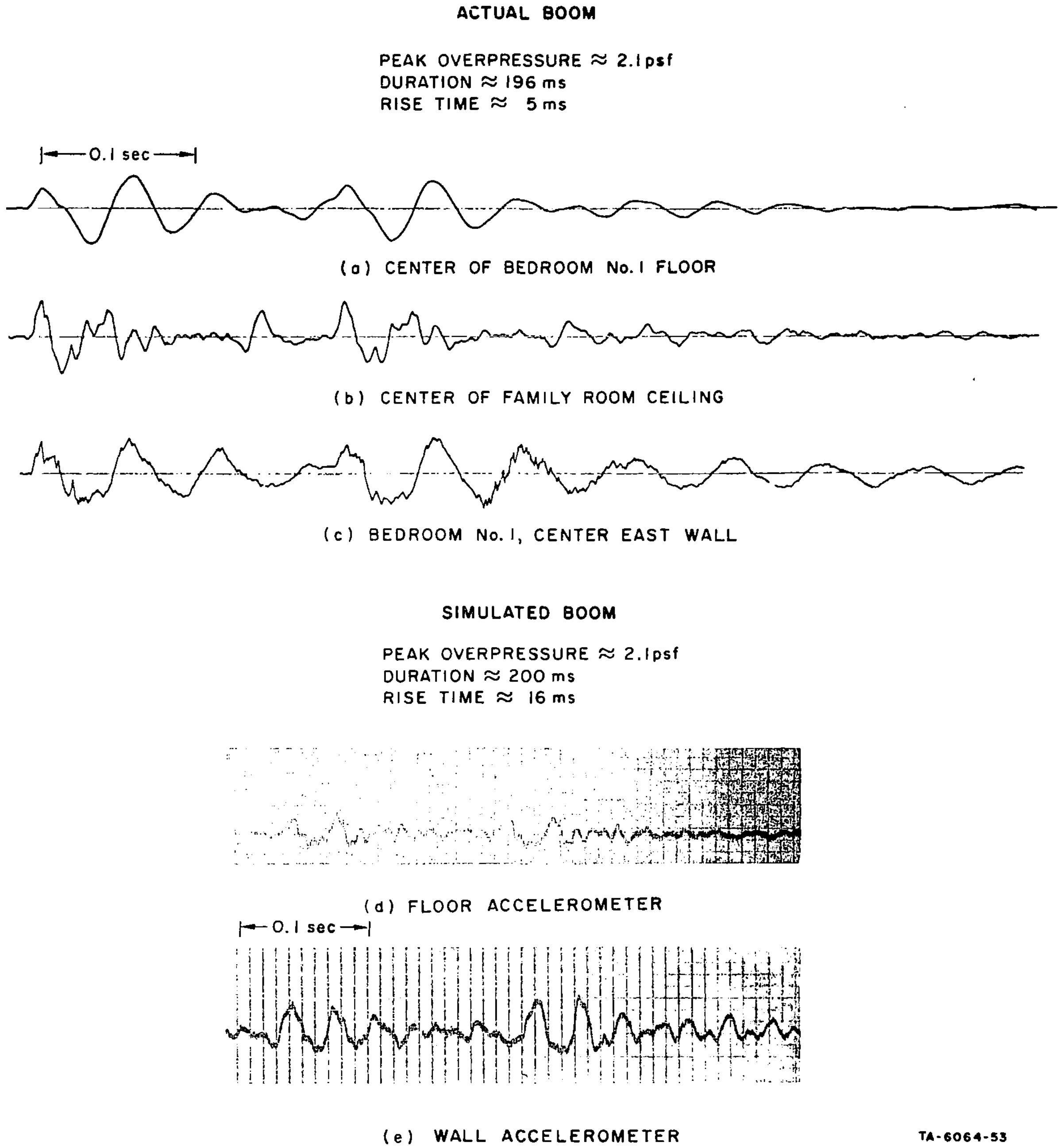

FIG. 8 ACCELERATIONS INDUCED BY AN ACTUAL B–58 SONIC BOOM IN A HOUSE AT EDWARDS AIR FORCE BASE (Ref. 4, Pg. G–II–33) AND BY A SIMULATED SONIC BOOM IN THE TEST ROOM FOR VARIOUS TRANSDUCER LOCATIONS

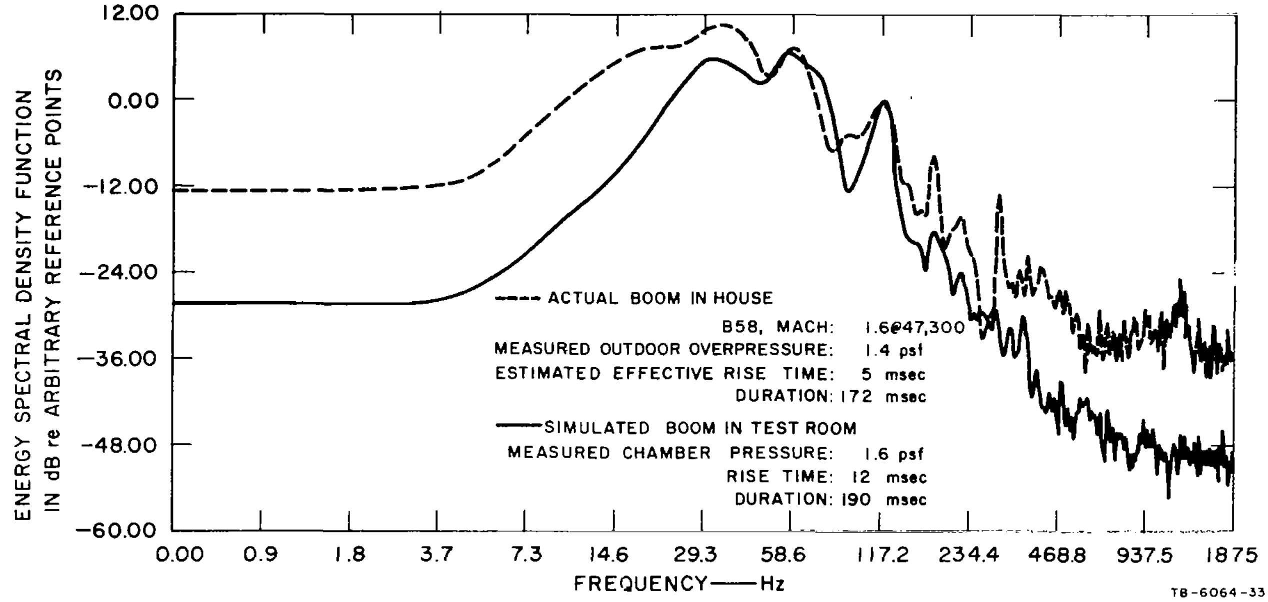

FIG. 9 INDOOR ENERGY SPECTRAL DENSITY FUNCTIONS OF AN ACTUAL 1.4 PSF B-58 SONIC BOOM AND A 1.6 PSF SIMULATED SONIC BOOM

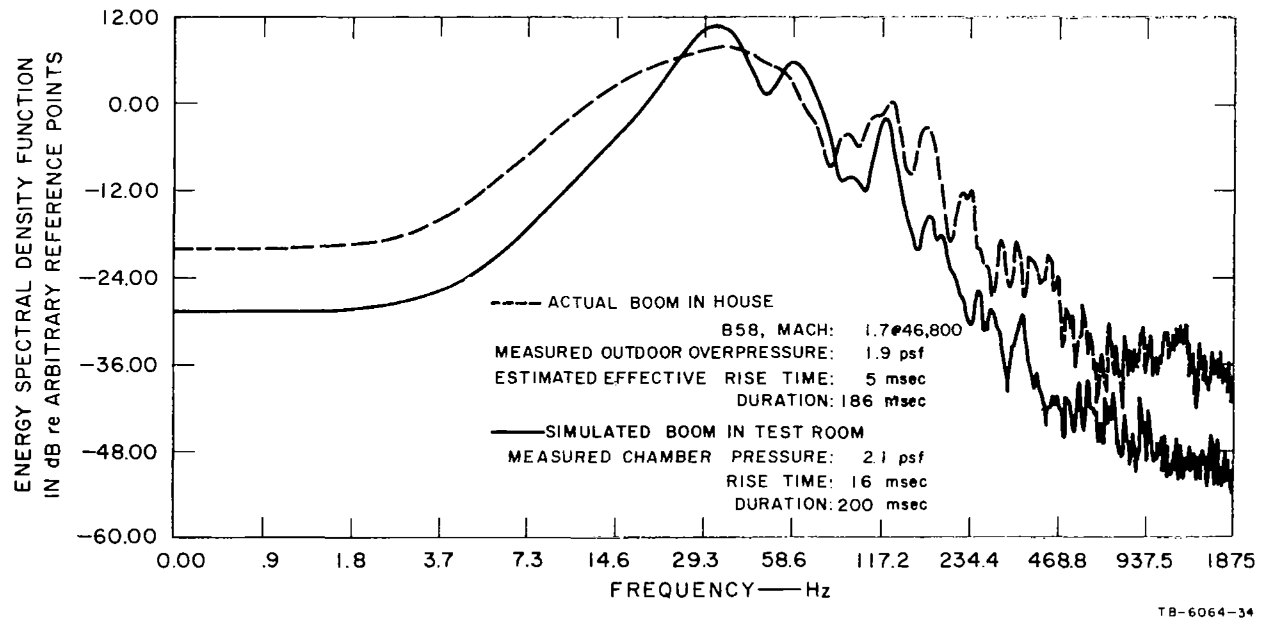

FIG. 10 INDOOR ENERGY SPECTRAL DENSITY FUNCTIONS OF AN ACTUAL 1.9 PSF B-58 SONIC BOOM AND A 2.1 PSF SIMULATED SONIC BOOM

Figure 9 shows a comparison of a 1.4 psf actual boom with a simulated boom of 1.6 psf and Fig. 10 shows a comparison of the indoor energy spectra of an actual boom of 1.9 psf and a simulated boom of 2.1 psf. Note the general similarity of the functions with peak intensities at about 30 Hz, and smaller peaks of about 117 and 175 Hz. The 12 dB difference between the actual and simulated boom at higher frequencies requires discussion.

The important parameters of a sonic boom, with respect to its acoustic spectra, are its amplitude, duration, and rise time. For the test conducted in the simulator, an attempt was made to simulate the peak amplitudes, rise time, and duration of booms from a B-58 aircraft. With the present simulator, however, it was not possible to achieve simulated booms having a rise time as short as that of some sonic booms from a B-58.* It can be shown theoretically (Ref. 5, Annex F) that the net effects of decreasing the rise time of the N wave of comparable peak amplitude and duration from 12 to 5 ms (the actual booms illustrated in Figs. 9 and 10 had rise times of about 5 ms, while the simulated booms had rise times of 12 and 16 ms) would be to increase spectral energy in the frequency regions above approximately 200 Hz; it is seen from Figs. 9 and 10 that, as expected, there is about 12 dB difference in the intensity at higher frequencies of the actual boom versus the simulated boom. In passing, note that the overall sound pressure level in the frequency region from 20-12,000 Hz measures some 5 dB greater for the actual boom than for the simulated boom when they have equal peak overpressure levels.

This difference between the simulated and actual sonic booms tends to make the simulated boom have a slightly less sharp "crack" than the typical actual boom. Nevertheless, the simulated boom is comparable to many actual sonic booms whose rise times are often lengthened because of atmospheric effects; in addition, the energy contributing most to the response of house structures and people, either indoors or outdoors, is present in the frequency region from about 20-200 Hz (Refs. 6,9, and 12).

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*Actual sonic boom rise times ranging from 1 to as high as 50 ms with a median of about 5 ms were recorded for B-58 aircraft at Edwards Air Force Base, Ref. 5.

Thus, in terms of its effect upon people and structures, it is believed that a reasonable simulation of a typical sonic boom having comparable peak overpressures can be achieved in the test room of the sonic boom simulator. Also, relatively minor modifications could be made in the present sonic boom simulator that would provide simulated booms having shorter rise times than the average of 12 ms used for the experiments in this report.

D. Low Frequency Analyses

Recent analyses of relations between acoustic and psychological data collected at Edwards Air Force Base indicate that acoustic energy present either indoors or outdoors in a frequency region below approximately 20 Hz does not contribute significantly to people's reactions to sonic booms (Refs. 9,12). This is apparently due to the fact that houses and, particularly, people do not respond effectively to energy in the frequency region below approximately 20 Hz. Part of the lack of responsiveness of the house structure (and perhaps people) at these low frequency energies in sonic booms is because the duration of the boom is so short--a matter of several hundred milliseconds; there is more response to steady-state (durations of seconds or minutes) stimulation of both houses and structures with low (below 20 Hz) frequencies of intense acoustic energy.

Nevertheless, a considerable amount of energy present in sonic booms is to be found in the region below 20 Hz (the effective cutoff frequency of the acoustic microphones used for the spectral analysis depicted in Figs. 9 and 10). To obtain a better idea of the low frequencies present in the room, a series of measures of low frequency variations in room pressure were obtained using a very sensitive pressure transducer (Stathan pressure transducer, Model PM5TC). The results, illustrated in Figs. 11 and 12, indicate clearly that the boom generator produced low frequency and relatively intense variations in pressure. Figure 11 compares the energy spectral density functions of two simulated sonic booms with chamber pressures of 2.1 and 0.8 psf. Of possible interest is the greater intensity, about 6 dB, of frequencies near 5 Hz compared to the peaks at frequencies near 40 Hz for the 2.1 psf boom. In contrast, the boom of

0.8 psf contains equally intense peaks near 5 and near 40 Hz. Comparable results are illustrated in Fig. 12 where the spectral distribution functions for these same booms are plotted.

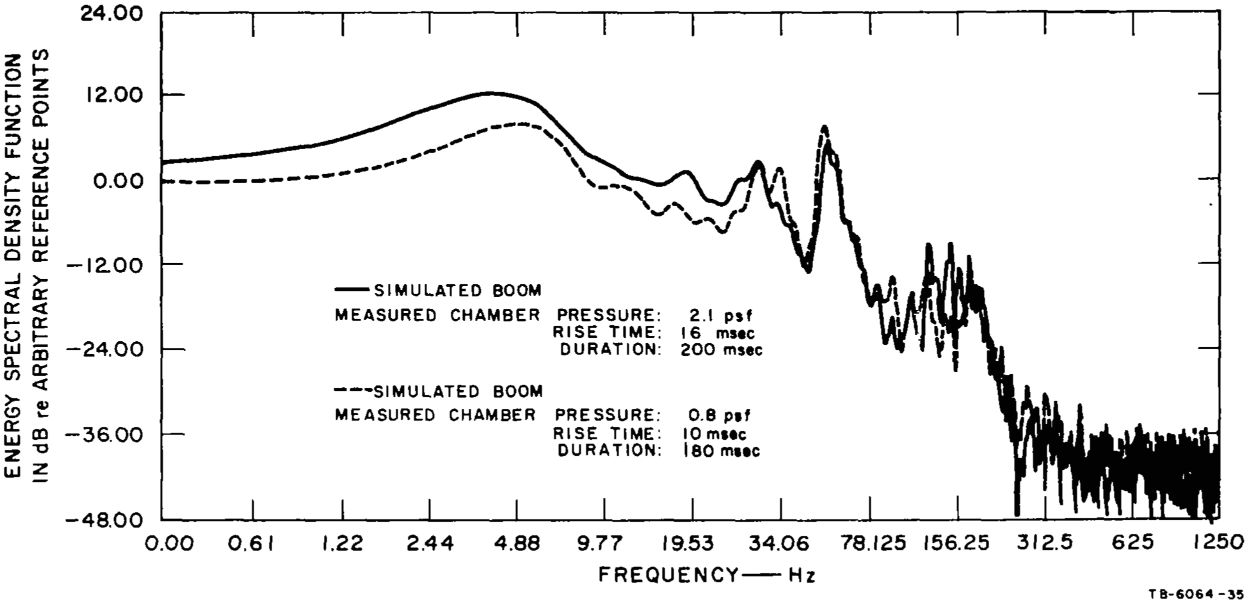

FIG. 11 LOW FREQUENCY INDOOR ENERGY SPECTRAL DENSITY FUNCTIONS OF 0.8 AND 2.1 PSF SIMULATED SONIC BOOMS

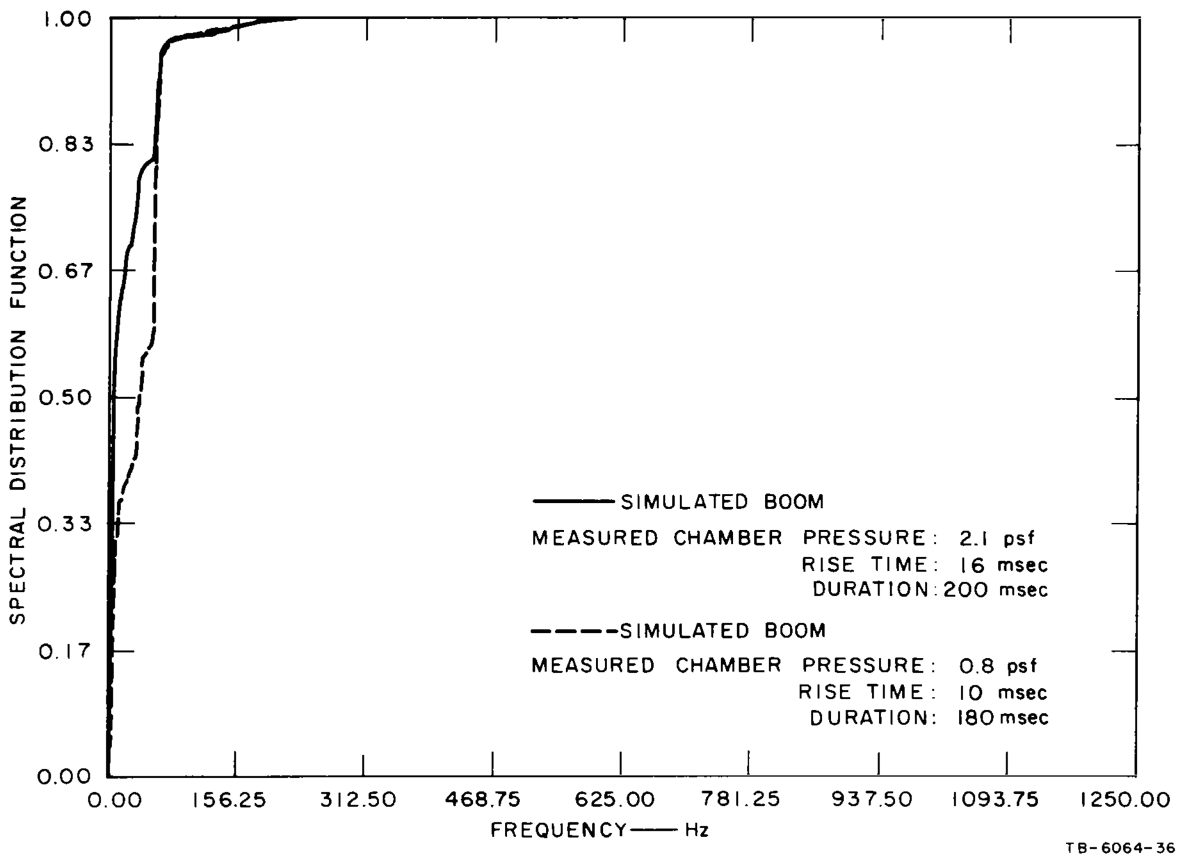

FIG. 12 LOW FREQUENCY INDOOR SPECTRAL DISTRIBUTION FUNCTIONS OF 0.8 AND 2.1 PSF SIMULATED SONIC BOOMS

III SLEEP EXPERIMENT

A. Objectives

The objectives of this study were to determine:

1. The effects of sonic booms and, comparatively, the effects of jet aircraft noise on the electroencephalographic activity and the behavioral awakening of a sleeping person

2. The extent to which individuals may adapt, according to these two measures, to sonic booms and jet aircraft noise

3. The differences in sensitivity among individuals to awakening by sonic booms and jet aircraft noise.

B. Method

1. Subjects

The experimental design illustrated in Table I includes the use of two simultaneously stimulated subjects per night. Each group consisted of two male students from Stanford University. All were 21 or 22 years of age with normal hearing. The subjects indicated they had not lived in noisy environments such as near airports. Although they had heard several sonic booms, they did not feel they had heard any more or less than had the majority of the population. They reported no strong feelings either for or against the supersonic transport.

2. Stimuli

Measured pressures and boom parameters generated in the test room by means of the simulator for this study are given in Table II. Indoor recordings of the four-engine turbofan jet aircraft flying directly overhead were presented, when required, through a loudspeaker mounted on the ceiling midway between the two subjects. Flyover intensities for the tests were selected to be equivalent to those present in bedrooms located directly under the flight paths of large jet aircraft very near commercial airports, and are presented as the entries for Group 3 in Table I.

Table I

EXPERIMENTAL DESIGN FOR
STUDY OF THE EFFECTS OF SIMULATED SONIC BOOMS ON SLEEPERS

Group	Stimulus	Week Night	WEEK 1	2	3	4	5	6	7	8	Total Stimulations/ Subject
1	Boom	1 2	[a] .6 psf [b] .8 psf	1.6 psf 2.1 psf	.8 psf .6 psf	1.6 psf 1.6 psf	.6 psf .8 psf	2.1 psf 2.1 psf	.6 psf .8 psf	1.6 psf 2.1 psf	192
2	Boom	3	.6 psf	.8 psf	1.6 psf	2.1 psf	.6 psf	.8 psf	1.6 psf	2.1 psf	96
3	Jet Flyover	4	83 PNdB [c]	93 PNdB	103 PNdB	113 PNdB	83 PNdB	93 PNdB	103 PNdB	113 PNdB	96
4	Boom & Flyover	5	EEG Change Thresholds Boom & Jet Flyovers of Varying Intensity								Indefinite

(a) Each cell entry indicates the boom or jet flyover intensity used during any one night. Twelve stimulations were planned each night. Cells to the left of dashed line (-----) were completed.

(b) Peak overpressure of boom as would be measured outdoors. Comparable peak level indoors about 8 dB less.

(c) Estimated peak perceived noise level, in PNdB, of noise from subsonic jet aircraft flyover if measured outdoors. Peak level measured indoors in test room was 20 PNdB less than estimated outdoor level.

Table II

CHARACTERISTICS OF EXPERIMENTAL SIMULATED BOOMS

Boom Pressure (outdoors) in psf	Boom Rise Time in ms (a)	Boom Duration in ms (b)	Sound Pressure Level in Room (c) (20-10,000 Hz)
.6	10	175	86
.8	10	180	87
1.6	12	190	96
2.1	16	200	100

(a) Rise time varied within ± 0.5 ms

(b) Duration varied within ± 1.0 ms

(c) In dB re 0.0002 dyne/cm^2
Bruel & Kjaer Precision Sound Level Meter, Type 2203
Condenser Microphone Cartridge Type 4131

3. Instrumentation

Two electrophysiological recordings from each subject were monitored continuously during the course of a night's work: (1) the frontal electroencephalogram (EEG), monopolar with respect to the homolateral ear, and (2) the bipolar rapid eye movements (REM), obtained from two electrodes proximal to the outer canthi. The electrodes (Grass Instruments, Model E5S) were affixed by surgical adhesive tape, since use of collodion and electrode paste was found to produce skin irritation after several sessions. For the same reason the frontal electrode was not placed consistently on either the right or left forehead; the positions of all electrodes were varied to minimize irritation. No significant variations in the EEG or REM were discernible as a result of these small shifts in electrode site. Electrophysiological signals picked up by the electrodes were amplified by Honeywell AC and DC amplifiers (models 108 and 109, respectively) and recorded on the Honeywell Visicorder (model 1508).

In addition to the electrophysiological signals, traces of stimulus occurrence and the subject's "awake response" were obtained. These traces are illustrated in Fig. 13. Stimulus occurrence was detected by an

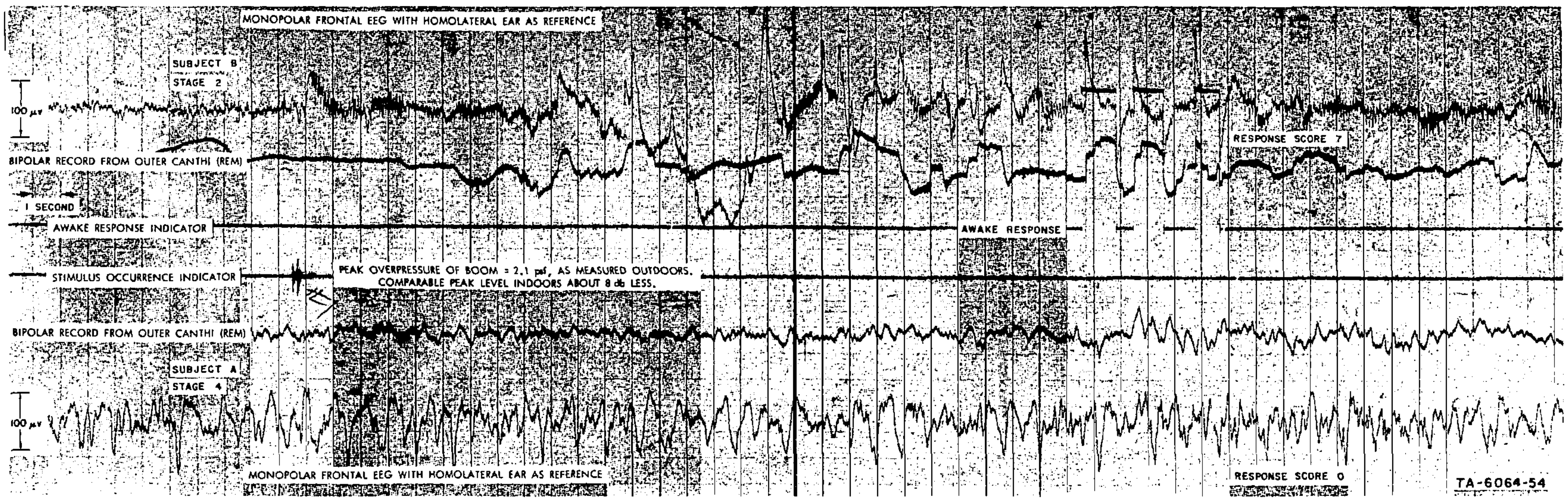

FIG. 13 SAMPLE TRACINGS OF STIMULUS OCCURRENCE AND AWAKE RESPONSE INDICATORS

accelerometer attached to the wall of the pressure chamber. The "awake response" occurred when a subject, upon being awakened by some stimulus, pushed a switch hanging from the head of his bed. If one subject operated the switch, a positive voltage appeared on the Visicorder; if the other subject operated the switch, a negative voltage appeared. An intercom between the test and control rooms provided continuous monitoring of the acoustic environment in the test room.

4. Procedure

On their first night in the laboratory, pairs of subjects were told informally of the purpose and nature of the experiment, told the number of days a week they would be required, shown the mechanics of the boom generator, and given a demonstration of a single boom of about one psf. The subjects then disrobed, put on pajamas, and had the electrodes set in place. Most subjects were allowed one night in which to accommodate to the environment and the electrodes; two subjects required two nights for accommodation. During the accommodation nights the EEG was monitored sporadically to determine whether the subjects were sleeping, and what was the condition of electrode attachments.

After the accommodation nights, EEGs were recorded continuously for two nights without any stimulation. If the records were similar, the second night was used as a baseline record. Only one subject required three nights to show two similar records and, in this case, the third night was used as a baseline EEG. On these accommodation nights, after the instrumentation was calibrated and checked, the subjects were repeatedly told to close the switch on their bed three times if they should awaken for any reason. Then, as if to check the status of the switches, the subjects were alternately asked to close them three times.

On the first and following experimental nights the electrodes were attached. The subjects were asked to test the awake switches and then to go to sleep. They were not told whether booms or flyovers would occur that night. After the experimenter was sure both subjects were sleeping, stimulation began. The stimulus sequence usually began 30-45 minutes after the subjects were told to go to sleep. The stimuli were given about every 15 minutes with a range of 10-30 minutes. The reason for this range is explained below.

Williams (Ref. 13) has indicated that the sleep stages occur throughout the night in the following percentages: stage 1, 2 percent; stage 2, 50 percent; stage 3, 5 percent; stage 4, 15 percent; stage REM, 20 percent; awake, 8 percent. (A description of these stages will be found in Appendix A.) Since the most common stages are 2, REM, and 3 and 4 combined*, it was decided to study the effects of stimulation during each of these stages, thereby sampling approximately 90 percent of the nighttime activity. To stimulate the subject too frequently during a night would have been undesirable since his usual sleep pattern would have been disrupted. It was estimated that if stimulation at low intensity levels occurred at about 15-minute intervals, the subject would be stimulated about four times in each of the three states of interest without any significant disruption of sleep pattern. As it turned out, it was impossible to adhere strictly to the 15-minute interval or, more importantly, to stimulate four times in each of the three sleep stages. Since there could be no assurance that two subjects would have identical sleep patterns, stimulation for one subject would occasionally be delayed because the other subject was in a sleep stage during which stimulation was not required.

Stimulations were varied so they did not always occur at a particular time during any given stage. There are approximately equal numbers of stimulations during the early, middle, and late minutes of the three sleep stages studied. Since the sleep cycle repeats itself about every 90 minutes (Refs. 13,15) and since a night's work consisted of 12 stimulations, the results are applicable to the first three or four hours of sleep. The subjects normally went to bed at about 11:00 p.m., and the experimental work for a night ended at about 3:30 a.m. During this time

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*Stage 3 is hard to distinguish from stage 4 and is sometimes considered, as we will see in this study, a single or very similar stage of sleep. See Refs. 7,15.

the subjects generally went through two complete sleep cycles; that is, two periods of stages 2, 3 and 4, and REM.

5. EEG Scoring

Several varieties of EEG responses were possible. Described in Table III is a scoring scheme that reflected the amount of awakening. It was developed with the assistance of Dr. Harold Williams of the University of Oklahoma Medical School. Examples of the EEG responses to simulated sonic booms will be found in Appendix A.

6. Termination of Experiment

Due to time and budgetary limitations the experiment as described in Table I has not been completed. Group 1 completed 11 nights, Group 2 completed four nights, Group 3 completed three nights, and Group 4 only accommodated to the environment. Hence, the results must be interpreted cautiously because of the premature termination of the study.

C. Results

1. Response and Adaptation to Sonic Booms--Group 1

The initial question was whether the subjects constituting Group 1 showed different sensitivities to booms. The data presented in Table IV indicate that the two subjects have similar sensitivities to booms in sleep stages 2 and REM, but are different in the combined 3 and 4 stage.

a. Sleep Stage 2

Comparison of the frequencies of scores for low (.6 and .8 psf) and high (1.6 and 2.1 psf) intensity booms suggested this to be a reasonable division of intensities. Indeed, statistical analysis verified the prediction, and in order to simplify presentation of the results, the responses to sonic booms will henceforth be grouped according to whether the booms were of low (average of .7 psf) or high (average of 1.9 psf) intensity as described. Table V shows clearly the effects of high and low intensity stimulation on EEG responses in stage 2 sleep.

The shift toward more awakening due to increased intensities of simulated booms during stage 2 sleep is illustrated in Fig. 14.

Table III

EEG SCORING CRITERIA

Score [a]	Change Required on EEG Record
0	No Change
1	Low Amplitude K Complex, less than 150 microvolts, occurring within one second of termination of stimulus, but usually is coincidental with stimulation
2	High Amplitude K Complex, above 150 microvolts, or several K responses, occurring within two seconds of termination of the stimulus
3	Presence of Alpha pattern or synchronization within two seconds of termination of stimulation
4	Movement of facial or eye muscles, or body movement, within six seconds of stimulus termination
5	Shift in sleep stage one step (e.g., from a stage 3 to a stage 2) within one minute of stimulus termination
6	Shift in sleep stage two steps (e.g., from a stage 4 to a stage 2) within one minute of stimulus termination. This category was never used, since a shift of two stages was always accompanied by awakening
7	Prolonged Alpha movement, and an Awake response, within one and one-half minutes of stimulus termination. The delay was required to allow the subject time to find the switch which was hanging from the bed headboard

(a) These scores are not independent since a high score usually included all the lower scores. For example: A response of 3 indicated that K complexes also occurred.

Table IV

FREQUENCY AND PERCENTAGE
OF EEG RESPONSE SCORES DURING THREE SLEEP STAGES

Subject Group 1		EEG Response Scores																				
		Stage 2 (b)							Stage 3 & 4 (c)							Stage REM (d)						
		0	1	2	3	4	5	7	0	1	2	3	4	5	7	0	1	2	3	4	5	7
A	(a) N =	6	3	8	8	2		1	37	9	11	14	3			31	5	1	2	1		
	%	21	11	29	29	7		4	50	12	15	19	4			78	13	3	5	3		
B	N =	3	6	21	16	7		6	15	15	10		6	4		19	2	1	1			
	%	5	10	36	27	12		10	30	30	20		12	8		83	9	4	4			

(a) Upper number is frequency, and lower is percentage within each sleep stage

(b) $X^2 = 6.62$, 5 df (degrees of freedom), N.S. (Not significant, so indicated if $p > 0.10$)

(c) Scores 4 and 5 combined,[1] $X^2 = 17.15$, 4 df, $.005 > p > .001$

(d) Scores 1 through 6 combined, $X^2 = 0.02$, 1 df, N.S.

(1) Tabularized Chi Square significance levels are good approximations if, in cases with two or more degrees of freedom, fewer than 20 percent of the cells have expected frequencies of less than 1 (Ref. 16). However, Walker and Lev (Ref. 17) indicate that "roughly approximate" probabilities for tests of significance are obtained if the expected frequencies in all cells are 2 or more. Because of lack of sufficient data, in most statistical analyses some response scores had to be combined to obtain the expected frequency of at least 2. The combinations are noted.

Table V

FREQUENCY AND PERCENTAGE OF EEG RESPONSE SCORES OF SUBJECTS A AND B TO LOW AND HIGH INTENSITY BOOMS DURING SLEEP STAGE 2

Outdoor Boom Intensity		EEG Response Scores						
		0	1	2	3	4	5	7
Low (.6 and .8 psf) Aver. .7 psf	N =	7	8	9	11			2
	% =	19	22	24	30			5
High (.16 and 2.1 psf) Aver. 1.9 psf	N =	2	1	10	13	9		5
	% =	5	3	25	33	23		13

Scores 4 and 7 combined, $X^2 = 17.38$, 4 df, $.005 > p > .001$

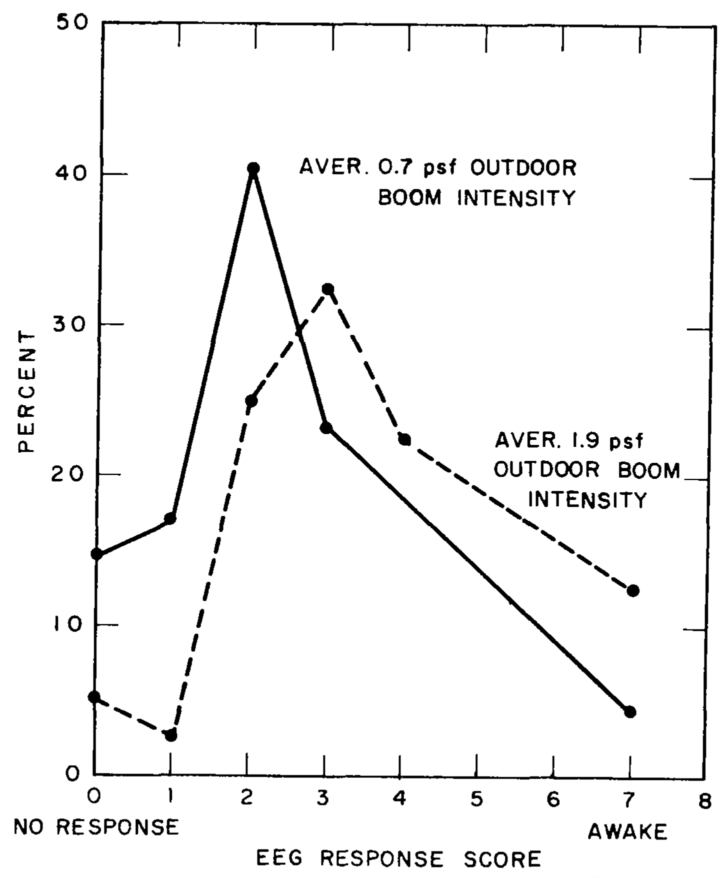

FIG. 14 STAGE 2 EEG RESPONSE TOWARD MORE AWAKENING AS FUNCTION OF SIMULATED BOOM INTENSITY

Cumulative percentages show that for low intensity booms, 96 percent of all EEG responses were 3 (Alpha or synchronization) or less. In contrast, only 65 percent of the EEG responses to high intensity booms were 3 or less.

Having shown that the two subjects responded significantly to variations in simulated boom intensity, the next question was whether they had adapted to booms, and whether adaptation was different for high and low intensity booms. The results indicate that adaptation to low intensity booms occurred, but not to those of high intensity. The range of EEG response scores on the first two experimental nights in comparison with the last two nights in which the stimuli were of equivalent intensities is shown in Table VI. A Chi Square computed with the scores arranged as shown in Table VI was of marginal significance (≈10 percent), but did suggest that if a difference existed, it was due to the large number of 0 responses obtained on nights 9 and 10. Indeed, recasting the data into the two by two table (see note at bottom of the table) provided statistical confirmation for the hypothesis. This finding suggests that adaptation to booms is due to an incremental change in sensitivity to booms rather than a small upward shift of overall sensitivity, and is consistent with the observation by some investigators (Refs. 7,15) that the most effective awakening stimuli are those that have meaning or significance for the sleeper--such as his name.

Table VI

FREQUENCY AND PERCENTAGE OF EEG RESPONSE SCORES OF SUBJECTS A AND B TO LOW INTENSITY BOOMS ON DIFFERENT NIGHTS DURING SLEEP STAGE 2

Nights and Boom Intensities		EEG Response Scores						
		0	1	2	3	4	5	7
Nights 1 and 2	N =		3	7	7			
(.6 and .8 psf)	% =		18	41	41			
Nights 9 and 10	N =	6	3	4	3			1
(.8 and .8 psf)	% =	35	18	23	18			6

Scores 1 through 7 combined, $X^2 = 5.06$, 1 df, $.025 > p > .02$

The effects of adaptation on the EEG responses of both subjects in stage 2 to low intensity booms are illustrated in Fig. 15. Note the significant shift downward of the curve for nights 9 and 10, and that the subjects responded to all the stimuli in the first two experimental nights but failed to respond to 35 percent of the low-intensity stimuli on nights 9 and 10.

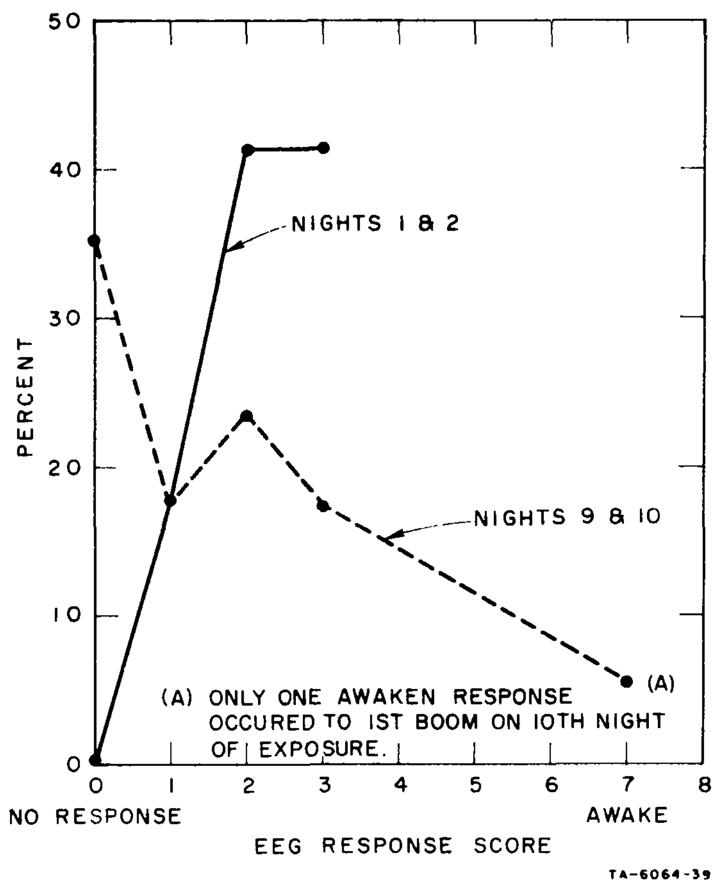

FIG. 15 ADAPTATION AS SHOWN IN STAGE 2 EEG RESPONSE TO LOW INTENSITY SIMULATED SONIC BOOMS

During sleep stage 2 subjects A and B showed little adaptation to high intensity booms, although there is a suggestion that some was beginning to occur. Table VII presents the data used for statistical analysis. The suggestion of the beginnings of adaptation is the occurrence of a 0 and 1 response in the last experimental nights and a decrease in the frequency of 7 responses from two on the second and third nights to one on the eighth night and none on the eleventh night.

Table VII

FREQUENCY AND PERCENTAGE OF EEG RESPONSE SCORES OF SUBJECTS A AND B TO HIGH INTENSITY BOOMS ON DIFFERENT NIGHTS DURING SLEEP STAGE 2

Nights and Boom Intensities		EEG Response Scores						
		0	1	2	3	4	5	7
Nights 3 and 4 (1.6 and 2.1 psf)	N =			5	4	4		2
	% =			33	27	27		13
Nights 8 and 11 (1.6 and 2.1 psf)	N =	1	1	4	9	4		1
	% =	5	5	20	45	20		5

Scores 0 and 1 deleted and score 7 combined with 4, $X^2 = 1.87$, 2 df, N.S.

b. Sleep Stage REM

With respect to sleep stage REM, the data indicate a differential response to high and low intensity stimuli, but no adaptation to booms of different intensities. Table VIII shows the EEG response score differences due to intensity, and Table IX presents the data concerning adaptation.

Table VIII

FREQUENCY AND PERCENTAGE OF EEG RESPONSE SCORES OF SUBJECTS A AND B TO LOW AND HIGH INTENSITY BOOMS DURING SLEEP STAGE REM

Outdoor Boom Intensity		EEG Response Scores						
		0	1	2	3	4	5	7
Low (.6 and .8 psf)	N =	31	2			1		
	% =	91	6			3		
High (1.6 and 2.1 psf)	N =	19	5	2	2			1
	% =	66	17	7	7			3

Scores 1 through 7 combined, $X^2 = 4.8$, 1 df, $.05 > p > .025$

Table IX

FREQUENCY AND PERCENTAGE OF EEG RESPONSE SCORES OF SUBJECTS A AND B TO LOW AND HIGH INTENSITY BOOMS ON DIFFERENT NIGHTS DURING SLEEP STAGE REM

Nights and Boom Intensities			EEG Response Scores						
			0	1	2	3	4	5	7
(a)	Nights 1 and 2	N =	8		2		1		
LOW	(.6 and .8 psf)	% =	73		18		9		
	Nights 9 and 10	N =	9		2				
	(.8 and .8 psf)	% =	82		18				
(b)	Nights 3 and 4	N =	9	3					
HIGH	(1.6 and 2.1 psf)	% =	75	25					
	Nights 7,8, and 11	N =	10	2	2				1
	(1.6,1.6, and 2.1 psf)	%	67	13	13				7

(a) Scores 1 through 7 combined, $X^2 = 0$, 1 df, N.S.

(b) Scores 1 through 7 combined, $X^2 = 0$, 1 df, N.S.

c. Sleep Stages 3 and 4

It was demonstrated previously (Table IV) that the two subjects of Group 1 responded differently to stimulation during sleep stages 3 and 4, so that further analysis regarding their response differences to booms of varying intensity and their adaptation must be preceded by an analysis of the individual subjects with respect to their responses during stages 3 and 4. Subject A was found to respond differently in stage 3 than in stage 4 while subject B was found to respond similarly in these stages. These analyses are presented in Table X.

Subject B was found to respond differentially to low and high intensity stimuli, with high intensity stimuli resulting in greater awakening. However, subject B did not show adaptation to either low or high intensity stimuli. Table XI presents the data regarding response scores to low and high intensity stimuli, and Table XII contains the adaptation analyses. Although the statistical test for adaptation was not significant, that some adaptation may have been occurring is suggested

Table X

FREQUENCY AND PERCENTAGE OF EEG RESPONSE SCORES OF SUBJECTS A AND B TO LOW AND HIGH INTENSITY BOOMS COMBINED DURING SLEEP STAGES 3 AND 4

EEG Response Scores		Subject A[a]		Subject B[b]	
		Stage 3	Stage 4	Stage 3	Stage 4
0	N =	6	31	6	9
	%	22	84	27	32
1	N =	7	2	6	9
	%	26	5	27	32
2	N =	8	3	4	6
	%	30	8	18	21
3	N =	4			
	%	15			
4	N =	2	1	3	3
	%	7	3	14	11
5	N =			3	
	%			14	
7	N =				1
	%				4

(a) Scores 3 and 4 combined, $X^2 = 24.6$, 3 df, $p < .001$

(b) Scores 5 and 7 combined, $X^2 = 1.9$, 4 df, N.S.

Table XI

FREQUENCY AND PERCENTAGE OF EEG RESPONSE SCORES OF SUBJECT B TO LOW AND HIGH INTENSITY BOOMS DURING SLEEP STATES 3 AND 4, COMBINED

Intensity		EEG Response Scores						
		0	1	2	3	4	5	7
Low	N =	13	11	2		1		
(.6 and .8 psf)	%	48	41	7		4		
High	N =	2	4	8		5	4	
(1.6 and 2.1 psf)	%	9	17	35		22	17	

Scores 4 and 5 combined, $X^2 = 21.15$, 3 df, $p < .001$

Table XII

FREQUENCY AND PERCENTAGE OF EEG RESPONSE SCORES OF SUBJECT B FOR EARLY AND LATE EXPERIMENT NIGHTS DURING SLEEP STAGES 3 AND 4, COMBINED

Nights and Boom Intensity			EEG Response Scores 0	1	2	3	4	5	7
(a) LOW	Nights 1 and 2 (.6 and .8 psf)	N =	3	4	1		1		
		%	33	44	11		11		
	Nights 9 and 10 (.8 and .8 psf)	N =	6	4					
		%	60	40					
(b) HIGH	Nights 3 and 4 (1.6 and 2.1 psf)	N =			6		3	1	
		%			60		30	10	
	Nights 7,8,11 (1.6,1.6 and 2.1 psf)	N =	2	4	2		2	3	
		%	15	31	15		15	23	

(a) Scores 1 through 4 combined, $X^2 = .49$, 1 df, N.S.

(b) Scores 1 through 5 combined, $X^2 = .30$, 1 df, N.S.

by the increased frequency of 0 scores for nights 9 and 10 and the increased frequency of 0 to 1 scores for nights 7, 8, and 11.

In contrast to the differential response to variation in stimulus intensity shown by Subject B, no such differential response was demonstrated by subject A in either sleep stage 3 or 4. These data are presented in Table XIII.

Because of the small frequencies obtained in stages 3 and 4, it is obvious that statistical tests for adaptation were based on very small samples and tended to be unreliable. However, the two X^2 analyses performed suggest that adaptation did not occur in either stage 3 or 4.

2. Response and Adaptation to Sonic Booms--Group 2

Subjects C and D of Group 2 were tested only four nights and little regarding adaptation to booms was learned. It was found, however, that this pair of subjects had statistically similar EEG response scores to stimulation during sleep stages 2, 3 and 4 combined, and REM. Subject A

Table XIII

FREQUENCY AND PERCENTAGE OF EEG RESPONSE SCORES OF SUBJECT A IN SLEEP STAGES 3 AND 4

Stage and Boom Intensity			EEG Response Scores						
			0	1	2	3	4	5	7
(a) STAGE 3	Low (.6 and .8 psf)	N =	3	3	5	2			
		%	23	23	38	15			
	High (1.6 and 2.1 psf)	N =	3	4	3	2	2		
		%	21	29	21	14	14		
(b) STAGE 4	Low (.6 and .8 psf)	N =	19	2					
			90	10					
	High (1.6 and 2.1 psf)	N =	12		3		1		
		%	75		19		6		

(a) Scores 3 and 4 combined, $X^2 = 1.28$, 3 df, N.S.

(b) Scores 1 through 4 combined, $X^2 = .664$, 1 df, N.S.

of Group 1, it will be remembered, showed different sensitivity to stimulation during stages 3 and 4. As in Group 1, scores in response to .6 psf stimulation were statistically similar to those at .8 psf, and scores in response to 1.6 psf and 2.1 psf stimulation were statistically equivalent.

3. Response and Adaptation to Noise from Subsonic Jet Aircraft--Group 3

The response of Group 3 to jet aircraft flyovers was dramatically different from that of Groups 1 and 2 to simulated booms. Because of the small number of observations for each sleep stage with any flyover intensity, statistical comparisons of flyover and boom data are likely to lead to spurious conclusions. On the first night of stimulation (with an outdoor intensity of 93 PNdB) 83 percent of the responses were 0, with only three scores being 1 or 2. On the second night (with an outdoor intensity of 103 PNdB) 20 percent of the responses were 0 and 33 percent were 7, with the remaining 47 percent being distributed among the other four scores without regard to sleep stage. On the third night (with an outdoor intensity of 113 PNdB) after a 5 response by both subjects to the first stimulation, 92 percent of the remaining responses were awakening, or 7. Thus, with high intensity flyover, it appears the subjects are likely to be awakened. Whether adaptation might occur is unknown. These data are summarized in Table XIV.

Table XIV

FREQUENCY AND PERCENTAGE OF EEG RESPONSE SCORES OF TWO SUBJECTS TO SUBSONIC JET FLYOVERS

Intensity	Estimated Equivalent Outdoor Intensity		EEG Response Scores						
			0	1	2	3	4	5	7
63 PNdB	93 PNdB	N =	20	2	2				
		%	83	8	8				
73 PNdB	103 PNdB	N =	4	2	2	3	1	4	8
		%	17	8	8	13	4	17	33
83 PNdB	113 PNdB	N =						2	22
		%						8	92

4. Sensitivity to Booms Versus Subsonic Jet Flyovers

It appears that sonic booms with outdoor intensities of 1.6 and 2.1 psf have awakening effects, regardless of sleep stage, approximately equivalent to the awakening effects of KC-135 B flyovers with outdoor intensities of 93 PNdB and 103 PNdB, as shown in Table XV. Whereas high intensity booms elicited fewer 0 responses than did flyovers of 93 PNdB, these booms resulted in more (about 15 percent) 0 responses than did flyovers of 103 PNdB. Further, high intensity booms consistently resulted in more EEG changes excluding shifts in sleep stage (score 5), but about 14 percent fewer sleep stage shifts and about 27 percent fewer awake responses (score 7).

D. Discussion

It has been demonstrated that adaptation to low (and, possibly, high) intensity booms occurs during stage 2 sleep. On the other hand,

Table XV

FREQUENCY AND PERCENTAGE OF EEG RESPONSE SCORES
TO DIFFERENT OUTDOOR INTENSITIES OF SUBSONIC JET FLYOVERS
COMPARED WITH HIGH INTENSITIES OF SONIC BOOMS

Flyover and Boom Intensity, Outdoors		EEG Response Scores						
		0	1	2	3	4	5	7
Flyover 93 PNdB	N =	20	2	2				
	%	83	8	8				
Boom, 1.6 and 2.1 psf	N =	38	14	26	17	17	4	6
	%	31	11	21	14	14	3	5
Flyover 103 PNdB	N =	4	2	2	3	1	4	8
	%	17	8	8	13	4	17	33
Flyover 113 PNdB	N =						2	22
	%						8	92

the data (remembering that only two subjects had been studied) indicate that adaptation during stage REM sleep does not occur. With respect to stage REM sleep our findings confirm those of Rechtschaffen, et al (Ref. 7) who report that the REM stage awakening theshold decreases as a function of accumulated sleep. Their findings suggest that adaptation to booms in REM sleep is unlikely because the sleeper becomes more sensitive to external stimuli the longer he sleeps. Thus, a boom of given intensity sounds much louder after three or more hours of accumulated sleep than it does with fewer hours of sleep. One might anticipate, therefore, that any adaptation to preceding nights stimulations which might be shown in the early hours of a given night may be cancelled out by the increased sensitivity to noise in the late hours of that night.

The differences noted between subjects A and B with respect to their score frequencies during stage 3 and 4 stimulation are consistent with those of other researchers who have found, for example, that the intensity of a 2000 Hz tone required to awaken different subjects may vary 15 to 100 dB above background noise levels. If adaptation (decreased sensitivity) between initial and subsequent nights of stimulation were to be found, it would seem most likely to appear in stages 3 and 4 since Rechtschaffen, et al (Ref. 7) found no increase in sensitivity to awakening within a single night's exposure when their subjects were in stages 3 and 4 (called Delta stage, in their terminology). We found no such adaptation during successive nights of exposure in any of these tests except for low intensity booms during stage 2.

The small amount of data obtained to date in the present study indicate that sonic booms of up to 2.1 psf (measured outdoors) may have approximately the same awakening effect as the flyover noises of subsonic jet aircraft of about 103 PNdB or less (measured outdoors). The tests were not continued long enough to measure any possible adaptation to the subsonic aircraft noise.

IV STARTLE EXPERIMENT

A. Objectives

The objectives of this study were to measure:

1. The physiological startle response to indoor sonic booms.
2. The effects of startle on the performance of a motor task.
3. The rate at which subjects adapt to indoor sonic booms as reflected by startle response and performance measures.

B. Method

1. Subjects

Twenty college students, 10 males and 10 females, with normal hearing were divided into four experimental groups and one control group. Males and females were evenly divided among the five groups.

2. Stimuli

Sonic booms of about 1.2 psf (outdoors) with 100 ms durations and 10 ms rise times were generated in the simulator for this experiment.

3. Instrumentation

The motor performance test (shown in Fig. 16) was a stylus-tracking board. The stylus-tracking device consisted of a square, diamond, and bullseye laid out on a board as printed circuits. The square and diamond were composed of six parallel tracks, 1/32 inch in width, separated by a space, 1/16 inch in width. The dimensions applied to the circle, but it contained five tracks about an "inactive" center. Each track had a different voltage impressed upon it such that when the circuit was closed through the stylus, each track had a unique level (position) on the Visicorder tracing. Upon initial testing it was found that use of the Visicorder trace to measure time was inaccurate. Therefore, counters were used. During this test only three tracks of the square were active. If the stylus contacted any one of the tracks, a counter counted (in one-tenth-second intervals) the duration of the contact and indicated the track activated. For this study the subjects were told to trace on the third track from the inside of the outermost group of tracks (the square on Fig. 16). Another counter recorded the total time required by the subject to make one circuit around the board. At the completion of a circuit the stylus contacted a brass strip which inactivated the track for ten seconds, and extinguished a light used to indicate when active and the subject was to begin another circuit.

Cues for being on the correct track were both visual and auditory. When the subject was on the correct track, four bright lights (seen in Fig. 16 as bright spots in the corners of the board) were extinguished. When he was off the correct track, a noisy relay turned the lights on. The two incorrect tracks, 2 and 4, were on either side of the correct one.

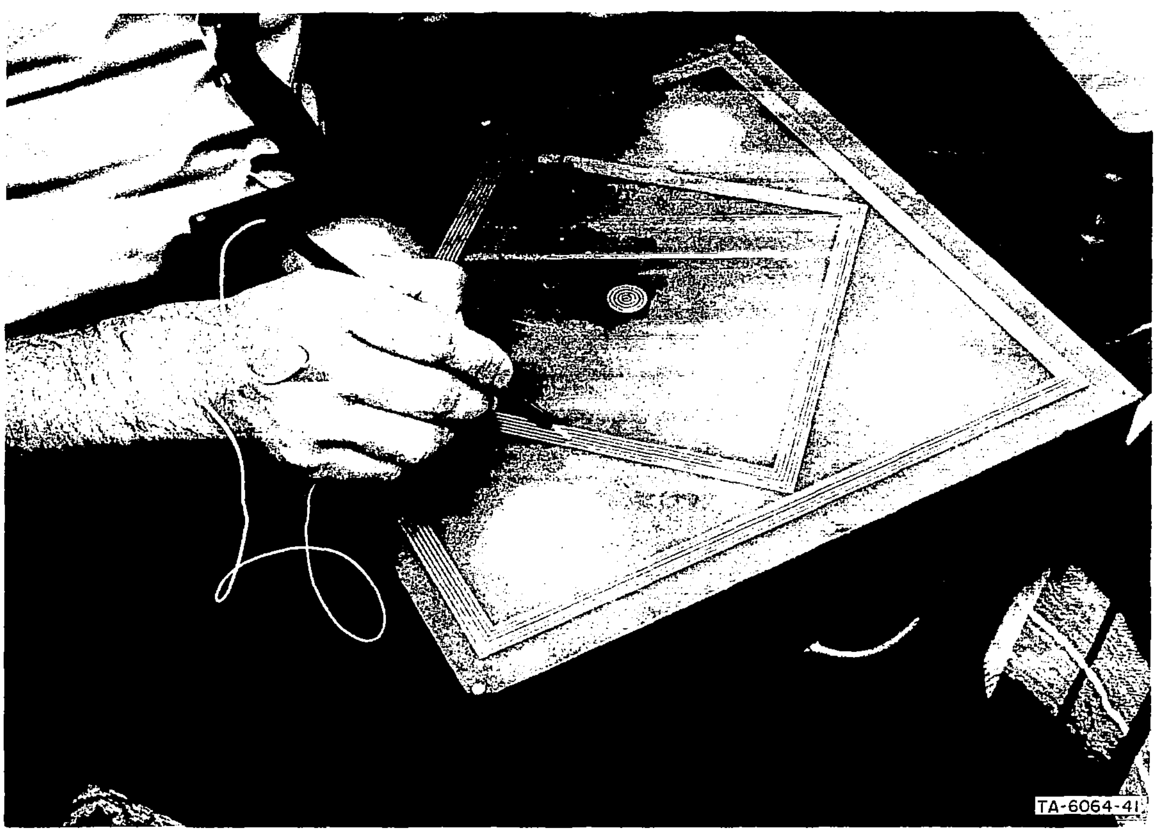

FIG. 16 MOTOR PERFORMANCE TEST BOARD

In addition to the performance measures the electromyographic response (EMG) of the trapezius muscle on the shoulder opposite the arm being used in the tracking task was recorded on a Honeywell Visicorder. The EMG was recorded at the contralateral trapezius to minimize movement "crosstalk" found in homologous muscles in the arm being used in the task. Rather than attempting to analyze the raw EMG, a circuit which integrated the EMG signal over a one-half-second interval was developed. Its output was a pulse, recorded on the Visicorder, with amplitude proportional to the energy generated by the muscle during the interval.

4. Procedure

The experiment included five groups. Each experimental group had four sessions (one day per week) of exposure to nine simulated sonic booms. Each session was approximately 45 minutes long, and consisted of nine periods of three minutes each during which a boom would occur randomly at 30, 60, or 90 seconds after the beginning of the period. Two-minute rest periods were included between boom periods.

Group 1 tracked, as will be described below, and was boomed throughout the four sessions. Group 2 was boomed through session 1 and began tracking with continued booming during session 2. Group 3 was boomed for two sessions before beginning the tracking task in session 3. Group 4 began tracking during session 4 after being boomed for the preceding three sessions. The Control Group tracked during four sessions but was never boomed. The design is illustrated in Fig. 17.

Each subject was instructed at the beginning of the first session during which he would track (session 1 for Group 1 and Control, session 2 for Group 2, etc.). Several trial tracking circuits (once around the board--see Fig. 17) were demonstrated, and the subject tried the task himself. After correction by the experimenter, the subject was told to practice until he was able to complete a single tracking circuit within 30 seconds or less, with a minimum of concern for the number of errors. After attaining this speed, the subject was not given any further instructions.

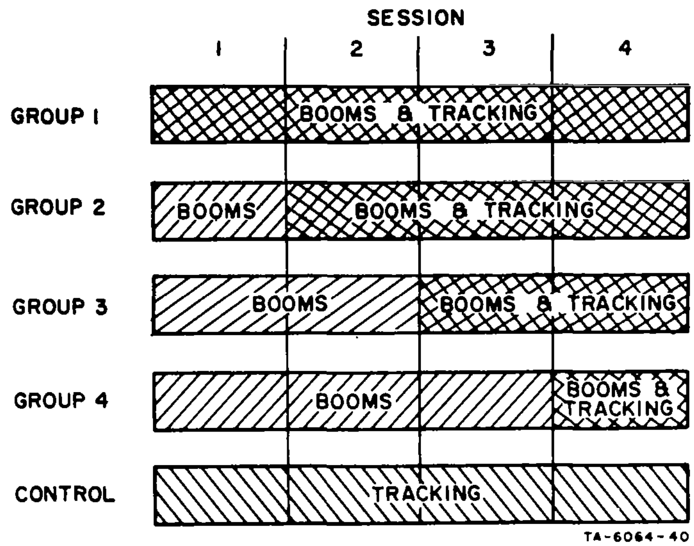

FIG. 17 EXPERIMENTAL DESIGN FOR STUDY OF "STARTLE" TO SIMULATED SONIC BOOMS

C. Results

1. Muscular Tension

Assuming a startle response (as indicated by increased muscular tension) to booms and adaptation of that response, the experiment was designed to test the hypothesis that Groups 2, 3, and 4, having more chance to adapt to booms before beginning the tracking task, should perform better than Group 1 on the initial trials when booms occur. Secondarily, if adaptation of startle occurs, the experimental groups should perform as well as the Control Group with respect to final performance levels.

That a muscular startle response did occur to the boom and that it did adapt to a large extent is illustrated in Figs. 18 and 19. Figure 18 shows that the groups boomed had significant EMG responses to being boomed (the difference in muscular tension or activity integrated over one-half second before the boom and one-half second after the boom), but that over four sessions the experimental groups' startle responses were reduced about half. Despite the reduction, after four sessions and 36 booms their response was still higher than, but approaching, that of the

Control Group. For the purpose of comparison, portions of the Control Group's EMG record were randomly designated as "Pre-boom" or "Boom," (sc. Fig. 18) and fortuitous measures of "startle," if any, were obtained therefrom. Group 4's EMG data are not included in these figures because of a malfunction of the recorder when they were being tested.

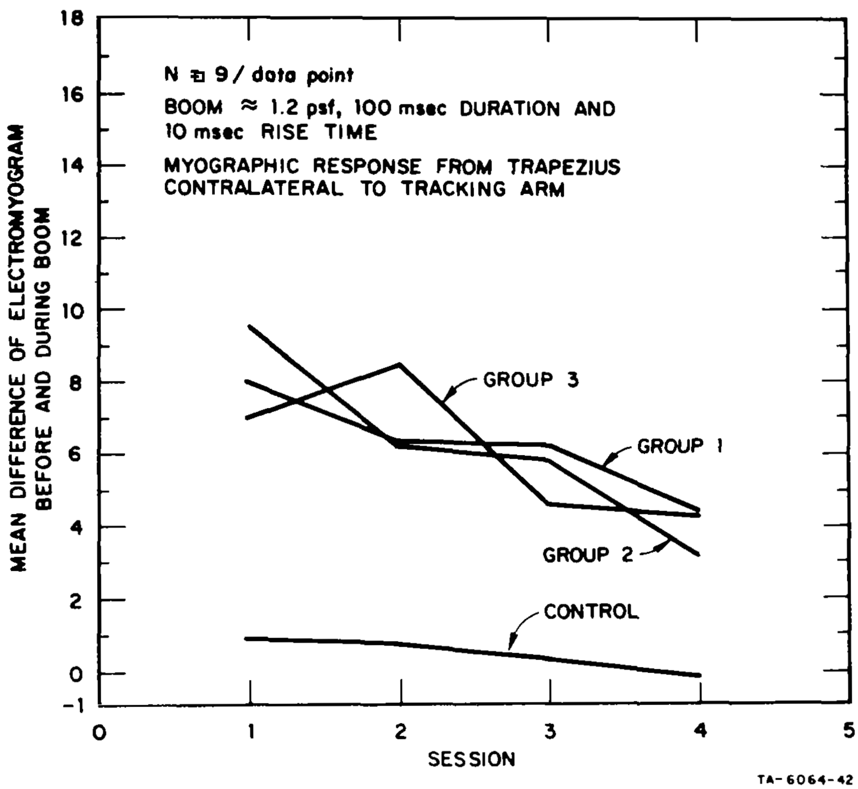

FIG. 18 MEAN NORMALIZED MUSCULAR STARTLE RESPONSE TO SIMULATED SONIC BOOMS AS A FUNCTION OF TEST SESSION

Both inter- and intra-session adaptation of the EMG startle response are illustrated in Fig. 19. During session 1 the magnitude of startle was variable; however, during sessions 2 and 3 it showed a consistent downward trend. In session 4 there appeared to be a slight downward trend, but note that its initial level was at about the final level (after nine booms) of the preceding two sessions. This finding

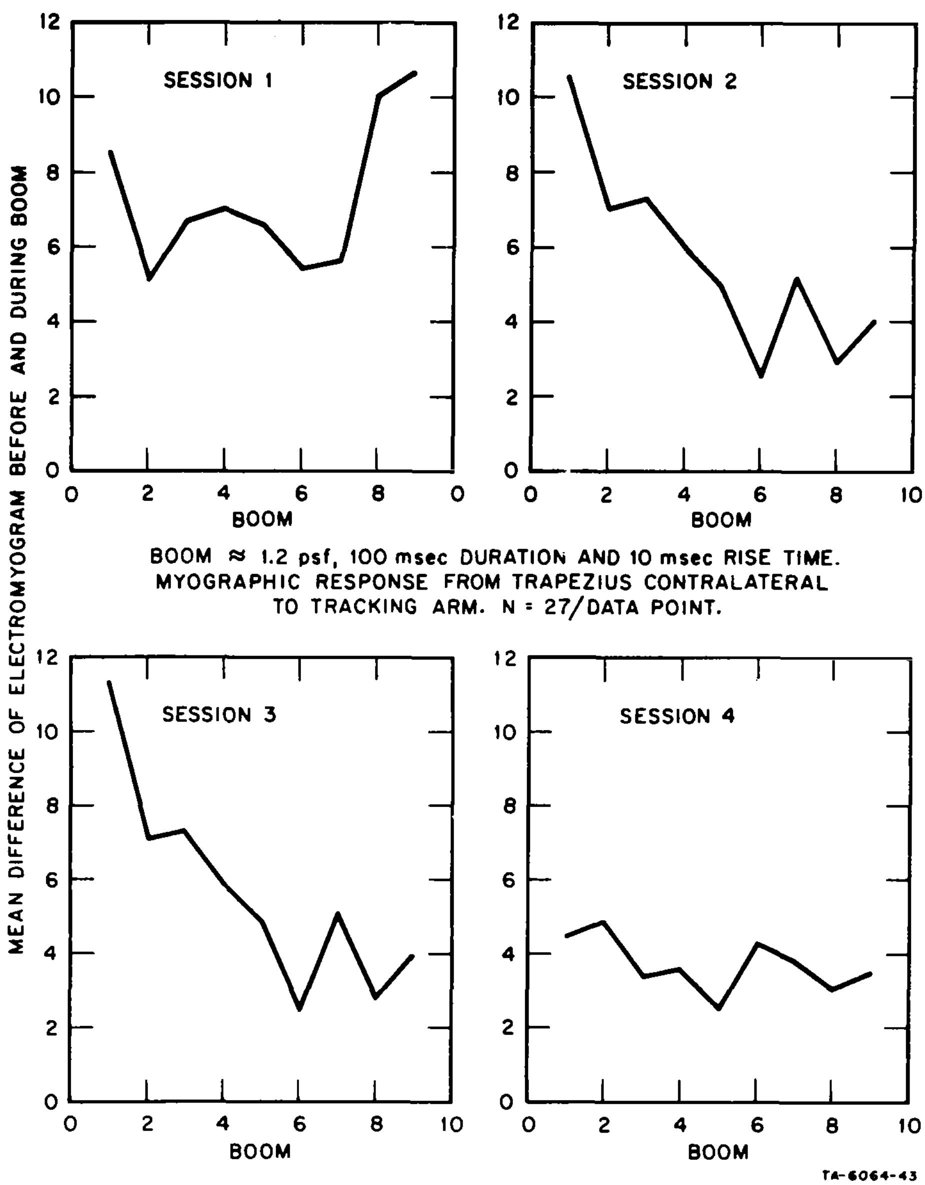

FIG. 19 MEAN NORMALIZED MUSCULAR STARTLE RESPONSE TO SIMULATED SONIC BOOMS AS A FUNCTION OF TEST SESSION AND NUMBER OF STIMULATIONS PER SESSION AVERAGED OVER ALL EXPERIMENTAL GROUPS

suggests that the rate, if not level, of adaptation had reached an asymptote.

2. Tracking Performance

The first hypothesis, that the tracking performance of Groups 2, 3, and 4 should be less affected by the boom than that of Group 1, was not substantiated statistically. With respect to the performance measure, the experimental groups were found to be performing at statistically equivalent levels on those circuits of the first tracking session before any booms occurred. A summary of the analysis of variance of the total circuit time (average of nine circuits per group) is presented in Table XVI. That the "tracks" are a significant source of variance was to be expected since the subjects were told which track was correct. In other words, the finding indicates simply that subjects were on the designated track for longer periods of time than they were on the adjacent incorrect tracks.

A summary of the analysis of variance of the mean time on the correct track during the session when tracking was first tested is presented in Table XVII. Inspection of the data revealed clearly that any differences between groups were obscured by the wide differences between individuals constituting the groups. This is evident from the relatively large error term in Table XVII.

Table XVI

SUMMARY OF THE ANALYSIS OF VARIANCE
AMONG GROUPS' TOTAL TRACKING TIME FOR FIRST TRACKING SESSION

Source	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio
Groups	1432.17	3	477.39	N.S.
Tracks	261451.63	2	130725.81	---
Error	5410.96	6	901.82	
TOTAL	268294.76	11		

Table XVII

SUMMARY OF THE ANALYSIS OF VARIANCE
OF MEAN TIME ON THE CORRECT TRACK WHEN TRACKING WAS INITIATED

Source	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio
Boom vs. No Boom	102.71	1	102.71	N.S.
Groups	4148.35	3	1382.78	N.S.
Boom x Group	5802.45	3	1934.15	N.S.
Error	35296.57	22	1604.39	
TOTAL	45350.08	29	1563.80	N.S.

That the boom produced some suggestive but unexpected changes in performance is illustrated in Fig. 20. Only in Group 1 (no adaptation sessions) did the boom result in a deterioration, about two seconds, in performance during the first session in which tracking was required. In the other groups (in which one, two, or three sessions of adaptation to boom was permitted), the booms appeared to improve performance by about one or two seconds. This result was obtained during the remainder of the tracking sessions. Again, however, the differences do not have statistical significance as shown in Table XVIII. In this case, the analysis included the circuits immediately before, during and immediately after the boom, and the time the subject was on the correct versus incorrect track. The reason for the significant track effect was noted previously; it indicates more time spent on the correct track than either of the incorrect tracks. The significant interactions primarily reflect the track effect. However, note in Fig. 20 that the changes in performance are relative to both the before and after boom circuits. This suggests that the changes are small and real despite the lack of statistical significance. It appears that continuous booming and tracking caused Group 1 to perform more deliberately than the other groups, as explained below.

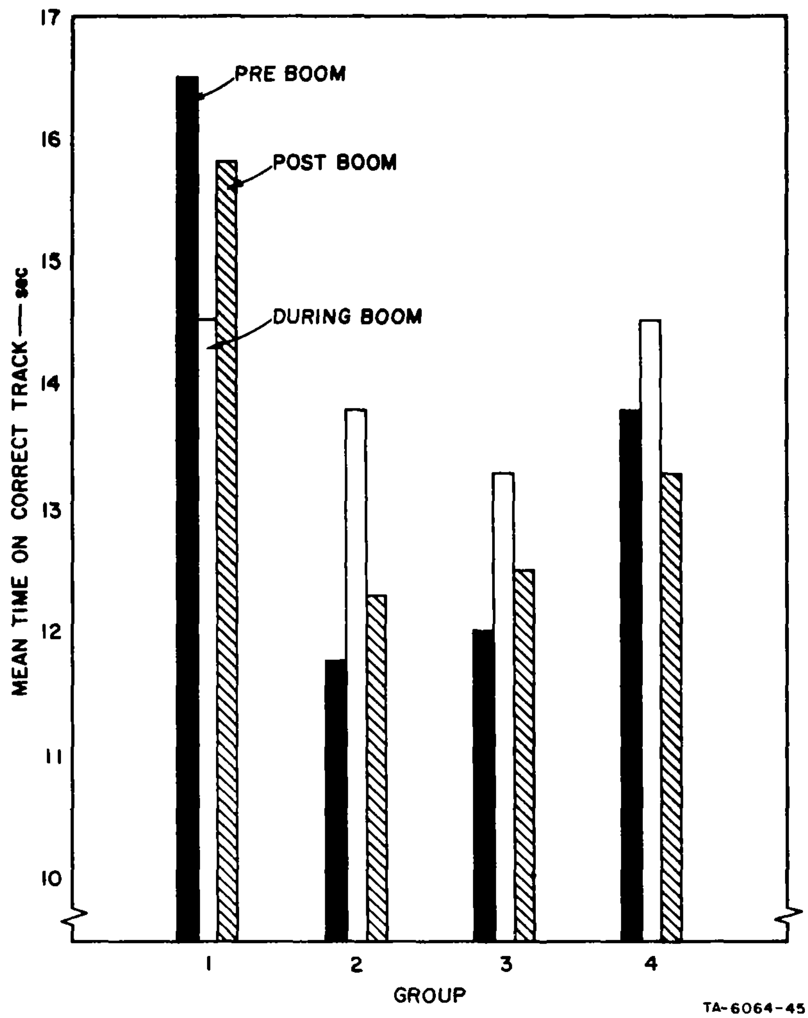

FIG. 20 MEAN TIME ON CORRECT TRACK (During second and subsequent tracking sessions)

Table XVIII

SUMMARY OF THE ANALYSIS OF VARIANCE
OF NO-BOOM TRACKING CIRCUIT TIME VS. BOOM TRACKING CIRCUIT TIME

Source	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio
Groups (G)	477.39	3	159.13	---
Tracks (T)	87150.59	2	43575.27	144.96
Before, During, or After Boom	53.62	2	26.81	N.S.
Groups x Tracks	1803.65	6	300.61	4.78 $p \approx .01$
Groups x Boom	276.79	6	46.13	N.S.
Track x Boom	2227.92	4	556.86	8.86 $p < .01$
G x T x Boom	753.71	12	62.80	
TOTAL	92743.62	35		

3. Adaptation Effects on Learning

The final hypothesis to be tested was that with more adaptation to booms, the effect of booms on performance would be less.

a. Time on Track

The findings illustrated in Fig. 21 suggest that introduction of the simulated sonic booms with the tracking task had a definite effect upon the development of tracking skill. Subjects in Group 1, who were boomed and tracked during the four sessions, never showed the learning found in the Control Group or the other three experimental groups who were permitted variable amounts of adaptation to booms. It should be noted that the data presented in Fig. 21 indicate the time required to complete one circuit regardless of errors and are averages of trials in which no booms occurred. Thus, they do not reflect changes in performance due to booms concidental with the performance measure. As noted previously, the five groups showed statistically equivalent performance initially. But, with adaptation of one session, Group 2 attained performance equivalent to that of the Control Group (no booms). It appears that Group 3 might soon have attained a similar performance level. In contrast, Group 1 showed no improvement, and possibly a slight deterioration in performance. A similar plot, which included circuits during which booms occurred, was essentially the same as Fig. 21 with but a one- or two-second displacement of some of the points.

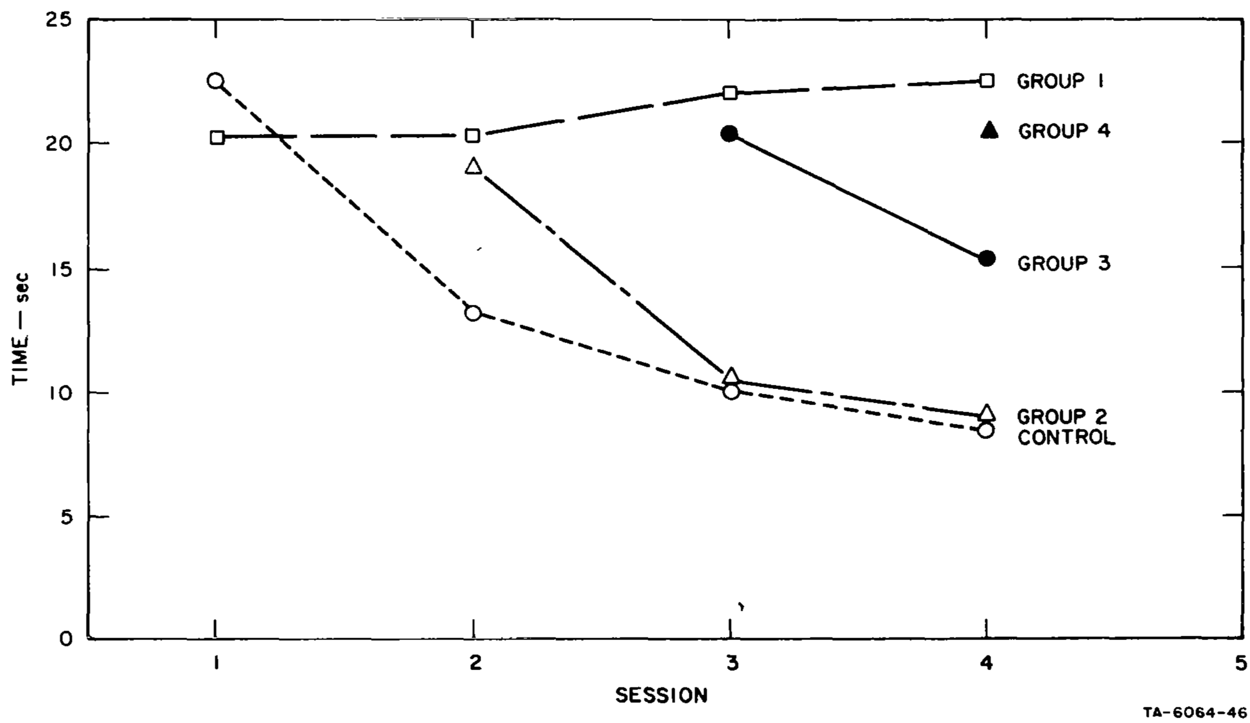

FIG. 21 NON-BOOM CIRCUIT TRACKING TIME AS A FUNCTION OF TEST SESSION

b. <u>Accuracy of Tracking</u>

With respect to accuracy of tracking, however, Group 1 improved while the other groups, including the Control Group, deteriorated. This effect held for comparisons of circuits which included booms and circuits which did not. Figures 22 and 23 illustrate these results; Figure 23 shows the accuracy during no-boom circuits only.

It appeared that the introduction of the simulated sonic boom together with tracking had an effect, although statistically insignificant, on tracking speed. In the case of Group 1, it was evident that the boom, in some way, prevented this group from decreasing its circuit tracking time but facilitated, perhaps because of the slower speed, maintenance, if not improvement, in tracking accuracy in this relatively unstructured experimental setting where no attempt was made to impose speed criteria once the experiment was begun. Study of the EMG records did not reveal any consistent changes which would provide an explanation for these findings.

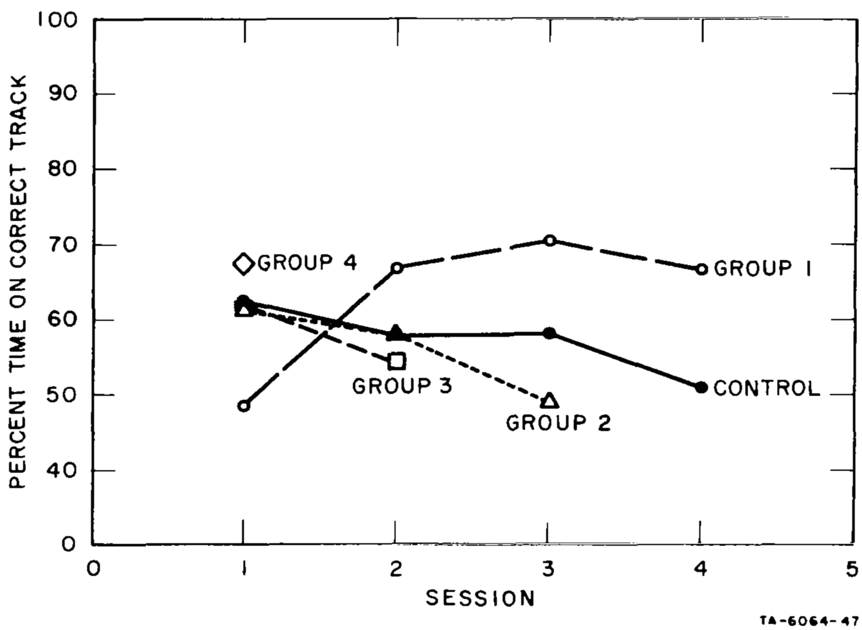

FIG. 22 ACCURACY OF TRACKING DURING BOOM AND NON-BOOM CIRCUITS

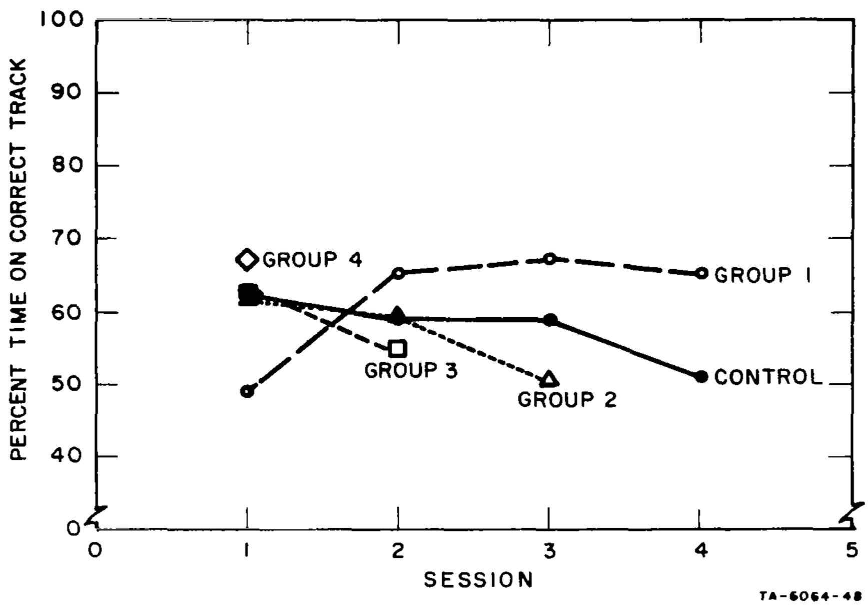

FIG. 23 ACCURACY OF TRACKING DURING NON-BOOM CIRCUITS

V SUMMARY AND CONCLUSIONS*

A. Simulator

The sonic boom simulator produced in a laboratory (having the internal appearance of a typical residential bedroom) a life-like simulation of the acoustic energies found indoors in a residential building exposed to an actual sonic boom. A consistent difference of about 12 dB at frequencies above 250 Hz was found due to a somewhat slower rise time of the simulated sonic boom in comparison to booms produced by actual aircraft. However, these frequencies contributed relatively little to the energy spectra of either simulated or actual booms. The simulator can be modified to provide booms of shorter rise times than those used in the present experiments.

B. Sleep Experiment

1. The effects of sonic booms on the sleeping individual is, to some extent, dependent on the individual.

2. From tests of two college students it is concluded that sonic booms with intensities of 1.6 and 2.1 psf (measured outdoors) result in significantly more awakening from stage 2 sleep (which is the most prevalent sleep stage and occupies about 50 percent of the sleep cycle) than do booms with lesser intensities (.6 or .8 psf).

3. Adaptation (sleep nights 1 and 2 compared with nights 9 and 10) to booms of .6 or .8 psf during stage 2 sleep occurs and appears to result from a quantal shift in sensitivity rather than small, progressive changes in sensitivity. Adaptation to booms with intensities of 1.6 and 2.1 psf was not found during these tests.

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*These findings are based on a study of a small homogenous group of subjects and, consequently, should be considered tentative at this time.

4. The awakening effects were about the same for both the low- and high-intensity booms during the sleep stage REM.

5. Subject A of Group 1 responded about the same as subject B when in either stage 2 or stage REM, but differently (subject A was less responsive to the booms than was B) when in stage 3 or 4, the so-called "Delta" stage. However, statistically significant adaptation to booms on the part of either subject was not found for these stages during these tests.

6. Two subjects showed equal or greater awakening to the flyover noises of a subsonic jet aircraft at intensities of 103 and 113 PNdB (measured outdoors) than did the subjects exposed to sonic booms at intensities of even 2.1 psf (measured outdoors). Possible adaptation to the subsonic jet aircraft noise could not be measured due to the small number of test sessions involved.

C. Startle Experiment

1. Startle to sonic booms, as measured by an increase in skeletal muscular tension, occurs. An electromyographic response to simulated booms persisted for 36 stimulations. Although inter- and intra-session adaptation to booms was found, it did not reduce to Control Group levels in this experimental situation where the subjects anticipated the booms.

2. Sonic booms occurring coincidentally with the acquisition of skill on a new motor tracking task appear to hinder the attainment of speed but facilitate (or perhaps permit) the attainment of accuracy. In contrast, pre-practice exposure to simulated booms does not hinder the attainment of normal tracking speed but does hinder the attainment of accuracy.

Appendix A

DESCRIPTION AND EXAMPLES OF THE STAGES OF SLEEP

Appendix A

DESCRIPTION AND EXAMPLES OF THE STAGES OF SLEEP

The following description of the EEG sleep stages* is exerpted from "Current Research on Sleep and Dreams" (Ref. 15, pp. 11-13) with the permission of the author, Mrs. Gay Gaer Luce+:

"Drowsiness

Usually, about 11 p.m., the acclimated volunteer will be relaxed. His body temperature is declining. His eyes are closed, and he is no longer moving. On the graph paper in the control room the jumble of rapid, irregular brain waves is beginning to form a new pattern, a regular rhythm known as the alpha rhythm. This pattern of 9-12 cycles a second indicates relaxed awakefulness. Subjectively, it is a serene and pleasant state, devoid of deliberate thought, into which images may float. A moment of tension or attempt to solve a mental problem will disrupt it (Kamiya, 1962).

"With further relaxation the alpha waves grow smaller, decreasing in amplitide. As alpha rhythm diminishes, a person's time perception seems to deteriorate, and two rapid flases of light may seem to blend into one (Anliker, 1963). As his alpha rhythm diminishes, the young volunteer hovers on the borders of drowsiness and sleep, perhaps seeing images, experiencing dreamlike thoughts or fragments (Foulkes and Vogel).

"Stage 1

Another pattern begins to emerge on the EEG paper. This new script is smaller, indicating lower voltages. It is uneven, desynchronized, and it changes swiftly. At this point one may experience a floating sensation, drifint with idle images as the alpha rhythm gives way to the low voltage, fast irregular rhythm of the first stage of sleep. (Kamiya, 1961; Foulkes and Vogel).

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*Examples of these sleep stages and the EEG responses, as obtained in the present study, to simulated sonic booms occurring during those stages will be found in Figs. 24, 25, 26, and 27 following the exerpt.

+References have not been deleted from the text for the benefit of those readers wishing to consult Mrs. Luce's original monograph for the full references.

The volunteer, in this phase, can be easily awakened by a noise or spoken word. His body muscles are relaxing. Respiration is growing more even and heart rate is becoming slower (Snyder, 1960). If awakened at this point a person may assert that he was not really asleep. This phase of consciousness is like a port of entry, a borderland, and lasts only a few minutes. Soon the background rhythm of the EEG grows slower.

"Stage 2

The script grows larger and the pens trace out quick bursts known as spindles, rapid crescendos and decrescendos of waves. The eyes of the young volunteer may appear to be slowly rolling. He is quite soundly alseep, yet it is not hard to awaken him. By now there has been a fundamental change in his brain function. One aspect of this change is suggested by a study in which volunteers slept with their eyes half open; illuminated objects were suspended before their eyes. On the whole they were not awakened by the light, nor did they remember seeing anything, but when awakened by a voice a few seconds later they often insisted they had been wide awake and thinking thoughts that, as narrated, had a vague and dreamlike quality (Foulkes and Vogel; Rechtschaffen and Foulkes). If awakened at this point a person might feel he had been thinking or indulging in reverie. Left undisturbed, however, he will soon descend into another level of sleep.

"Stage 3

The spindle bursts and somewhat irregular brain wave rhythm begins to be interspersed with large slow waves. These occur at about one a second, and are high in amplitide. The electrical input may run as high as 300 microvolts in stage 3, as compared with the 60 microvolts of the waking alpha rhythm. Now it will take a louder noise to awaken the sleeping person or animal, perhaps a repetition of his name. His muscles are very relaxed. He breathes evenly, and his heart rate continues to slow down. His blood pressure is falling, and his temperature continues to decline. Innocuous sensory events are making almost no impression on the awareness of the sleeper, and were he among the people who do sleep with their eyes half open, he would not be seeing anything (Fuchs and Wu, 1948).

"Stage 4

This stage might be called a most oblivious sleep. The muscles are very relaxed, and the person rarely moves (Jacobson et al., 1964). It is hard to awaken him with the low noise or buzzer that would have aroused him earlier. His heart rate and temperature are still declining, and his respiration is slow and even. Waken the volunteer now with a loud noise or by calling his name and he may come into focus slowly, and may feel that he was not experiencing any mental activity (Rechtschaffen et al., 1962, 1963; Kales et al., 1963). The EEG pens scratch out a continuous train of slow, high amplitude waves. The sleeper is utterly removed from the world, although his brain wave responses would indicate that every sound and the lightest touch are received in his brain. Indeed, during this synchronous, slow-wave sleep the brain shows a very large response to outside stimuli such as sounds, but the brain systems that make this stimulation into conscious sensation appear not to be working in their usual way (Allison, 1965; Hernandez-Peon, 1963; Rosner et al., 1963; Williams et al., 1962, 1964; Weitzman and Kremen, 1965). This may account for the eerie apparition, the somnambulist, who will rise from bed in this stage of sleep, negotiate a room full of furniture, look straight at people with eyes open, yet appear not to perceive them, and return to bed , usually recalling nothing of the interlude when awakened (Jacobson et al., 1965). Stage 4 appears to be one of the times when children commonly wet their beds, a time when a person is, by some criteria, most deeply asleep (Pierce et al., 1961, 1963; Scott, 1964). Although people can be trained to discriminate between sounds, to hear spoken words, to press a button during another stage of sleep, their performance during stage 4 is not nearly so frequent (Granda and Hammack, 1961; Mandell et al., 1965; Williams et al., 1963).

"A normal person will spend a considerable portion of the night in this stage, especially if he has lost sleep (Agnew et al., 1964). If annoyed from outside, he will tend to drift into a lighter phase of sleep, but if annoyances prevent him from spending a certain portion of his night in stage 4, on subsequent nights he will make it up by spending substantially more time in stage 4. Although he seems hard to awaken from this phase, paradixically he may be even harder to awaken from the first stage of sleep--if he happens to be in the throes of dreaming.

"<u>Stage 1 REM</u>

About an hour or so after falling asleep, the sleeper may begin to drift back up into the lighter phases of sleep (Dement and Kleitman, 1957). Roughly 90 minutes have passed, and the volunteer's sleep has resumed the pattern of stage 2. Now, suddenly, the pens of the EEG begin to jabber, scratching out wild oscillations. He has turned over in bed, and moved. As the osscillations die away the brain wave record shows an irregular low-voltage, rapidly changing script like that of stage 1. Now two pens that are activated by movements of the eyes make rapid darts, as if the eyes had turned to look at something. Intermittently the pens continue. The eyes move as if following a film (Aserinsky and Kleitman, 1955; Dement and Kleitman, 1957; Roffwarg et al., 1962). These rapid eye movements, known as REMs, signal a phase of vivid dreaming, a most unique state of consciousness

(Dement, 1965). In this phase, it will take a relatively huge amount of noise to awaken a person--yet a very slight noise, with significance, may quickly alert him (Goodenough, 1963).

"Sound a click in the sleeper's ear, and his brain wave response will not resemble that of stage 4--but shows a great resemblance to the response during waking. Although it may be hard to awaken a person at this time, in many ways his brain activity paradoxically resembles waking, and REM sleep is often called paradoxical sleep. It is believed by some investigators to be a unique state, totally different from the rest of sleep, and subserved by different brain mechanisms.

"The entire body shows pronounced changes now (Snyder, 1960, 1962, 1964, 1965,. Gone is the even breath and pulse. The organs that show the most striking changes in sleep are those indicating fright or anger. Everyone is familiar with the blanched skin, wide eyes, rapid heart beat and knotted stomach of fright. These changes are controlled by the closely related nerves of the autonomic nervous system, which regulates the organs of the chest and viscera, changes in the skin and eyes, with the help of hormones secreted by the adrenal glands. The autonomic system modifies its organic domain in unison, and is tuned in to the emotional state of the creature. During slow wave sleep the heart rate, respiration, and blood pressure fall to their lowest levels of the day, falling at sleep onset and continuing to drop until about an hour before awakening. During REM sleep, however, the heart rate, blood pressure, and respiration become exceedingly variable, sometimes fluctuating wildly. Usually there is a long interval of REM sleep during the latter part of the night, the time when a person's temperature has fallen to its nadir. During the REM period in the early hours of morning the activity of the autonomic system often becomes most intense, inducing what have been called "autonomic storms," which may account for the statistically frequent occurrence of heart attacks at this time, and further study of this period may make it possible to anticipate and prevent such coronaries.

"Many of the physical changes that attend the REM state can be observed from watching the sleeper. At the onset the muscles of the head and chin will relax completely (Berger, 1961; Jouvet, 1963; Jacobson et al., 1964; Dement, 1965). This is so regular that the loss of tonus in the muscle under the chin can serve to activate an alarm, signalling the onset of REM sleep. Most teeth-grinding occurs at this time (Reding et al., 1964). From infancy through adulthood, the REM period is attended by penile erections in males (Fisher et al., 1965). Rapid, jerky movements of the eyes can be seen, even in many blind people (Berger et al., 1962; Gross et al., 1965).

"Most stiking of all, however, is the now substantial evidence that this is a period of vivid dreaming for all humankind, and the suggestion that it is a period of consciousness in which monkeys and perhaps other animals experience vivid imagery. Awakened during REM sleep, a person will amost inevitably report mentation that differs from waking thought, dramatic, and often bizarre--generally recognized as a dream (Dement and many others). Yet, if he is awakened a few minutes after the rapid eye movements cease, when he has lapsed into another phase of sleep, the dream will have evaporated. The average individual spends a total of about 5 years of his life in such vivid dreaming, but for the most part he is amnesic, remembering very little.

"The discovery of the REM phase of sleep and subsequent findings about the body and brain during this state have raised many fundamental questions about the organization and function of the central nervous system, and has stimulated a rapidly growing body of research which will be explored at greater length in later sections of this paper.

"It has been said that the average adult dreams about every 90 minutes, and that the full cycle of sleep stages spans an interval of 90-120 minutes, corresponding to a subcycle within the circadian temperature rhythm.

"This generalization is somewhat misleading, although it has been widely propagated in the press, for dreaming, dreamlike experiences, fragments, images, mentation occur in all phases of sleep, although recall varies. Sleep is a succession of repeated cycles. Nevertheless, one's progression through a night does not resemble the passage of a train on a circular track, arriving at different stations at a predictable time. People of about the same age do not follow such a rigid timetable of sleep, and all humanity does not rise and fall on the waves of a single tide.

"<u>The Whole Night</u>

A reexamination of the nightly EEG patterns of sleep has been conducted recently with 16 medical students, each of whom spent four nights in the laboratory. Only two uniform patterns emerged. The entire group showed a greater incidence of REM periods during the last third of the night, and the slow-wave sleep of stage 4 predominated during the first third of the night. Not only was there no consistent time schedule of sleep stages for the group--but individuals showed slightly different patterns on different nights. Excepting for their REM periods they did not spend more than 10 minutes at a time in any EEG phase, and throughout the night stage 2 with its spindles occurred evenly, like a transition period, a bridge (Williams, Agnew, and Webb, 1964). Evidence from a number of studies suggests that each of us has a characteristic sleep pattern, an EEG script that is identifiable and individual, although we vary somewhat from night to night. So far no rules have been found for describing the succession of EEG phases that all people will pass through in a night's sleep, but more sophisticated analyses may indeed reveal an inherent order in the sequence of cycles (Zung et al., 1965; Hammack et al., 1964).

"However much people differ in detail, normal people show roughly the same overall pattern. They sleep for a long interval once in 24 hours, at the time of their lowest body temperature. They spend roughly the same proportion of the night in REM sleep and stage 4, distributing them over the night in roughly the same manner."

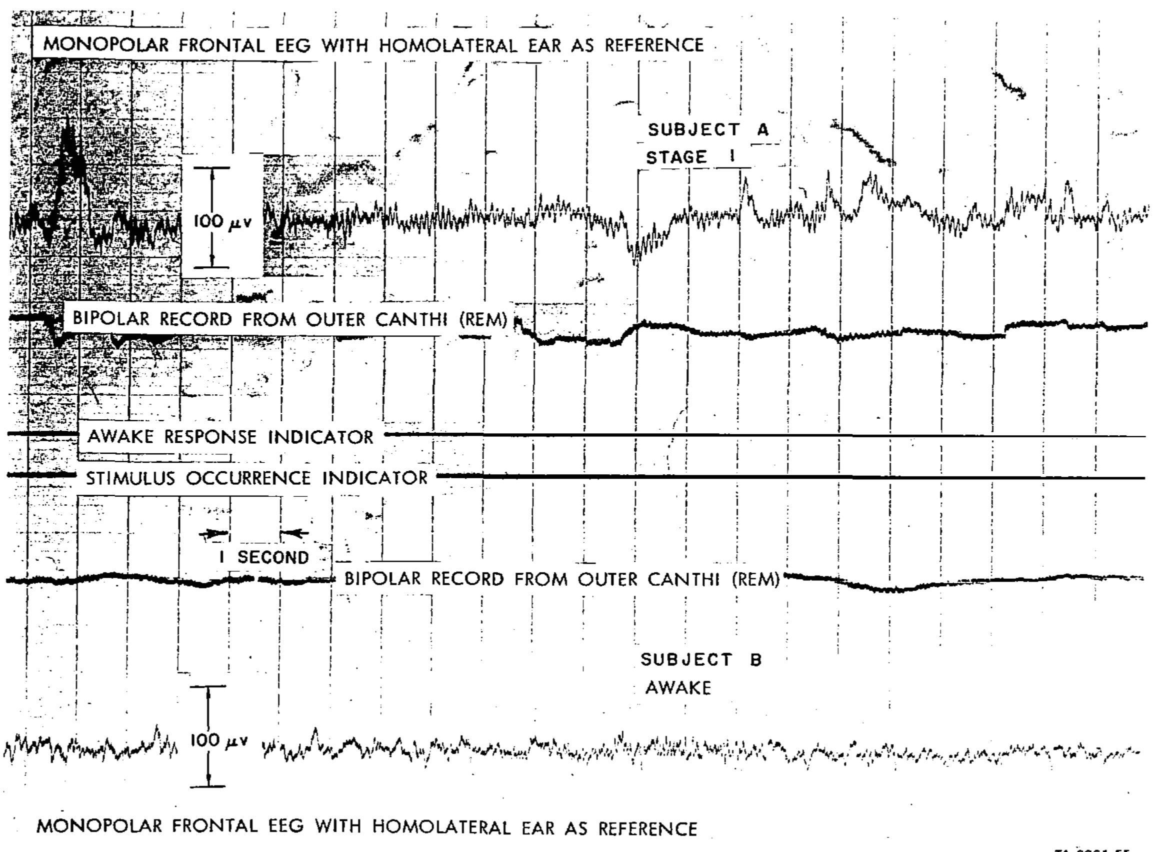

FIG. 24 EXAMPLE OF EEG DURING AWAKE AND SLEEP STAGE 1

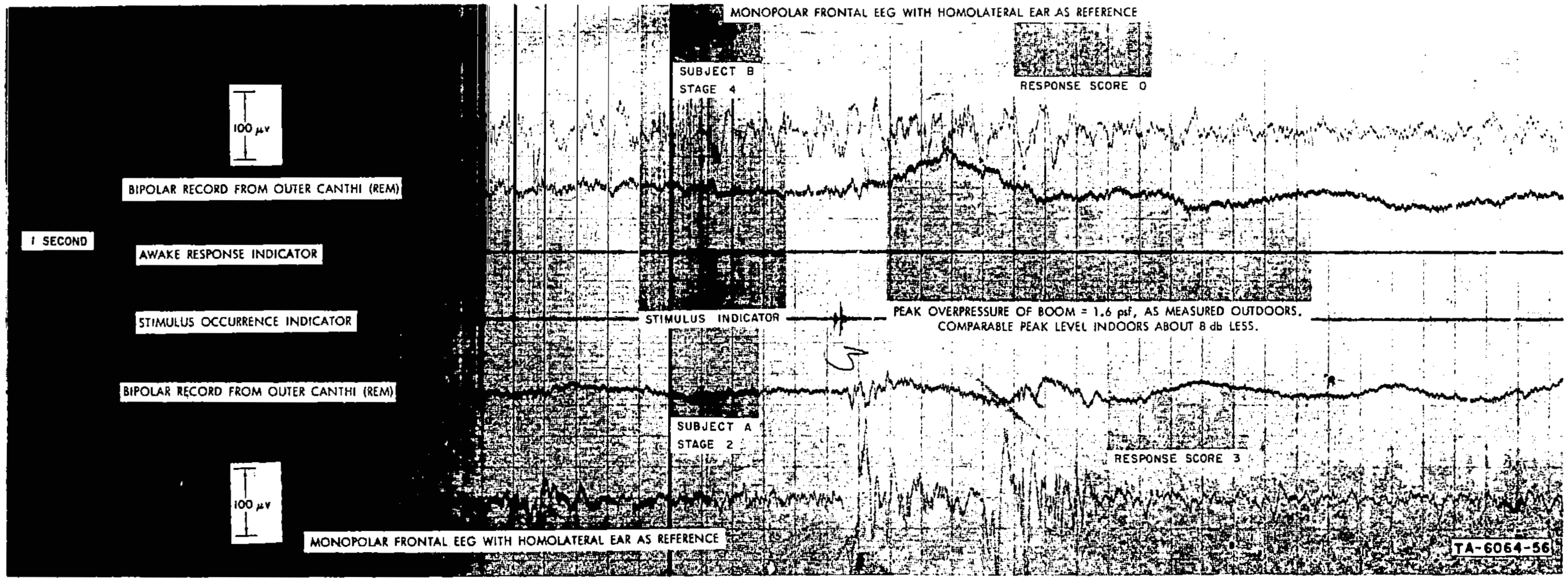

FIG. 25 EXAMPLE OF EEG DURING SLEEP STAGES 2 AND 4

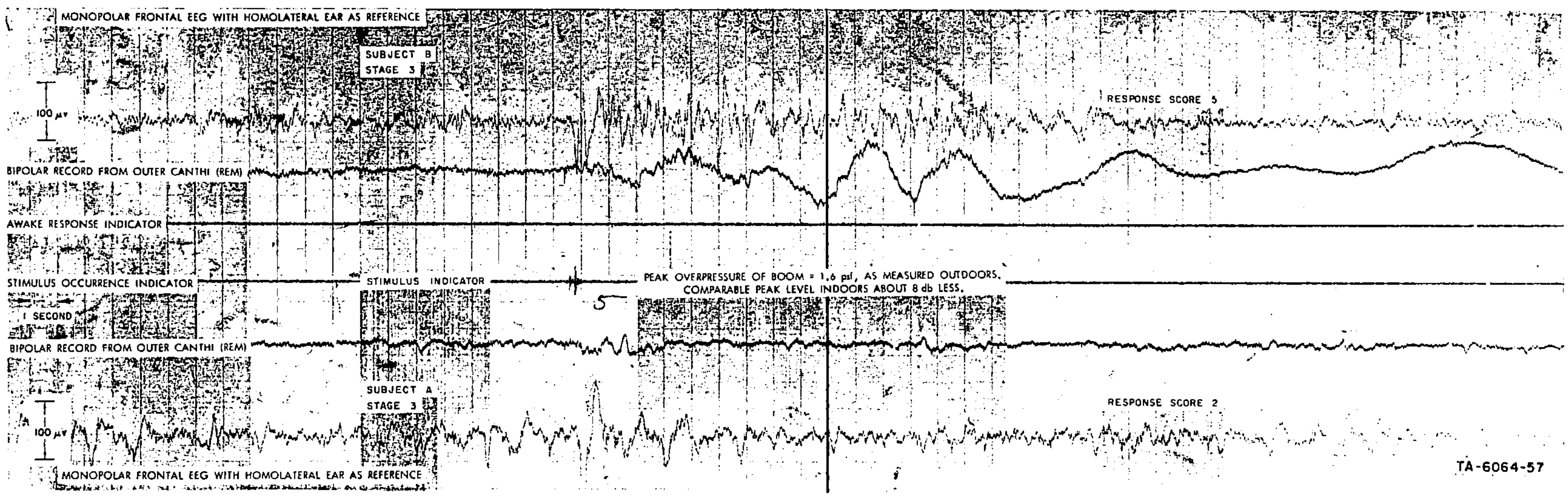

FIG. 26 EXAMPLE OF EEG DURING SLEEP STAGE 3

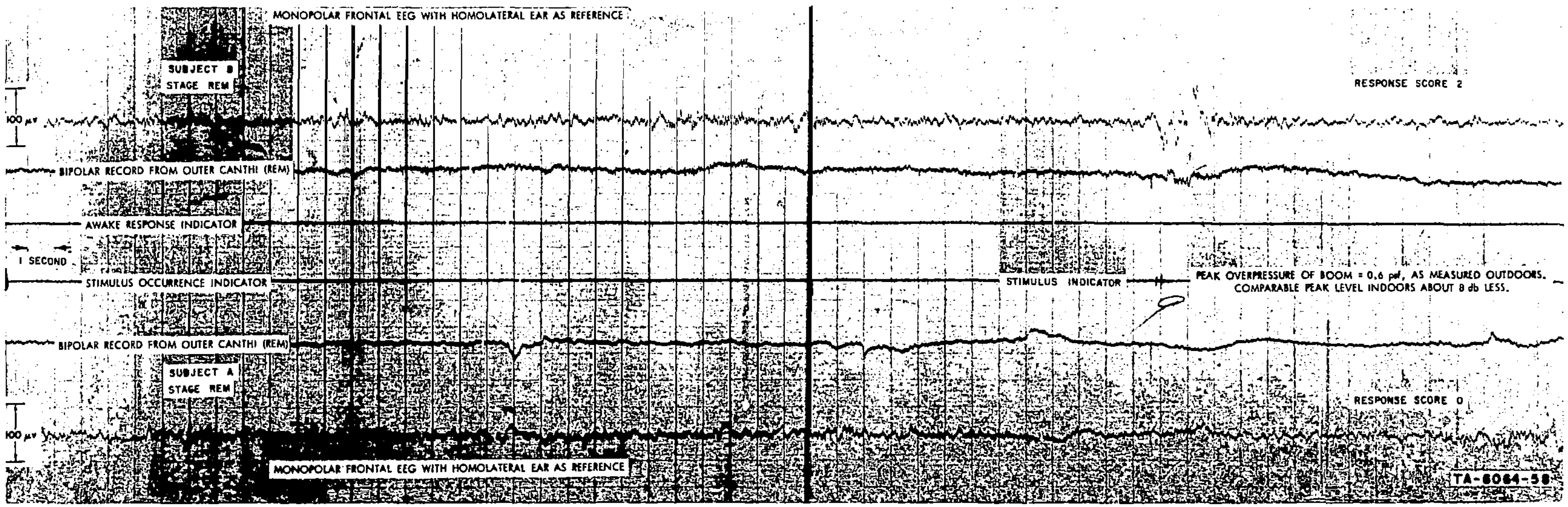

FIG. 27 EXAMPLE OF EEG DURING SLEEP STAGE REM

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