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EFFECTS OF AIRCRAFT NOISES ON THE SLEEP OF WOMEN

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16. Abstract

The electroencephalographic and behavioral responses during sleep of eight women subjects, aged 29 to 49 years, to subsonic jet flyover noise and simulated sonic booms were tested over 14 consecutive nights. Stimulus intensities were 101, 113, and 119 PNdB (as if measured out-of-doors) for the subsonic jet flyover and 0.67, 2.50, and 5.0 psf (as if measured out-of-doors) for the simulated sonic booms.

It was found that the women were awakened, on the average, by approximately 42 percent of the flyover noises and by approximately 15 percent of the simulated sonic booms. Comparison of the results of this study with those of a similar study using men as subjects revealed that women were awakened more frequently by the subsonic jet flyover noise then were the men, while men were awakened more frequently by the simulated sonic boom.

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EFFECTS OF AIRCRAFT NOISES ON THE SLEEP OF WOMEN

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I INTRODUCTION

Stanford Research Institute, under contract with the National Aeronautics and Space Administration, has conducted a series of studies[1–4*] which describe the effects of subsonic jet aircraft noise and sonic booms on human sleep. These studies used adult males as subjects. Although the research literature contains little information about the sleep patterns of women[†] (or, more importantly for our purposes, the effects of noise thereon), some research[6] and anecdotal information suggest that women may be more sensitive to noise during sleep than men. In light of this general lack of data about the sleep of women, the study described below was undertaken.

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[*] References are listed at the end of this report.

[†] See Ref. 5, for example.

II OBJECTIVE

This study was designed to determine the extent to which aircraft noises (subsonic jet aircraft engine noise and simulated sonic booms) as might be experienced in real life would disturb women's sleep and to compare these effects with those found in earlier studies on men.

III PROCEDURE

A. Subjects

Eight female volunteers served as subjects. Their ages, in years, were 29, two of 30, 33, two of 36, 40, and 49. All had normal hearing were in good physical condition; none were taking any type of medication. The subjects described themselves as normal sleepers and not particularly disturbed by noise at night. Four of the subjects were secretaries; there was also a school teacher, one computer programmer, one housewife, and one nurse.

The subjects resided in various apartments that were some distance from commercial aviation traffic patterns. In addition, before the study began, the subjects indicated that they had no particular bias for or against jet aircraft noise of either sub- or supersonic variety.

B. Test Procedure

The subjects came to the laboratory for two sessions; an interval of about three weeks separated the sessions. During the first session of three consecutive nights, the subjects were accommodated to sleeping in the laboratory with electroencephalographic (EEG) electrodes attached to their heads. The EEG records obtained during the last two nights of this session were used by the investigators to study and score the EEG records and to permit programming of an experimental computer designed to analyze and score the sleep EEG records.[4]*

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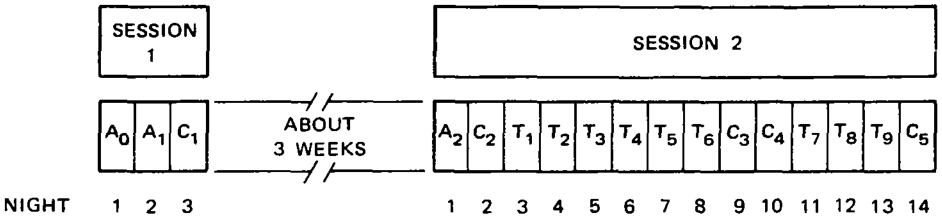
*Although we found good agreement between sleep stages scored by eye and by computer, the computer's visual output (an electrostatic printer) had a delay of about 100 seconds. This delay precluded using the computer for immediate scoring of sleep stages, which (to some extent), controlled the time of stimulus presentation, or for estimating when the subject "returned" to sleep after being awakened. Therefore, the sleep stages and responses to stimuli reported herein are those obtained through visual analysis of the EEG.

The second session of 14 consecutive nights was divided into control (no noises) and test (noises presented) nights. The sequence of control and test nights is illustrated in Figure 1. In general, the subjects regarded the laboratory as a good place to sleep, since it was quiet, well air-conditioned, and the beds comfortable. None of the subjects voiced any significant discomfort to the electrodes after the first accomodation night and all subjects appeared to be sleeping normally; hence, it was concluded that a single accommodation night during the second session was sufficient. (See also Refs. 7 and 8).



CODE: A_0 – Accommodation to Laboratory, Electrodes not Attached, No Stimuli Presented
$A_{1,2}$ – Same as A_0 except Electrodes Attached and EEG Recorded
C_n – Control Night—No Stimuli Presented, EEG Recorded
T_n – Test Night—Stimuli Presented, EEG Recorded

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FIGURE 1 SEQUENCE OF CONTROL AND TEST NIGHTS

All subjects participated fully in the schedule shown. On the first night in the laboratory, the purpose of the experiment was explained briefly, a few questions were answered, and the subjects went to bed. Two subjects, each in a single bed, occupied each of two identical rooms. Each subject always slept in the bed assigned her on the first night. On night A_0, each subject was instructed to use her "awake" switch* if she should awaken for any reason. This instruction was repeated on night C_2. In addition, each night (after the subjects were in bed and the electronic systems checked and calibrated) the subjects were asked to use their "awake" switches as if to check that the switches were operating properly. The subjects were given no further instructions. They were never told whether the noises would occur, and if they asked in the morning how many stimuli had been presented the preceding night, they

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*These switches were affixed to the headboards of the beds, within easy reach of the subjects.

were given vague answers such as "several," "a couple," "more than that," or "fewer than that."

Usually the stimulus sequence for a given room began about 45 to 60 minutes after the subjects were in bed and after both subjects in that room were at least in sleep stage 2. A subsonic jet flyover noise or a simulated sonic boom--as if heard indoors--was presented at random and at an intensity chosen randomly from among the three possible intensities. The randomization was restricted such that the flyover noise and sonic boom were to be presented six times each during a test night, twice at each of three intensities. Thus twelve stimulus presentations were scheduled each night. On occasion, however, because one or another subject awakened early (about 5:15 a.m.) and did not go back to sleep before arising (generally about 6:00 a.m.), the stimulus sequence was aborted. An average of about ten stimuli were presented nightly over the nine test nights in each room, with a range of nine to twelve stimuli per night.

C. Stimuli

Table 1 presents some characteristics of the subsonic jet flyover noise and the simulated sonic boom. The stimuli were presented about once every 35 minutes, on the average, but never more frequently than once every 20 minutes. This amount of variability between stimulus presentation is not inconsistent with aircraft overflight patterns, especially as they might be experienced in homes some distance from larger major airports; homes directly below the landing patterns at major airports might experience the noises much more frequently.

Stimulus intensities were selected to be representative of those from subsonic jet aircraft now in commercial use and (in the case of booms) those expected from the supersonic transport. For practical reasons, stimulus intensities are usually described in terms of out-of-doors levels. Intensities indoors (viz., in the test room,) were as indicated in Table 1.

The sonic boom simulators used in these tests generate and modulate "booms" in a manner similar to that found in typical homes struck by an actual sonic boom. (Reference 1 provides a complete description of the simulator.) The subsonic jet noise was a selected recording obtained in a bedroom of a typical house when a subsonic jet aircraft was passing overhead at an altitude of about 500 ft; it was played back at various intensities, depending upon the particular experimental conditions.

Table 1

PARAMETERS OF THE SIMULATED SONIC BOOMS
AND SUBSONIC JET FLYOVER NOISES

Stimulus	Peak Intensity*	Duration* (ms)	Rise Time* (ms)	Duration to 20-dB Down Points (s)	Maximum Intensity Near Subject's Ear† (dBA)
Simulated Sonic Boom	5.0 psf	300	7	--	84
	2.5 psf	300	7	--	79
	0.6 psf	300	6	--	68
Subsonic Jet Flyover	119 PNdB	--	--	10	86
	113 PNdB	--	--	10	80
	101 PNdB	--	--	10	68

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* As if measured out-of-doors.

† Measured, using B&K sound level meter (Microphone Type 413) and General Radio Real Time Analyzer Type 1921. Slight variations (within 2 dB) between rooms and different presentations of the stimuli, particularly booms, exist. The values reported are averages over some 10 repetitions in each room.

D. Scoring the Electroencephalogram

The electroencephalograms (EEG) from standard electrode placements recommended by Rechtschaffen and Kales[9] and as used in the earlier study[3] were monitored continuously throughout the night (from about 10:30 p.m. until about 5:30 a.m.) in order to determine the stage of sleep and the effects of noise thereon.

Electrode placements were:

- An EEG from a right or left (C_3 or C_4) central electrode monopolar with respect to the contralateral mastoid (A_1 or A_2).
- Two electrodes proximal to the outer canthi of each eye and both monopolar with respect to a single reference electrode just above the nasion. These electrodes are used to record the eye movements required to indicate sleep stage REM (rapid eye movements).
- Bipolar electrodes on the lower chin, one to two cm to the right and left of the midline. The myographic activity recorded is used to assist in scoring sleep stage REM.

Four categories were used to score the responses of subjects to the stimuli. The first three categories are scores obtained by examination of the EEG; the fourth category was used only if the subject pressed her "awake switch." Table 2 presents the criteria used to assign these scores.

E. Control Trials

The laboratory in which the study was conducted consists of two identical test rooms, each with its own sonic boom generator, loudspeaker system, electroencephalograph, and other electronic and mechanical hardware. In addition, the rooms are isolated so that a stimulus presented in one room is not detectable in the other. With this laboratory arrangement, test trials can alternate with control trials in any given room. For example, if the first stimulus for the night were presented to Room 1, then that period (during the stimulation of Room 1) was considered a control trial for subjects in Room 2. The next stimulus, which was identical to that just presented in Room 1, was presented in Room 2, and the period during which the stimulus is present in Room 2 was considered a control trial for the subjects of Room 1. This process of alternating test and control trials in any given room continued throughout the night,

Table 2

SCORING CRITERIA FOR ELECTROENCEPHALOGRAMS

Response Type Score	Response Required
0	No change in EEG. This category also includes "K complexes," brief bursts of Alpha (about 10 Hz activity), spindles, and eye movements, as appropriate for the subject's sleep stage.*
1	Sleep stage change of one or two steps, but without arousal. The change must occur within 30 seconds of stimulation and continue for at least an additional 40 seconds.
2	Arousal of at least 10 seconds duration, but without use of the "awake" switch. Typically such a record shows brief bursts of Alpha, 10 or more seconds of low-amplitude Beta (20-40 Hz) activity, and gross body movements.
3	Awake response, in which the subject after arousal will move about and use the "awake" switch. Usually the response occurs within one minute of stimulus termination.

*"K complexes," Alpha, spindles, and eye movements occur normally in the EEG in some sleep stages. If such activity was scored as a response, the subjects in those stages would appear to be overly sensitive to stimulation as compared to stages in which the activity does not normally occur (Ref. 2, p. 10).

resulted in an approximately equal number of test and control trials for each subject on any given night during which stimuli were presented.

As can be seen in Table 3, the subjects changed sleep stage in only five instances (about 1 percent of the 361 control trials). The subjects were never aroused (score of 2) during these control periods; however, a single subject did behaviorally awaken once (use the "awake" switch). We conclude, therefore, that the results described below are mainly responses to the subsonic jet flyover noises and simulated sonic booms, and do not reflect spontaneous or normally occuring changes in sleep.

Table 3

RESPONSE FREQUENCIES DURING CONTROL TRIALS
(Numbers in parentheses are percentages)

Test Room Number	Number of Control Trials	Response Type				Number of Test Trials
		0	1	2	3	
1	181	178 (98.3)	3 (1.7)	0	0	185
2	180	177 (98.3)	2 (1.1)	0	1 (0.6)	183

F. Control Nights

The primary purpose of the control nights (labeled C_n in Figure 1) was to obtain some measure of the extent to which stimuli presented during a night changed overall sleep patterns when compared to nights during which stimuli were not presented, particularily with respect to nights C_3 and C_4. A secondary purpose was to preclude an anticipation of hearing noises each night. Due to a lack of time for the necessary detailed analysis of all the sleep records, this report does not describe the effect of noise on sleep patterns throughout the night as compared to patterns obtained when noise was not present. Such a report may be published subsequently.

IV RESULTS

A. Comparability of Subjects

Our previous study[3] indicated that different sensitivities to noise during sleep might be expected within an age group. The data obtained in this study do not lead to a similar conclusion, rather the subjects responded to the stimuli as might be expected if a normal distribution of sensitivity to noise is assumed. Table 4 shows the response frequencies of each of the eight subjects. These data suggest relatively wide differences between subjects. However, as illustrated in Figure 2, the response frequencies of five of the eight subjects showed an apparently normal degree of similarity and overlap. Three subjects (LL, EM, and FP) appear to be at the extremes, but probably within the limits of a normal distribution. We therefore conclude that the data obtained are representative of those expected in a normal distribution, and treated them accordingly. The sensitivity differences in men reported earlier[3] may have been related to the particular subjects (6 in each of two age groups) studied.

B. Responses to Flyover Noise and to Sonic Booms

Clear differences in the responses to subsonic jet noise and simulated sonic booms were found, as shown in Table 5. Whereas the frequencies of Type 1 and 2 responses to the flyover noise and booms were similar (a difference of about 4 percentage points in the frequency of Type 1 responses and about 1 point for Type 2 responses), much larger differences in the frequency of Type 0 and Type 3 responses were obtained: about 22 percent more Type 0 responses and about 26 percent fewer awake responses (Type 3) to simulated sonic booms, as compared to the frequency of those responses to subsonic jet flyover noise.

C. Response to Subsonic Jet Flyover Noise

As the intensity of the flyover noise was increased from 101 to 119 PNdB, the frequency of Type 0 responses decreased about 33 percent (from 51 percent to 18 percent), while the frequency of awake responses increased about 36 percent. No systematic change in the frequency of Type 1 responses was noted, although the other EEG-determined response

Table 4

RESPONSE FREQUENCIES OF EIGHT FEMALE SUBJECTS TO SUBSONIC JET FLYOVER NOISE AND SIMULATED SONIC BOOMS

(Numbers in parentheses are percentages)

Subject	Age (in years)	Response Type			
		0	1	2	3
FP	49	27 (28.7)	14 (14.9)	4 (4.3)	49 (52.1)
GM	40	33 (37.5)	17 (19.3)	7 (8.0)	31 (35.2)
EM	36	27 (28.7)	17 (18.1)	12 (12.8)	38 (40.4)
PS	36	39 (41.1)	16 (16.8)	8 (8.4)	32 (33.7)
TP	33	38 (48.1)	17 (21.5)	11 (13.9)	13 (16.5)
CG	30	36 (39.6)	32 (35.2)	13 (14.3)	10 (11.0)
LG	30	32 (36.4)	26 (29.5)	7 (8.0)	23 (26.1)
LL	29	63 (66.3)	19 (20.0)	4 (4.2)	9 (9.5)

$\chi^{2*} = 90.69$, 21 df (degrees of freedom), $p < 0.001$.

*Chi-square is a technique for estimating the statistical significance of the differences observed between the several distributions of response frequencies.[10]

(arousal, or a response of 2) showed a slight increase of about 3 percentage points. These data are presented in Table 6.

The somewhat greater rate of growth of awakening at higher stimulus intensity levels may be of interest. An increase of 6 PNdB (from 113 to 119 PNdB) resulted in an increase of about 14 percent in the frequency of Type 3 responses, or a rate of about 2.3 percent per dB increase of intensity. In contrast, an increase of 12 PNdB at lower stimulus levels

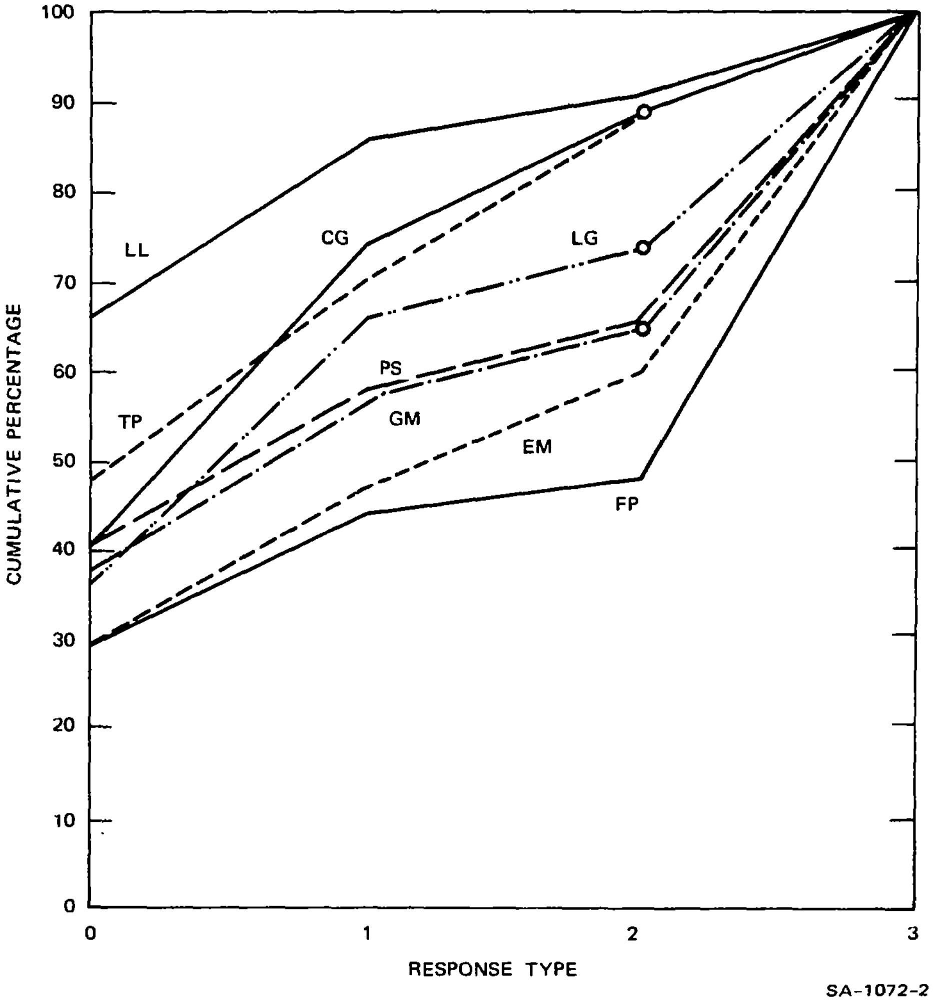

FIGURE 2 RELATIVE SENSITIVITY OF EIGHT WOMEN TO SUBSONIC JET AIRCRAFT NOISE AND SIMULATED SONIC BOOMS

Table 5

RESPONSE FREQUENCIES OF WOMEN TO SUBSONIC JET FLYOVER NOISE AND SIMULATED SONIC BOOMS

(Numbers in parentheses are percentages)

Stimulus	Response Type			
	0	1	2	3
Flyover Noise	102 (29.7)	67 (19.5)	30 (8.7)	144 (42.0)
Sonic Booms	196 (51.0)	91 (23.7)	36 (9.4)	61 (15.9)

$\chi^2 = 65.3$, 3 df, $p < 0.001$.

Table 6

RESPONSE FREQUENCIES OF WOMEN TO SUBSONIC JET FLYOVER NOISE AT THREE INTENSITIES[†]

(Numbers in parentheses are percentages)

Intensity of Flyover Noise (in PNdB*)	Response Type			
	0	1	2	3
101	56 (50.9)	21 (19.1)	8 (7.3)	25 (22.7)
113	26 (22.4)	27 (23.3)	11 (9.5)	52 (44.8)
119	20 (17.9)	15 (13.4)	11 (9.8)	66 (58.9)

[*] As if measured out-of-doors.

[†] Totals in this and subsequent tables are not equal to those of Table 5, since occasionally a stimulus occurred during sleep stage 1, and the results thereof are excluded.

$\chi^2 = 44.6$, 6 df, $p < 0.001$.

(from 101 to 113 PNdB) resulted in an increase of about 22 percent in awake responses, or a rate of 1.8 percent per dB. These results are consistent with trends of the data reported by Kryter[11] for annoyance (Fig. 211, pg 372) or general disturbance by (Fig. 220A, pg 389) aircraft noise.

In the previous studies[2,3] the sleep stage during which the stimulus occurred was found to be related to or modified by the responses to the flyover noise. Similar results from this study are presented in Table 7.

Table 7

RESPONSE FREQUENCIES OF WOMEN TO SUBSONIC
JET FLYOVER DURING THREE SLEEP STAGES
(Numbers in parentheses are percentages)

Sleep Stage	Response Type			
	0	1	2	3
2	60 (36.4)	18 (10.9)	15 (9.1)	72 (43.6)
Delta (3 and 4)	14 (17.9)	29 (37.2)	10 (12.8)	25 (32.1)
REM (Rapid Eye Movement)	28 (29.5)	16 (16.8)	5 (5.3)	46 (48.4)

$\chi^2 = 31.4$, 6 df, $p < 0.001$.

The subjects were awakened least frequently (but also showed the lowest incidence of Type 0 responses--about 32 percent and 18 percent, respectively) to flyover noise occurring during sleep stage Delta (stages 3 and 4 combined). Flyover noises occurring during sleep stages 2 and REM were found to awaken the subjects some 10 to 15 percent more frequently than similar noises occurring during sleep stage Delta; however, the subjects obtained the highest frequency of Type 0 responses during these stages.

The relatively low frequency of Type 0 and Type 3 responses occurring during sleep stage Delta appears to hold at the three intensities of flyover tested. As shown in Table 8, the frequency of Type 3 responses is lowest during sleep stage Delta at the three stimulus levels. The smallest percentage of Type 0 responses was also observed at two of the three intensities (101 and 119 PNdB), although at the two highest flyover intensities (113 and 119 PNdB) the frequencies of Type 0 responses during stages Delta and REM are almost equal, and probably statistically insignificant.

Table 8

RESPONSE FREQUENCIES OF WOMEN TO SUBSONIC JET FLYOVER NOISE AT THREE INTENSITIES DURING THE THREE SLEEP STAGES

(Numbers in parentheses are percentages)

Flyover Intensity (in PNdB*)	Sleep Stage	Response Type 0	Response Type 1	Response Type 2	Response Type 3
101†	2	33 (55.0)	7 (11.7)	5 (8.3)	15 (25.0)
	Delta	4 (25.0)	9 (56.3)	1 (6.2)	2 (12.5)
	REM	19 (55.9)	5 (14.7)	2 (5.9)	8 (23.5)
113‡	2	13 (24.1)	7 (13.0)	6 (11.1)	28 (51.8)
	Delta	8 (21.1)	12 (31.6)	4 (10.5)	14 (36.8)
	REM	5 (20.8)	8 (33.3)	1 (4.2)	10 (41.7)
119§	2	14 (27.5)	4 (7.8)	4 (7.8)	29 (56.9)
	Delta	2 (8.3)	8 (33.3)	5 (20.8)	9 (37.5)
	REM	4 (10.8)	3 (8.1)	2 (5.4)	28 (75.7)

[*] As if measured out-of-doors.

[†] $\chi^2 = 17.2$, 6 df, $0.01 > p > 0.005$

[‡] $\chi^2 = 6.9$, 6 df, N.S.

[§] $\chi^2 = 21.5$, 6 df, $0.005 > p > 0.001$.

Table 8 also indicates that the frequency of behavioral awakenings in each sleep stage increased as the stimulus intensity increased, and that the frequency of Type 0 responses decreased with intensity increases in sleep stages Delta and REM. No systematic changes were observed in the frequencies of Type 1 or 2 responses with increases of stimulus intensity. (A possible exception is the general increase of arousal responses during stage Delta with increases in flyover level.)

D. Response to Simulated Sonic Booms

The subjects typically showed an increasing frequency of Type 3 responses to sonic booms of higher intensity, and a decreasing frequency of Type 0 responses. No systematic changes were found in the frequency of Type 1 and Type 2 responses. These results are presented in Table 9.

Table 9

RESPONSE FREQUENCIES OF WOMEN
TO SIMULATED SONIC BOOMS AT THREE INTENSITIES
(Numbers in parentheses are percentages)

Intensity of Sonic Boom (psf*)	Response Type			
	0	1	2	3
0.67	92 (70.8)	27 (20.8)	9 (6.9)	2 (1.5)
2.50	59 (49.2)	35 (29.2)	13 (10.8)	13 (10.8)
5.0	43 (33.1)	29 (22.3)	14 (10.8)	44 (33.8)

*As if measured out-of-doors.

$\chi^2 = 67.8$, 6 df, $p < 0.001$.

As noted in response to the flyover noises, the subjects typically were awakened least frequently during sleep state Delta, but during this stage they also showed the lowest frequency of Type 0 responses. These results are presented in Table 10. Note, however, the statistical analysis of the data (Table 11) indicates that the stage effect was confined to sonic booms of the two highest intensities (2.5 and 5.0 psf). Since

Table 10

RESPONSE FREQUENCIES OF WOMEN
TO SIMULATED SONIC BOOMS
DURING THREE SLEEP STAGES
(Numbers in parentheses are percentages)

Sleep Stage	Response Type			
	0	1	2	3
2	111 (54.1)	29 (14.1)	21 (10.2)	44 (21.5)
Delta	27 (34.6)	37 (47.4)	10 (12.8)	4 (5.1)
REM	56 (57.7)	25 (25.8)	5 (5.2)	11 (11.3)

$\chi^2 = 56.7$, 6 df, $p < 0.001$.

the trend of the data for booms of lowest intensity (0.67 psf) is consistent with that for the two higher intensity booms and with that for flyover noise (Table 8), the lack of a statistically significant difference of the lowest boom level may be due to the inaccuracy of the statistical estimation technique used (see the footnote of Table 11). It is concluded, therefore, that the stage effect (the relative infrequency of Type 3 and Type 0 responses to the noises during stage Delta as compared to their frequency during stages 2 or REM) holds, regardless of the stimulus intensity.

E. Adaptation

1. Flyover Noise

For purposes of this study, "adaptation" was defined primarily as a statistically significant reduction over time in the frequency of awake response (Type 3 scores) and secondarily as an increase in the frequency of no-responses (Type 0 scores). This test was applied to a comparison of the response frequencies during test nights 1 and 2 with those during test nights 5 and 6. Nights 5 and 6 were selected because they were followed by two control nights, during which some loss of adaptation might occur. Assuming such a loss, comparisons made with later nights (nights T_7, T_8, and T_9, for example) would be unlikely to show significant adaptation. The data presented in Table 12 indicate

Table 11

RESPONSE FREQUENCIES OF WOMEN TO SIMULATED SONIC BOOMS
AT THREE INTENSITIES DURING THE THREE SLEEP STAGES
(Numbers in parentheses are percentages)

Intensity of Sonic Boom (in psf[*])	Sleep Stage	Response Type			
		0	1	2	3
0.67[†]	2	50 (69.4)	12 (16.7)	8 (11.1)	2 (2.8)
	Delta	16 (64.0)	9 (36.0)	0 0	0 0
	REM	26 (78.8)	6 (18.2)	1 (3.0)	0 0
2.50[‡]	2	30 (54.5)	9 (16.4)	7 (12.7)	9 (16.4)
	Delta	9 (30.0)	16 (53.3)	4 (13.3)	1 (3.3)
	REM	20 (57.1)	10 (28.6)	2 (5.7)	3 (8.6)
5.0[§]	2	31 (39.7)	8 (10.3)	6 (7.8)	33 (42.3)
	Delta	2 (8.7)	12 (52.2)	6 (26.1)	3 (13.0)
	REM	10 (34.5)	9 (31.0)	2 (6.9)	8 (27.6)

[*] As if measured out-of-doors.

[†] $\chi^2 = 9.8$, 6 df,[**] N.S.

[‡] $\chi^2 = 16.6$, 6 df, $0.02 > p > 0.01$.

[§] $\chi^2 = 31.5$, 6 df, $p < 0.001$

[**] In cases with more than two degrees of freedom, good approximations of significance level are obtained if fewer than 20 percent of the cells have expected frequencies of about 1 (Ref. 10). In cases such as this where the rule was not met and the responses could not be combined with good reason, the columns including the zeros (responses 2 and 3) were excluded from the χ-square calculation. The χ-square Distribution Table was then entered with the degrees of freedom in effect had the column not been excluded. Implicitly it is assumed that the expected probabilities for the cells of the column in question are zero. Since the degrees freedom are increased through this procedure, the calculated χ^2 must have a greater magnitude to be significant.

Table 12

RESPONSE FREQUENCIES OF WOMEN TO SUBSONIC JET FLYOVER NOISE DURING COMBINATIONS OF TEST NIGHTS, SHOWING ADAPTATION
(Numbers in parentheses are percentages)

Test Nights	Response Type			
	0	1	2	3
T_1 and T_2 versus*	9 (14.8)	6 (9.8)	10 (16.4)	36 (59.0)
T_5 and T_6	31 (49.2)	17 (27.0)	4 (6.3)	11 (17.5)
T_1, T_2 and T_3 versus†	18 (19.1)	12 (12.8)	13 (13.8)	51 (54.3)
T_7, T_8 and T_9	42 (33.1)	24 (18.9)	5 (3.9)	56 (44.1)

$^*\chi^2 = 33.2$, 3 df, $p < 0.001$.

$^\dagger\chi^2 = 12.1$, 3 df, p $0.01 < p < 0.005$.

that some adaptation to the flyover noises did occur. The frequency of awake responses was reduced significantly (from 59 percent to about 18 percent) and the frequency of no-responses increased from about 15 percent to 49 percent when responses during nights T_1 and T_2 were compared with those during nights T_5 and T_6.

The response frequencies during nights T_1, T_2, and T_3 are compared with those during nights T_7, T_8, and T_9 in the lower half of Table 12. Response frequencies obtained during nights T_7, T_8, and T_9 are in the predicted direction to demonstrate adaptation and statistically different from those obtained during the first three test nights. However, the increase in frequency of Type 3 responses (from 17.5 percent on nights T_5 and T_6 to about 44 percent on the last three nights) and the reduced frequency of Type 0 responses (from about 49 percent on nights T_5 and T_6 to about 33 percent on nights T_7, T_8, and T_9) indicates a loss of some of the adaptation that had occurred during the first six consecutive test nights, by a lacuna of two nights of quiet.

2. Simulated Sonic Booms

There appeared to be some small adaptation to sonic booms. As can be seen in Table 13, the initial frequency of awakening, 22 percent on nights T_1 and T_2, reduced to 15 percent during nights T_5 and T_6. Very little difference in the number of Type 0 responses was found. However, despite the lack of statistically significant differences, the trend of the data--particularly as described below--do indicate that adaptation to the booms had occurred.

Table 13

RESPONSE FREQUENCIES OF WOMEN TO SIMULATED SONIC BOOMS DURING COMBINATIONS OF TEST NIGHTS, SHOWING ADAPTATION
(Numbers in parentheses are percentages)

Test Nights	Response Type			
	0	1	2	3
T_1 and T_2 versus*	33 (42.3)	15 (19.2)	13 (16.7)	17 (21.8)
T_5 and T_6	38 (41.3)	29 (31.5)	11 (12.0)	14 (15.2)
T_1, T_2 and T_3 versus†	47 (40.5)	27 (23.3)	17 (14.7)	25 (21.5)
T_7, T_8 and T_9	85 (62.5)	29 (21.3)	7 (5.1)	15 (11.0)

*$\chi^2 = 4.1$, 3 df, N.S.

†$\chi^2 = 16.9$, 3 df, $p < 0.001$.

Comparing response frequencies during nights T_1, T_2, and T_3 (lower half of Table 13) suggests that some adaptation to the sonic booms occurred that was not negatively affected by two control nights *being interspersed between a series of test nights. Note also the reduction* in Type 3 responses and the increased frequency of Type 0 responses on comparing nights T_7, T_8, and T_9 with nights T_5 and T_6.

F. Time to Return to Sleep after Behavioral Awakening

It may be of some interest to consider the durational aspects of behavioral awakening, i.e., Given the subject was awakened by some stimulus, how much time was required before she returned to sleep? For purposes of this discussion, sleep is defined as sleep stage 2. Since there is no prima facie reason for expecting an immediate return to the stage from which she was awakened, one might reasonably expect at least a brief return to sleep stage 2 before going into the "deeper" stages (stages 3 or 4) or sleep stage REM.

On the average, as shown in Table 14, the subjects returned to sleep in about the same time whether they were awakened by flyover noise or sonic booms. A slight tendency to be awake slightly longer (a fraction of a minute) after being awakened by flyover noise is apparent, but such small differences presumably have no practical significance.

Table 14

TIME TO RETURN TO SLEEP STAGE 2
AFTER BEHAVIORAL AWAKENING

Measure of Central Tendency	Stimulus	
	Flyovers*	Sonic Boom†
Mean	5.3 min	5.0 min
Median	3.7 min	3.0 min
Mode	2 min	2 min
Range	1-24 min	1-22 min

*1 measure of 60 min not included.

†1 measure of 48 min not included.

G. Comparison of Men and Women

The sleep of women was more disturbed by the flyover noise than was that of the men, while the middle-aged men[3] were slightly more disturbed by the sonic booms than were the women. As can be seen in Table 15, the women were awakened about twice as frequently as were the men by the

Table 15

RESPONSE FREQUENCIES OF MIDDLE-AGE MEN AND WOMEN TO SUBSONIC JET FLYOVER NOISE AND SIMULATED SONIC BOOMS

(Numbers in parentheses are percentages)

Stimulus and Intensity*	Sex	Age in Years	Response			
			0	1	2	3
Flyover Noise† (101, 113, 119 PNdB)	Women	29, 30, 30, 33, 36, 36, 40, 49	102 (30.2)	63 (18.6)	30 (8.9)	143 (42.3)
	Men	45, 45, 53, 57	200 (49.3)	90 (22.2)	34 (8.3)	82 (20.2)
Sonic Booms‡ (0.67, 2.50, 5.0 psf)	Women	29, 30, 30, 33, 36, 36, 40, 49	194 (51.1)	91 (23.9)	36 (9.5)	59 (15.5)
	Men	45, 45, 53, 57	223 (56.6)	77 (19.5)	13 (3.3)	81 (20.6)

*As if measured out-of-doors.

†$\chi^2 = 47.5$, 3 df, $p < 0.001$.

‡$\chi^2 = 17.2$, 3 df, $p < 0.001$.

flyover noise, and the women showed about 20 percent fewer Type 0 responses than did the men. In contrast, in response to the simulated sonic booms, the men obtained about 5 percent more awake responses and about 5 percent more Type 0 responses than did the women. The women obtained significantly more arousal responses (Type 2) than did the men. (Analysis of the relative contribution of the χ-squares of each cell to the χ-square of the whole table, indicates that 67 percent of the value of the total χ-square was attributable to the Type 2 responses.)

Note, however, that women were awakened more frequently and obtained fewer Type 0 responses than did the men at all intensities of the flyover noise. While in response to booms the responses of the men and women were statistically different at the two lower boom levels (0.67 and 2.50 psf) only. At boom levels of 5.0 psf, the responses of men and women were similar statistically, but the men still responded with more behavorial awakenings than did the women. At all levels of the sonic boom, the women consistently were aroused (Type 2 response) more frequently than were the men. These data are presented in Table 16.

H. Subjective Effects of the Noises on Sleep

The eight subjects of this study were tested in two groups of four. A questionnaire administered on several occasions to both groups was completed by each subject in order to estimate the subjective effects of noise on their sleep. Although the questionnaires administered to the two groups were not identical (the result of an effort to improve it), certain questions in the two forms were the same, and only the results from these questions are discussed here.

1. Actual Versus Reported Number of Awakenings

In contrast to the general but slight tendency for middle-aged men to underestimate the number of times they actually were behaviorally awakened each night, the women tended to overestimate. Women, on the average, reported being awakened once more frequently each night than indicated by the actual number of "awake" switch uses, while the men, on the average, reported being awakened less frequently (about 0.5 awakening per night) than the number of times the switch was activated. These results may reflect the generally higher frequency of arousals (Type 2 response) by women than by men to both booms and flyovers (see Tables 15 and 16).

2. Perceived Disruption of Sleep by Booms Versus Flyovers

It may be of some interest to note an apparent discrepancy between the number of times the subjects thought they were awakened by the two stimuli and their perception of the "most disturbing" noise. Table 17 shows that, whereas the subjects thought themselves to be awakened much more frequently by flyover noise then by booms (and the objective data, presented earlier, are in agreement), they thought the sonic booms to be more disturbing than flyover noise.

Table 16

RESPONSE FREQUENCIES OF MIDDLE-AGE MEN AND WOMEN
TO SUBSONIC JET FLYOVER NOISE AND SIMULATED SONIC BOOMS
EACH AT THREE INTENSITIES
(Numbers in parentheses are percentages)

Stimulus	Intensity[*]	Sex	Response Type			
			0	1	2	3
Flyover Noise	101[†] PNdB	Women	56 (50.9)	21 (19.1)	8 (7.3)	25 (22.7)
		Men	111 (78.7)	20 (14.2)	1 (0.7)	9 (6.4)
	113[‡] PNdB	Women	26 (22.4)	27 (23.2)	11 (9.5)	52 (44.8)
		Men	56 (40.0)	39 (27.9)	8 (5.7)	37 (26.4)
	119[§] PNdB	Women	20 (17.9)	15 (13.4)	11 (9.8)	66 (58.9)
		Men	33 (26.4)	31 (24.8)	25 (20.0)	36 (28.8)
Sonic Booms	0.67[**] psf	Women	92 (70.8)	27 (20.8)	9 (6.9)	2 (1.5)
		Men	102 (79.7)	8 (6.2)	7 (5.5)	11 (8.6)
	2.5[††] psf	Women	59 (49.3)	35 (29.1)	13 (10.8)	13 (10.8)
		Men	80 (52.3)	36 (23.5)	2 (1.3)	35 (22.9)
	5.0[‡‡] psf	Women	43 (33.1)	29 (22.3)	14 (10.8)	44 (33.8)
		Men	41 (36.3)	33 (29.2)	4 (3.5)	35 (30.9)

[*] As if measured out-of-doors.

[†] $\chi^2 = 27.7$, 3 df, $p < 0.001$.

[‡] $\chi^2 = 14.0$, 3 df, $0.005 < p < 0.001$.

[§] $\chi^2 = 22.4$, 3 df, $p < 0.001$.

[**] $\chi^2 = 17.3$, 3 df, $p < 0.001$.

[††] $\chi^2 = 17.5$, 3 df, $p < 0.001$.

[‡‡] $\chi^2 = 5.7$, 3 df, N.S.

Table 17

RELATIONSHIP BETWEEN PERCEIVED FREQUENCY OF AWAKENING BY AND DISTURBANCE ATTRIBUTED TO FLYOVER NOISE VERSUS BOOMS
(Numbers in parentheses are percentages)

Subjects:	Flyover Noise	Booms
Thought they were awakened by	56 times (77.8)	16 times (22.2)
Thought the (stimulus indicated) most disturbing	34 times (15.0)	17 times (85.0)

3. Perceived Fatigue at Night and Quality of Sleep

It was thought, on the basis of some earlier work,[12] that the subject's self-assessment of her state of fatigue before retiring might influence her responsiveness to noise during sleep and her assessment of the quality or the degree of disturbance of the night's sleep. Each evening the subjects (only four of the eight subjects) checked a seven-point scale ("Very Wide Awake" and "Unable to Keep Eyes Open," at the extremes) to indicate their relative fatigue, and in the morning, shortly after arising, described the extent to which their sleep was disturbed. The disturbance item contained four categories ranging from "Very Much Disturbed" to "Not Disturbed," as is shown in Table 18. The response categories were combined (in Table 18) since the subjects apparently had difficulty discriminating between some of the categories, especially those near the middle of the response range, and in order to more easily discern trends in light of the limited sample. In general, the trend of the data is what might be expected: For example, given a moderately sleepy state at night, the relative frequency of "Not Disturbed" responses is reduced as the result of nights with noise. Granted that the small sample precludes any generalizations, the trend of the data suggests the approach may be of some value for future studies.

4. Perceived Frequency of Awakening and Quality of Sleep

Table 19 shows the subjective assessment of the degree of sleep disturbance as related to the frequency of reported awakenings. As the number of reported awakenings increased, the frequency of "Moderate"

Table 18

RELATIONSHIP BETWEEN SUBJECTIVE FATIGUE STATE AT NIGHT AND THE PERCEIVED QUALITY OF SLEEPING THE FOLLOWING MORNING

(Numbers in parentheses are percentages)

Condition	Quality of Sleep	Subjective State at Night						
		Very Wide Awake	Wide Awake	Slightly Sleepy	Moderately Sleepy	As Tired As Usual At This Hour	Extremely Fatigued	Unable To Keep Eyes Open
Control Nights (without noise)	Very much disturbed	0		0			0	
	Slightly disturbed	0		2			0	
	Only a little disturbed							
	Not disturbed	1 (16.7)		5 (83.3)			0	
Test Nights (with noise)	Very much disturbed	0		1			0	
	Slightly disturbed	4 (18.2)		15 (68.2)			3 (13.6)	
	Only a little disturbed							
	Not disturbed	0		6 (75.0)			2 (25.0)	

Table 19

RELATIONSHIP BETWEEN NUMBER OF REPORTED AWAKENINGS
AND SUBJECTIVE ASSESSMENT OF SLEEP QUALITY
(Numbers in parentheses are percentages)

<table>
<tr><th rowspan="2">Reported Number of Awakenings (Question 3)</th><th colspan="4">Subjective Disturbance (Question 6)</th></tr>
<tr><th>Very Much Disturbed</th><th>Slightly Disturbed</th><th>Only a Little Disturbed</th><th>Not Disturbed</th></tr>
<tr><td>0</td><td>0</td><td colspan="2">5
(33.3)</td><td>10
(66.7)</td></tr>
<tr><td>1 or 2</td><td>1
(9.1)</td><td colspan="2">7
(63.6)</td><td>3
(27.3)</td></tr>
<tr><td>3 or 4</td><td>0</td><td colspan="2">10
(83.3)</td><td>2
(16.7)</td></tr>
<tr><td>5 to 7</td><td>0</td><td colspan="2">4
(100)</td><td>0</td></tr>
</table>

Phi′ = 0.39 (Ref. 10, pp. 604-606).

disturbances increased while the frequency of "Not Disturbed" decreased. As noted in the preceding section, the limited sample precludes any generalizations, but the results do suggest that further work with the described approach is warranted.

V DISCUSSION

Generally, the lowest frequency of awake responses to flyover noise and sonic booms was found during sleep stage Delta, but also the lowest frequency of Type 0 responses was found. Conversely, the highest frequencies of awake responses and the lowest frequencies of Type 0 responses were obtained in stages 2 and REM. The physiological or psychological significance, if any, of this pattern of responses to noise during sleep is unclear. However, the implications for determination of response thresholds during the different sleep stages are worthy of note: If an attempt is made to determine an EEG change threshold, it appears that the lowest threshold (compared to that of stages 2 and REM) will be obtained during stage Delta, but the highest thresholds will be obtained during stage Delta if behavioral awakening is the criterion response.

If one studies the effect of changes in stimulus intensity on a given response in any given sleep stage (Tables 8 and 11), only a slight, at best, systematic effect can be discerned. The most obvious exception is that of behavioral awakening (Type 3 response), which generally shows an increased frequency of awakening for each sleep stage with increases of intensity. On the basis of the data available it appears our earlier suggestion[2] and that of others[13-15] (based on somewhat different grounds) that behavioral awakening seems to be the most meaningful data to be obtained regarding the effects of noise on sleep is indirectly substantiated by the lack of a systematic pattern in the EEG-determined responses to changes in noise intensity. It might be added, parenthetically, that the general increase in perceived disturbance with perceived number of awakenings as shown in Table 19 (or with the number of actual awakenings) also emphasizes the relative importance of behavioral awakening as a criterion for sleep disturbance.

With respect to differences in response due to gender, the data presented above suggest that, on the average, middle-aged women tend to be more frequently awakened by noise (flyovers and sonic booms in this case) than do men, and that women tend to be awakened more frequently by subsonic flyover noise then by simulated sonic booms. Middle-aged men, in contrast, were awakened as frequently by the subsonic flyover noises as by the simulated sonic booms, but more frequently by the booms than were the women. Wilson and Zung[6] who used a variety of stimuli--such as doorbells, bagpipes, and chinese gongs--showed similar response differences between sexes.

The results may reflect actual sex-related differences in general sensitivity to noise during sleep, especially in light of the fact that the women are being compared with men older by some 15 years, on the average. Our previous studies[2,3] clearly indicate that, other things being equal, the older subject is more sensitive to noise during sleep.

On the other hand, alternative explanations are possible, and the alternatives may have heuristic value. One alternative deals with the question of experimental method. In our previous studies,[1-3] the subjects were tested no more frequently than twice a week on nonconsecutive nights. The differences obtained may reflect, in part, an effect resulting from the number of consecutive nights of stimulation. That some adaptation is lost or reduced by nights of no stimulation is suggested by the apparent increased sensitivity to noise after two nights of sleeping in the quiet (Tables 12 and 13).

Another possibility is that the women may have had better hearing than the men, although the audiograms of both groups were within normal limits. It is known[16] that women show less hearing loss than men at comparable ages, but the differences become particularly pronounced at frequencies above about 1000 Hz after the age of about 40 years. Comparison of the frequency spectra of subsonic jet flyover noises with those of sonic booms indicate that most of the acoustic energy in flyover noises falls in the 125- to 4000-Hz range, while in sonic booms most of the energy is below about 100 Hz.[11] Our male subjects had an average age of 50 years, and the women one of 35 years, or particularly those ages at which women are more likely than are men to hear the higher frequencies contained in the subsonic jet flyover noises.

A final alternative is that, since the sample size was small (twelve subjects), the results simply reflect the peculiarities or idiosyncracies of the particular subjects studied.

VI CONCLUSIONS

Certain conclusions (tentative at this time because of sample size) may be drawn:

(1) On the average, eight middle-aged women, with a mean age of 35 years, were awakened by about 42 percent of subsonic jet flyover noises ranging in intensity from 101 to 119 PNdB, as measured out-of-doors. They were awakened by about 15 percent of the simulated sonic booms ranging in intensity from 0.67 to 5.0 psf, as measured out-of-doors.

(2) On the average, in middle-age women a subsonic jet flyover noise of about 101 PNdB was as awakening as simulated sonic booms of about 3.8 psf (both sounds as if measured out-of-doors).

(3) On the average, the female subjects tended to be more frequently awakened and aroused by noise during sleep than were the men in previous studies. In particular, women were about twice as likely to be awakened by subsonic jet flyover noise of the same intensity as were the middle-aged men. In contrast, the men tended to be slightly--about 1.5 times--more likely to be awakened by sonic booms of the same intensity than were the middle-aged women.

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