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DISTURBANCE OF HUMAN SLEEP BY SUBSONIC JET AIRCRAFT NOISE AND SIMULATED SONIC BOOMS

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16. Abstract

Four subjects in each of three age groups (young - about 7 years of age, middle-age - about 51 years, and old - about 71 years of age) were exposed for 20 nights to simulated sonic booms and subsonic jet flyover noises. Four intensities of each stimulus were usually presented twice each night. The results show that the children were relatively unresponsive to the booms or the flyover noise regardless of intensity. The middle-aged men were behaviorally awakened by about 18 percent of the booms and by about 18 percent of the flyover noises. The older men, in contrast, were awakened by about 32 percent of the booms and to about the same extent by flyover noises. Two subgroups of relatively low and high sensitivity to noise during sleep were found in both the middle-aged and old groups.

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I INTRODUCTION

While under contract to the National Aeronautics and Space Administration, Stanford Research Institute developed a simulator of the indoor vibratory and acoustical effects of sonic booms.[1*] Two previous experimental studies of the effects of booms and subsonic jet aircraft noise on sleep have been conducted with the aid of this simulator. In the first,[1] a pilot study, six college students were subjects; in the second,[2] six subjects ranging in age from 7 to 72 years were tested.

The results of the second study were considered tentative because only two subjects were in each of the three age groups. Consequently, the study reported herein used four additional subjects in each of the three age groups in order to explore further the effects of sonic booms and subsonic aircraft noise on sleep in persons of different ages.

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*References are listed at the end of the report.

II OBJECTIVES

The objectives of the study reported herein were to determine: (1) the effects, over a period of about 20 nonconsecutive nights, of sonic booms and subsonic jet flyover noise on human sleep, and (2) the relative sensitivity of individuals between and within different age groups to those stimuli.

III PROCEDURES

A. Subjects

Four volunteers in each of three age groups were subjects. They were: young--two males, each five years of age, and two females, six and eight years of age; middle-aged--four males, 45, 45, 53, and 57 years of age; and old--four males, 69, 70, 74, and 75 years of age.

Audiograms obtained before the experimental tests indicated that 10 of 12 subjects had hearing thresholds within normal limits.[3,4] The two oldest subjects, ages 74 and 75 years, appeared to have losses no greater than expected at frequencies of 2000 Hz and below, but at and above 4000 Hz these men had losses that were about 45 dB more than the 45-50 dB expected for males of that age. It should be noted that the literature[3,4] provides little exact hearing loss data for subjects beyond the age of 60 or so years, and that the data provided are quite variable. Our estimates of the expected losses are extrapolations and, thus, include some error of an unknown magnitude.

The subjects did not live near airports or in the flight paths of large numbers of aircraft. Although they had heard sonic booms and subsonic jet aircraft noise, no particular bias either for or against super- or subsonic jet aircraft noise was reported. (See, for example, the response to Question 16 of Questionnaire 2 as discussed on page 47.) In addition, the middle-aged and old subjects thought themselves to be normally sound sleepers and not to be especially disturbed by noise during sleep.

B. Test Procedure

On the first night in the laboratory the subjects were told informally about the purposes of the experiment, and what was expected of them, and any questions were answered fully. The subjects then put on their pajamas and the electrodes were attached.

Since the middle-aged and old subjects were tested only two non-consecutive nights per week, and in light of the findings of Kales, et al.[5] that for elderly persons "... several nights of adjustment to the new situation...." are required, it was thought that at least six nights for accommodation to the laboratory should be permitted each subject. All subjects, including the children, attained this goal, and most were accommodated for seven nights. The reason for the small, and presumably insignificant, differences in number of accommodation nights was that two subjects were unable to show up for one of the accommodation sessions.

The groups of older subjects participated in all 20 scheduled experimental nights, as well as two interspersed control nights and one final control night; the children, because of dissatisfaction by the parents with the effects of the experimental schedule on their weekends, completed only 10 of the 20 scheduled experimental nights and only one of three control nights.

Two subjects, each in a single bed, occupied each of two rooms. Each subject always slept in the bed assigned to him on the first night. Each night after the subjects were in bed and the electronic systems checked and calibrated, the subjects were asked to push their "awake switches" as if to check that the switches were operating properly. These switches were affixed to the headboards of the beds. Finally, before the lights were extinguished the subjects were told to push the awake switch three times if they awoke for any reason during the night. The subjects were given no other instructions. They were never told whether noise, either simulated booms or flyovers, would occur.

Generally about 45 minutes after the subjects retired and after both subjects in one room were asleep--one subjects was in sleep stage 3 or 4 and the other in any stage except sleep stage 1--the stimulus sequence for that room for the night began. A simulated sonic boom or a subsonic jet flyover noise--as heard indoors--was presented at random and at an intensity randomly chosen from among the four intensities possible, with the restriction that the booms and jet noise be presented eight times each, twice at each intensity. The stimulus parameters for the boom and flyover noise are presented in Table I.

Stimuli to any room were presented on the average about once every 20 minutes with a range of seven to about 50 minutes. Variability in time between stimulations was necessary in order to permit subjects awakened by one stimulus to return to stage 2, at least, before presentation of the next stimulus. When a stimulus was presented in one room, that period served as a control trial for the subjects in the other room. Stimulus presentations alternated between the two rooms. Thus, it will be seen that for any given pair of subjects in a single room the sequence of trials was alternately experimental and control trials.

Using standard electrode placements, as recommended by Rechtschaffen and Kales,[6] the EEGs were monitored continuously throughout a session to determine stage of sleep and the effects of the stimuli thereon. For each subject these placements included:

(1) An electroencephalogram from a right or left (C_3 or C_4) central electrode monopolar with respect to the contralateral mastoid.

(2) Two eye movement electrodes proximal to the outer canthi of each eye and both monopolar with respect to a single electrode just above the nasion.

(3) Bipolar electrodes on the lower chin, one to two cm to the right and left of the midline.

Table I

PARAMETERS OF SIMULATED SONIC BOOMS

AND SUBSONIC JET FLYOVER NOISE

Stimulus	Peak* Intensity (in psf)		Duration* (in ms)	Rise Time* (in ms)
Simulated Sonic Boom	5.0		290	12
	2.5		264	7
	1.25		260	6
	.65		260	5
	Peak* Intensity in:		Duration to 20 dB Downpoints (in seconds)	Peak Intensity in Test Room**
	PNdB+	EPNdB§ 15		
Subsonic Jet Flyover	119	114	10	86
	113	108	10	80
	107	102	10	74
	101	96	10	68

*As if measured outdoors. Slight variations between the two test rooms exist. The values presented in the table are means of several measures obtained in each room.

+As if measured outdoors. Levels indoors (in test room) about 25 PNdB less.

§Estimated.

**In dB re 0.0002 microbar.

C. Stimuli

The parameters of the booms and flyovers were indicated in Table I, and will be repeated later. It is sufficient to note here that they were selected to be representative of those expected from the supersonic transport (in the case of booms) and subsonic jet aircraft now in commercial use. Out-of-door levels are a practical means of expressing the intensities of these stimuli, and are usually used in describing sonic booms and flyover noise. The intensities of these stimuli were, of course, less in the test room, as is indicated in Table I.

The sonic boom simulators used for these tests generate and modulate "booms" in such a way that the noise and vibrations generated are similar to those found in a typical home struck by actual sonic booms. (A complete description of the simulator can be found in Ref 1.) 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 feet; it had a duration between 20 dB downpoints of about ten seconds and was played back at various intensities depending upon the particular experimental conditions.

D. Scoring of the Electroencephalograms (EEG)

A four-category technique for scoring the responses of the subjects to the stimuli was used. The first three categories are scores obtained by examination of the EEG by two observers, and the fourth category was used only if the subject pressed his awake switch. Criteria for assigning scores are presented in Table II.

Table II

EEG SCORING CRITERIA

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.*
1	Sleep stage change of one or two steps, but without arousal. The change must occur within 30 seconds of stimulation and continue for an additional 40 seconds, at least.
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).

IV RESULTS

A. Comparability of Age Groups

On the basis of the previous study,[2] a small amount of data in the literature, and anecdotal information, large differences in the responses of the age groups to the subsonic jet flyover noise and simulated sonic booms were anticipated. In Table III it can be seen that with increasing age the responsiveness to both noises during sleep increased, as is indicated by the decreasing percentages of 0 responses with increasing percentages of awake responses, i.e., scores of 3, and increasing percentages of responses scored 1 and 2.

Table III

RESPONSE FREQUENCIES OF THREE AGE GROUPS
TO SIMULATED SONIC BOOMS AND SUBSONIC JET FLYOVER NOISE

Group	Age (years)	Frequency (N) and Percent of All Responses	Response			
			0	1	2	3
Young	5 to 8	N	481	87	8	2
		Percent	83.2	15.1	1.4	0.3
Middle-Aged	45 to 57	N	575	208	55	204
		Percent	55.2	19.9	5.3	19.6
Old	69 to 75	N	371	190	79	200
		Percent	44.2	22.6	9.4	23.8

$X^2 = 265.99$, 6 df (degrees of freedom), $p < .001$.

B. Comparability of Individuals within Age Groups

1. Children

In only one of the four children were the stimuli of sufficient intensity to elicit an awake response, as is shown in Table IV. Since

Table IV

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

Subject	Age (years)	Frequency (N) and Percent of All Responses	Response 0	1	2	3
Y_1 (female)	8	N	111	28	6	0
		Percent	76.6	19.3	4.1	0
Y_2 (male)	5	N	132	13	0	0
		Percent	91.0	9.0	0	0
Y_3 (male)	5	N	126	17	1	0
		Percent	87.5	11.8	0.7	0
Y_4 (female)	6	N	112	29	1	2
		Percent	77.8	20.1	0.7	1.4

$X^2 = 22.40$, 9 df,* $0.01 > p > 0.005$.

*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. 7). In cases such as this where the rule was not met, the column including the zeros (response 3) was excluded from the Chi-square calculation. The Chi-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 of freedom are increased through this procedure, the calculated X^2 must have a greater magnitude to be significant.

these two awake responses occurred in a single child during sleep stage REM (rapid eye movement) to flyover noises of 101PNdB and 113PNdB, it is concluded that the children responded similarly to each other despite the obtained statistical significance.

2. <u>Middle-Aged Men</u>

Two (M_3 and M_4) of the four middle-aged subjects were awakened significantly more frequently by the stimuli than were subjects M_1 and M_2. In Table V it can be seen that subjects M_3 and M_4 showed significantly

Table V

RESPONSE FREQUENCIES OF FOUR MIDDLE-AGED MEN TO SIMULATED SONIC BOOMS AND SUBSONIC JET FLYOVER NOISE

Subject	Age (years)	Frequency (N) and Percent	Response			
			0	1	2	3
M_1	45	N Percent	184 69.7	55 20.8	16 6.1	9 3.4
M_2	53	N Percent	169 64.0	58 22.0	29 11.0	8 3.0
M_3	45	N Percent	111 42.2	57 21.7	8 3.0	87 33.1
M_4	57	N Percent	111 42.2	38 15.1	2 0.8	100 39.8

$X^2 = 209.18$, 9 df, $p < 0.001$.

fewer 0 responses and significantly more 3, or awake, responses. That the difference is not due solely to age is indicated by the fact that M_3 was one of the two youngest (45 years of age) of the four middle-aged subjects, while M_4 was the eldest (57 years) of the group.

Assuming the two pairs of middle-aged subjects to be showing some differences in sensitivity to noise during sleep, the responses of the pairs (arbitrarily divided in pairs termed low and high sensitivity) to simulated booms and flyovers were compared statistically. The data pertinent to this analysis are presented in Tables VI and VII. With

Table VI

RESPONSE FREQUENCIES OF FOUR MIDDLE-AGED MEN
OF LOW AND HIGH SENSITIVITY TO SIMULATED SONIC BOOMS

Estimated Sensitivity of Subjects	Subject	Age (years)	Frequency (N) and Percent	Response 0	Response 1	Response 2	Response 3
Low*	M_1	45	N	96	24	6	4
			Percent	73.8	18.5	4.6	3.1
	M_2	53	N	91	28	7	4
			Percent	70.0	21.5	5.4	3.1
High†	M_3	45	N	53	25	4	51
			Percent	39.8	18.8	3.0	38.3
	M_4	57	N	65	20	0	41
			Percent	51.6	15.9	0	32.5

*X^2 = 0.51, 3 df, N.S.

†X^2 = 6.68, 3 df, N.S.

respect to responses to simulated booms, it can be seen in Table VI that the two subjects, M_1 and M_2, who apparently were of low sensitivity did not differ significantly from each other and, similarly, that the highly sensitive subjects, M_3 and M_4, did not differ significantly from each other.

Table VII

RESPONSE FREQUENCIES OF FOUR MIDDLE-AGED MEN

OF LOW AND HIGH SENSITIVITY TO SUBSONIC JET AIRCRAFT NOISE

Estimated Sensitivity of Subjects	Subject	Age (years)	Frequency (N) and Percent	Response			
				0	1	2	3
Low*	M_1	45	N	88	31	10	5
			Percent	65.7	23.1	7.5	3.7
	M_2	53	N	78	30	22	4
			Percent	58.2	22.4	16.4	3.0
High†	M_3	45	N	58	32	4	38
			Percent	43.9	24.2	3.0	28.8
	M_4	57	N	46	18	2	59
			Percent	36.8	14.4	1.6	47.2

*$X^2 = 5.23$, 3 df, N.S.

†$X^2 = 10.34$, 3 df, $0.02 > p > 0.01$.

The data in Table VII show that the subjects M_1 and M_2 were less sensitive than M_3 and M_4, as was the case with sonic booms. It is also seen in Table VII that while M_1 and M_2 were not statistically different with respect to their responses to subsonic jet aircraft flyover noise, the subjects M_3 and M_4, judged highly sensitive, were different from each other in this regard. Inspection of the Chi-squares of the individual cells (the cell Chi-squares are summed to obtain the Chi-square for the table) revealed that the different frequencies of awake responses, scores of 3, by M_3 and M_4 contributed slightly more than half the value of the Chi-square for the table. It is suggested, therefore, that despite the statistically significant difference with respect to jet noise only the responses of subjects M_3 and M_4 are sufficiently similar in other respects to permit their continued classification as highly sensitive and to permit pooling the responses of these two subjects.

3. Old Men

As was observed in the case of the middle-aged men, statistically significant differences between the four old men, with respect to their responses to simulated booms and subsonic jet flyover noise, were found; these data are presented in Table VIII.

Table VIII

RESPONSE FREQUENCIES OF FOUR OLD MEN
TO SIMULATED SONIC BOOMS AND SUBSONIC JET FLYOVER NOISE

Subject	Age (years)	Frequency (N) and Percent	Response			
			0	1	2	3
O_1	70	N	109	34	16	50
		Percent	52.2	16.3	7.7	23.8
O_2	69	N	76	40	20	73
		Percent	36.4	19.1	9.6	34.9
O_3	75	N	96	46	24	45
		Percent	45.5	21.8	11.4	21.3
O_4	74	N	90	70	19	32
		Percent	42.7	33.2	9.0	15.1

$X^2 = 41.00$, 9 df, $p < 0.001$.

Although the response frequencies permit dividing the subjects into low and high sensitivity categories, the division was not as obvious as it was with the middle-aged men. Inspection of a plot of the cumulative percentages of the responses of each subject to simulated booms and subsonic jet flyover noise, as shown in Figure 1, indicated

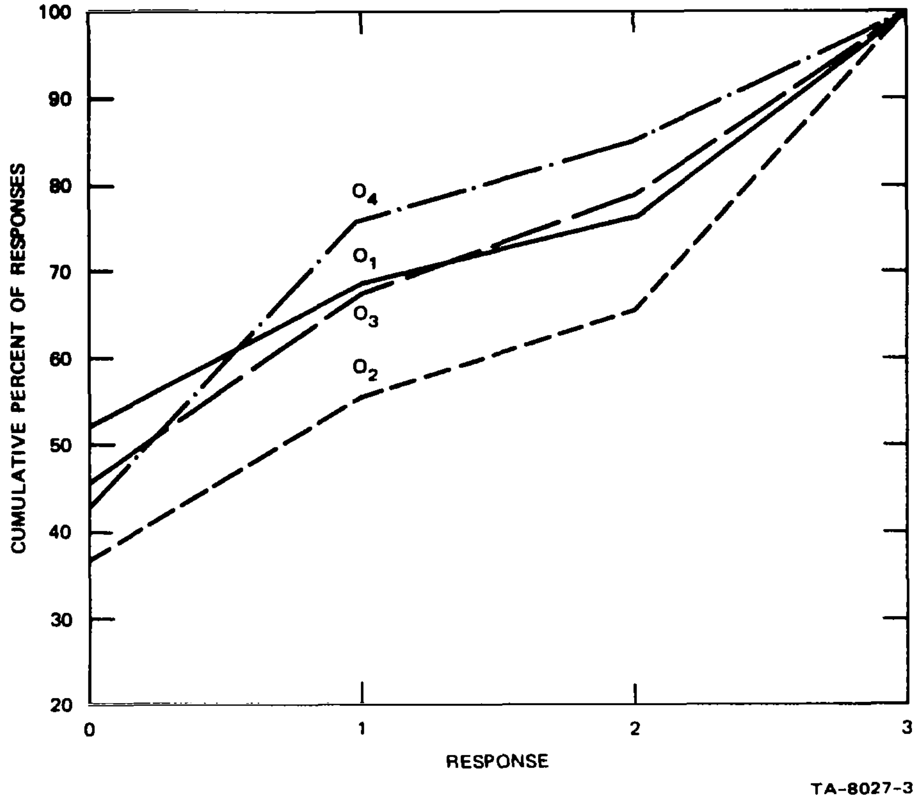

FIGURE 1 RELATIVE SENSITIVITY OF FOUR OLD SUBJECTS TO SIMULATED SONIC BOOMS AND SUBSONIC JET AIRCRAFT NOISE

that subject O_2 was the most sensitive of the four old men. When similar plots (not included in this report) of the responses to booms and fly-overs alone were drawn, subject O_2 was again found to be the most sensitive, i.e., he obtained the smallest percentage of 0 responses and the highest percentage of 3 responses, and his response curve did not overlap at any point with the curves of the other three subjects.

Subject O_4 could be placed into a category labelled "least sensitive" because, even though his percentage of 0 responses (42.7 percent) was less than that obtained by O_1 and O_3, he was awakened much less frequently than were the other old subjects (see Table VIII and Figure 1). However, the relatively large contribution of the subject O_4-Response 1 cell Chi-square (about 25 percent) to the total Chi-square of Table VIII, as compared to about a 15 percent contribution by the subject O_4-Response 3 cell Chi-square, suggests that subject O_4 differs from subjects O_1 and O_3 more with respect to proneness to shift steps in sleep stage (response 1) than with respect to proneness to awakening (response 3).

C. Comparability of the High and Low Sensitivity Subgroups between Age Groups

If the responses of subjects in the middle-aged and old groups categorized as being of low or high sensitivity are pooled, the middle-aged and old subjects of low sensitivity can be compared, as can be the subgroups of higher sensitivity. These comparisons are shown in Table IX.

It will be noted that the old subject, O_2, was only slightly more sensitive to both noises than were the highly sensitive middle-aged subjects. Although the relative number of 0 responses obtained by the highly sensitive old subject was less than that obtained by the highly sensitive middle-aged subjects (M_3 and M_4), there was no corresponding increase

Table IX

RESPONSE FREQUENCIES OF MIDDLE-AGED AND OLD MEN OF LOW AND HIGH SENSITIVITY TO SIMULATED SONIC BOOMS AND SUBSONIC JET AIRCRAFT NOISE

Sensitivity Category	Subject	Age (years)	Number (N) and Percent	Response 0	Response 1	Response 2	Response 3
Low*	M_1 and M_2	45, 53	N	353	113	45	17
			Percent	66.9	21.4	8.5	3.2
	O_1, O_3 and O_4	70, 75 74	N	295	150	59	127
			Percent	46.8	23.8	9.4	20.0
High†	M_3 and M_4	45, 57	N	222	95	10	187
			Percent	43.2	18.5	1.9	36.4
	O_2	69	N	76	40	20	73
			Percent	36.4	19.1	9.6	34.9

*$X^2 = 79.45$, 3 df, $p < 0.001$.

†$X^2 = 22.62$, 3 df, $p < 0.001$.

in the percentage of 3 responses by subject O_2. If anything, inspection of the Chi-squares of each cell suggests that the major difference between the highly sensitive middle-aged and old subjects was the relatively large number of 2 responses obtained by O_2. In contrast, the old and middle-aged subjects of low sensitivity were distinguishable on the basis of the relative number of 0 and 3 responses: the older subjects of low sensitivity obtained fewer 0 responses and were awakened more frequently (response 3).

The analyses above indicate that, although the children can be treated as a single group, the middle-aged and old subjects may be divided into categories of low and high sensitivity for any subsequent analyses.

D. <u>Response of Subjects during Control Trials</u>

The groups uniformly demonstrated very few changes in sleep stage or awakenings during the control trials. As can be seen in Table X,

Table X

RESPONSE FREQUENCIES OF THREE AGE GROUPS DURING CONTROL TRIALS

Group	Control Stimulus	Number (N) and Percent	Response 0	Response 1	Response 2	Response 3
Young	Booms	N	279	3	0	0
		Percent	98.9	1.1		
	Flyover Noise	N	281	3	0	0
		Percent	98.9	1.1		
Middle-Aged	Booms	N	515	3	3	1
		Percent	98.7	0.6	0.6	0.2
	Flyover Noise	N	523	2	3	2
		Percent	98.7	0.4	0.6	0.4
Old	Booms	N	420	1	1	0
		Percent	99.5	0.2	0.2	
	Flyover Noise	N	344	3	0	1
		Percent	98.9	0.9		0.3

about 99 percent of all control trials resulted in no change (response 0) in the behavior of the subjects. The middle-aged group showed some slight tendency to change sleep stage (1 and 2 responses) and to awaken more frequently than did the children or old men. Among the middle-aged men, only one subject, who had been classified (see above) as being of low sensitivity to noise, accounted for all of the awake responses (scores of 3). It is clear, nevertheless, that normal, spontaneous changes in behavior probably contributed little to the responses to the simulated sonic booms and jet flyover noises reported herein.

E. Response to Simulated Sonic Booms

From the data presented in Table XI it is clear that (1) the three age groups responded differently to the simulated sonic booms, and (2)

Table XI

RESPONSE FREQUENCIES OF THREE AGE GROUPS TO SIMULATED SONIC BOOMS

Age Group	Relative Sensitivity	Frequency (N) and Response	Response 0	Response 1	Response 2	Response 3
Young		N	246	45	3	0
		Percent	83.7	15.3	1.0	
Middle-Aged*	Low	N	187	52	13	8
		Percent	71.9	20.0	5.0	3.1
	High	N	118	45	4	92
		Percent	45.6	17.4	1.5	35.5
Old†	Low	N	156	78	29	57
		Percent	48.8	24.4	9.1	17.7
	High	N	40	22	5	37
		Percent	38.5	21.2	4.8	35.5

*$\chi^2 = 91.44$, 3 df, $p < 0.001$.

†$\chi^2 = 15.09$, 3 df, $p < 0.001$.

that the subjects previously classified as being of relatively low and high sensitivity responded quite differently to the booms. In general, with increasing age the percentage of 0 responses decreased and the percentage of awake responses (scores of 3) increased. It also appears that with increasing age changes in the EEG (scores of 1) and arousal (scores of 2) as a result of external stimuli are likely, old subjects are more likely than the middle-aged and young subjects to show brief arousals to stimuli during sleep.

1. Children

The children were found to be uniformly unresponsive to simulated sonic booms, as is indicated by the absence of any awake responses (scores of 3). However, it will be seen in Table XII that as the

Table XII

RESPONSE FREQUENCIES OF CHILDREN TO SIMULATED SONIC BOOMS OF DIFFERENT INTENSITIES

Boom Intensity in psf	Frequency (N) and Percent	Response			
		0	1	2	3
0.65	N Percent	64 94.1	4 5.9	0	0
1.25	N Percent	69 87.3	7 8.9	3 3.8	0
2.5	N Percent	53 76.8	16 23.2	0	0
5.0	N Percent	60 76.9	18 23.1	0	0

Responses 1 and 2 combined, and response 3 excluded, $X^2 = 11.19$, 6 df, N.S. ($p > 0.05$).

intensity of the boom increased there occurred a simultaneous decrease in the percentage of 0 scores with an increase in the relative number of sleep stage changes (scores of 1).

These results are consistent with those obtained previously.[2] In that study only three intensities of booms (0.63, 1.25, and 2.5 psf) were tested, and there appeared to be no statistically significant change in response rates at the different intensities. However, the trend of those data, i.e., a decrease in the number of 0 scores with increases in boom intensity, is similar to that shown here.

The effects of simulated sonic booms on children do not appear to depend upon the stage of sleep during which the boom occurs. As can be seen in Table XIII, booms occuring during sleep stages 2, Delta (sleep

Table XIII

RESPONSE FREQUENCIES OF CHILDREN TO SIMULATED SONIC BOOMS DURING DIFFERENT SLEEP STAGES

Sleep Stage	Frequency (N) and Percent	Response			
		0	1	2	3
2	N Percent	112 84.8	19 14.4	1 0.8	0
Delta	N Percent	74 77.1	21 21.9	1 1.0	0
REM	N Percent	53 89.8	5 8.5	1 1.7	0

Responses 1 and 2 combined, $X^2 = 4.698$, 4 df, N.S.

stages 3 and 4 combined), and REM (Rapid Eye Movement) did not result in statistically significant differences in the frequency of responses to those booms.

2. Middle-Aged Men

The effect of simulated sonic booms on the middle-aged men was found to depend, in part, at least, upon the general sensitivity of the subjects to noises during sleep. As can be seen in Table XIV, the subjects

Table XIV

RESPONSE FREQUENCIES OF MIDDLE-AGED MEN OF HIGH AND LOW SENSITIVITY TO SIMULATED SONIC BOOMS OF DIFFERENT INTENSITIES

Relative Sensitivity	Boom Intensity in psf	Frequency (N) and Percent	Response			
			0	1	2	3
Low*	0.65	N	54	3	5	2
		Percent	84.4	4.7	7.8	3.1
	1.25	N	53	6	3	0
		Percent	85.5	9.7	4.8	0
	2.5	N	53	19	1	3
		Percent	69.7	25.0	1.3	4.0
	5.0	N	27	24	4	3
		Percent	46.6	41.4	6.9	5.1
High†	0.65	N	48	5	2	9
		Percent	75.0	7.8	3.1	14.1
	1.25	N	29	12	1	19
		Percent	47.5	18.8	1.6	31.1
	2.5	N	27	18	1	32
		Percent	34.6	23.1	1.3	41.0
	5.0	N	14	10	0	32
		Percent	25.0	17.9	0	57.1

*X^2 = 39.64, 9 df, p <0.001.

†X^2 = 43.09, 9 df, p <0.001.

of low sensitivity responded similarly to booms of the two lower intensities (0.65 and 1.25 psf), but as the intensity was increased to 2.5 psf and then to 5.0 psf the relative frequency of 0 responses decreased with substantial increases in the percentage of 1 and 2 responses. (It is possible that the increase of 1.1 percent--from 4.0 to 5.1 percent --in the relative number of 3 responses may be statistically and behaviorally significant, but analysis of the cell Chi-squares suggests that the increase of about 16 percent--from 25.0 to 41.4 percent--in the number of 1 responses was the largest contributor to the Chi-square of the table.)

In contrast, the highly sensitive middle-aged men obtained more responses of 1 and 3, and fewer 0 responses, to booms of even the lowest intensity (0.65 psf) than did subjects of low sensitivity. In addition, as the intensity of the booms was increased, the highly sensitive subjects were awakened more frequently and the percentage of 0 responses decreased. It will be seen, in Table XIV, that for the middle-aged subjects of both low and high sensitivity these changes in response frequencies with increases in boom intensity were statistically significant.

On the basis of our previous studies[1,2] and other investigations (see, for example, Refs. 8, 9, and 10) it is to be anticipated that the response to booms depends upon the stage of sleep during which the noise occurs. As will be seen in Table XV, the middle-aged subjects of both low and high sensitivity were awakened about twice as frequently during sleep stages 2 and REM as they were during sleep stage Delta. However, although the subjects were awakened least frequently during sleep stage Delta, in this sleep stage the subjects, regardless of sensitivity, were most likely to respond to the booms by shifting into sleep stage 2.

Note also, in Table XV, that the responses of the highly sensitive subjects during the three sleep stages were found to be different statistically, while such was not the case with the subjects of low

Table XV

RESPONSE FREQUENCIES OF MIDDLE-AGED SUBJECTS OF RELATIVELY LOW AND HIGH SENSITIVITY TO SIMULATED SONIC BOOMS DURING DIFFERENT SLEEP STAGES

Relative Sensitivity	Sleep Stages	Frequency (N) and Percent	Response			
			0	1	2	3
Low*	2	N	105	23	8	6
		Percent	73.9	16.2	5.6	4.2
	Delta	N	45	20	2	1
		Percent	66.2	29.4	2.9	1.5
	REM	N	76	10	3	3
		Percent	82.6	10.8	3.3	3.3
High†	2	N	68	18	4	56
		Percent	46.6	12.3	2.7	38.4
	Delta	N	22	18	0	8
		Percent	45.8	37.5		16.7
	REM	N	59	15	1	45
		Percent	49.2	12.5	0.8	37.5

*$X^2 = 11.54$, 6 df, N.S.

†$X^2 = 23.63$, 6 df, $p < 0.001$.

sensitivity. However, the trend of the data with respect to the relative frequency of the different responses in the three stages of sleep is similar in both subgroups.

3. Old Men

As was found with respect to children and middle-aged men, the old men, regardless of sensitivity, responded to simulated sonic booms of higher intensity with a statistically significant reduction in the relative number of 0 responses and with a general increase in the percentage of 3 responses. In Table XVI, it can be seen that as boom

Table XVI

RESPONSE FREQUENCIES OF OLD MEN OF RELATIVELY LOW AND HIGH SENSITIVITY TO SIMULATED SONIC BOOMS OF DIFFERENT INTENSITIES

Relative Sensitivity	Boom Intensity in psf	Frequency (N) and Percent	Response			
			0	1	2	3
Low*	0.65	N	46	17	6	4
		Percent	63.0	23.3	8.2	5.5
	1.25	N	49	21	8	6
		Percent	58.3	25.0	9.5	7.1
	2.50	N	43	24	8	15
		Percent	47.8	26.7	8.9	16.7
	5.0	N	18	16	7	32
		Percent	24.7	21.9	9.6	43.8
High†	0.65	N	12	5	0	4
		Percent	57.1	23.8		19.1
	1.25	N	13	7	0	8
		Percent	46.4	25.0		28.6
	2.50	N	10	2	3	13
		Percent	35.7	7.1	10.7	46.4
	5.0	N	5	8	2	12
		Percent	18.5	29.6	7.4	44.4

* $X^2 = 53.29$, 9 df, $p < 0.001$.

† $X^2 = 17.28$, 9 df, $0.05 > p > 0.025$.

intensity is increased from 0.65 to 5.0 psf the subjects of low sensitivity showed a decrease in percentage of 0 responses from about 63 percent to about 25 percent, while the highly sensitive subject showed a decrease from about 57 percent to about 18 percent. Simultaneously, the percentage of awake responses (scores of 3) increased from about 6 percent to about 44 percent in the group of low sensitivity, and from about 19 percent to about 44 percent in the highly sensitive subject.

The data presented in Table XVI suggest that, although the high and low sensitivity subgroups differ from each other with respect to their responses to booms ranging between 0.65 and 2.50 psf in intensity, at intensities of 5.0 psf the two subgroups respond similarly. A Chi-square of 0.917 (9 df, N.S.) was obtained from a statistical comparison of the response frequencies of the relatively high and relatively low sensitivity subgroups to booms of 5.0 psf.

It can be seen in Table XVII that when the booms occurred during sleep stage Delta, the old subjects, regardless of relative sensitivity, responded with significantly more 1 responses and significantly fewer 3 responses than were obtained when booms occurred during sleep stage 2 or REM. This result, for the old men, is consistent with that found in the case of the children (Table XIII) and the middle-aged men (Table XV).

F. Response to Subsonic Jet Aircraft Noise

As was found with respect to simulated sonic booms (Table XI), the responses of the three age groups to subsonic jet flyover noise were significantly different: with increasing age the relative number of 0 responses decreased and, simultaneously, the incidence of behavioral awakening increased. In addition, with respect to the relatively low and high sensitivity subjects within the middle-aged and old categories, the

Table XVII

RESPONSE FREQUENCIES OF OLD MEN OF RELATIVELY LOW AND HIGH SENSITIVITY TO SIMULATED SONIC BOOMS DURING DIFFERENT SLEEP STAGES

Relative Sensitivity	Sleep Stage	Frequency (N) and Percent	Response 0	1	2	3
Low*	2	N	97	44	19	45
		Percent	47.3	21.5	9.3	21.9
	Delta	N	22	26	5	0
		Percent	41.5	49.1	9.4	
	REM	N	28	7	3	5
		Percent	65.1	16.3	7.0	11.6
High†	2	N	22	7	3	21
		Percent	41.5	13.2	5.7	39.6
	Delta	N	6	14	2	6
		Percent	21.4	50.0	7.1	21.4
	REM	N	6	1	0	8
		Percent	40.0	6.7		53.3

*$\chi^2 = 30.43$, 6 df, $p < 0.001$.

†$\chi^2 = 19.12$, 6 df, $0.005 > p > 0.001$.

percentage of awakening was significantly greater for the highly sensitive group and the percentage of 0 responses was significantly lower for the subgroups of lower sensitivity. The data in support of these findings are presented in Table XVIII.

1. Children

Changes in the response frequencies of children to increases in flyover intensity are shown in Table XIX. Although the percentage

Table XVIII

RESPONSE FREQUENCIES OF THREE AGE GROUPS

TO SUBSONIC JET FLYOVER NOISE

Age Group	Relative Sensitivity	Frequency (N) and Percent	Response 0	1	2	3
Young		N	235	42	6	2
		Percent	82.5	14.7	2.1	0.7
Middle-Aged*	Low	N	166	61	32	9
		Percent	61.9	22.8	11.9	3.4
	High	N	104	52	6	95
		Percent	40.5	20.2	2.3	37.0
Old†	Low	N	139	69	30	70
		Percent	45.2	22.4	9.7	22.7
	High	N	36	18	15	36
		Percent	34.3	17.1	14.3	34.3

*$X^2 = 103.67$, 3 df, $p < 0.001$.

†$X^2 = 8.76$, 3 df, $0.05 > p > 0.025$.

of 0 responses decreases and the percentage of 1 responses generally increases as a result of increases in flyover intensity, the fact that only two awake responses occurred, and those to flyovers of 101 and 113 PNdB, suggest that for children awakening is more dependent upon internal factors than upon the intensity of stimuli in the environment.

No effect on response frequencies due to sleep stage was found in the children. In Table XX it will be seen that, although some differences in the percentages of responses during the three sleep stages of interest were found, the differences were statistically insignificant. This result is similar to that obtained with sonic booms. However, in

Table XIX

RESPONSE FREQUENCIES OF CHILDREN

TO SUBSONIC JET FLYOVER NOISE OF DIFFERENT INTENSITIES

Flyover Intensity in PNdB	Frequency (N) and Percent	Response			
		0	1	2	3
68	N Percent	68 91.7	5 6.9	0	1 1.4
74	N Percent	57 82.6	10 14.5	2 2.9	0
80	N Percent	62 83.8	9 12.2	2 2.7	1 1.3
86	N Percent	50 71.4	18 25.7	2 2.9	0

Response 3 excluded, $X^2 = 12.84$, 6 df, $0.05 > p > 0.025$.

Table XX

RESPONSE FREQUENCIES OF CHILDREN

TO SUBSONIC JET FLYOVER NOISE DURING THREE SLEEP STAGES

Sleep Stage	Frequency (N) and Percent	Response			
		0	1	2	3
2	N Percent	89 76.7	24 20.7	3 2.6	0
Delta	N Percent	99 90.0	11 10.0	0	0
REM	N Percent	38 79.1	7 14.6	1 2.1	2 4.2

Response 3 excluded, $X^2 = 8.13$, 4 df, N.S.

response to flyover noises the children showed the most frequent 0 response (about 90 percent) during sleep stage Delta as compared to the percentages of 0 responses during sleep stages 2 and REM, whereas to simulated sonic booms during sleep stage Delta the children obtained the least frequent 0 response (about 77 percent). Since there is no a priori rationale for predicting that flyover noises during sleep stage Delta would have less effect (a higher percentage of 0 responses) and booms during sleep stage Delta more of an effect (a lower percentage of 0 responses), it must be concluded that the response differences observed in the children during the three sleep stages to simulated sonic booms and subsonic jet flyover noise are in large part due to sampling errors and are of little consequence.

2. Middle-Aged Men

Variations in subsonic jet flyover noise intensity resulted in changes in the response patterns of the middle-aged men. However, the changes appear to be dependent upon the relative sensitivity of the subjects. For example, it will be seen in Table XXI that with respect to the middle-aged men of low sensitivity increasing the flyover intensity from 101 to 119 PNdB resulted in an increase of about 5 percent (from 2.8 to 7.8 percent) in the number of awake responses (scores of 3). In contrast, in the high sensitivity group a similar increase in intensity resulted in an increase in awakenings of about 40 percent (from 10.1 percent awake responses to flyovers of 101 PNdB to 50.8 percent awake responses to flyovers of 119 PndB). A similar result with respect to responses to simulated sonic booms was found.

With respect to the effects of subsonic jet flyover noise on the response frequencies of middle-aged men during the different sleep stages, two responses different from those observed in response to booms

Table XXI

RESPONSE FREQUENCIES OF MIDDLE-AGED MEN

OF RELATIVELY LOW AND HIGH SENSITIVITY

TO SUBSONIC JET FLYOVER NOISE OF DIFFERENT INTENSITIES

Relative Sensitivity	Flyover Intensity in PNdB	Frequency (N) and Percent	Response			
			0	1	2	3
Low*	101	N	61	8	1	2
		Percent	84.7	11.1	1.4	2.8
	107	N	42	14	2	0
		Percent	72.4	24.1	3.5	
	113	N	39	25	8	2
		Percent	52.7	33.8	10.8	2.7
	119	N	24	14	21	5
		Percent	37.5	21.9	32.8	7.8
High†	101	N	50	12	0	7
		Percent	72.5	17.4		10.1
	107	N	28	9	2	22
		Percent	45.9	14.8	3.3	36.0
	113	N	17	14	0	35
		Percent	25.8	21.2		53.0
	119	N	9	17	4	31
		Percent	14.8	27.9	6.6	50.8

*$X^2 = 62.11$, 9 df, $p < 0.001$.

†$X^2 = 63.63$, 9 df, $p < 0.001$.

were found. First, for booms (see Table XV) the response frequencies of the low sensitivity group were found not to vary as some function of sleep stage; the responses to flyover noise did vary with sleep stage, as is shown in Table XXII. The distribution of responses in these two

Table XXII

RESPONSE FREQUENCIES OF MIDDLE-AGED MEN OF RELATIVELY HIGH AND LOW SENSITIVITY TO SUBSONIC JET FLYOVER NOISE DURING DIFFERENT SLEEP STAGES

Relative Sensitivity	Sleep Stage	Frequency (N) and Percent	Response 0	Response 1	Response 2	Response 3
Low*	2	N	95	32	19	4
		Percent	63.3	21.3	12.7	2.7
	Delta	N	34	22	9	2
		Percent	50.7	32.8	13.4	3.0
	REM	N	38	6	2	3
		Percent	77.6	12.2	4.1	6.1
High†	2	N	63	31	4	57
		Percent	40.6	20.0	2.6	36.8
	Delta	N	7	8	3	13
		Percent	22.6	25.8	9.7	41.9
	REM	N	32	9	0	23
		Percent	50.0	14.1		35.9

* $X^2 = 12.93$, 6 df, $0.05 > p > 0.025$.

† $X^2 = 26.36$, 6 df, $p < 0.001$.

cases was similar (for example, the percentage of 0 responses was lowest during sleep stage Delta for both booms and flyovers, while the percentage of 1 scores was highest) but the differences in percentages were of smaller magnitude in the case of responses to simulated booms. Since the computed statistic for the boom data was near the magnitude required for significance (with 6 df, a Chi-square of 12.6 is required for the 0.5 level of confidence, whereas the obtained Chi-square was 11.5) it is concluded that the response to simulated sonic booms, as well as subsonic jet flyover noise, is in part dependent upon the stage of sleep during which those stimuli occur.

The second discrepancy between responses to sonic booms and flyovers was the relatively large number of awake responses by the highly sensitive subjects to flyover noises occuring during sleep stage Delta. About 42 percent of the flyovers occurring during sleep stage Delta resulted in awake responses, in contrast to about 36 percent awakening to flyovers during sleep stages 2 and REM. These same subjects were awakened least frequently, about 17 percent of the time, by booms occurring during sleep stage Delta as compared to being awakened by about 38 percent of the booms that occurred during sleep stages 2 and REM. There are some data (Ref. 8, for example) that suggest awakening thresholds during sleep stage 3 to be lower than those for sleep stage 4, (stages 3 and 4 comprise sleep stage Delta). If the subjects in question were stimulated more frequently by flyovers during sleep stage 3 than by booms during sleep stage 4, then the finding of more frequent awake responses to flyovers during sleep stage Delta is not unreasonable. The data pertinent to this hypothesis are presented in Table XXIII. It can be seen that not only were relatively more booms than flyovers presented while the subjects were in sleep stage 3 but, in addition, the subjects were awakened by the flyovers considerably more frequently. It should be noted also that when either stimulus was presented during sleep stage 4 none of the subjects were awakened. These data suggest that flyovers occurring during sleep stage 3 are more arousing than the simulated sonic booms; this finding will be discussed subsequently in greater detail.

3. Old Men

Although the old men of relatively low sensitivity were found to respond differently to changes in flyover noise intensity, the old man

Table XXIII

PERCENT AWAKE RESPONSES OF MIDDLE-AGED MEN
OF RELATIVELY HIGH SENSITIVITY TO FLYOVER NOISE
AND SONIC BOOMS OCCURRING DURING SLEEP STAGES 3 AND 4

Stimulus Type	Sleep Stage			
	3		4	
Subsonic Jet Flyover Noise	27/257[*] = 10.5%	11/27[†] = 40.7%	4/257[*] = 1.6%	0/4[†] = 0%
Simulated Sonic Booms	39/259 = 15.1%	2/39 = 5.1%	9/259 = 3.5%	0/9 = 0%

[*] Percent of the total number of stimuli of the type indicated presented in the sleep stage specified.

[†] Percent of stimuli presented in the indicated sleep stage that resulted in an awake response (score of 3).

of relatively high sensitivity did not show statistically different responses to similar changes of intensity. As will be seen in Table XXIV, with increases in intensity of the subsonic jet flyover noise the low sensitivity group showed an increased percentage of awake responses (scores of 3) and a decreasing percentage of 0 responses. In contrast, the so-called high sensitivity subject showed a similar but less systematic pattern of changes with increasing flyover intensity, and the magnitudes of the changes were not nearly so great as those observed in the group of low sensitivity. For example, increasing the flyover intensity from 101 to 119 PNdB resulted in a decrease of about 37 percent (from 62.0 to 24.7) in the 0 responses of the group of low sensitivity, while with the subject of high sensitivity the same change of intensity resulted in a decrease of about 26 percent (from 47.8 to 22.2) in the frequency of 0 responses.

Table XXIV

RESPONSE FREQUENCIES OF OLD MEN OF RELATIVELY LOW AND HIGH SENSITIVITY TO SUBSONIC JET AIRCRAFT FLYOVER NOISES OF DIFFERENT INTENSITIES

Relative Sensitivity	Flyover Intensity in PNdB	Frequency (N) and Percent	Response			
			0	1	2	3
Low*	101	N	44	16	4	7
		Percent	62.0	22.5	5.6	9.8
	107	N	40	16	3	8
		Percent	59.7	23.9	4.5	11.9
	113	N	34	19	8	24
		Percent	40.0	22.4	9.4	28.2
	119	N	21	18	15	31
		Percent	24.7	21.2	17.7	36.5
High†	101	N	11	5	4	3
		Percent	47.8	21.7	17.4	13.0
	107	N	10	4	1	8
		Percent	43.5	17.4	4.4	34.7
	113	N	9	4	4	15
		Percent	28.1	12.5	12.5	46.9
	119	N	6	5	6	10
		Percent	22.2	18.5	22.2	37.1

*$X^2 = 43.76$, 9 df, $p < 0.001$.

†$X^2 = 11.59$, 9 df, N.S.

Since the trend of the data for the single highly-sensitive subject is similar to that of the subjects of low sensitivity, it is concluded that the statistical insignificance of an intensity effect (in the case of the highly-sensitive subject) may be attributed to sampling errors, and that old subjects of high and low sensitivity show significant changes in response with changes in flyover intensity.

The responses during the different sleep stages of the old men to subsonic jet flyover noises were similar to those obtained to simulated sonic booms. As will be seen in Table XXV, for old subjects of both low

Table XXV

RESPONSE FREQUENCIES OF OLD MEN OF RELATIVELY LOW AND HIGH SENSITIVITY TO SUBSONIC JET FLYOVER NOISES DURING DIFFERENT SLEEP STAGES

Relative Sensitivity	Sleep Stage	Frequency (N) and Percent	Response			
			0	1	2	3
Low*	2	N	86	43	16	55
		Percent	43.0	21.5	8.0	27.5
	Delta	N	16	17	8	4
		Percent	35.5	37.8	17.8	8.9
	REM	N	21	7	3	5
		Percent	58.3	19.4	8.3	13.9
High†	2	N	22	8	12	22
		Percent	34.4	12.5	18.7	34.4
	Delta	N	2	8	2	4
		Percent	12.5	50.0	12.5	25.0
	REM	N	9	2	1	8
		Percent	45.0	10.0	5.0	40.0

*$X^2 = 17.63$, 6 df, $0.01 > p > 0.005$.

†$X^2 = 16.43$, 6 df, $0.02 > p > 0.01$.

and high relative sensitivity, behavioral awakening (response 3) was obtained least frequently during sleep stage Delta as compared to the frequency obtained during sleep stages 2 and REM. However, during this same sleep stage, Delta, the subjects obtained the lowest percentage of 0 responses and the highest percentage of 1 responses.

G. Comparison of Responses to Simulated Sonic Booms and Flyovers

Regardless of subject sensitivity, no significant differences in the response frequencies to the particular simulated sonic booms and particular subsonic jet flyover noise were found. These data are presented in Table XXVI. In this table it will be seen that only the low sensitivity middle-aged men showed statistically significant differences in responses to booms and flyovers. However, that significance appears to be due primarily to the relatively small number of 2 responses to booms or, conversely, the relatively large number of 2 responses to flyovers. Since only a slight statistical difference in the frequency of awake responses to booms and flyovers was found, and since the practical significance of the increase in the percentage of 2 responses to flyover noises is unclear, it is thought that the statistical differences in this case are of little consequence. Note, however, that in the main the subgroups responded in a characteristic manner to flyover noise relative to their responses to booms: flyovers typically resulted in fewer 0 responses and in more responses scored 2 and 3.

To assure that the lack of statistically significant response differences to booms and to flyovers, shown in Table XXVI, was not simply a result of data aggregation, the responses of the middle-aged and old groups at the extremes of the range of intensities tested were compared. The results are presented in Table XXVII, where it will be seen that only one comparison of the 16 comparisons made was found to be significant

Table XXVI

RESPONSE FREQUENCIES OF THREE AGE GROUPS TO SIMULATED SONIC BOOMS AND TO SUBSONIC JET FLYOVER NOISE

Age Group	Relative Sensitivity	Stimulus	Frequency (N) and Percent	Response 0	1	2	3
Young*		Boom	N	246	45	3	0
			Percent	83.7	15.3	1.0	0
		Flyover	N	235	42	6	2
			Percent	82.5	14.7	2.1	0.7
Middle-Aged	Low†	Boom	N	187	52	13	8
			Percent	71.9	20.0	5.0	3.1
		Flyover	N	166	61	32	9
			Percent	61.9	22.8	11.9	3.4
	High§	Boom	N	118	45	4	92
			Percent	45.6	17.4	1.5	35.5
		Flyover	N	104	52	6	95
			Percent	40.5	20.2	2.3	37.0
Old	Low**	Boom	N	156	78	29	57
			Percent	48.8	24.4	9.1	17.7
		Flyover	N	139	69	30	70
			Percent	45.2	22.4	9.7	22.7
	High††	Boom	N	40	22	5	37
			Percent	38.5	21.2	4.8	35.5
		Flyover	N	36	18	15	36
			Percent	34.3	17.1	14.3	34.3

*$\chi^2 = 3.22$, 3 df, N.S.

†$\chi^2 = 9.93$, 3 df, $0.02 > p > 0.01$.

§$\chi^2 = 1.67$, 3 df, N.S.

**$\chi^2 = 2.67$, 3 df, N.S.

††$\chi^2 = 5.62$, 3 df, N.S.

Table XXVII

RESPONSE FREQUENCIES OF MIDDLE-AGED AND OLD SUBJECTS OF RELATIVELY HIGH AND LOW SENSITIVITY TO SIMULATED SONIC BOOMS AND TO SUBSONIC JET FLYOVER NOISE AT TWO INTENSITIES EACH

Age Group	Relative Sensitivity	Stimulus and Intensity	Frequency (N) and Percent	Response			
				0	1	2	3
Middle-Aged	Low	Boom @ 0.65 psf	N Percent	54 84.4	3 4.7	5 7.8	2 3.1
		Flyover @ 101 PNdB	N Percent	61 84.7	8 11.1	1 1.4	2 2.8
	Low*	Boom @ 5.0 psf	N Percent	27 46.6	24 41.4	4 6.9	3 5.1
		Flyover @ 119 PNdB	N Percent	24 37.5	14 21.9	21 32.8	5 7.8
	High	Boom @ 0.65 psf	N Percent	48 75.0	5 7.8	2 3.1	9 14.1
		Flyover @ 101 PNdB	N Percent	50 72.5	12 17.4	0 0	7 10.1
	High	Boom @ 5.0 psf	N Percent	14 25.0	10 17.9	0 0	32 57.1
		Flyover @ 119 PNdB	N Percent	9 14.8	17 27.9	4 6.6	31 50.8
Old	Low	Boom @ 0.65 psf	N Percent	46 63.0	17 23.3	6 8.2	4 5.5
		Flyover @ 101 PNdB	N Percent	44 62.0	16 22.5	4 5.6	7 9.8
	Low	Boom @ 5.0 psf	N Percent	18 24.7	16 21.9	7 9.6	32 43.8
		Flyover @ 119 PNdB	N Percent	21 24.7	18 21.2	15 17.7	31 36.5
	High	Boom @ 0.65 psf	N Percent	12 57.1	5 23.8	0 0	4 19.1
		Flyover @ 101 PNdB	N Percent	11 47.8	5 21.7	4 17.4	3 13.0
	High	Boom @ 5.0 psf	N Percent	5 18.5	8 29.6	2 7.4	12 44.4
		Flyover @ 119 PNdB	N Percent	6 22.2	5 18.5	6 22.2	10 37.1

*$X^2 = 14.53$, 3 df, $0.005 > p > 0.001$.

statistically. It might be expected on the basis of the data shown earlier in Table XXVI, that the response frequencies to 5.0 psf booms versus 119 psf flyovers of the middle-aged subjects of low sensitivity were found to be statistically different, and that difference was largely due to discrepancies between responses scored as 2, and, to a lesser extent, between responses scored as 1. In general, there appeared to be no consistent differences in responses to the booms and flyovers when categorized according to relative intensity. In short, it appears that increasing the boom intensity by a factor of 18 dB, from 0.65 to 5.0 psf, had a comparable awakening effect as did increasing the subsonic aircraft noise by 18 dB, from 101 to 119 PNdB; further, a boom of .65 psf (measured outdoors) has about the same awakening effect as does the noise of a subsonic aircraft of 101 PNdB (as measured outdoors).

H. Adaptation to Simulated Sonic Booms and Subsonic Jet Flyover Noise

It will be remembered that the subjects were tested on two non-consecutive nights weekly. This schedule of testing not only is somewhat unreal in comparison to people living near airports who hear the aircraft daily, but also makes the demonstration of adaptation (as indicated by an increase in the percentage of 0 responses and a reduction in the percentage of 3 responses) to the test stimuli somewhat unlikely. Nevertheless, the responses of the test subjects to the flyover noise and sonic booms during the first five nights of testing were compared with their responses during the last five test nights. Although the trend of the data, shown in Table XXVIII, suggests that in most cases some adaptation had occurred, in only one case (that of the middle-aged subjects of high sensitivity responding to sonic booms) were the response changes of statistical significance.

Table XXVIII

RESPONSE FREQUENCIES ON THE FIRST AND LAST FIVE TEST NIGHTS OF THREE AGE GROUPS TO SIMULATED SONIC BOOMS AND SUBSONIC JET FLYOVER NOISES

Age Group	Relative Sensitivity	Stimulus Type	Test Nights	Frequency (N) and Percent	Response 0	Response 1	Response 2	Response 3
Young		Sonic Booms	1-5	N	107	24	3	0
				Percent	79.9	17.9	2.2	
			6-10	N	139	21	0	0
				Percent	86.9	13.1		
		Flyover Noise	1-5	N	105	16	2	2
				Percent	84.0	12.8	1.6	1.6
			6-10	N	130	26	4	0
				Percent	81.3	16.3	2.5	
Middle-Aged	Low	Sonic Booms	1-5	N	44	15	2	3
				Percent	68.8	23.4	3.1	4.7
			16-20	N	50	14	0	0
				Percent	78.1	21.9		
		Flyover Noise	1-5	N	35	17	5	2
				Percent	59.3	28.8	8.5	3.4
			16-20	N	49	19	5	1
				Percent	66.2	25.7	6.8	1.4
	High	Sonic Booms*	1-5	N	25	10	2	29
				Percent	37.9	15.2	3.0	43.9
			16-20	N	36	15	0	17
				Percent	52.9	22.1		25.0
		Flyover Noise	1-5	N	31	9	2	18
				Percent	51.7	15.0	3.3	30.0
			16-20	N	28	19	3	22
				Percent	38.9	26.4	4.2	30.5
Old	Low	Sonic Booms	1-5	N	40	17	3	15
				Percent	53.3	22.7	4.0	20.0
			16-20	N	45	23	7	6
				Percent	55.6	28.4	8.6	7.4
		Flyover Noise	1-5	N	35	18	5	14
				Percent	48.6	25.0	6.9	19.4
			16-20	N	42	15	5	17
				Percent	53.2	19.0	6.3	21.5
	High	Sonic Booms	1-5	N	9	7	2	13
				Percent	29.0	22.6	6.5	41.9
			16-20	N	8	6	0	10
				Percent	33.3	25.0		41.7
		Flyover Noise	1-5	N	9	9	7	8
				Percent	27.3	27.3	21.2	24.2
			16-20	N	6	6	2	12
				Percent	23.1	23.1	7.7	46.2

* $X^2 = 8.09$, 3 df, $0.05 > p > 0.025$.

I. Subjective Responses to Subsonic Jet Aircraft Noise and Simulated Sonic Booms

In addition to the effects of noise on behavioral awakening and electroencephalographic sleep, the subjective effects of that noise were assessed through the use of two types of questionnaires, administered only to the middle-aged and old subjects. One questionnaire, a copy of which is presented as Appendix A, was used to determine the subjective effects of noise on feelings of well-being the next morning, selected attitudes toward the stimuli, and the accuracy of memory for the number and type of awakening stimuli. This questionnaire was administered twice: (1) in the morning after the tenth test night, and (2) in the morning after the twentieth test night.

The second questionnaire, Appendix B, was used to assess the subjective effects of nighttime noise on performance. Consequently, the subjects were required to complete the questionnaire at home about 5:00 p.m. of the day following the twentieth test night.

1. Responses to the First Questionnaire (Appendix A)

This questionnaire was administered twice to each subject and, in general, the responses of any subject during the first administration were very similar to those on the second. However, in order to account for the variability and yet have a single number to describe the group response, the responses of each subject on each administration of the questionnaire were treated separately. Thus, there were a total of eight responses in either age group to any question.

Question 3--About 75 percent of the middle-aged and all of the old-aged subjects thought the laboratory environment on non-test nights was conducive to restful sleep. The partially dissenting opinion was attributed to the complaint by one subject that "at times" his movement was "restricted" and "confined" by the electrode harness, and the other middle-aged subject was disturbed, at times, by the air-conditioner. The other subjects thought the test environment a good place to sleep because the room was "dark, quiet, and cool."

Questions 1, 2, 4, and 7--As will be seen in Table XXIX, a large majority (about 75 percent, on the average) of the middle-aged

Table XXIX

PERCENT OF A GIVEN RESPONSE TO THE TOTAL RESPONSES TO QUESTIONS 1, 2, 4, AND 7 OF QUESTIONNAIRE A

Age Group	Condition of Previous Night	Question No.	Percent of Subjects Reporting	
			Seven Hours' Sleep	Arise Feeling "Fully Rested"
Middle-Aged	No Stimuli	1 & 2	62.5	75.0
	Booms and Flyovers	4 & 7	27.5	27.5
Old	No Stimuli	1 & 2	87.5	100
	Booms and Flyovers	4 & 7	62.5	87.5

and old subjects normally had about seven hours' sleep and arose feeling "fully rested." However, with stimulation during the night, the number of middle-aged and old subjects who felt as if they obtained the usual number of hours of sleep (7 hours) was reduced significantly, and their descriptions of the restfulness of the sleep obtained were also less than "fully rested."

Questions 6 and 9--The two age groups reported subsonic jet aircraft noise and sonic booms to be unequally disturbing, as is shown in Table XXX. Jet aircraft noises were most disturbing to the middle-aged

Table XXX

PERCENT OF MIDDLE-AGED AND OLD SUBJECTS
REPORTING SUBSONIC JET AIRCRAFT NOISE
OR SIMULATED SONIC BOOMS TO BE MOST DISTURBING TO SLEEP

Age Group	Most Disturbing		
	Jet Aircraft	Sonic Booms	No Response
Middle-Aged	87.5	12.5	0
Old	12.5	50.0	37.5

group, and sonic booms disturbed the old subjects most. In the main, the responses of any subject to questions 6 and 9 were the same, so that the responses to both questions were aggregated to produce the percentages of Table XXX.

Questions 8a and 11--Although more than a simple majority of the middle-aged and old subjects thought they would adapt to the noise, and despite the lack of much evidence that adaptation had occurred, all of the old subjects thought they had adapted to the noise, while only 37.5 percent of the middle-aged subjects thought they had. These data are presented in Table XXXI. In light of the electroencephalographic results, i.e., little evidence of adaptation, the middle-aged subjects apparently were more aware of the effects of the noise on their sleep than were the old subjects.

Question 5--It might be predicted on the basis of the findings in response to questions 8a and 11 that the middle-aged men would know more accurately the number of times they were behaviorally awakened (i.e., used the awake switch) the previous night than the old subjects. Such was found not to be the case: the middle-aged subjects obtained an average error (actual number of times switch was used on a particular

Table XXXI

PERCENT OF MIDDLE-AGED AND OLD SUBJECTS WHO THOUGHT THEY WOULD ADAPT TO THE NOISE AND THEY HAD ADAPTED TO NOISE

Age Group	Question and its Number	Percent Responding: Yes	No	No Response
Middle-Aged	Will get used to noise (11)	50.0	37.5	12.5
	Have gotten used to noise (8a)	37.5	62.5	0
Old	Will get used to noise (11)	62.5	25.0	12.5
	Have gotten used to noise (8a)	100	0	0

night in response to the boom or flyover noise minus number of times subject reported the following morning that he had been awakened by one stimulus or the other) of 0.5, while the old subjects obtained an average error of 0.2. Granting the small difference between the average errors, these results suggest the middle-aged subjects underestimated the number of times they were awakened to a greater extent than did the old subjects.

2. Responses to the Second Questionnaire (Appendix B)

The data obtained from the second questionnaire probably are of little significance because of the small sample. Consequently, they will not be described in detail.

Perhaps of some interest may be the responses to the two questions (4 and 8) that deal with subjective feeling state after two test nights (nights that included stimulation by simulated sonic booms and subsonic jet flyover noise) and two questions (6 and 9) concerning performance the day following a night of stimulation. To be found in Table XXXII are the opinions of the middle-aged and old subjects--expressed as

Table XXXII

OPINIONS OF MIDDLE-AGED AND OLD SUBJECTS
CONCERNING THE EFFECTS OF EXPERIMENTAL DISRUPTIONS
OF THE PRECEDING NIGHTS SLEEP ON TWO SELF-PERCEPTIONS THE SUBSEQUENT DAY

Question and its Number	Percent of Subjects Responding:			
When awake did you feel you: (4 and 8)	Slept Better Than at Home?	Slept as Well as at Home?	Slept Poorly?	Slept Very Poorly?
	25.0	37.5	37.5	0
On usual daily tasks did you: (6 and 9)	Perform Better Than Usual?	Perform as Well as Usual?	Perform Poorly?	Perform Very Poorly?
	12.5	50.0	37.5	0

a percentage of the total number of responses (16)--to two questions, each referring to a preceding test night and its subsequent effects. It will be seen that although 25 percent of the subjects thought they slept better than at home, only 12.5 percent thought they performed their usual tasks better than normally. In contrast, 37.5 percent of the responses indicated the subjects slept poorly and an equivalent number (the same subjects in all cases) thought their performance the following day was effected negatively. None of the subjects described incidents indicating poor performance (questions 7 and 10), but the

74-year-old subject did describe an indication of better performance in his work as a part-time hardware salesman.

Finally, only one of the eight subjects indicated that aircraft noise was disturbing at home during the night in response to question 16. Of the remaining seven, five indicated traffic noise as being bothersome, one reported barking dogs, and an apartment dweller cited loud talking in the hallway as an irritant.

J. Comparison of the Most Recent Results with Those Obtained in a Previous Study (Ref. 2)

In general, the responses of the three age groups reported above are similar to those obtained in a previous study[2] of two subjects in each of the three age groups. Included in Table XXXIII are the response frequencies of the three age groups from both studies to simulated sonic booms of 0.63, 1.25, and 2.50 psf and subsonic jet flyover noises of 101, 107, and 113 PNdB ordered in terms of apparent sensitivity. It can be seen that among the children the response rates to the stimuli are very similar. The middle-aged subjects of the first study showed responses between that of the low and high sensitivity subgroups, but obviously are more similar to the low sensitivity subgroup than to the subgroup of high sensitivity. The previous group of old subjects appears to have been more sensitive to the stimuli than was the old subgroup of high sensitivity in the present study.

K. Frequency of Behavioral Awakening of Subjects in Four Age Groups--Compilation of Results from This Study and Refs. 1 and 2

An increased frequency of behavioral awakening to simulated sonic booms and subsonic jet aircraft noise of increasing intensity was found in the three older age groups. As will be seen in Table XXXIV, the

Table XXXIII

RESPONSE FREQUENCIES OF SIX SUBJECTS IN EACH OF THREE

AGE GROUPS TO SIMULATED SONIC BOOMS AND SUBSONIC JET FLYOVER NOISES

Age Group	Age (years)	Source of Data, i.e, Study	Relative Sensitivity	Frequency (N) and Percent	Response		
					0	1 & 2	3
Young	5, 5, 6, 8	Present		N	481	95	2
				Percent	83.2	16.5	0.3
	7 and 8	Previous		N	371	58	2
				Percent	86.0	13.5	0.5
Middle-Aged	45 and 53	Present	Low	N	302	85	9
				Percent	76.2	21.5	2.3
	41 and 54	Previous	Low	N	262	111	19
				Percent	66.8	28.4	4.8
	45 and 57	Present	High	N	199	76	124
				Percent	49.9	19.0	31.1
Old	70, 74, and 75	Present	Low	N	256	150	64
				Percent	54.5	31.9	13.6
	69	Present	High	N	65	39	51
				Percent	41.9	25.2	32.9
	69 and 72	Previous	High	N	50	43	131
				Percent	22.3	19.2	58.5

Table XXXIV

PERCENT AWAKE RESPONSES OF FOUR AGE GROUPS TO SIMULATED SONIC BOOM AND SUBSONIC JET AIRCRAFT NOISE AT SEVERAL INTENSITIES

Stimulus Intensity	Age Range			
	5-8 Years	21-22 Years	41-57 Years	69-75 years
Boom Intensity*				
0.63-0.65 psf	0/144 = 0†	2/144 = 1.4%	11/175 = 6.3%	77/188 = 41.0%
1.25 psf	1/181 = 0.6%		21/205 = 10.2%	29/134 = 21.6%
1.9-2.5 psf	0/180 = 0	6/120 = 5.0%	38/224 = 17.0%	28/118 = 23.7%
5.0 psf	0/78 = 0		35/91 = 38.5%	44/100 = 44.0%
Flyover Intensity*				
93 PNdB		0/24 = 0		
101 & 103 PNdB	1/148 = 0.7%	8/24 = 33%	9/190 = 4.7%	44/194 = 22.7%
107 PNdB	1/178 = 0.6%		30/195 = 15.4%	29/108 = 26.9%
113 PNdB	7/187 = 3.9%	22/24 = 91.7%	43/208 = 20.7%	39/117 = 33.3%
119 PNdB	0/70 = 0		36/125 = 28.8%	41/88 = 46.6%

*As if measured outdoors.

†(Number of awake responses/total number of stimuli at the indicated intensity) X 100 = percent.

children appeared to be uniformly unresponsive to either stimulus regardless of intensity. In addition, the old subjects were awakened much more frequently by the simulated booms of 0.63 psf than to booms of 1.25 and 2.5 psf. This discrepancy is due largely to the very high awakening rate of the pair of old subjects of the first study[2] to booms of 0.63 psf. They were awakened by 63 percent of the booms of 0.63 psf, while the four old men of this study were awakened by only 12 percent (averaged over subjects of low and high sensitivity) of the 0.63 psf booms.

At a given intensity, however, the frequency of awakening is positively correlated with age. The responses of the college-age subjects[1] to subsonic jet flyover noise clearly are an exception to the rule, since their frequency of awakening to even low intensity flyover noise is higher than might be predicted on the basis of their chronological age.

V DISCUSSION

In general, the results obtained in the most recent study fit reasonably well with those obtained previously. However, one difference has been found that possibly requires examination and explanation.

In the earlier study there appeared to be no differences in response frequencies or, more importantly, frequency of awakening to booms of different intensities, although such an effect was found for flyover noise. In the more recent study an intensity effect was noted for both simulated sonic booms and flyover noise. While it is possible that during sleep stimuli with durations as short as those of booms (about 300 ms) are indistinguishable with respect to intensity, it is more reasonable, we believe, to attribute the apparent lack of an intensity effect in the preceding study to sampling errors or procedural differences between the two studies.

Throughout the nights of the earlier study the intensity of each of the stimuli was repeated at the same level, with the level changing from night-to-night, whereas in the present study the intensity of the stimuli was varied within each test night. It could be theorized that stimuli repeated at a single intensity throughout the night acquire a different "meaning"[8,10] and, hence, are responded to less than when the level is varied. However, the facts that the effects of variations in intensity of the subsonic aircraft noise were similar in the two studies, and that awakening occurred somewhat more frequently in the first study than in the second, regardless of the type of stimulus, suggest that such theorizing is not warranted on the basis of present data.

VI CONCLUSIONS

1. The sleep of children (5 to 8 years of age) tends to be essentially unaffected by either simulated sonic booms or subsonic jet flyover noise over a wide range of intensities (from 0.63 to 5.0 psf for sonic booms, as measured outdoors, and 101 to 119 PNdB for flyover noise, as measured outdoors).

2. On the average, middle-aged men, about 50 years of age, in a "typical" house are awakened by about 18 percent of the simulated sonic booms ranging in intensity from 0.63 to 5.0 psf, and to an equal extent by subsonic jet flyover noises ranging in intensity from 101 to 119 PNdB.

3. On the average, old men, about 72 years of age, in a "typical" house are awakened by about 32 percent of booms ranging from 0.63 to 5.0 psf in intensity, and to about the same extent by subsonic jet flyover noises of 101 to 119 PNdB.

4. Within both the middle-aged and the old groups there appear to be at least two identifiable subgroups of different sensitivity to noise during sleep. For the middle-aged group the so-called high sensitivity subgroup is about ten times more likely to be awakened by simulated booms or flyover noise then is the subgroup of low sensitivity. In contrast, the old subgroup of high sensitivity is only about twice as likely to be awakened by the stimuli as is the old subgroup of low sensitivity.

5. On the average, for middle-aged and old groups, sonic booms of 2.0 psf are as awakening as subsonic jet flyover noises of about 110

PNdB (both sounds as if measured outdoors). (These data are in agreement with those of Kryter et al.[11] and Broadbent and Robinson[12] with respect to the awake subject, and to those reported earlier for the sleeping human.[2]) In addition, for any increase or decrease of about 6 PNdB in flyover noise the change in rate of awakening is approximately the same as doubling or halving the intensity of the sonic boom.

Appendix A

FIRST QUESTIONNAIRE

NAME ______________________________ DATE __________

1. How many hours of sleep do you normally get? ________

2. How do you generally awaken?

   Fully rested ________

   Partially rested ________

   Tired ________

   Very tired ________

   Rested, but groggy ________

   Other (describe) ________

3. If there were no noises do you think the room in which you have been sleeping would be conducive to restful sleep? (yes, no, explain)

   ____

   ____

   ____

4. How do you feel this morning?

   Fully rested ________

   Partially rested ________

   Tired ________

   Very tired ________

5. How many times did each of the following noises awaken you?

   Noise in laboratory ________

   Jet aircraft ________

   Booms ________

6. Which noise do you think was the most disturbing?

   Jet aircraft ________

   Booms ________

   Noise in laboratory ________

7. Do you feel as if you had:

A full night's sleep ________

6 hours of sleep ________

4 hours of sleep ________

2 hours of sleep ________

Been awake all night ________

8. Do you think you have become used to the noises so that they disturb your sleep less than previously? (Yes, No) _______. Assuming the noises are equally loud, which do you think is easiest to get used to?

Noise in the laboratory ________

Booms ________

Jet aircraft ________

9. Which do you think is hardest to get used to?

Noise in the laboratory ________

Booms ________

Jet aircraft ________

10. Think back to the first couple of nights during which you heard those noises. As you remember it, which did you find <u>most</u> disturbing?

Noise in the laboratory ________

Booms ________

Jet aircraft ________

11. Did you think <u>at that time</u> that you would get used to the noise? (Yes, No) ________.

Appendix B

SECOND QUESTIONNAIRE

In addition to the effects of noise on your sleep patterns, we are interested in how you feel the day after you slept in the laboratory. Please answer the following questions. Please circle the number that best describes your opinion.

(1) Recall the first several nights you slept in the laboratory in which no noises were presented - do you feel that on the average

1	2	3	4
You slept much better than at home	You slept as well as at home	You slept poorly	You slept very poorly

(2) About noon the day after those nights, did you feel

1	2	3	4
More rested than I usually do at that hour	As well as I usually do at that hour	Little more tired than I usually do	Much more tired than I usually do at that hour

(3) Think back to the last night in which you slept in the laboratory

What was the day______________________, and date _______________?

(4) When you awoke did you feel

1	2	3	4
You slept much better than at home	You slept as well as at home	You slept poorly	You slept very poorly

(5) About noon the next day did you feel

1	2	3	4
More rested than I usually do at that time	As well as you usually do at that hour	A little more tired than I usually do	Much more tired than I usually do at that hour

(6) On that day when you were doing your usual daily tasks (for example, working around the house or at your job) did you feel as if you were

1	2	3	4
Performing better than usual	Performing as well as usual	Performing poorly compared to usual	Performing very poorly compared to usual

(7) Can you describe, in your own words, what happened or tell of an incident which indicated better or poorer performance?

____

____

____

____

(8) You slept in the laboratory last night. How did you feel when you awoke?

1	2	3	4
Slept better than usual	Slept as well as usual	Slept poorly	Slept very very poorly

(9) While you were performing your usual daily work (gardening, working around the house, or at your usual job) did you

1	2	3	4
Perform better than usual	Perform as well as usual	Perform a little poorly	Perform very poorly

(10) Can you cite an incident illustrating how you performed better or more poorly than usual?

____

____

____

____

(11) How many times do you think you were awakened last night? ______

(12) How many times were you awakened by booms? ______

How many times by aircraft noise? ______

How many times by any other noises? ______

(13) If you heard the noises last night, did they seem louder or quieter early in the morning? ____________________

(14) Throughout the study which noise did you find most disturbing and annoying?

Aircraft noise ________

Sonic booms ________

Or are they equally disturbing? _______

(15) How do the aircraft noises and sonic booms you hear in the laboratory compare with those you usually hear at home while sleeping?

1	2	3	4
Much less disturbing	As disturbing as those at home	A little more disturbing	Much more disturbing than those at home

(16) What nighttime noises do you find disturbing at home?

____

(17) Do you have any additional observations about the effects of the noises on your sleep, physical state, or attitudes?

____

____

____

____

____

____

NAME ______________________________ DATE ________________

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