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16. Abstract

The present study reports the results of a sonic boom field study conducted in Sweden during October 1972. Ten female subjects were tested indoors on each of six days. Two age groups were studied: 20-35 and 50-65 years. Fighter aircraft flying at various heights over the test site produced booms with outdoor overpressures ranging from 60-640 N/m^2. The number of booms extended from 5 to 13 per day. Subjects performed indoors on an arm-hand steadiness task. The results indicated that outdoor overpressures ranging from 70-120 N/m^2 (26-35 N/m^2 indoors) produced reflexive arm-hand movements in about 10 per cent of the subjects. Booms of 300 N/m^2 (67 N/m^2 indoors) and greater produced responses in about 75 per cent of the subjects. Between these extremes of overpressure there was the suggestion of a critical overpressure range lying between 150-180 N/m^2 (40-46 N/m^2 indoors) in which an abrupt increase in startle response occurred. In all aspects of the startle response studied, older subjects were less responsive than the younger ones. There was some evidence of response habituation to low and moderately intense booms, but not to high intensity booms.

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SONIC BOOM STARTLE EFFECTS — REPORT OF A FIELD STUDY

I. Introduction.

Although a number of studies have been conducted to investigate the extent of performance disruption resulting from sonic boom exposure, the results, unfortunately, have been somewhat inconclusive and exact dose-response relationships are still lacking. As noted elsewhere,[9] exposure to real or simulated sonic booms has been reported to produce results ranging from performance impairment,[4 8 11] to generally non-significant effects,[3] to an actual improvement in performance.[10] With the exception of the study by Rylander et al.,[8] all the other studies employed simulated or recorded sonic booms. Since few simulators are capable of faithfully producing sonic boom signatures within the range of rise times and overpressures likely to be generated by SST-type aircraft, some of the discrepancies between the results of these studies may be due to qualitative as well as quantitative differences in the types of booms produced. It is believed, for example, that the rise time of sonic booms is a major determinant of the startle response. May[5] found that subjective ratings of startle magnitude to actual sonic booms increased rapidly with rise times of 3 msecs or less. Of the above-mentioned studies using simulated booms, all employed booms having rise times greater than this value. (Rise times reported ranged from approximately 7 to 21 msecs.) Since the rise times of booms produced by actual aircraft are frequently less than 3 msecs, there is some question as to whether laboratory studies using representative overpressure levels, but failing to demonstrate significant startle effects, are employing boom signatures which accurately reflect those likely to be encountered under actual field conditions.

In an effort to study exposure effects under more realistic conditions, a field experiment was conducted during October 1972 on the island of Gotland located approximately 100 kilometers off the southeast coast of Sweden. The essential purpose of this study was to obtain information on sonic boom exposure which would be difficult, if not virtually impossible, to obtain with most existing simulation facilities. The study, which was initiated by the Swedish Department of Environmental Hygiene, represented the joint efforts of investigators from various institutes evaluating different aspects (involuntary motor responses, physiological reactions, animal responses, structural changes in buildings, community reactions, etc.) of sonic boom exposure. Only those data relating to human startle responses (as reflected in performance on an arm-hand steadiness task) will be reported here.

One of the primary goals of the startle tests was to determine more precisely the dose-response relationships between sonic booms and the magnitude and frequency of startle reactions. It was hoped that threshold levels could be established below which sonic booms would not be expected to produce startle or other measurable responses. A second aspect was to study the startle reactions of subjects differing widely in age. On the basis of animal research showing diminished startle response with increasing age,[1] it was expected that older subjects (50 to 65 years) would show less startle response to the booms than younger (20 to 35 years) subjects. A final aspect was to study habituation effects to sonic booms and to determine whether these effects differed as a function of boom level.

II. Method.

A. *Subjects.* Subjects consisted of 60 paid, female volunteers recruited from surrounding communities. Two age groups were employed: 20–35 and 50–65 with five *S*s from each group tested each day. There were a few subjects whose ages slightly exceeded these limits, and each was placed in the most appropriate age group.

All subjects received a brief audiometric examination at the test site. Because of background noise, only hearing losses exceeding 20 dB at 500, 2000, and 6000 Hz could be measured reliably. Table 1 shows the number of subjects in each age group having a hearing loss in both ears which exceeds 20 dB.

TABLE 1. Subjects Showing Hearing Loss in Both Ears Exceeding 20 dB.

Frequency (Hz)	*Old*	*Young*
500	4	2
2,000	0	0
6,000	3	0
500 + 2,000	0	0
2,000 + 6,000	1	0
500 + 2,000 + 6,000	3	2
500 + 6,000	4	0
Total with hearing loss	15	4

B. *Apparatus.* The task apparatus provided each subject consisted of an electro-mechanical device for measuring arm-hand steadiness. The tip of a small rod was aimed at the center of a 5 mm circle, and it was the subject's task to try to keep it in that position during each test run. The base of the rod was attached to three potentiometers by means of a gimbal and this, in turn, was mounted on an 18 x 12 x 7 cm plastic instrument case. The three potentiometers allowed recording left-right, toward-away, and up-down movements. Preliminary data, however, indicated that the amplitudes of the up-down and toward-away responses to a startle stimulus were virtually identical. Consequently, only the left-right and toward-away movements were actually recorded for each subject. Figure 1 shows a photograph of the steadiness device.

Outputs from each of the steadiness testers were led to two 16-channel Elma-Schonander Mingograf Model 1600 chart recorders. The re-

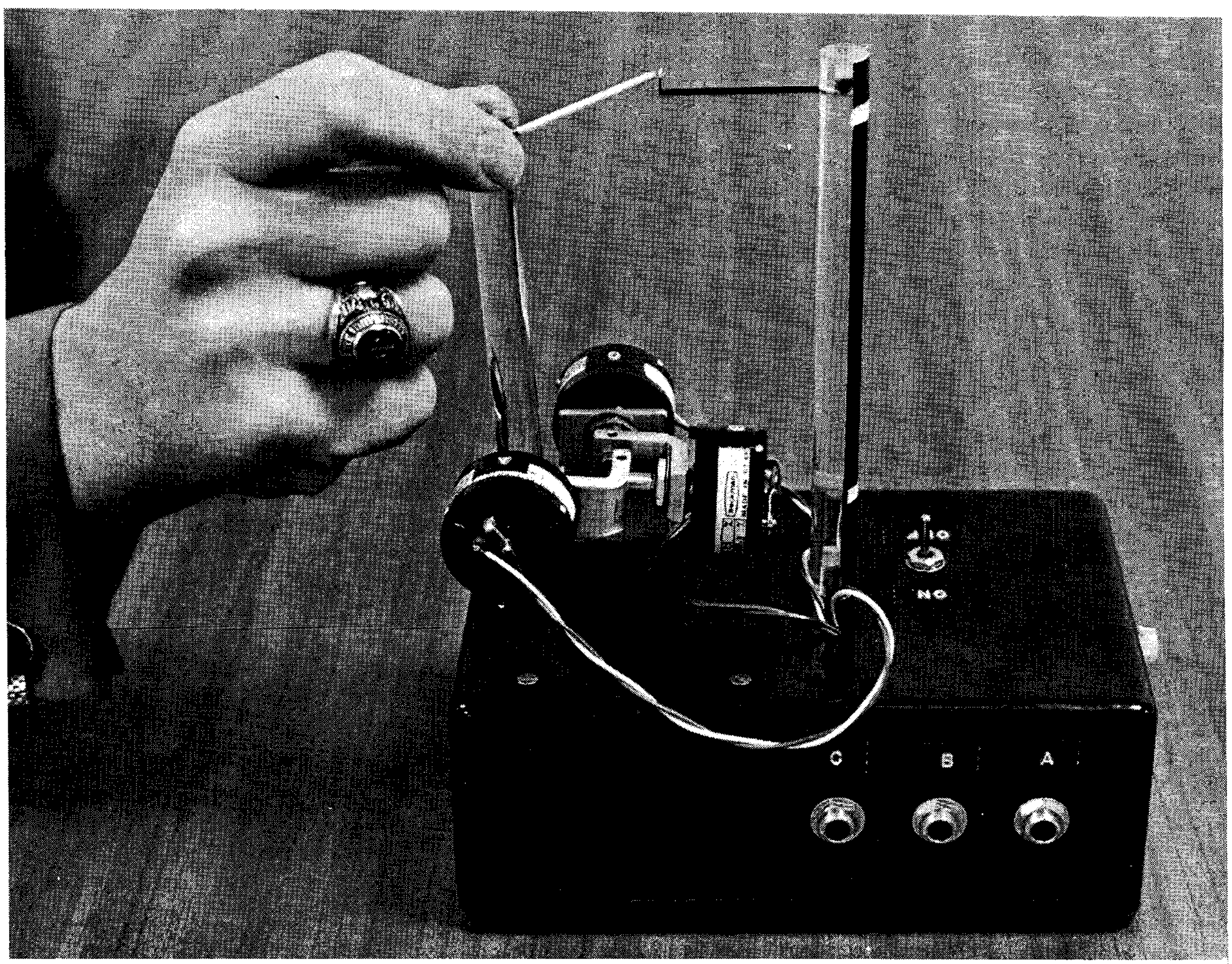

FIGURE 1. One of the steadiness testers with pointer held in correct position.

corders were calibrated to yield 1 mm of pen deflection for 1 mm of hand movement in either plane. Paper speed was 25 mm/sec.

Startle responses to the sonic booms were also recorded on film by means of Fairchild Type KKA4 16 mm cameras. The cameras operated at 64 frames/sec. (A report of the film data will be published at a later date.)

C. *Test Building.* The test building was a converted summer restaurant situated 200 meters from the sea and 15 meters above sea level. The building was one story in height, of frame construction, and approximately six meters wide by 42 meters long. All walls contained windows which were specially designed to withstand the high winds often present in the area. The test building is shown in Figure 2.

The subjects' test room was approximately six meters square and located at one end of the building. None of the test equipment, with the exception of the cameras and the subjects' steadiness testers, was physically located in the test room. Subjects were located behind two diagonally placed stands in such a way that each row of subjects faced one of the two banks of cameras. The steadiness testers were located on top of the stands, and each stand was constructed in such a manner that it could be separately adjusted to the heights of the subjects. Background noise level in the test room was 72 dB(A) with cameras operating and 52 dB(A) without camera noise present. Figure 3 shows a view of the subjects standing in position behind the steadiness testers.

D. *Physical Measurements.* Noise levels of the booms and subsonic flights were obtained from several microphones (sensitivity 0.01 Hz−10 KHz) located both inside and outside the test building. An instrumentation tape recorder

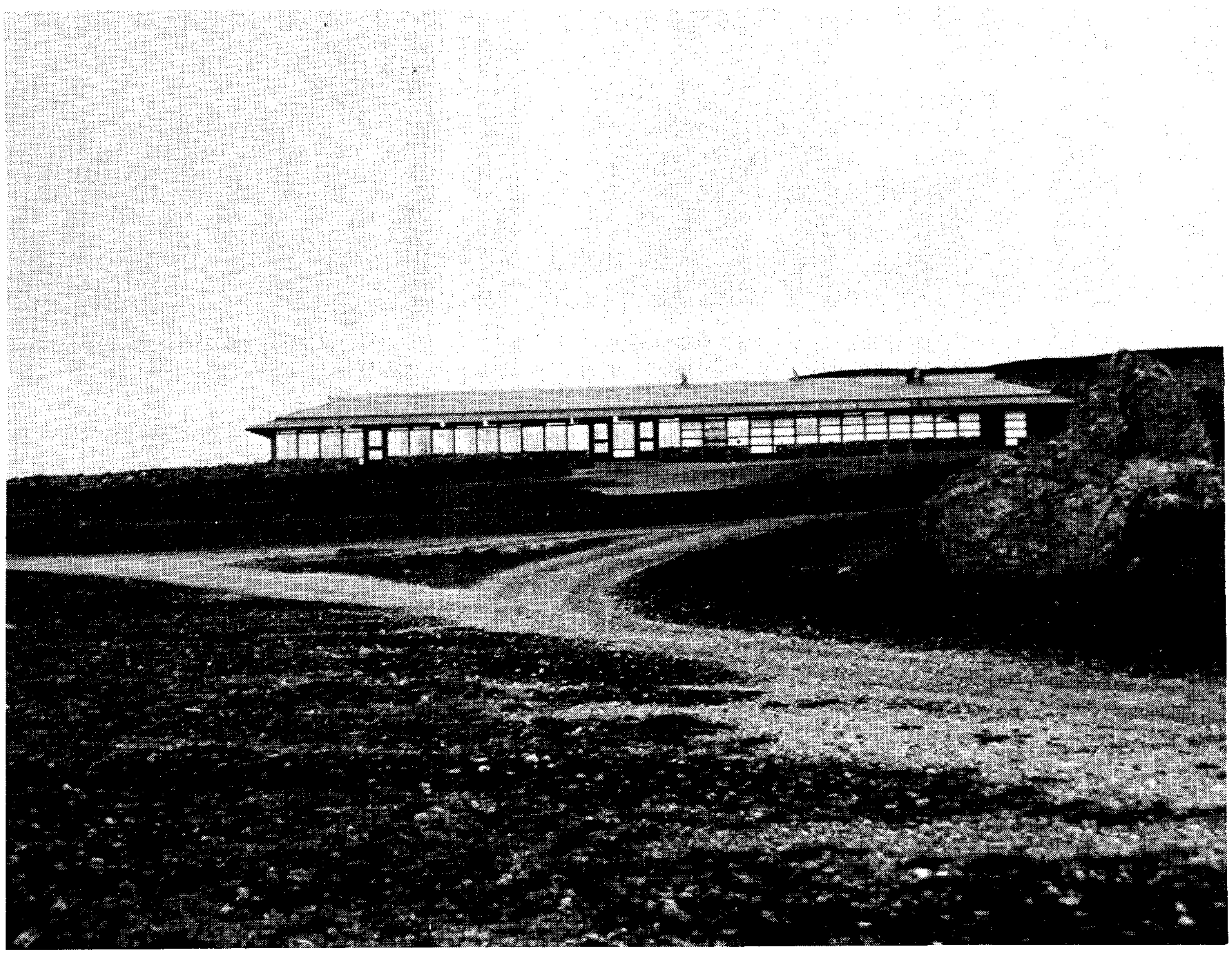

FIGURE 2. View of the test building.

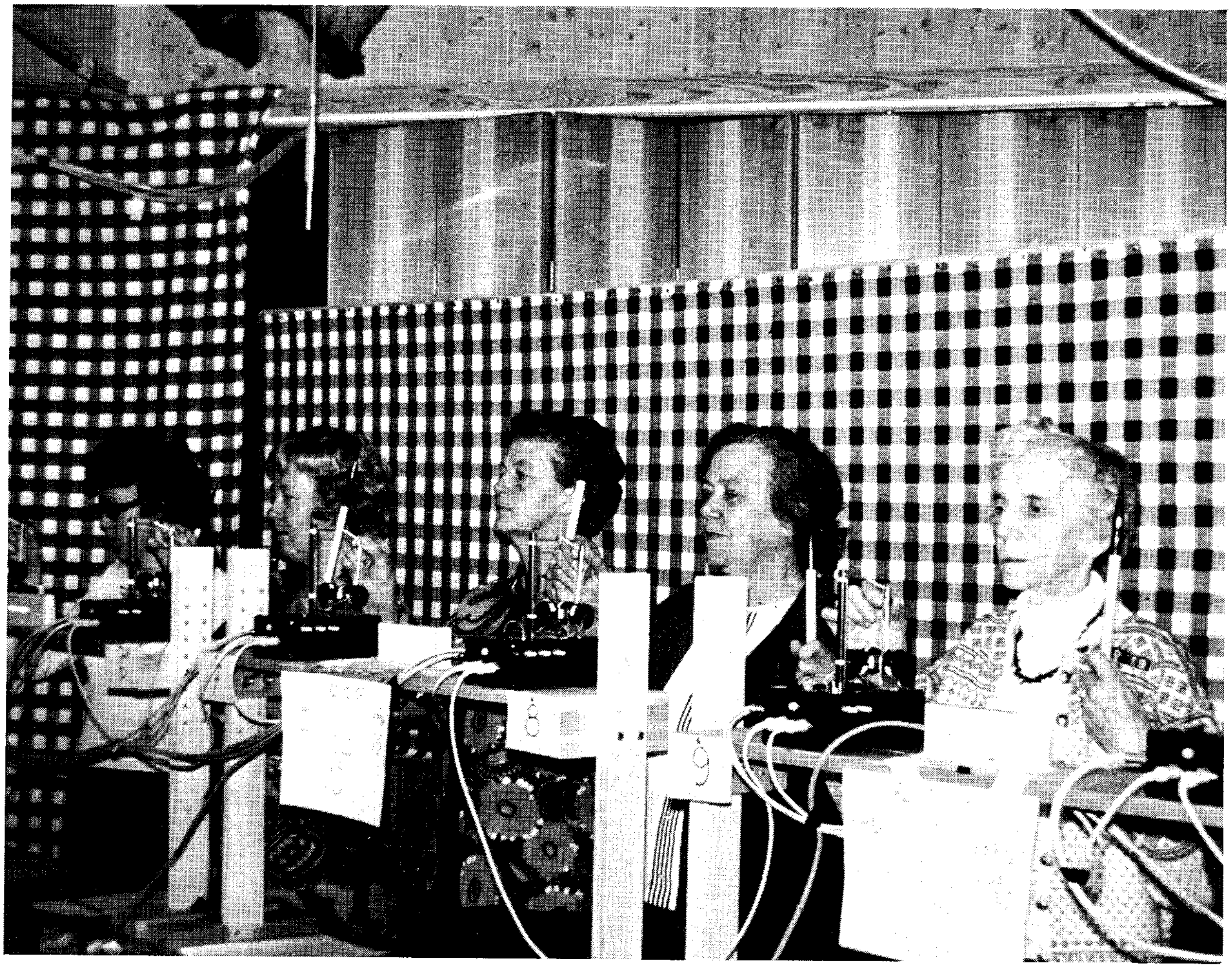

FIGURE 3. Five of the test subjects in the positions they assumed prior to a test run. The wooden pointers held in their left hands were used as aids in photographing arm movements during boom exposures.

using frequency modulation allowed recordings of frequencies from DC to 2.5 KHz. A microphone in the subjects' test room led to one of the channels of each Elma-Schonander recorder to record noise onset. Measurements of the sonic booms included outdoor overpressure, rise time, and duration as well as indoor overpressure. Subsonic measurements included indoor and outdoor dB (lin) and dB(A) levels. These data for each supersonic and subsonic flight are given in Appendix I.

E. *Flight Program and Experimental Design.* The test site was overflown at various altitudes by SAAB J35 Draken aircraft from fighter wings located on the mainland. The original flight program called for five supersonic and five subsonic overflights on each of four successive days. By varying altitude of the supersonic

TABLE 2. Basic Flight Plan for Days One to Four and Expected Outside Overpressures (in N/m^2).

	Flight Number				
Day	*1*	*2*	*3*	*4*	*5*
1	50	100	150	200	50
2	100	150	200	50	100
3	150	200	50	100	150
4	200	50	100	150	200

flights from 6500 to 2000 meters, it was hoped that approximate overpressures of 50, 100, 150, and 200 N/m^2* could be achieved on the first and fifth flight of each day, with these same overpressures programmed in a partially counterbalanced fashion for flights two through four. Table 2 shows the original flight program and expected outside overpressure levels.

* 47.880258 Newtons (N)/m^2=1.0 psf.

It was expected that this program would allow determination of habituation effects by comparing flight one with flight five on each day. In addition, it would allow determination of dose-response relationships, relatively independent of habituation effects, by combining similar overpressure levels across days. However, as can be seen in Table 3, the actual overpressures differed markedly in some instances from the expected levels. This made precise determinations of habituation effects more difficult than was expected.

TABLE 3. Actual Outside Overpressures (in N/m^2) for Days One to Four.

	Flight Number				
Day	*1*	*2*	*3*	*4*	*5*
1	70	130	170	250	105
2	110	160	330	120	130
3	180	370	60	250	80
4	240	100	140	250	290

In addition to the basic flight program, four additional supersonic flights were added to days three and four with overpressures ranging from 130 to 420 N/m^2. Half of these were with cameras operating and half without in order to investigate the possible effect of the background noise level made by the cameras on startle responses. On the basis of a superficial examination of the response data obtained during these flights, it appeared that startle responses might be occurring more frequently without the camera noise present. Consequently, day five consisted of six overflights without cameras and with boom levels ranging from 60 to 340 N/m^2. On the last test day (day six), 13 overflights were made with overpressures randomly distributed across flights and ranging from 70 to 640 N/m^2. Subjects used on this day had all been employed on previous days, and the essential intent of this last day of tests was to provide further information on habituation effects as well as to provide more data on dose-response relationships to booms covering a wide range of overpressures.

As noted, it was also intended to study response to subsonic flights of varying noise levels, with these flights inserted among the supersonic flights. However, subsonic overflights were discontinued after the first two days since, with the exception of one flight, no apparent startle responses occurred. Appendix I shows the time of occurrence and noise level for each of the subsonic flights.

In addition to the actual exposure tests, control tests under identical experimental conditions were introduced at random times to control for expectancy effects. Following the last flight of each day, a 22 caliber starter pistol was fired in order to provide a reference response to a known startling stimulus. Noise level of the gun at the subjects' location was 107 dB(lin).

On days three, four, and five, reaction times to a series of four 1000 Hz, 70 dB(A) tones were obtained. The required response was a movement of the pointers of the steadiness testers away from the center position as rapidly as possible as soon as each tone was heard. It was felt desirable to obtain a measure of reaction time for comparison with response latencies to both the sonic booms and the pistol shot.

F. *General Experimental Procedure.* Following initial instructions, the subjects assumed their positions behind the stands and the stands were adjusted for height. They were told that they could remain seated in chairs located behind the stands until informed that a test was to begin. At that time they were to stand up, grasp the top of the shaft holding the pointer with the thumb and index fingers of their right hand, and attempt to keep it aimed at the small circle until told that the test was completed.

The exact timing of the boom exposure was obtained via direct radio contact with the pilot. In addition, a fisherman who was stationed 10 km from the test site directly along the flight path radioed to the test building when he experienced the boom. Warning lights, invisible to the subjects, signaled to the experimenter when to start the cameras and chart recorders. The cameras and recording equipment were started approximately 20 secs before the expected time of boom arrival and continued until after the boom had occurred. Although this noise served as a definite cue to the subjects that a boom might shortly occur, uncertainty was still present since the subjects never knew whether a given test was a control run or an actual boom, and the exact timing of the boom's occurrence was sufficiently difficult that the boom never occurred exactly 20 secs after the equipment was turned on. Thirty secs after boom exposure (or after the time a boom would be expected to occur in the case of a control run) the subjects were told that they could be seated until the next test occurred.

As noted earlier, the last test of each day was the pistol shot exposure. The experimental procedure employed was identical to that of the other tests, and subjects had no prior knowledge that the last test would be anything other than a boom or control test. The series of reaction time trials was included during the day when a sufficient time period between booms was available.

G. *Scoring and Measurement of Performance Data.* The basic criteria for deciding whether a response to a sonic boom was an involuntary, reflexive startle response or whether it could be more appropriately considered a voluntary or "reaction-time" response were obtained from the response latencies to the pistol shot. Mean latency of response to this stimulus was 180 msecs with a standard deviation of 64 msecs and a range of 100 to 400 msecs. Although information in the literature regarding latency of the arm-hand response to startle is rather sparse, Landis and Hunt[2] gave a latency range of 125 to 195 msecs for the arm-hand response to a pistol shot. This range would include approximately 76 per cent of the latencies obtained to the pistol shot in the present study.

Examination of the latencies to the shot revealed that most of the longer latencies were associated with the older subjects, and a statistical comparison of the mean latencies of the young ($\bar{X}$=150 msecs) and old ($\bar{X}$=212 msecs) subjects was significant ($t=3.54$; $p<.01$). While the longer latencies of some of the older subjects might suggest that a reflexive startle response was not evoked in these subjects, it could also mean that startle responses in older subjects have generally longer latencies. As noted in the introduction, Birren[1] found startle latencies of older rats to be considerably longer (up to 100 per cent longer) than those of the younger animals.

There was no apparent way to be absolutely certain on the basis of the latency data alone that any given response to the shot, regardless of its latency, always represented a startle reaction. However, since there was little overlap between the distribution of reaction times to the 1000 Hz tone ($\bar{X}$=313 msecs; SD=62.6 msecs) and the distribution of latencies to the pistol shot, and in view of the likely possibility that older individuals have lengthened startle latencies, it was decided that there was no justifiable reason for not including the entire range of latencies to the pistol shot in establishing latency criteria for startle response to the booms. Thus, any boom response falling within the range of 80 to 420 msecs was considered to be a reflex response. It should be emphasized that the authors are fully aware that in adopting this latency range a certain small percentage of responses would probably be classified as startle reactions that might be more appropriately considered voluntary or orienting responses to the booms.

In addition to the latency criteria, a response was not counted if its amplitude did not exceed the maximum peak-to-peak amplitude of hand tremor in the two-sec period prior to the boom. Finally, a subject's reaction was not scored as a startle response if the latency and amplitude requirements were not met in both the left-right and the toward-away planes of movement. This last requirement was felt necessary since the natural pattern of arm-hand startle response involves movement in both the above planes, and this was invariably the response pattern to the pistol shot. If a given subject's response met all these requirements, the left-right and toward-away amplitudes were averaged together to yield a single amplitude measure.

H. *Measure of Boom Intensity.* Preliminary analyses of the startle response data indicated that the clearest relationships appeared to be obtained using outside, rather than inside, overpressure levels. Also, since this is the most generally used measure of boom intensity, it was felt that the obtained relationships would be most readily related to other sonic boom data if the results were expressed in terms of this measure. No attempt was made to categorize booms with respect to rise time. Although rise time is believed to be a significant variable influencing both the loudness and startle effects of sonic booms,[6 7 9 10] the distribution of rise times associated with the booms in the present study was considered too leptokurtic ($\bar{X}$=2.51 msecs; SD=2.34 msecs), and the number of booms having the same overpressure but differing in rise time too few, to warrant the inclusion of rise ime as a variable in determining dose-response relationships.

III. Results.

A. *Dose-Response Relationships.* Functional relationships between the magnitude or extent of startle response and boom intensity were determined primarily from the response data obtained during the first five boom exposures of the first four test days. (It will be recalled that on some of these days more than five booms were presented.) Of the various ways in which these data may be examined, the only dose-response comparison completely free of possible habituation effects is the comparison of the response to the first boom occurring on each of the four days. These data are shown in Figures 4 and 5 for per cent response and mean amplitude of response respectively. The most significant aspect of these two figures is the relative lack of response to booms of approximately 100 N/m² and below with a rather abrupt increase occurring to the 180 N/m² boom. The 240 N/m² boom shows a further increase in per cent response, but not in response amplitude.

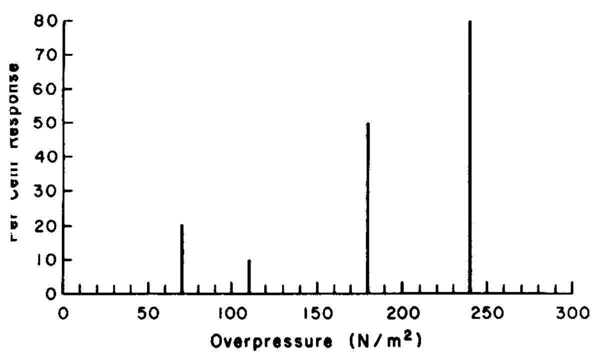

FIGURE 4. Overpressures of the first booms occurring on days one through four and percentage of subjects showing a startle response to each.

A second method of exploring dose-response relationships involved combining comparable overpressure levels across days. Thus, the first five booms for each day were ranked from one to five according to overpressure, and the data for each level separately averaged across days. Referring back to Table 3, the lowest level booms for days one through four occurred on flights one, one, three, and two for the first four days respectively. The data for these four flights were

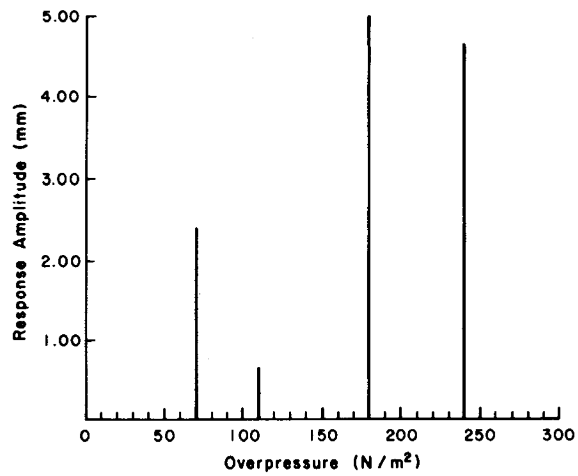

FIGURE 5. Overpressures of the first booms occurring on days one through four and mean amplitudes of movement to each.

averaged together and constituted the data for the lowest level booms to occur across all four days. Data for the other levels were obtained in a similar manner. Although there was some overlap between levels, this was generally rather minimal, and there was no way that this could be avoided if legitimate statistical comparisons were to be made. Per cent response and mean response amplitude for the five levels (as well as the pistol shot) are shown in Figures 6 and 7 respectively. Although these data are not as free of possible habituation or other progressive effects as are the data shown in Figures 4 and 5, nevertheless, the correspondence between the sets

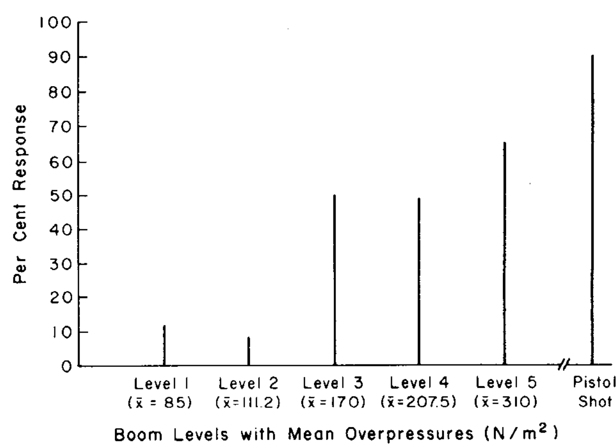

FIGURE 6. Averages across days one through four of the lowest to highest boom levels within each day and total percentage of subjects showing a startle response to each level. Also shown is the total percentage response to the pistol shot.

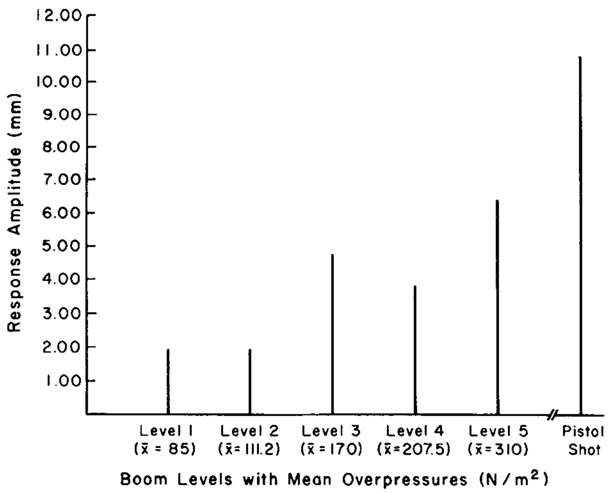

FIGURE 7. Averages across days one through four of the lowest to highest boom levels within each day and mean response amplitudes of subjects showing a startle response.

of data is rather striking. In both Figures 4 and 6, there is an abrupt increase in per cent response to booms of approximately 170–180 N/m². A similar relationship is apparent with the amplitude data shown in Figures 5 and 7. A comparison of the data of all four figures would suggest the existence of some critical overpressure level in the vicinity of 170 N/m² in which a noticeable increase in startle response occurs relative to the minimal response occurring to booms of about 100 N/m² or less.

In order to evaluate the apparent relationship between response amplitude and overpressure, statistical comparisons were made of differences between certain of the levels shown in Figure 7. The first comparison involved identifying those subjects who responded to either or both of the two highest levels and to either or both of the two lowest levels to which they were exposed on their particular days. Mean response amplitudes were obtained to the lowest and two highest levels for each subject and differences tested for significance by means of a t test for repeated observations. The obtained value was significant (t=2.67; p<.05). A similar approach was used to compare mean response amplitude of the level three booms with mean amplitude of the level five booms. Although the data presented in Figure 7 suggest a difference between these two levels, the t test was non-significant (t=1.17; p>.05). A final test involved comparing response amplitude to the highest boom level with response amplitude to the pistol shot. Since mean response amplitude to the pistol shot was almost twice the amplitude of response to the level five booms, it is not too surprising that this comparison was significant (t=3.97; p<.01).

B. *Dose-Response Relationships Without Background Camera Noise.* Although filming response to the sonic booms was a major aspect of the study, several additional boom tests with and without cameras and run at the conclusion of the major tests on days three and four suggested that the noise of the cameras (approximately 72 dB(A)) tended to mask the sonic booms and reduce the startle response. Consequently, subjects were exposed to six sonic booms on the fifth day of tests without cameras operating. Per cent response and response magnitude to the booms presented on this day are shown in Figures 8 and 9 respectively. A comparison of Figures 8

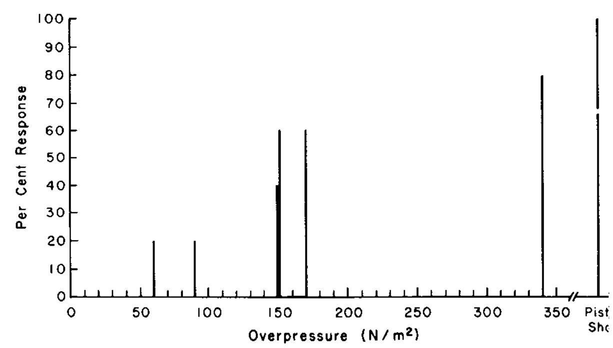

FIGURE 8. Per cent startle response to the booms an pistol shot occurring on day five with camera nois absent.

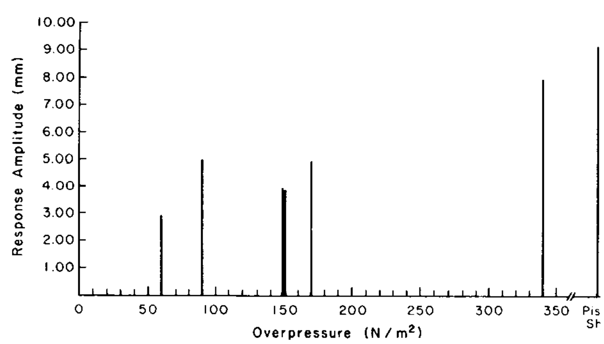

FIGURE 9. Mean amplitudes of response to the boor and pistol shot occurring on day five with came noise absent.

and 9 with Figures 4, 5, 6, and 7 reveals that th general pattern of the data obtained without th cameras quite closely parallels the data obtaine with camera noise present. This degree of correspondence is somewhat surprising in view of the fact that it was not possible to present the boom levels on day five in any form of counterbalanced fashion in order to control for progressive exposure effects. Both per cent response and response amplitude are generally higher without cameras than with (compare Figures 8 and 9 with Figures 6 and 7), although the absolute magnitudes of the differences are not large. It is interesting to note in Figure 8 that the abrupt increase in per cent response occurred at about the same overpressure level (150–160 N/m^2) as was found with camera noise present as shown in Figures 4 and 6.

C. *Age Effects.* The data obtained for the first five booms of days one to four were examined for possible age effects. In order to determine whether older subjects differed from the younger in terms of frequency of response to the booms, each subject was initially classified according to whether she showed a startle response to zero to one, two to three, or four to five of the booms to which each was exposed. The resulting frequencies are shown in Table 4. Since previous research had suggested that the startle response diminished with age, the chi square test conducted on the data in Table 4 was evaluated against one-tailed probability values. The obtained chi square of 5.37 was significant ($p<.05$; one-tailed), indicating fewer startle responses in the older subjects. A comparison of response frequency to the pistol shot was also significant (chi square=4.73; $p<.05$; one-tailed) with the older subjects being less responsive.

TABLE 4. Boom Response as a Function of Age With Subjects Classified According to Whether They Responded to Zero to One, Two to Three, or Four to Five of the Booms to Which They Were Exposed. Data Are For Days One to Four Only.

Age Group	*Number of Booms to Which Each Group Responded*		
	0–1	*2–3*	*4–5*
Young	7	9	4
Old	11	9	0

Chi square=5.37 $p<.05$ (one-tailed)

The two age groups were compared with respect to magnitude of response by obtaining each subject's mean response amplitude across the five booms. Mean amplitudes were 5.64 mm and 2.90 mm for the young and old groups respectively. A t test for independent groups yielded a significant t-value of 2.24 ($p<.05$; one-tailed).

As discussed earlier, the two age groups also differed significantly in their latencies to the pistol shot. In addition, there was a significant difference between the mean response latency to the booms of the young (X=206 msecs) and old (X=241 msecs) subjects. The obtained t was 2.68 ($p<.01$; one-tailed).

D. *Habituation Effects.* Habituation to the booms was assessed by examining the response data obtained from flights one and five on days one through four, and also by examining the data of the sixth test day in which subjects who had participated in one of the previous test days were again exposed to a series of booms.

Table 5 gives the percentages of subjects showing measurable startle responses to the first and fifth boom occurring on the first four days of tests. Although a comparison of flight one with flight five shows a decrease in mean per cent response, it is difficult to evaluate the meaning of this decrease since actual overpressures on the first and fifth flight of each day were not comparable. By referring back to Table 3, it can be seen, however, that the booms on flights one and five of days one and two differed the least in overpressure, and there was no apparent evidence of habituation to these booms. Although the first and last booms on day four differed by 50 N/m^2, with the last being the greater, it is interesting to note that per cent response decreased from 80 per cent to 40 per cent. This is the only evidence of any apparent habituation that may be gained from a comparison of the first and last booms over the four days. Overpressures for the first and last booms on day

TABLE 5. Percentage of Subjects Showing a Measurable Startle Response to the Booms Occurring During Flights One and Five on Days One to Four.

Day	*Flight Number*	
	One	*Five*
1	20	10
2	10	20
3	50	0
4	80	40
Mean Per Cent Response	40	17.5

three differed too greatly to allow any meaningful comparison with respect to habituation.

Table 6 shows mean response amplitudes for flights one and five of those subjects who produced measurable startle responses. Interpretation of these data is difficult for the same reasons given with respect to the data presented in Table 5. There is obviously no evidence of habituation on days one, two, and four. Amplitudes, in fact, show an increase. There is no way of evaluating the possible statistical significance of the increase during days one and two because of the small number of subjects involved. The increase in mean amplitude from boom one to boom five on day four was non-significant ($t=0.33$; $p>.05$), suggesting that the apparent increase during days one and two can probably also be attributed to chance factors.

TABLE 6. Mean Response Amplitude (in mm) of Those Subjects Showing a Measurable Startle Response to the Booms Occurring During Flights One and Five on Days One to Four.

	Flight Number	
Day	*One*	*Five*
1	2.40	5.75
2	0.63	5.10
3	5.00	--*
4	4.65	8.02
Mean Amplitude	3.17	6.29

* No subjects gave a response to the boom occurring on this flight.

A more adequate appraisal of possible habituation effects was gained from an analysis of the data of the subjects tested on day six, all of whom had been exposed to booms on previous days. The 13 booms presented on this day ranged in overpressure from 70 to 640 N/m² with the various levels distributed in a random manner within the series. With the exception of two flights at the end of the series, all boom exposures were without the cameras operating. The two flights with cameras operating were included primarily for comparison with the pistol shot data and the results are not analyzed here.

Figure 10 shows per cent response to each of the 11 booms. It is of interest to compare this figure with Figures 4, 6, and 8. All the data in these figures are in general agreement that booms having outside overpressures of approximately

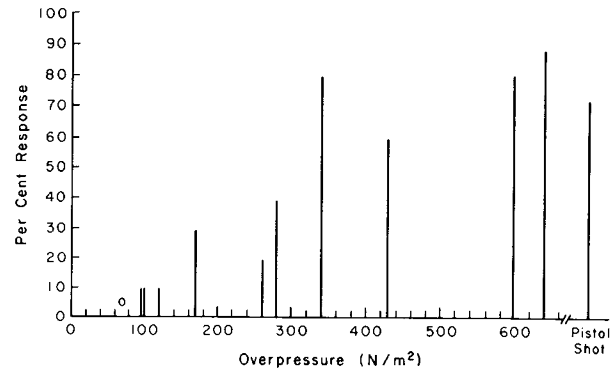

FIGURE 10. Percentage of subjects showing a startl response to the booms occurring on day six.

300 N/m² or greater produced startle response in 60 to 90 per cent of the subjects, with 75 pe cent being the approximate mean value. Previou exposure to sonic booms appeared not to affec the percentage of subjects responding to boom of this magnitude. For low magnitude boom (70 to 120 N/m²), per cent response ranged fron 0 to 20 per cent, with the mean response bein about 10 per cent. Since the lowest per cen response occurred during day six (Figure 10) this suggests a slight habituation effect to th low level booms.

For booms with overpressures between ap proximately 150 to 290 N/m² the percentage o subjects responding varied from 20 to 80 pe cent with these percentages seemingly related t previous exposure. Thus, the percentages show in Figure 10 for this overpressure range exten from 20 to 40 per cent while those shown i Figures 4 and 6 extend from 50 to 80 per cen The largest per cent response (80) within th overpressure range occurred in response to th first boom presented to one of the groups on day one to four, while the lowest percentages wei obtained to the booms presented on day six. I addition, per cent response within this rang extended from 40 to 60 per cent for booms pr sented on day five (Figure 8). Since both day five and six were without camera noise presen there is fairly convincing evidence that habitu tion effects occurred within this overpressu range.

It is interesting that the rather abrupt increa in per cent response noted earlier in Figures 6, and 8 and which appeared to occur with ove pressures of 150–180 N/m² was also seeming present in the data of Figure 10. Although tl increase was less pronounced, it occurred at about the same overpressure (170 N/m^2).

Figure 11 shows the response amplitude data for day six. It would appear from this figure that there is no relationship between response amplitude and overpressure, which is contrary to the results of the combined data for days one to four reported earlier. However, it should again be remembered that some of the data points, especially for the low overpressure levels, are based on the responses of only one or two subjects. One of the subjects on day six was

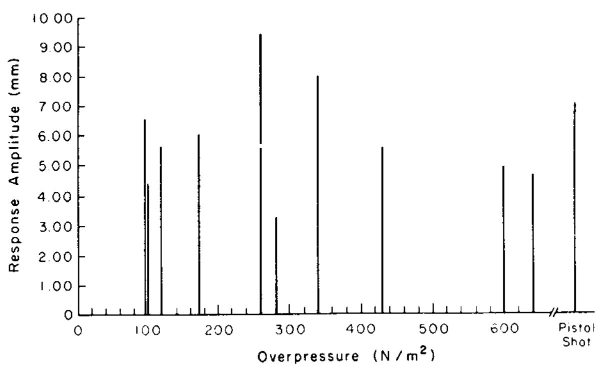

FIGURE 11. Mean amplitudes of response to the booms occurring on day six.

atypical in that she responded to 12 of the 13 booms with large amplitude responses to each. This subject was largely responsible for the apparent lack of relationship between response amplitude and overpressure shown in Figure 11. The fact that the mean response amplitude (6.23 mm) during day six for the seven booms having overpressures of 370 N/m^2 or below (which was the highest level presented during days one to five) exceeded the mean amplitude (3.76) for the combined data of days one to four might in part be attributed to a facilitation effect resulting from the lack of camera noise during day six. If this was the case, however, there was no apparent habituation effect for response amplitude since the day six value exceeded the mean amplitude (4.76 mm) for day five. It will be recalled that camera noise was not present during day five.

E. *Response to Subsonic Flights.* The only apparent startle response to the subsonic flights of days one and two occurred to the last flight of day two. Peak noise level of the flight, as measured outdoors, was 138 dB(A). Since the latency criteria employed for the sonic booms could not be used for subsonic sounds because their more gradual onset made latency measurements impossible, only amplitude data could be obtained. During the two-sec period following the approximate onset of the noise, nine of the ten subjects gave a response that exceeded their pre-stimulus amplitude values. Mean amplitude increase to this subsonic flight was 4.05 mm which closely approximated the mean response to the sonic booms.

F. *Conversion of Outdoor Overpressures to Indoor Overpressures.* Although all data were evaluated with reference to outside overpressure levels, it was felt desirable to provide information which would allow prediction of indoor overpressure from any given outside overpressure. Consequently, the data relating indoor overpressure to outdoor overpressure were plotted and the regression line determined. The data are shown in Figure 12 along with the correlation and regression equation. It is evident from the correlation and shape of the plot that prediction of indoor overpressures can be made with considerable occuracy from a knowledge of the outdoor levels.

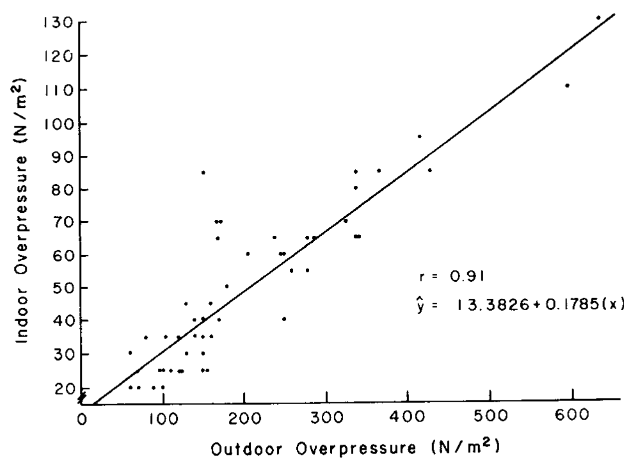

FIGURE 12. Outdoor vs. indoor overpressure levels.

IV. Discussion.

The results of the present study indicated that sonic booms experienced indoors with outdoor overpressures ranging from 70 to 120 N/m^2 (indoor levels of 26 to 35 N/m^2)* produced startle responses in about 10 per cent of the sub-

* All indoor levels given are predicted values.

ject population. On the other hand, sonic booms with outdoor overpressures of approximately 300 N/m^2 (67 N/m^2 indoors) or greater elicited startle reactions in about 75 per cent of the subjects. Although response amplitudes to the lowest intensities were generally less than those to the highest, the range of individual differences in response amplitude across all boom exposures was quite large ($<$1.00 mm to 21.00 mm), and fairly sizable amplitudes were occasionally found even to the lowest intensities. Of the two measures (per cent response and response amplitude), per cent response was the more consistent measure of dose-response relationships. Outdoor overpressures between 150 to 280 N/m^2 (40 to 63 N/m^2 indoors) elicited startle responses in 20 to 80 per cent of the subjects, with the larger percentages occurring among those subjects experiencing booms within this range as their first exposure and the smaller percentages associated with the day six subjects, all of whom had been exposed to booms on previous days. Although this is a rather wide range of overpressure and per cent response, the data across all days were quite consistent in suggesting that within this range there existed some form of "critical" level of overpressure lying between 150 to 180 N/m^2 (40 to 46 N/m^2 indoors) in which a rather abrupt increase in per cent response occurred. Generally, this amounted to an increase of about 30 to 40 percentage points above the minimal response to the 70 to 120 N/m^2 booms.

It is unfortunate that the number of booms having very low overpressures was insufficient to establish accurately a "threshold" level below which startle responses would not be expected to occur. Per cent response to booms having outdoor overpressure levels of 60 to 70 N/m^2 (24 to 26 N/m^2 indoors) ranged from 0 to 20 per cent. The single boom to which no subjects responded occurred on day six. Since these subjects had been exposed to booms previously, this might suggest that booms of perhaps 50 N/m^2 or less might be close to the threshold level for indoor startle effects for a population exposed to frequent booms. However, further research is needed to establish clearly this threshold level.

With respect to age, the results revealed that the older age group responded less frequently to the booms and with lower amplitudes of movement than the young group. In addition, the older group was less responsive to the pistol shot and had longer response latencies to both the pistol shot and the sonic booms. These results support the earlier-mentioned findings concerning startle response in animals as a function of age and suggest a general pattern of declining responsiveness to startle with increasing age which may, at least in part, be attributed to the increased hearing loss with age.

There was some evidence of habituation to sonic boom exposure but, within the range of exposures studied, this appeared to be rather slight. There was a reduction in per cent response to the 70 to 120 N/m^2 booms and to the moderately intense booms (150 to 290 N/m^2) among the subjects on day six, especially with respect to the response during day five. For booms of 300 N/m^2 or greater, however, the overall pattern reflected a rather stable per cent response to the booms regardless of prior exposure. Possibly the number of boom exposures in the present study was not sufficient to reveal pronounced habituation effects. On the basis of the habituation which did appear to occur, it could be hypothesized that prolonged exposure to sonic booms, even if they occurred unexpectedly, would probably result in a further reduction in the number of persons responding. It is doubtful that complete habituation would ever occur in all individuals even to the lowest levels employed in the present study.

Studies reviewed by Thackray[9] have found human startle responses to impulsive noise to be reduced in the presence of continuous background noise. Although there was a slight increase in startle responsiveness to sonic booms noted in the present study with camera noise absent, this was considered to be minimal. Higher levels of background noise could conceivably result in a much greater reduction in startle response to sonic booms.

Subsonic overflights, with one exception, were not found to evoke startle reactions in any of the subjects. The one flight in which apparent startle responses were noted was an extremely low level overflight with a peak outdoor noise level of 138 dB(A).

V. General Summary and Conclusions.

The present study was concerned with the startle effects of sonic booms as experienced in oors. The results indicated that outside over-*ressures ranging* from 70 to 120 N/m^2 (26 to 5 N/m^2 indoors) produced apparent reflexive rm-hand responses in about 10 per cent of the ubjects, while sonic booms of 300 N/m^2 (67 N/m^2 ıdoors) and over produced responses in about 5 per cent of the subjects. Between these ex-remes, both per cent and magnitude of response vere more variable, with some suggestion of a ritical range lying between 150 to 180 N/m^2 40 to 46 N/m^2 indoors) in which there was a ather steep increase in per cent response to the ooms. Although there was some evidence that ery low overpressures produced arm-hand re-ponse amplitudes of lower magnitude than those roduced to the highest levels, there was a wide ange of individual differences in response ampli-ude to the booms (<1.00 mm to 21.00 mm), and ven low level booms occasionally produced large esponses. Of the two measures (per cent re-ponse and response amplitude), per cent re-ponse was the more consistent measure of dose-esponse relationships. An overpressure level elow which startle responses did not occur was ıot clearly established, but the results suggested hat the startle threshold probably was in the icinity of 50 N/m^2 (22 N/m^2 indoors) or less. Older subjects were found to be less responsive o the booms than younger subjects in every ıspect of the startle response examined. There vas some evidence of habituation to low and noderate level sonic booms, but no real evidence of habituation to extremely high boom levels. Background noise levels of 72 dB(A) appeared to reduce response to low and moderate level booms, but not to high level booms.

In conclusion, it should be emphasized again that the present study examined only the startle effects of sonic booms experienced *indoors*, in a building of frame construction, and under semi-laboratory conditions. Dose-response relation-ships for booms experienced outdoors cannot be extrapolated from the data obtained. Also, the data were obtained on female subjects only, and while there is no evidence in the literature sug-gesting the existence of sex differences in startle response, the possibility nevertheless exists. Finally, virtually all of the booms had rather fast rise times. The importance of rise time as a significant variable influencing the loudness and startle effects of sonic booms is now well known. While rise times of booms occurring under actual flight conditions cannot be predicted or con-trolled, it must be emphasized that booms pro-duced in the present study with equivalent overpressures, but considerably longer rise times, might have markedly reduced the startle effects. Questions relative to the effect of changes in rise time on the startle response can only be answered with simulation facilities capable of producing booms with rise times extending over the com-plete range of rise times likely to be associated with the booms produced by SST-type aircraft.

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APPENDIX I--Exposure Data

Day and Date	Exposure No.	Time	Type	Camera	OUTDOOR MEASUREMENTS					INDOOR MEASUREMENTS		
					N/m^2	Duration (msecs)	Rise Time (msecs)	dB(lin)	dB(A)	N/m^2	dB(lin)	dB(A)
	1	10:15	Boom	x	70	100	2			25		
	2	10:20	Subs	x								
	3	10:25	Subs	x				< 95	< 95		< 95	< 92
	4	11:15	Boom	x	130	110	4			30		
	5	11:25	Subs	x				106	99		< 95	< 92
	6	13:15	Boom	x	170	125	2			65		
.0/16/72	7	13:20	Subs	x				105	102		< 95	< 92
	8	14:05	Boom	x	250	90	1			60		
	9	14:10	Subs	x				111	107		< 95	< 92
	10	14:40	Boom	x	105	107	4			35		
	11	14:45	Subs	x				106	97		< 95	< 92
	12	15:00	Pistol	x							-	-
	13	10:05	Boom	x	110	91	4			25		
	14	10:15	Subs	x				115	114		107	< 92
	15	10:55	Boom	x	160	89	6			45		
	16	11:00	Subs	x				114	112		107	< 92
	17	11:45	Boom	x	330	83	4			70		
0/17/72	18	11:50	Subs	x				115	111		107	94
	19	13:15	Boom	x	120	103	4			35		
	20	13:20	Subs	x				117	116		99	< 92
	21	14:05	Boom	x	130	66	< 0.1			-		
	22	14:10	Subs	x				132	138		112	103
	23	14:15	Pistol	x							106	100
	24	10:05	Boom	x	180	115	4			50		
	25	10:30	Boom	x	370	83	< 0.1			85		
	26	10:55	Boom	x	60	115	2			30		
	27	11:20	Boom	x	250	91	12.5			60		
	28	11:45	Boom	x	80	90	4			35		
0/19/72	29	13:15	Boom	x	140	103	3			40		
	30	13:30	Boom	No	160	90	4			35		
	31	14:05	Boom	x	130	84	2			45		
	32	14:20	Boom	No	150	94	1			30		
	33	14:30	Pistol	x							107	100
	34	10:00	Boom	x	240	83	1			65		
	35	10:40	Boom	x	100	94	2			25		
	36	10:50	Boom	x	140	85	1			35		
	37	11:25	Boom	x	250	84	< 0.1			40		
	38	11:30	Boom	x	290	81	1			65		
	39	13:10	Boom	x	150	86	1			35		
0/20/72	40	13:15	Boom	No	150	86	2			40		
	41	13:45	Boom	X	340	86	2			80		
	42	13:50	Boom	No	420	81	2			95		
	43	14:00	Pistol	X								

APPENDIX 1 (CONTINUED)

Day and Date	Expo- sure No.	Time	Type	Camera	OUTDOOR MEASUREMENTS N/m^2	Duration (msecs)	Rise Time (msecs)	dB(lin)	dB(A)	INDOOR MEASUREMENTS N/m^2	dB(lin)	dB(A
	44	10:40	Boom	No	90	115	4			20		
	45	10:50	Boom	No	60	148	6			20		
	46	13:20	Boom	No	340	99	< 0.1			85		
5 10/24/72	47	13:25	Boom	No	150	-	6			85		
	48	14:20	Boom	No	150	99	< 0.1			25		
	49	14:25	Boom	No	170	100	5			70		
	50	14:35	Pistol	No							109	100
	51	10:05	Boom	No	340	75	1			65		
	52	10:10	Boom	No	120	94	< 0.1			25		
	53	11:10	Boom	No	170	95	3			40		
	54	11:20	Boom	No	280	99	1			55		
6 10/25/72	55	11:25	Boom	No	430	91	< 0.1			85		
	56	11:40	Boom	No	600	76	2			110		
	57	13:25	Boom	No	100	98	< 0.1			25		
	58	13:30	Boom	No	70	119	< 0.1			20		
	59	13:35	Boom	No	260	91	4			55		
	60	14:25	Boom	x	280	83	3			65		
	61	14:30	Boom	No	100	101	< 0.1			20		
	62	14:35	Boom	x	[460]	not on tape				-		
	63	14:40	Boom	No	640	90	4			130		
	64	14:45	Pistol	No							105	100

– Indicates Measure Not Obtained
x Indicates Cameras Used