# HUMAN RESPONSE TO AIRCRAFT-NOISE-INDUCED BUILDING VIBRATION

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## SUMMARY

A series of pilot studies has been conducted in both the field and the laboratory to investigate the effects of noise-induced building structure vibration and the rattle of objects on human response to aircraft flyover noise. The field studies were conducted in actual airport communities, and the specific objectives included the determination of subjective detection thresholds for vibration and rattle, as well as the effect of vibration and rattle upon aircraft noise annoyance. The laboratory study, conducted at Langley Research Center, was concerned primarily with the factor of rattle. The specific objectives included the determination of rattle detection thresholds, rattle annoyance thresholds, and the effect of rattle on the overall annoyance response to an aircraft flyover noise event.

As a result of these studies, the vibration detection threshold was determined and building structural vibration was found to increase the annoyance response produced by an aircraft noise event. The rattle of objects was observed very infrequently in the field study and in the laboratory study rattle was found to be of no significance and not important.

## INTRODUCTION

Airport community noise surveys (ref. 1) and complaint records (ref. 2) have often highlighted building vibrations and associated rattle of objects within buildings as a source of annoyance to residents living in airport communities. This vibration/rattle may be a potential detriment to helicopter development and operations because of the low frequency and impulsive nature of helicopter noise signals. The impact of aircraft noise (inclusive of helicopter noise) on people who are exposed to the noise while indoors can be illustrated as shown schematically in figure 1. Aircraft operations generate noise which impinges upon the exterior of a house and is then transmitted through the house structure to the interior where it is perceived by the resident. In some cases, the noise impingement and sound transmission process will produce structural vibration and/or the rattle of objects within the home. If the magnitude of any (or all three) of these physical stimuli are above an individual's detection threshold, it is likely that the individual will not only perceive them but will combine them in some way to produce a total annoyance response. The resultant annoyance response of a community resident to an aircraft noise is, therefore, dependent upon some type of integration of the three physical stimuli. The noise generation and propagation into the interior of the house together with the associated building vibration and rattle constitute the major physical aspects of this environment. The subjective response to the

physical environment, however, involves a determination of separate noise, vibration, and rattle detection thresholds and the manner in which these separate physical factors combine to produce a total annoyance. This paper presents the results of a series of field and laboratory studies that were conducted to (1) obtain detailed measurements of the noise/vibration/rattle environment, (2) obtain subjective annoyance responses to the combined environment, and (3) attempt to define the psychophysical relationship between the subjective responses and the physical environment.

The field studies were conducted in actual airport communities. Specific objectives of the community studies included the determination of subjective detection thresholds for vibration and rattle, as well as the effect of vibration/rattle upon aircraft noise annoyance. The laboratory study conducted at Langley Research Center was concerned primarily with investigating the relative importance or influence of the factor of rattle upon subjective annoyance. The laboratory setting was selected for the rattle investigation since it is very difficult to define and measure rattle in the complex environment of a field study. Specific objectives of the laboratory study were to determine, under controlled conditions, the rattle detection threshold, rattle annoyance threshold, and the effect of rattle on aircraft noise annoyance.

## COMMUNITY STUDY

### Procedure

The community study reported herein was conducted in the communities surrounding John F. Kennedy International Airport (New York City) in conjunction with the government's assessment program of the Concorde supersonic transport (ref. 2). A number of homes in the Kennedy Airport area were utilized for this study, and the subjects who participated included both residents and members of the NASA monitoring team. The test procedures can be best described in conjunction with the photograph of figure 2. This photograph shows a typical group of subjects participating in the subjective response tests as well as some of the instrumentation used to obtain the physical noise and vibration measurements. Microphones were located both indoors and outdoors (not shown) for recording the aircraft noise levels. Accelerometers were used to measure the acceleration levels of the window, wall, and floor (vertical and horizontal). All the physical data were recorded on magnetic tape in a mobile acoustic van (located outside the residence) for later analysis. Since this was a community study utilizing aircraft flyover events as they naturally occurred, no control over the sound sources was possible. Consequently, both subjective ratings and physical measurements were obtained for each flyover event that occurred during a test session which nominally lasted about 1/2 to 1 hour at each site.

The technique used to obtain the subjective response ratings for each flyover is illustrated by the sample flyover event rating form of figure 3. Each flyover event was assigned a flyover number by the test director, and the number was written on the rating form in the appropriate space by each subject. At the conclusion of each event, the test director instructed the subjects to

rate the flyover at which time the subjects would indicate on their rating form whether or not they had detected vibration, rattle, or noise; whether or not the vibration, rattle, or noise was annoying; and finally an overall annoyance rating of the flyover on a numerical category scale which ranged from 0 to 9, where "0" was defined as "zero annoyance" and "9" was defined as "maximum annoyance." Since many of the resident subjects had difficulty in differentiating between noise, vibration, and rattle and in properly using the rating form, only the data from the NASA "trained" subjects of the assessment team are utilized in this paper.

## Test Results

A total of 109 aircraft flyover events at 8 houses were experienced by a total of 16 test subjects. With regard to rattle detection, the subjective ratings indicated that on only three occasions did one half or more of the subjects detect rattle. This implies that rattle may exert only a minor influence upon a person's annoyance response to aircraft noise. However, due to the scarcity of data, it was determined that a final conclusion with respect to the importance of rattle should await the results of a laboratory investigation in which this factor was studied under controlled conditions. These results are presented later in this paper.

Vibration was detected by 50 percent or more of the subjects on 21 occasions at 3 of the 8 houses. All three of these houses were located inside the 40 NEF contour, and each had conventional wooden floors above a crawl space. The results of this phase of the experiment are shown in figure 4 in which the percent of subjects detecting vibration is plotted as a function of the level of vertical floor vibration in dB units (ref. 1 μg). The threshold of vibration detection is defined as the level at which 50 percent of the observers feel the vibration. Consequently, for these data, the threshold of detection is seen to be in the range of from 62 to 68 dB, vertical floor acceleration. The range of 62 to 68 dB corresponds approximately to 100 to 105 dB, outside sound pressure level. Thus, it appears that aircraft-generated outside sound pressure levels greater than 100 dB are capable of inducing vibrations of a magnitude sufficient to exceed the threshold of vibration detection of the occupants within.

Figure 5 presents the results of the category scaling experiment of the overall annoyance rating of the flyover events. Average annoyance ratings are shown as a function of outside A-weighted sound pressure level for two categories of events, namely for aircraft flyovers in which the threshold of vibration detection was achieved, and for those aircraft flyover events for which the threshold of vibration detection was not achieved. The lines shown in the figure were drawn based on a least-square linear fit of the two sets of data. The figure and "paired t-tests" (based on the actual data of one curve versus the predicted data of the other curve) show that aircraft flyovers for which there was vibration detection were evaluated as significantly more annoying than aircraft flyovers for which vibration was not detected. An implication of these data is that structural building vibration does have a significant and detrimental effect on the annoyance response of people to aircraft flyover noise. Since most studies of the effects of aircraft noise on people have not considered building

vibration, these results may explain some of the subjective response variation that occurs within and between various studies.

## LABORATORY STUDIES

### Rattle Detection and Annoyance Thresholds

The laboratory study of rattle detection, rattle annoyance, and rattle effects on aircraft noise annoyance was conducted in the Langley aircraft noise reduction laboratory. The facility used in the study was the interior effects room (IER) which is shown in figure 6. This room is configured to resemble a typical residential living room, and its construction is considered representative of that found in a standard residential house. It consists of painted dry wall over 50.8-mm by 101.6-mm (2 by 4) studs on 406.4-mm (16 in) centers. The dimensions of the room are approximately 4 by 6 by 2.5 meters. Noise stimuli are presented in the room by means of four loudspeakers which are located outside and above each corner of the room.

Experimental design.- The experimental design of the rattle detection and the rattle annoyance experiments involved presentation of an aircraft noise at a constant level with varying amounts of rattle. As shown in figure 7, the peak A-weighted sound pressure level of the aircraft flyover noise was held constant at 71 dB while the rattle level was varied from 45 to 61 dB(A) (measured at the subjects' seating positions). For control and repeatability, the rattle level was produced by tape recording the sound of drinking glasses rattling when excited by an electromechanical shaker mounted to a china cabinet containing the glasses and which was driven by a tape recording of the aircraft flyover. For playback, the tape recording of the rattle was synchronized with the aircraft flyover noise and was introduced into the IER through a small loudspeaker located under a china cabinet while the aircraft noise was played through the overhead, outside speakers. The level of the rattle noise was adjusted by changing the gain setting of the tape recorder playback.

A total of 24 paid, volunteer subjects participated in this experiment. Each noise and rattle level combination was randomized and repeated once and each subject heard every combination. As further shown in figure 7, the determination of detection and annoyance thresholds was addressed in two separate tasks. For detection, the subjects were asked to rate whether or not they detected the objects in the china cabinet rattling. For the annoyance threshold task, subjects were asked to rate whether or not the rattling sounds they heard were annoying. In either case, the expected results would be an increasing number of yes responses with increasing rattle level. The thresholds for detection and for annoyance are defined as the level for which 50 percent of the subjects detected the rattle.

Results.- The results of the threshold determination tasks are shown in figure 8 which displays the percent of "yes" responses for both tasks as a function of rattle level in dB(A) units. The results shown in figure 8 indicate that the threshold of annoyance occurred at approximately 56 dB(A) which is

about 9 dB higher than the threshold of detection which occurred at 47 dB(A). That is, the threshold of annoyance is 9 dB higher than the threshold of detection and probably represents an important result. Also, the 56 dB(A) required to achieve rattle annoyance threshold is believed to be abnormally high in a household setting. Therefore, if rattle is important as a factor to evaluation of aircraft noise, its effects could operate only through detection since rattle levels needed to achieve annoyance are not believed to occur.

## Effect of Rattle on Aircraft Noise Annoyance

Experimental design.- In order to determine if the perception of rattle affects subjective response to aircraft flyover noise, an additional experiment was conducted based upon the experimental design shown in figure 9. Tape recorded aircraft noise was presented to the subjects at four different A-weighted sound pressure levels, both with and without accompanying rattle. A total of 24 subjects participated in the test. Twelve of the subjects were exposed to noise/rattle combinations, whereas the remaining 12 subjects were exposed to noise only. The subjects used the magnitude estimation procedure to provide subjective evaluations of the aircraft noises with or without accompanying rattle. For this task, all subjects were presented with an aircraft noise at a level of 76 dB with no rattle. This standard sound was assigned an annoyance value of 100 and was presented periodically throughout testing. The evaluation task for the subjects was to assign numbers to successive comparison aircraft noises (given in fig. 9) to reflect how much greater or less the annoyance of the comparison noise was relative to the standard noise. For example, if the annoyance of the comparison noise was felt to be twice, three times, one-tenth, or one-half the annoyance of the standard noise, the subject would assign 200, 300, 10 or 50 to the comparison noise, respectively.

If rattle has an adverse effect on a person's annoyance of aircraft noise, then a noise with rattle would be rated as subjectively more annoying than a noise without rattle. This determination could be made since, as mentioned earlier, only half of the subjects were exposed to combined noise and rattle.

Results.- The results of this study are presented in figure 10. This figure shows the magnitude estimations of subjective annoyance obtained from the various subject groups (both with and without rattle) as a function of aircraft A-weighted noise level. Figure 10 indicates that increases of noise level produces increased magnitude estimations of annoyance regardless of whether or not rattle was present. However, the most important implication of the data of figure 10 is the fact that there is no appreciable difference between the "rattle" and "no rattle" conditions. That is, the presence of rattle did not, in a practical sense, affect the subjective response to aircraft noise.

The implications from these laboratory studies are that any rattle produced by aircraft flyover noise should not, of itself, produce annoyance in a listener. Furthermore, the presence of rattle does not increase the annoyance

caused by aircraft flyover noise. Caution should be exercised, however, in extrapolating these laboratory findings to the real-world environment of the airport community where the noise impact is confounded by complicating factors not present in the laboratory such as proprietorship, intrusion into relaxation time, etc.).

## HELICOPTER FLYOVER STUDY

A helicopter flyover subjective response study has very recently been conducted at Wallops Flight Center, and data analysis is currently underway. This study utilized approximately 100 test subjects (fig. 11) in four groups; two indoors and two outdoors. Two types of house structures were utilized (one brick veneer and one wood siding) and extensive physical measurements of structural vibration were obtained in the same mammer as the Kennedy Airport study. In the data analysis of this study, acceleration levels of building structural elements will be quantified as a function of the helicopter noise level and will be compared with the similar data from CTOL aircraft. A primary question of this study is to determine if the helicopter noise data correlates with CTOL noise data, or if some characteristic of the helicopter noise signal (rotor bang, low frequency, etc.) causes it to be unique. In addition, the subjective response data will be analyzed to determine if it is related to amount of helicopter caused building vibration in a fashion analogous to the way the subjective data were related to the CTOL noise data for the study conducted at John F. Kennedy International Airport.

## CONCLUDING REMARKS

Based on an extensive physical measurement program and a limited subjective response pilot study conducted in the J. F. Kennedy International Airport communities of New York City (in conjunction with the government's assessment program of the Concorde SST), the following concluding remarks can be made:

1. A vibration detection threshold was determined for CTOL aircraft and was found to correspond to an outside overall sound pressure level of approximately 100 to 105 dB. This implies that aircraft-generated noises of this level can produce perceivable structural vibrations.

2. The perception of vibration was found to produce an increase in the annoyance associated with an aircraft flyover event giving the implication that vibration is an important factor which should be considered in the assessment of aircraft flyover noise.

3. The results of the community study and a laboratory pilot study suggested that the effects of rattle upon subjective aircraft noise annoyance are negligible. This is based upon the fact that the phenomenon of rattle was observed for less

:han 3 percent of the aircraft noise events during the field study, and in the .aboratory study, the presence of rattle did not appreciably influence ;ubjective evaluations of annoyance to flyover noise.

## REFERENCES


.. Second Survey of Aircraft Noise Annoyance Around London (Heathrow) Airport. H.M.S.O., London, 1971.

:. Staff-Langley Research Center: Concorde Noise-Induced Building Vibrations International Airport Dulles - Final Report. NASA TM 74083, 1977.

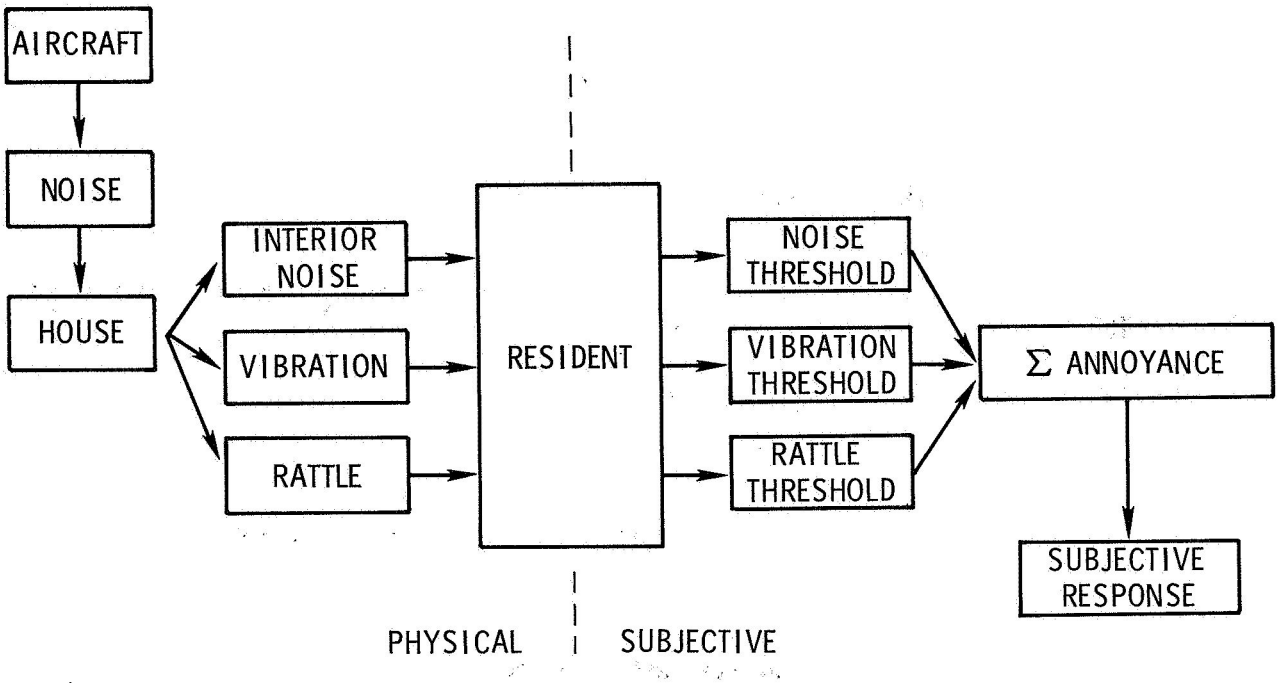


Figure 1.- Schematic illustration of impact of aircraft noise on people exposed to noise while indoors.

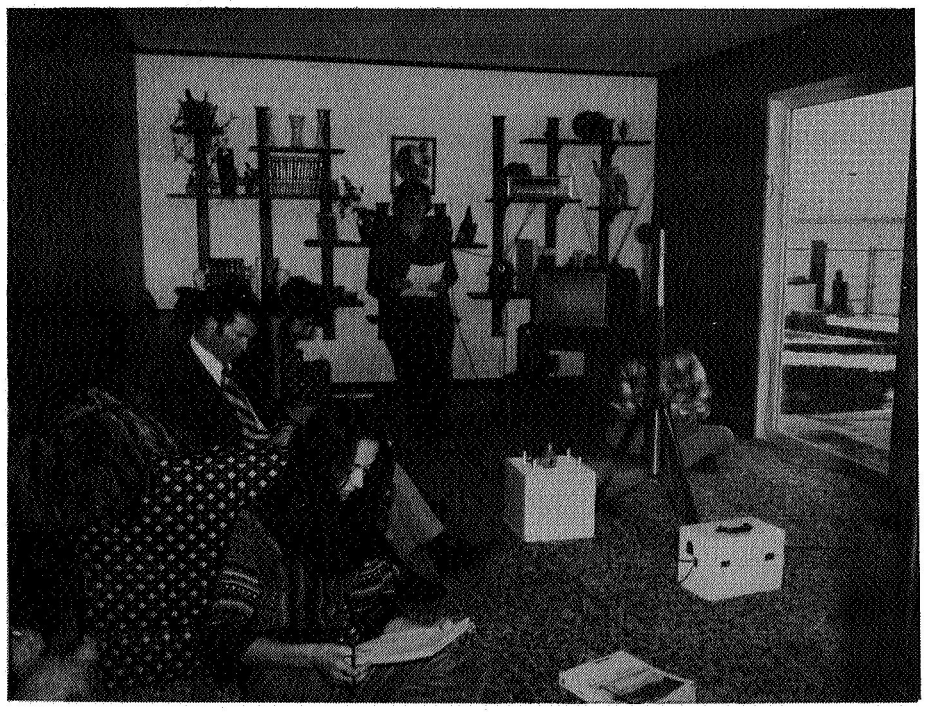

Figure 2.- Community noise study; human response to noise, vibration and rattle.

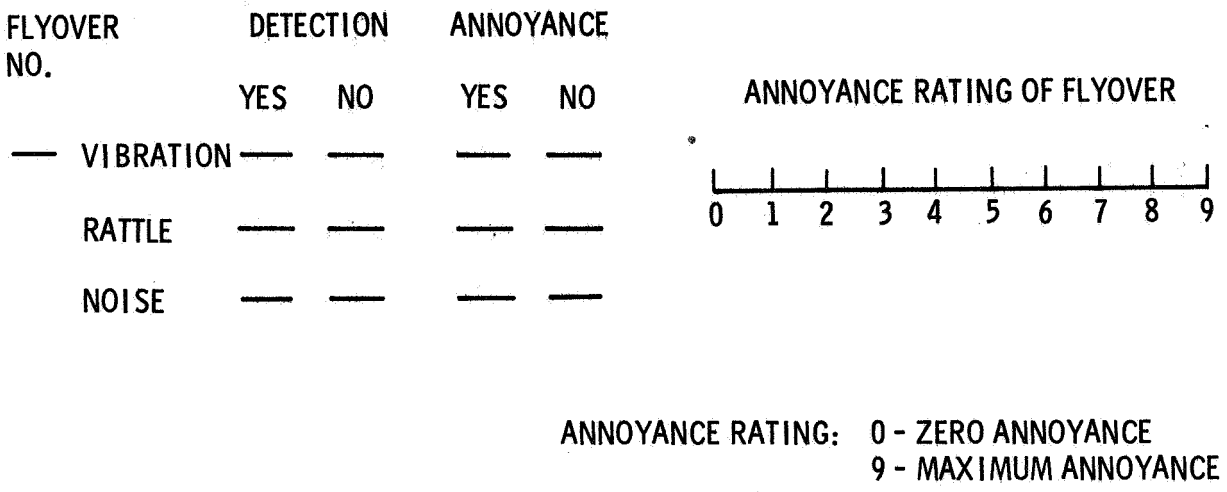


Figure 3.- Sample flyover event rating form used in community noise study.

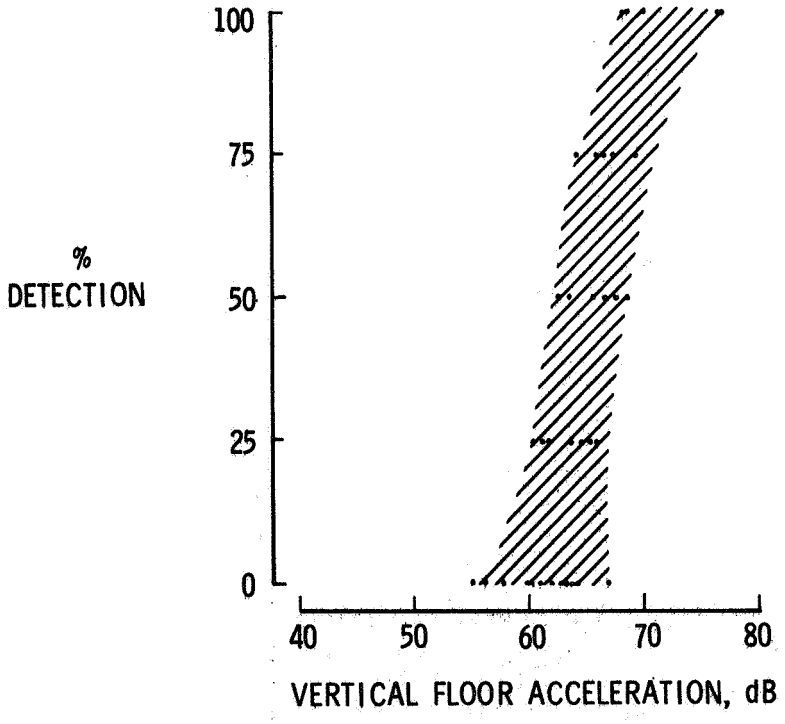


Figure 4.- Results of experiment to determine vibration detection threshold.

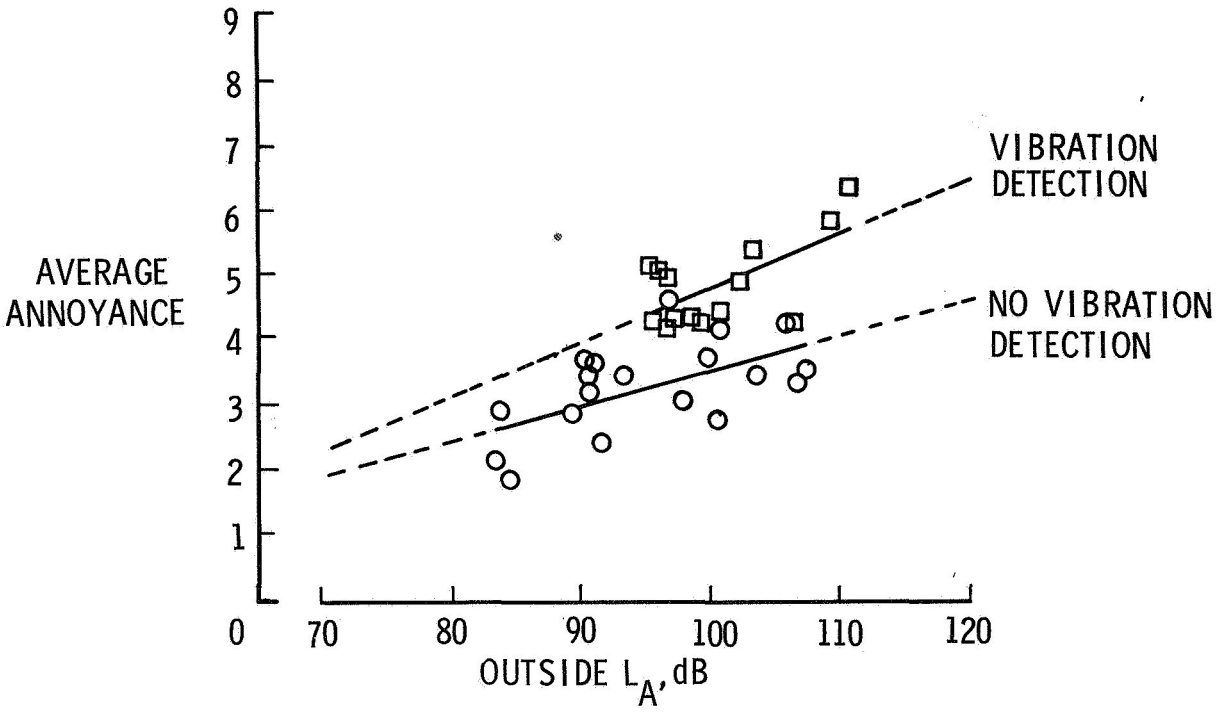


Figure 5.- Effect of vibration on overall subjective annoyance to aircraft flyover noise.

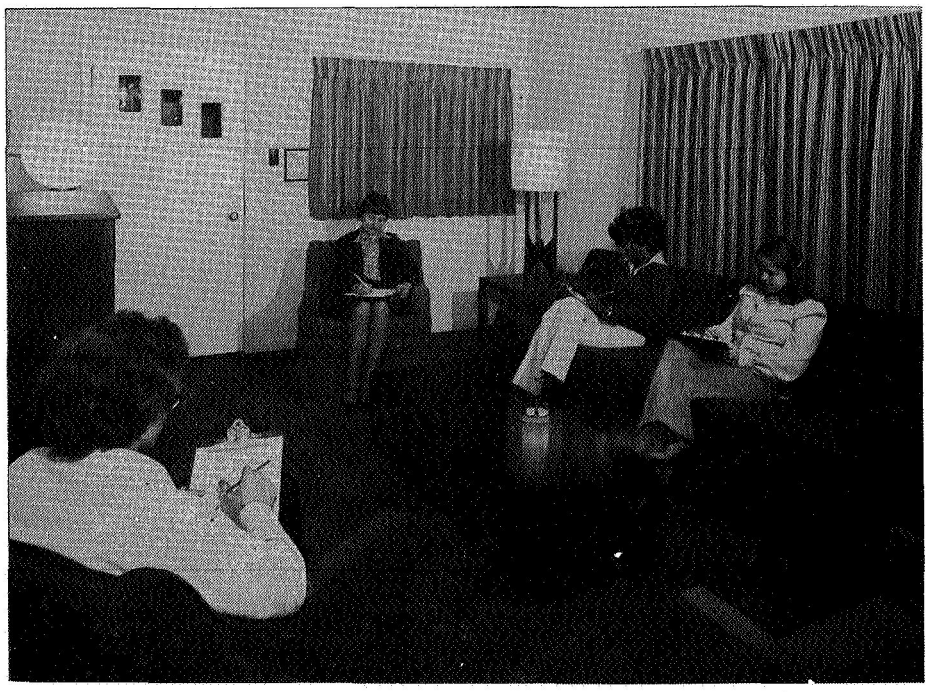

Figure 6.- Interior effects room of Langley aircraft noise reduction laboratory.

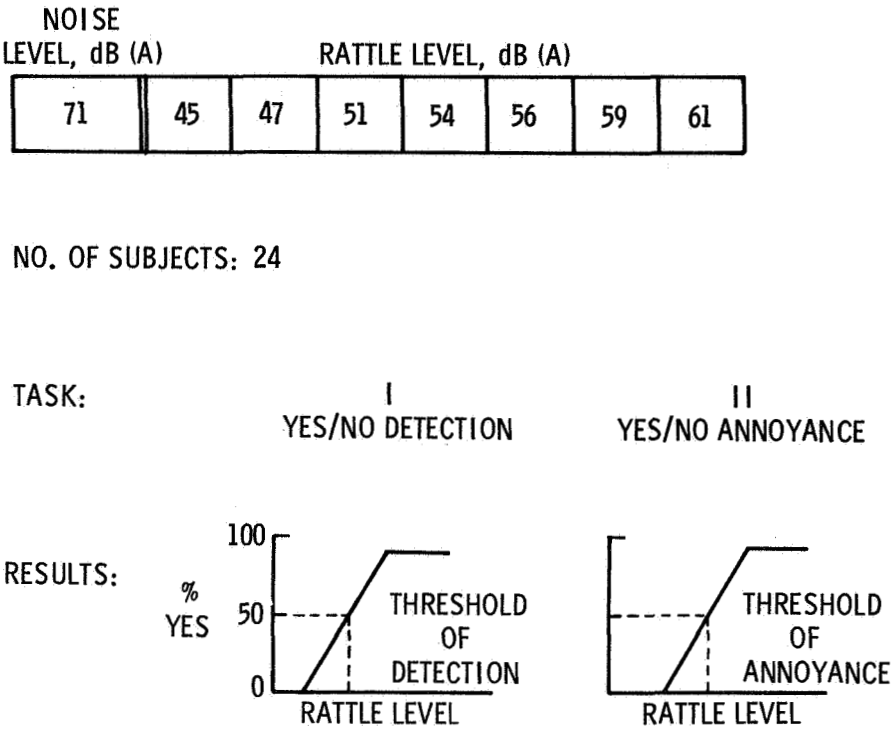


Figure 7.- Experimental design of determination of rattle detection threshold and rattle annoyance threshold.

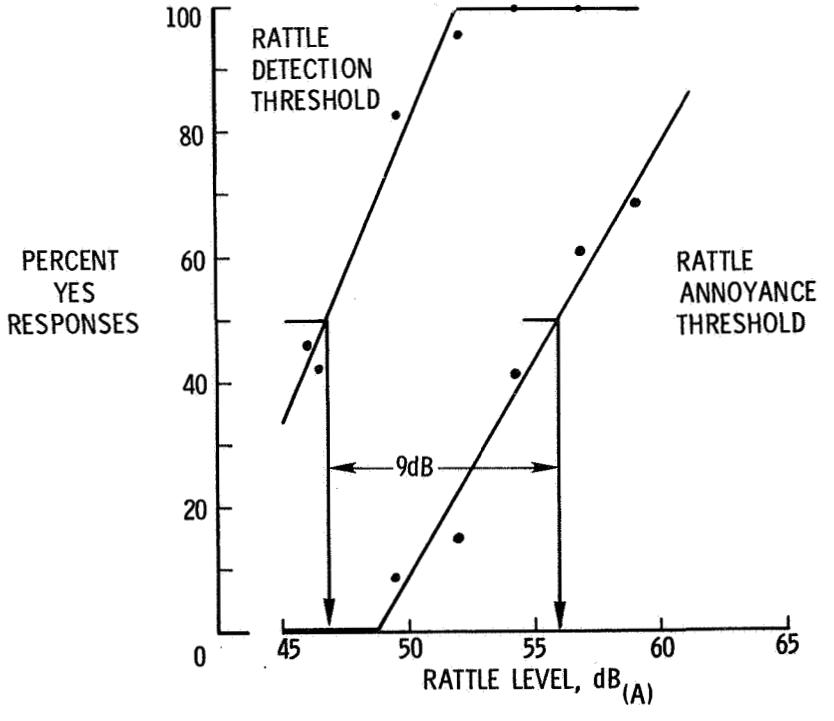


Figure 8.- Comparison of rattle detection and rattle annoyance thresholds.

RATTLE LEVEL, dB (A)

| NOISE LEVEL, dB (A) | RATTLE | NO RATTLE |
|---|---|---|
| 71 | 62 | — |
| 74 | 62 | — |
| 78 | 62 | — |
| 81 | 62 | — |

NO. OF SUBJECTS: 24

TASK: MAGNITUDE ESTIMATION
ANNOYANCE TO AIRCRAFT

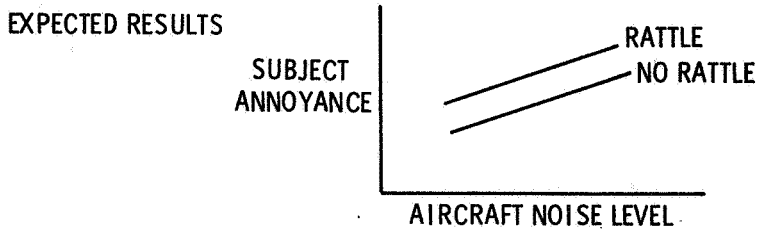


Figure 9.- Experimental design of determination of effect of rattle on aircraft noise annoyance.

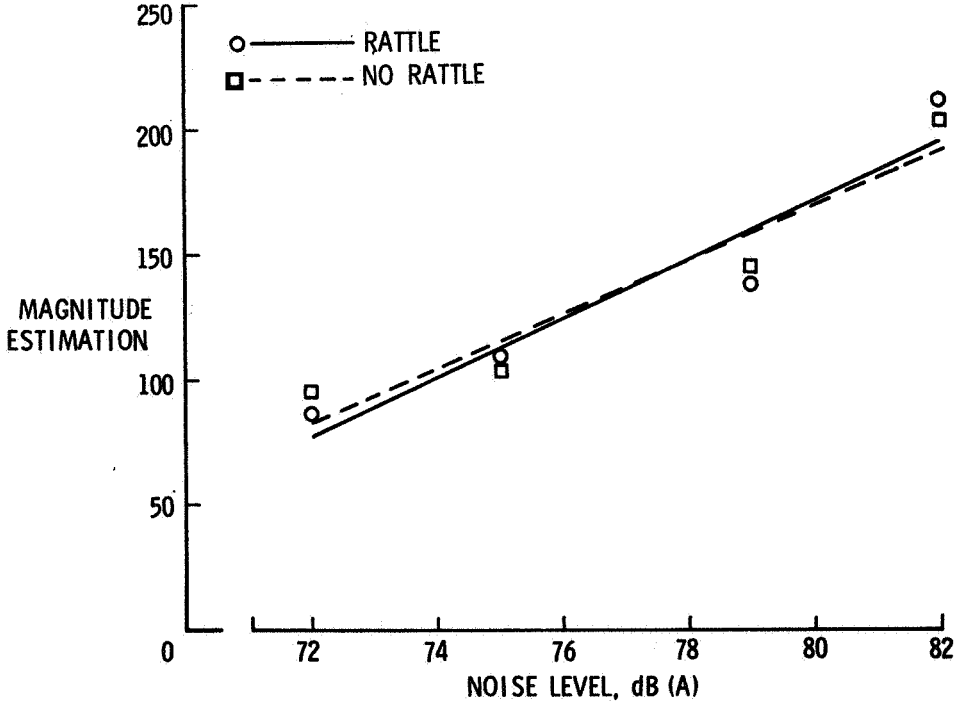


Figure 10.- Effect of rattle on aircraft noise annoyance.

| | |
|---|---|
| NUMBER OF SUBJECTS: | ≈ 100 |
| SUBJECT LOCATION: | INDOORS AND OUTDOORS |
| PHYSICAL MEASUREMENTS: | STRUCTURAL VIBRATION |
| SOURCE DIFFERENCES: | AMOUNT OF ROTOR BANG |

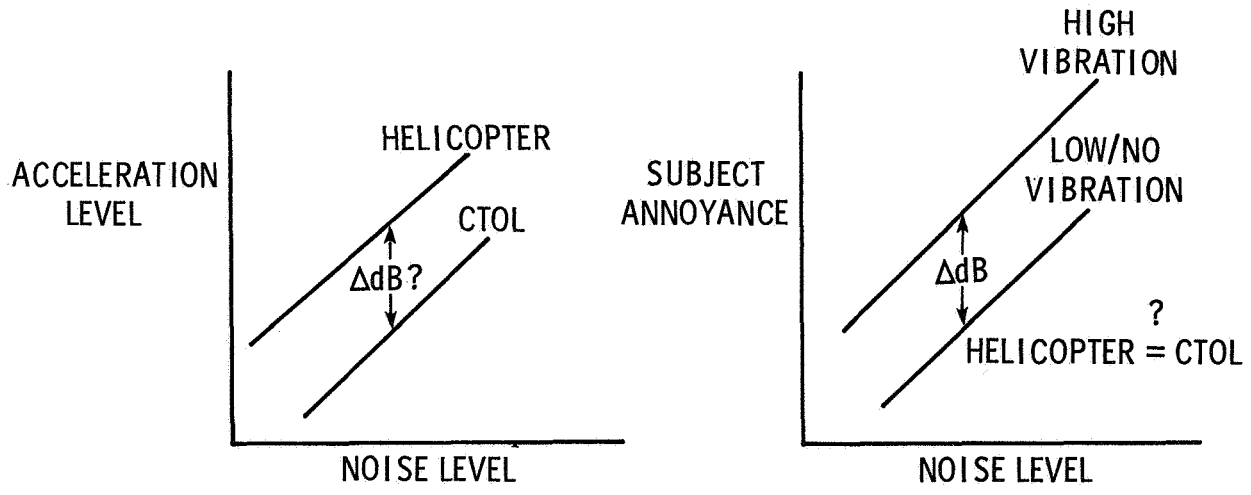


Figure 11.- Subjective response to helicopter flyover noise study.