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Subjective Field Study of Response to Impulsive Helicopter Noise

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SUMMARY

Two experiments were conducted in which subjects judged the noisiness and other subjective noise characteristics of flyovers of two helicopters and a propeller-driven airplane. A total of 72 flyovers were judged. The purpose of the experiments was to examine the effects of impulsiveness on the subjective response to helicopter noise. In the first experiment, subjects were located outdoors and indoors. The impulsive characteristics of one helicopter was systematically varied by changing the main rotor speed while maintaining a constant airspeed. This resulted in other characteristics of the noise being held relatively constant. In the second experiment, all subjects were located outdoors and only the helicopters were used. In this experiment, descent and level flight conditions were examined.

Results from both experiments indicated that at equal effective perceived noise levels (EPNL) the more impulsive helicopter was judged less noisy than the less impulsive helicopter. Also the ability of EPNL to predict noisiness was not improved by the addition of either of two proposed impulse corrections. A subjective measure of the impulsive nature of the sounds was found to be related to error in predictive ability of EPNL. This measure, however, was not significantly related to either impulse correction.

INTRODUCTION

Several studies (refs. 1 and 2, for example) have indicated that the annoyance potential or "noisiness" of helicopter noise is less reliably predicted by most noise metrics than that of conventional take-off and landing airplane noise. This is of particular significance for noise certification and regulatory purposes.

The character of noise produced by helicopters is very diverse. Each of the primary noise sources - main rotor, tail rotor, and propulsion systems - produce very distinctive noises. The noises of these individual sources can also be quite variable, both between different helicopter models and for a given model under different operating conditions. Because of this diversity, the metrics selected for certification or regulatory purposes must be capable of accounting for a wide range of spectral and temporal variables.

Although the wide diversity in characteristics of helicopter noise exists, the lack of reliable prediction of noisiness is most frequently attributed to the impulsive nature of the noise from some types of helicopters or certain operating conditions. As a consequence, several proposals for corrections to noise metrics commonly used for aircraft noise certification or assessment have been made to account for impulsiveness. Although several research studies have been conducted to determine whether such impulsiveness corrections improve the ability of noise metrics such as effective perceived noise level (EPNL) to predict noisiness of helicopter noise, the results of these efforts have been inconclusive. References 3 and 4 concluded that no impulsiveness correction was necessary, whereas reference 5 concluded that corrections for both the magnitude and repetition rate of impulses were necessary to adequately predict noisiness. Although the cited references are only a few examples of a relatively large number of studies, they do illustrate the extreme variation in results.

One possibility for the inconclusiveness of subjective helicopter noise studies is the difficulty in adequately reproducing the complex waveforms or temporal patterns resulting from the low-frequency pulsative or impulsive character of helicopter noise. As a consequence, a number of psychoacoustic tests such as those reported in reference 6 have been conducted with headphones in an effort to preserve both temporal and spectral characteristics. These tests obviously do not simulate whole body exposure. Other tests such as references 4 and 5 have used loudspeakers for presentation of recorded helicopter noises with little regard for the preservation of phase information contained in the waveform.

Because of the inconsistencies in previous studies and an urgent need for information to determine if an impulsiveness correction was necessary for noise certification purposes, the Federal Aviation Administration requested that the NASA Langley Research Center conduct a psychoacoustic study of helicopter noise with two specific objectives. The first was to determine if subjects in outdoor and indoor situations consistently judge helicopters flyover noises with high levels of impulsiveness noisier than similar flyover noises at the same EPNL but with lower levels of impulsiveness. The second was to determine if an impulsiveness correction proposed by the International Organization for Standardization (ISO) significantly improves the predictive ability of EPNL for the same situations.

The tests were conducted at NASA Wallops Flight Center and used overflights of real aircraft. This was done to prevent the possibility of the results being affected by difficulties in reproducing recorded aircraft noise over loudspeakers or headphones.

NOISE MEASURES AND ABBREVIATIONS

Primary noise measures:

EPNL effective perceived noise level, EPNdB

L_A A-weighted sound pressure level, dB

PNLT tone-corrected perceived noise level, PNdB

SEL sound exposure level, A-weighted sound pressure level with integrated duration correction, dB

A more detailed description of the primary noise measures used in this report can be found in reference 7.

Secondary noise measures:

ECF_1 effective impulsiveness correction using proposed ISO method, dB

ECF_2 effective impulsiveness correction using peak A-weighted sound pressure level method, dB

$EPNL_1'$ impulsiveness-corrected effective perceived noise level using ISO method, EPNdB

$EPNL_2'$ impulsiveness-corrected effective perceived noise level using peak A-weighted sound pressure level method, EPNdB

$PNLT_1'$ tone- and impulsiveness-corrected perceived noise level using ISO method, PNdB

Abbreviations:

CTOL conventional take-off and landing

ISO International Organization for Standardization

LaRC NASA Langley Research Center

max maximum

NASA National Aeronautics and Space Administration

SG subject group

SJI subjective judgments of impulsiveness

SSV subjective scale value

EXPERIMENTAL DESIGN AND PROCEDURE

Concept

The approach for this combined outdoor and indoor subjective field experiment was to provide close control over pertinent acoustical variables as is done in laboratory experiments. The intensity of impulsiveness or blade slap noise was to be systematically varied. Other acoustical parameters such as duration, level, and spectra of noise not attributable to blade slap noise were to be held constant.

Under the assumption that such control was possible by proper selection of the type of helicopter, operating conditions, and flight parameters, a factorial experimental design was formulated. This design controlled for impulsiveness, altitude, and observer-to-aircraft angle of elevation. The altitude and angle of elevation provided predictable control of level, spectra, and duration of the nonimpulsive-associated noise so that determinations could be made of the relationship of annoyance potential with various physical descriptors customarily used to predict CTOL airplane noise annoyance.

Two helicopters and a propeller-driven airplane were included in the experiment design. The nature of the tests and test procedures selected for the experiment were dictated by several considerations. To prevent confounding of subject effects and experimental factors, it was decided that each subject would judge the complete set of aircraft flyover noises. This requirement coupled with problems of getting subjects to reliably return for subsequent days of testing, necessitated a 1-day test. The total number of conditions investigated coupled with safety considerations and acquisition of acoustical data required that each event be judged separately rather than as comparisons between pairs of events. The use of magnitude estimation procedures was precluded because of difficulties in establishing a suitable reference noise for a field study. Past experience in laboratory studies at LaRC indicated that a small reduction in standard deviation in judgments was afforded by the use of a continuous scale of the judged attribute rather than by the use of a category scale. As a result, a continuous numerical scale ranging from "0, Not Noisy at All" to "10, Extremely Noisy" was used for the judgments of annoyance potential.

A different group of subjects made judgments on other characteristics of the flyover noises. The subjects characterized each flyover noise in terms of noticeability of six adjective descriptors using a five-point category scale for each descriptor. These descriptors were selected from a long list of adjective descriptors used in subjective tests described in reference 6. In that report, three of the chosen descriptors - thumping, slapping, and hammering - were repeatedly identified as best describing impulsive helicopter noise. Similarly three other descriptors - droning, buzzing, and swishing - were identified as best describing nonimpulsive helicopter noise.

Test Aircraft

The requirement that the primary test helicopter be capable of producing blade slap noise of varied but repeatable degrees of impulsiveness while maintaining constant level, duration, and spectra of nonimpulsive noise, greatly reduced the number of eligible helicopters. Previous experience with a Bell 204B helicopter (fig. 1) based at LaRC indicated that the degree of impulsiveness could be varied by varying the rotor speed in rpm over the range of 91 percent to 100 percent maximum certified rotor speed while maintaining a constant airspeed of 58 m/s (110 knots). Subsequent field measurements and subjective listening experiences substantiated these indications. The duration, level, and character of other noise sources (predominantly tail rotor noise) were found to be much less affected by change in rotor speed than the impulsive blade slap noise.

A second helicopter, an OH-58A (fig. 2), was used in the experiment to produce less impulsive noise than the 204B. The noise of this helicopter is dominated by tail rotor noise. Because of lower blade tip speed, it was not possible to vary the impulsive characteristics over as large a range as for the 204B. As a consequence, the rotor speed was held constant at the standard operating condition of 100 percent maximum certified speed. A constant airspeed of 58 m/s (110 knots) was maintained for each flyover in the series.

A T-28A single-engine, propeller-driven, fixed-wing airplane (fig. 3) was selected to provide nonhelicopter noise condition. It was flown at 58 m/s for the series of required flights so that the duration of noises would be similar to those for the helicopters. Extended landing gear and full flaps and maximum climb power were used to maintain this comparatively low speed and still produce sufficient noise levels. It was desirable that the upper extreme of the subjects' judgments be set by the nonhelicopter noise to reduce possible bias against the most severe blade slap condition. The noise levels for the T-28A were sufficient for this purpose.

Selected characteristics of each of the aircraft used in the tests are given in table I.

Test Site

The test site for the experiment was the NASA Wallops Flight Center. This selection was based on control of airspace, control of background noise, availability of proper tracking facilities, and availability of unoccupied houses for indoor testing. Two houses were selected which were of different construction and orientation to the flight paths and which were in line with an open area for use by the outdoor subject groups. House K-3 (fig. 4) was of brick veneer construction and house K-25 (fig. 5) was of frame construction with aluminum siding. The orientation of the houses and outdoor subject groups to the flight paths is shown in figure 6. The flight paths were either directly over the houses and outdoor subject groups or displaced 120 m or 370 m to the west.

Figure 7 presents a view of the outdoor test subjects taken towards the southwest. House K-25 is shown in the lower left corner of the photograph. The general area is characterized by mixed hardwood and softwood trees in light spring foliage. The area behind the outdoor subjects (fig. 8) opened onto the east-west runway. This particular orientation of subjects and flight paths was found in preliminary tests to produce the least reflection of the impulsive helicopter noises at the outdoor subject location.

Test Subjects

A total of 91 test subjects were used in the experiments. These subjects were local residents from areas within 25 km of the Wallops Flight Center and were recruited and paid by an NASA contractor. Eighty of the subjects were female of mean age 40 years, range 18 to 72 years. The male subjects had a mean age of 24 years and range of 19 to 31 years. Each subject was given an audiogram prior to the experiment to insure normal hearing ability.

Upon arrival at the test site, each subject was randomly assigned to one of the test groups. Twenty subjects were assigned to group 1 (SG-1) for outdoor judgments of the characteristics of the noises. Sixteen subjects were assigned to group 2 (SG-2) for judgments of annoyance potential of the noises in the brick house (K-3). Fifteen subjects were assigned to group 3 (SG-3) to make judgments of annoyance potential in the frame house (K-25). Forty subjects were assigned to group 4 (SG-4) for judgments of annoyance potential in the outdoor situation.

Experimental Design

First experiment.- The experimental design of operations for the primary helicopter, the 204B, was factorial with three levels of impulsiveness, two altitudes, two angles of elevation, and two replications. Since it was not possible to vary the impulsiveness of the other aircraft, only altitude, angle of elevation, and replications were considered as variables. The same altitudes and angles of elevation were used for the OH-58A and T-28A as were used for the 204B.

The complete sequence of flyover events presented to the subjects during the first (morning) experiment is given in table II. One flight of each aircraft was presented prior to the judged events, 1 to 48. These preliminary events were to familiarize the subjects with the noises and procedures to be used. It should be noted that the sequence of 204B events for the last half of the experiment was the reverse of the sequence for the first half. This was done to provide a counterbalance to prevent an order bias for the primary experimental conditions. It was not possible to fly the aircraft in a completely random sequence to encompass all the variables because of safety considerations in traffic control. The aircraft were flown in the sequence of 204B, OH-58A, 204B, and T-28A. This sequence was repeated for one-half of the 48 flyovers necessary to complete the experiment design and was then reversed for the remaining half of the flyovers. Since the outdoor subjects could easily see the aircraft it was assumed that such a sequence would produce no additional bias.

Second experiment.- A second experiment of limited level flights and descent operations was conducted during the afternoon. In this experiment, only the two helicopters were used. The orientation of subject groups and flight paths is presented in figure 9. The primary purpose for the experiment was to provide a wider range of impulsiveness conditions for each helicopter by providing the proper conditions for vortex interaction bang. This experiment was factorial in design with two helicopters; three flight conditions, level flight, 3° descent, and 6° descent; two sideline distances, overhead and 120 m; and two replications. The level flight conditions were flown at constant speed of 58 m/s as in the first experiment. The descent operations were flown at speeds of approximately 48 m/s for the 204B and 34 m/s for the OH-58A. The sequence of flyover events presented to the subjects is given in table III.

Prodedure

Upon arrival at NASA Wallops Flight Center, the subjects were assigned to one of the four test groups, seated in their respective test areas, and given written instructions and scoring sheets. The groups in the two houses were given identical instructions to those judging noisiness outdoors (appendix A). The instructions given to SG-1, who made judgments of the character of the noises, are reproduced in appendix B. The test conductor for each group gave a brief verbal reinforcement of the instructions and answered any questions. Reproductions of the scoring sheets used for the two tasks are presented in appendixes C and D. The subjects made mental judgments of the familiarization noises and the test conductor again asked if there were any questions. Ten-minute rest breaks were given between events 12 and 13 and between events 36 and 37. A 30-min rest break was given between events 24 and 25 at which time the aircraft were refueled. Except for the rest periods, the time between events averaged 2 1/2 min.

Following the completion of the first experiment, the subjects were given a 1-hour lunch period. During the second experiment, those subjects who had previously made indoor noisiness judgments (SG-2 and SG-3) were relocated out doors and were instructed to make judgments of the character of the noises. Subject groups 1 and 4 were instructed to make the same type of judgments, character and noisiness, respectively, as they made during the morning experiment. A 10-minute rest break was given between flyovers 12 and 13.

DATA ACQUISITION AND ANALYSIS

Acoustic Data Acquisition

The primary acoustic data for the test were acquired with two microphones located near the outdoor subject groups (figs. 6 and 9). Outputs from the microphones were split into a total of five data channels adjusted for different levels of attenuation to provide a wide dynamic range and were recorded on separate tracks of an FM tape recorder. The response of the data acquisition system was flat within ±1 dB over a frequency range of 5 Hz to 10 kHz.

Similar data acquisition systems were used for each of the two houses. Microphones were located inside and outside each house (fig. 6). The inside microphone signals were split into two channels one of which was passed through a 500-Hz high-pass filter to provide better dynamic range for the higher frequency range. These signals were recorded simultaneously on FM recorders for each house. The three FM recorders were synchronized with time codes.

Acoustical Analyses

The acoustical analyses for this report include only measurements made near the outdoor test subjects. Analyses were performed on the data channel of the FM recordings which provided the greatest dynamic range, without overload, for each flyover. Each flyover was first analyzed to provide 1/2-sec, 1/3-octave-band sound pressure levels for use in providing calculated measures in terms of EPNL and other common noise rating scales. The noises were then analyzed to provide two measures of impulsiveness.

One measure of impulsiveness being considered as a possible correction to EPNL for helicopter noise certification is the method proposed by the ISO. For this method, the acoustic signal is A-weighted and sampled at 5 kHz. For every 0.5-sec period of the signal, an impulsiveness descriptor I is calculated from the sampled voltage V_i such that

$$I = \frac{n \sum_{i=1}^{n} V_i^4}{\left(\sum_{i=1}^{n} V_i^2 \right)^2} - 1 \tag{1}$$

where $n = 2500$.

The impulsivity is then converted to decibel-like units according to

$$X = 10 \log I \tag{2}$$

A correction ΔC_1 is applied to the PNLT value for each 0.5-sec period according to

$$\Delta C_1 = 0.8(X - 3) \tag{3}$$

with the limits that

$$0 \text{ dB} \leqq \Delta C_1 \leqq 5.5 \text{ dB}$$

The values of the impulsiveness-corrected perceived noise level

$$PNLT_1' = PNLT + \Delta C_1 \tag{4}$$

are then numerically integrated over the acoustic signal duration to provide an impulsiveness-corrected effective perceived noise level $EPNL_1'$. In further discussion in this report, an effective impulsiveness correction factor for the ISO method will be defined as

$$ECF_1 = EPNL_1' - EPNL \tag{5}$$

where EPNL is the customary effective perceived noise level defined in FAR 36 (ref. 8).

Another measure of impulsiveness of interest as a correction to EPNL for helicopter noise certification is of somewhat simpler in concept. For this measure, the correction applied to the PNLT value for each 0.5-sec period is

$$\Delta C_2 = L_{A,peak} - L_{A,rms} - 12 \text{ dB} \tag{6}$$

where $L_{A,peak}$ is the peak A-weighted sound pressure level and $L_{A,rms}$ is the root-mean-square A-weighted sound pressure level for the 0.5-sec time period. The factor of 12 dB is subtracted so that no correction is applied to broadband random noise. These corrections are applied to the 0.5-sec PNLT values and integrated to provide an impulsiveness-corrected effective perceived noise level $EPNL_2'$. Similarly, an effective impulsiveness correction factor for this method will be defined as

$$ECF_2 = EPNL_2' - EPNL \tag{7}$$

Tabulated values of the levels in terms of several common measurement scales, impulsiveness-corrected EPNL, and effective impulsiveness corrections are presented in table IV for each flyover of the first experiment. Included in table IV are the altitude and sideline distance from the outdoor subject groups to the point of closest approach for each flyover. Tabulated values of the same type of data for the second experiment are given in table V.

Subjective Data Analysis

Noisiness judgments.- The judgments made by subjects on the graphical noisiness scales were converted to numerical scores over the range 0.0 to 10.0 by direct measurement. These data were tabulated and coded onto computer cards for analysis. The primary analysis of the data consisted of obtaining the mean and standard deviation of the judgments of all subjects for each flyover noise. The means and standard deviations of the noisiness judgments for the first and second experiments are given in table VI and table VII, respectively. For discussion purposes in the remainder of the report, the means of the subjective judgments will be referred to as SSV, subjective scale values. These values were used in various regression and correlation analyses in conjunction with noise levels in terms of various descriptors.

Impulsiveness judgments.- The numerical category judgments made by subjects on the character of the noises were converted to numerical scores related to impulsiveness in the following manner. If a subject judged a noise greater than

3 on the "Thumping" scale, greater than 2 on the "Slapping" scale, or greater than 2 on the "Hammering" scale, the subject was considered to have judged the noise highly impulsive. The percentage of subjects judging each noise highly impulsive was calculated and will be referred to as SJI, subjective judgments of impulsiveness, for the remainder of the report. These values are given for the first and second experiment in table VI and table VII, respectively. The selection of different cutoff points for the different scales was based on differences found in the statistical distributions of the judgments for each scale.

RESULTS AND DISCUSSION

Effects of Noise Level and Aircraft Type on Noisiness

First experiment - outdoor judgments.- The general data trends for judgments made by the outdoor subject group, SG-4, in the first experiment are presented in figure 10. The mean subjective judgments SSV are plotted against the measured EPNL values for each of the flyovers presented for judgment. The diamond symbols, representing the T-28A airplane, form a very consistent pattern with very little deviation from a straight line. The data for the 204B helicopter, although in general alinement with the T-28A data, indicate more variability about a straight line. The data for the OH-58A helicopter in general have even greater variability and lie outside the range of the T-28A and 204B data. It is evident that the subjects considered the OH-58A more objectionable at a given EPNL than the 204B.

These trends are in good agreement with outdoor subjective tests conducted in reference 3. In those tests, an OH-58 helicopter, a UH-1B helicopter (military equivalent of 204B), and a C-47 propeller-driven airplane were judged along with other military helicopters. Those data also indicated little difference in annoyance trend with level for the C-47 and UH-1B but showed an increased annoyance trend, equivalent to a 3-dB to 4-dB increase in level, for the OH-58.

First experiment - indoor judgments.- Data trends for the subject groups SG-2 and SG-3 located inside the brick and frame houses, respectively, during the first experiment are presented in figures 11 and 12. The SSV data are presented in both figures plotted against the outdoor measured EPNL values for each flyover. In both cases, the data indicate greater variability than for the outdoor judgment data.

The subjective data from both indoor groups of subjects indicate less difference between aircraft types than the outdoor data. It was found, however, for the data from the group in the frame house that the judgments were generally greater for sideline flights than for overhead flights for equivalent noise levels. This was most probably due to the orientation of the house to the flight paths which allowed the roof to shield a large window in the subject test room for the overhead flights.

Second experiment.- The trend of judgments of noisiness for subject group SG-4 with EPNL is given in figure 13 for the second experiment in which level and descending flights were presented. Also included in this figure are lines indicating linear least-squares regressions of data from the first experiment. As can be seen, the two experiments agree quite well. The same relative differences exist between the data for the 204B and OH-58A.

The close agreement between the two experiments indicates that the subjects were using the rating scale in a very consistent manner and that differences in judgments between helicopter types were true reflections of perceptual differences in the noise characteristics which are not taken into account in the EPNL noise descriptor.

Regression and Correlation Analyses

Various linear least-squares regression analyses of the subjective data, SSV, were performed on noise levels in terms of EPNL and other descriptors. Table VIII presents the results of the regression analyses of outdoor SSV on EPNL for each experiment, separately and combined, and for each aircraft type, separately and combined.

Although there are differences in slopes of the regression lines between the first and second experiments for each aircraft type or combination, when the two experiments are combined the slopes are very near the slopes of the first experiment. This fact coupled with a general decrease in standard error of estimate for the combined experiments case is indicative of the consistency of judgments between experiments.

The small standard error of estimate for the T-28A airplane is indicative of the precision of the mean judgments for a relatively consistent noise source. The standard error of estimate is equivalent to slightly less than an error of 1 dB in predictive ability. The slopes of the regressions of the 204B for the first experiment or combined experiments are not significantly different from that of the T-28A. The lower slope values for the OH-58A, which in the first experiment and combined experiments are significantly different from those of the 204B, are probably the result of the nonlinear characteristics of the subjective scale at low scale values.

Correlation matrices of subjective data, several common physical measures, the two impulsiveness-corrected EPNL measures, and the two effective impulsiveness correction factors are presented in tables IX, X, and XI. In each table, matrices are presented for the 204B, the OH-58A, and all aircraft combined. Table IX presents the matrices for the first experiment; table X, the second experiment; and table XI, the combined experiments.

For the first experiment (table IX), the correlations between the outdoor judgments and the indoor judgments in the brick house were greater than between the outdoor judgments and indoor judgments in the frame house. The difference between judgments of overhead and sideline flights has been previously mentioned and is thought to be the reason for the difference in correlation.

The correlations of the outdoor subjective data with the physical measures not corrected for impulsiveness for all aircraft combined were generally high. The correlations for the 204B were consistently higher than for the OH-58A. With only two exceptions, the correlations of subjective judgments with the impulsiveness-corrected EPNL measures were less than for uncorrected EPNL. For the 204B and OH-58A separately in the first experiment, the correlation with $EPNL_2$ was slightly greater than with EPNL. The differences, however, were not statistically significant at the 5 percent level. In no case did the $EPNL_1'$ produce any improvement over EPNL.

Effects of Impulsiveness

Residual error analyses.- The residuals (deviations of data about a regression line) from the regression of outdoor subjective judgments of the 204B flights of the first experiment on EPNL were examined for trends associated with the physical measures of impulsiveness. Figure 14 presents these residuals and the associated effective impulsiveness corrections ECF_1. The data have been categorized into the four flight-path conditions. No obvious consistent trends are noted either within or across the flight-path conditions. Figure 15 presents the residuals and the associated effective corrections ECF_2. Within each flight-path condition, there is a trend for increased residual and, therefore, noisiness for increased impulsiveness measured in terms of ECF_2. However, across the flight-path conditions the trend is greatly reduced and the inclusion of the ECF_2 correction would produce negligible improvement as was evidenced by the lack of a statistically significant improvement in correlation.

Subjective judgments of impulsiveness.- The subjective judgments of impulsiveness (SJI) for the 204B flights of the first experiment are presented in figure 16 for each flight-path condition and rotor speed. It can be seen that, in general, the subjects discriminated the impulsiveness differences between rotor speed as well as differences between flight paths in a consistent manner. Figure 17 presents the SJI data as related to EPNL and indicates high correlation, $r = 0.896$, between level and judged impulsiveness (r is correlation coefficient). An ideal measure of impulsiveness would not be affected by the noise level. Since it would not be possible to separate the level and impulsiveness effects, an alternative approach was used to compare the subjective noisiness judgments and subjective impulsiveness judgments. Figure 18 presents the residuals from the regression of SSV on EPNL plotted against the residuals from the regression of SJI on EPNL. An obvious trend with positive slope can be seen. This trend indicates that at least a portion of the error in prediction of noisiness by EPNL was related to a perceptible characteristic of the noise associated with impulsiveness. The inability of the two physical measure of impulsiveness to quantify this characteristic adequately is evidenced by the lack of significance in correlation between the subjective measure, residual of SJI on EPNL, and the physical measures ECF_1 ($r = 0.071$) and ECF_2 ($r = 0.222$).

Multiple regression analyses.- Linear multiple regression analyses were conducted with EPNL and impulsiveness corrections as independent variables and SSV as dependent variables. The results of the analyses for the 204B helicopter are presented in table XII. The results are categorized for the first and second experiments separately and combined. Similar analyses using EPNL and SJI as independent variables are also presented. For the first, second, and combined experiments, the multiple regressions with the variable ECF_1 produced no improvement in correlation above those with only EPNL as the independent variable. (Compare tables XII and VIII.)

The additional variable ECF_2, while producing increased correlation in the first and second experiments separately, did not do so when the experiments were combined. The regression coefficient for the variable ECF_2 was positive in the first experiment and negative in the second experiment. The addition of SJI as a variable did improve the correlation for the first, second, and combined experiments; however, the improvement was not significant in the second experiment. The high correlation between EPNL and SJI is evidenced by the large reduction in slope for EPNL in the multiple regression cases. The significant improvement in correlation in the first and combined experiments is indicative, however, that some characteristic, the perception of which was embedded in the SJI values, is not accounted for by EPNL.

CONCLUSIONS

An experimental study was conducted to examine the effects of impulsiveness on subjective response to helicopter noise. Subjects located both outdoors and indoors judged the noisiness and other characteristics of two helicopters and a propeller-driven airplane during controlled flyovers at different altitude and sideline distances. The more impulsive of the helicopters was operated to provide several levels of impulsiveness. The other helicopter, the noise of which was dominated by tail rotor noise, was operated over the same flight paths and at the same speed but with little variability in impulsiveness.

Based on analyses of outdoor and indoor subjective data and outdoor acoustic data the following conclusions were made:

1. The noise produced by the more impulsive helicopter was consistently judged less noisy than the noise produced by the less impulsive helicopter for equal EPNL.

2. No significant improvement in the noisiness predictive ability of EPNL was provided by either an impulsiveness correction proposed by the International Organization for Standardization or an impulsiveness correction based on A-weighted crest factor.

3. A subjective measure of impulsiveness, developed from judgments of characteristics other than noisiness, was found to be related to residual error in predictive ability of EPNL. This measure, however, was not significantly related to the proposed impulsiveness correction factors under study. This is indicative that some characteristic related to impulsiveness is perceivable by subjects but is not accounted for by either EPNL or the proposed impulsiveness corrections.

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APPENDIX A

INSTRUCTIONS FOR NOISINESS JUDGMENTS

The instructions given to the outdoor subject group and the ones in the houses who were making noisiness judgments are reproduced in this appendix.

INSTRUCTIONS

The experiment in which you are participating is to help us understand the characteristics of aircraft sounds which cause annoyance in airport communities. We would like you to judge how NOISY some airplane and helicopter sounds are. By noisy, we mean -- UNWANTED, OBJECTIONABLE, DISTURBING, or UNPLEASANT.

The experiment consists of two sessions and each session contains 24 aircraft sounds. A scoring sheet will be provided for each session and will contain scales like the one below for your judgment of each sound:

Not Noisy at all	0	1	2	3	4	5	6	7	8	9	10	Extremely Noisy

After listening to each sound, please indicate how noisy you judge the sound to be by placing a mark across the scale. If you judge a sound to be only slightly noisy, then place your mark closer to the NOT NOISY AT ALL end of the scale. Similarly, if you judge a sound to be very noisy, then place your mark closer to the EXTREMELY NOISY end of the scale. A mark may be placed anywhere along the scale, not just at the numbered locations. You will be instructed when to make your judgment. There are no right or wrong answers; we are only interested in your judgments of each sound.

Thank you for your help in conducting the experiment.

APPENDIX B

INSTRUCTIONS FOR JUDGMENTS OF THE CHARACTERISTICS OF NOISES

The instructions given to the test group who were making judgments of the characteristics of the noises are reproduced in this appendix.

INSTRUCTIONS

The experiment in which you are participating is to help us understand the characteristics of aircraft noise which can cause annoyance in airport communities. We would like you to describe the characteristics of some airplane and helicopter sounds.

The experiment consists of two sessions and each session contains 24 aircraft sounds. In previous experiments, people have used the following words to describe the sound of aircraft: DRONING, BUZZING, SWISHING, THUMPING, SLAPPING, AND HAMMERING. A scoring sheet will be provided for each session and will contain scales like the one below for your judgment of each sound:

	Droning	Buzzing	Swishing	Thumping	Slapping	Hammering	Other
Extremely Noticeable	4	4	4	4	4	4	4
Very Noticeable	3	3	3	3	3	3	3
Moderately Noticeable	2	2	2	2	2	2	2
Slightly Noticeable	1	1	1	1	1	1	1
Not Noticeable	0	0	0	0	0	0	0

We would like you to judge how much droning, buzzing, swishing, thumping, slapping, and hammering is present in each aircraft sound by circling the appropriate number. If you feel that none of these words describe the sound, please enter your own descriptor in the column marked "other."

You will be instructed when to make your judgment. There are no right or wrong answers; we are only interested in your judgment of each sound.

Thank you for your help in conducting the experiment.

APPENDIX C

RATING SHEET USED FOR NOISINESS JUDGMENTS

The rating sheet used by the subjects for noisiness judgments is given in this appendix.

RATING SHEET

Subject ____________________ Session ______________________

Sound													
1	Not Noisy at all	0	1	2	3	4	5	6	7	8	9	10	Extremely Noisy
2	Not Noisy at all	0	1	2	3	4	5	6	7	8	9	10	Extremely Noisy
3	Not Noisy at all	0	1	2	3	4	5	6	7	8	9	10	Extremely Noisy
4	Not Noisy at all	0	1	2	3	4	5	6	7	8	9	10	Extremely Noisy
5	Not Noisy at all	0	1	2	3	4	5	6	7	8	9	10	Extremely Noisy
6	Not Noisy at all	0	1	2	3	4	5	6	7	8	9	10	Extremely Noisy
7	Not Noisy at all	0	1	2	3	4	5	6	7	8	9	10	Extremely Noisy
8	Not Noisy at all	0	1	2	3	4	5	6	7	8	9	10	Extremely Noisy
9	Not Noisy at all	0	1	2	3	4	5	6	7	8	9	10	Extremely Noisy
10	Not Noisy at all	0	1	2	3	4	5	6	7	8	9	10	Extremely Noisy
11	Not Noisy at all	0	1	2	3	4	5	6	7	8	9	10	Extremely Noisy

APPENDIX D

RATING SHEET USED FOR JUDGMENTS OF THE CHARACTERISTICS OF NOISES

The rating sheet used for judging the characteristics of the noises is given in this appendix.

RATING SHEET

Subject ____________________ Session ____________________

Sound 1	Droning	Buzzing	Swishing	Thumping	Slapping	Hammering	Other ____
Extremely Noticeable	4	4	4	4	4	4	4
Very Noticeable	3	3	3	3	3	3	3
Moderately Noticeable	2	2	2	2	2	2	2
Slightly Noticeable	1	1	1	1	1	1	1
Not Noticeable	0	0	0	0	0	0	0

Sound 2	Droning	Buzzing	Swishing	Thumping	Slapping	Hammering	Other ____
Extremely Noticeable	4	4	4	4	4	4	4
Very Noticeable	3	3	3	3	3	3	3
Moderately Noticeable	2	2	2	2	2	2	2
Slightly Noticeable	1	1	1	1	1	1	1
Not Noticeable	0	0	0	0	0	0	0

Sound 3	Droning	Buzzing	Swishing	Thumping	Slapping	Hammering	Other ____
Extremely Noticeable	4	4	4	4	4	4	4
Very Noticeable	3	3	3	3	3	3	3
Moderately Noticeable	2	2	2	2	2	2	2
Slightly Noticeable	1	1	1	1	1	1	1
Not Noticeable	0	0	0	0	0	0	0

Sound 4	Droning	Buzzing	Swishing	Thumping	Slapping	Hammering	Other ____
Extremely Noticeable	4	4	4	4	4	4	4
Very Noticeable	3	3	3	3	3	3	3
Moderately Noticeable	2	2	2	2	2	2	2
Slightly Noticeable	1	1	1	1	1	1	1
Not Noticeable	0	0	0	0	0	0	0

Sound 5	Droning	Buzzing	Swishing	Thumping	Slapping	Hammering	Other ____
Extremely Noticeable	4	4	4	4	4	4	4
Very Noticeable	3	3	3	3	3	3	3
Moderately Noticeable	2	2	2	2	2	2	2
Slightly Noticeable	1	1	1	1	1	1	1
Not Noticeable	0	0	0	0	0	0	0

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TABLE I.- TEST AIRCRAFT CHARACTERISTICS

Characteristic	Helicopter		Airplane
Manufacturer	Bell	Bell	North American
Model	204B	OH-58A	T-28A
Power plant	Lycoming T53	Allison T63	Wright R1300-1
Type	Turboshaft	Turboshaft	7 cylinder radial
Rated output, kw	821 (1100 shp)	236 (317 shp)	597 (800 hp)
Maximum gross weight, kg .	3864	1318	3072
Maximum air speed, m/s . .	62	62	129
Number of blades			
Main rotor	2	2	-----
Tail rotor	2	2	-----
Propeller	-----	-----	2
Diameter, m			
Main rotor	14.63	10.16	-----
Tail rotor	2.59	1.57	-----
Propeller	-----	-----	3.05
Nominal rotor speed, rpm			
Main rotor	324	354	-----
Tail rotor	1662	2624	-----
Propeller	-----	-----	2400
Blade passage frequency, Hz			
Main rotor	10.8	11.8	-----
Tail rotor	55.4	87.5	-----
Propeller	-----	-----	80.0
Tip speed, m/s			
Main rotor	248	188	-----
Tail rotor	225	216	-----
Propeller	-----	-----	383

TABLE II.- SEQUENCE OF FLYOVER EVENTS FOR FIRST EXPERIMENT

Stimulus	Aircraft	Altitude, m	Sideline distance, m	Rotor speed, percent max
1	204B	90	0	91
2	OH-58A	90	0	
3	204B	90	120	96
4	T-28A	270	370	
5	204B	270	370	100
6	OH-58A	90	120	
7	204B	270	0	96
8	T-28A	90	0	
9	204B	90	120	100
10	OH-58A	270	370	
11	204B	270	370	91
12	T-28A	270	0	
13	204B	90	0	100
14	OH-58A	270	0	
15	204B	270	0	91
16	T-28A	90	120	
17	204B	270	370	96
18	OH-58A	90	0	
19	204B	270	0	100
20	T-28A	270	370	
21	204B	90	0	96
22	OH-58A	270	370	
23	204B	90	120	91
24	T-28A	270	0	
25	T-28A	90	120	
26	204B	90	120	91
27	OH-58A	270	0	
28	204B	90	0	96
29	T-28A	270	0	
30	204B	270	0	100
31	OH-58A	270	370	
32	204B	270	370	96
33	T-28A	90	0	
34	204B	270	0	91
35	OH-58A	90	120	
36	204B	90	0	100
37	T-28A	270	370	
38	204B	270	370	91
39	OH-58A	90	0	
40	204B	90	120	100
41	T-28A	90	120	
42	204B	270	0	96
43	OH-58A	270	0	
44	204B	270	370	100
45	T-28A	90	0	
46	204B	90	120	96
47	OH-58A	90	120	
48	204B	90	0	91

TABLE III.- SEQUENCE OF FLYOVER EVENTS FOR SECOND EXPERIMENT

Stimulus	Aircraft	Glide slope, deg	Sideline distance, m
1	204B	3	0
2	OH-58A	6	120
3	204B	6	0
4	OH-58A	0	120
5	204B	0	120
6	OH-58A	3	120
7	204B	0	0
8	OH-58A	3	0
9	204B	6	120
10	OH-58A	0	0
11	204B	3	120
12	OH-58A	6	0
13	OH-58A	6	0
14	204B	3	120
15	OH-58A	0	0
16	204B	6	120
17	OH-58A	3	0
18	204B	0	0
19	OH-58A	3	120
20	204B	0	120
21	OH-58A	0	120
22	204B	6	0
23	OH-58A	6	120
24	204B	3	0

TABLE IV.- MEASURED NOISE LEVELS FOR FIRST EXPERIMENT

Aircraft	Rotor speed, percent maximum	Nominal flight path		Measured flight path		L_A	PNLT	SEL	EPNL	$EPNL'_1$	$EPNL'_2$	ECF_1	ECF_2
		Altitude, m	Sideline distance, m	Altitude, m	Sideline distance, m								
204B	91	90	---	73	0	83.9	98.2	89.5	95.1	99.9	101.2	4.8	6.1
204B	91	90	120	104	146	80.3	93.8	87.2	92.3	95.8	96.7	3.5	4.4
204B	91	270	---	268	13	72.1	86.5	82.6	87.4	92.0	92.8	4.6	5.4
204B	91	270	370	259	411	70.7	84.4	81.4	85.4	87.9	88.5	2.5	3.1
204B	91	90	---	89	27	83.1	98.0	89.8	94.6	99.6	101.6	5.0	7.0
204B	91	90	120	85	146	79.2	94.0	87.3	92.7	96.3	97.4	3.6	4.7
204B	91	270	---	265	18	75.4	91.0	84.2	89.6	93.8	95.5	4.2	5.9
204B	91	270	370	268	402	72.0	86.3	80.5	84.7	87.6	88.9	2.9	4.2
204B	96	90	---	91	18	86.3	99.7	92.0	97.5	102.5	102.8	5.0	5.3
204B	96	90	120	88	139	80.4	94.5	88.2	94.0	97.7	98.2	3.7	4.2
204B	96	270	---	260	115	75.5	88.9	84.2	88.2	92.9	94.5	4.7	6.3
204B	96	270	370	274	411	70.7	85.6	81.4	86.6	89.9	89.8	3.3	3.2
204B	96	90	---	88	4	84.8	97.9	90.3	95.9	100.7	101.0	4.8	5.1
204B	96	90	120	76	132	82.6	96.8	89.5	95.5	99.6	100.2	4.1	4.7
204B	96	270	---	265	7	75.4	92.4	86.1	92.2	97.1	97.0	4.9	4.8
204B	96	270	370	265	404	72.1	86.1	82.3	96.9	90.6	91.0	3.7	4.1
204B	100	90	---	88	0	88.0	102.2	93.8	99.7	104.9	105.4	5.2	5.7
204B	100	90	120	84	132	82.6	99.2	91.9	98.0	102.4	101.8	4.4	3.8
204B	100	270	---	277	11	77.0	92.8	87.5	93.1	97.7	98.8	4.6	5.7
204B	100	270	370	250	426	77.2	93.2	85.1	91.6	95.0	94.2	3.4	2.6
204B	100	90	---	79	18	86.0	101.4	93.6	99.4	104.6	105.8	5.2	6.4
204B	100	90	120	81	128	83.9	101.2	92.5	98.6	103.1	103.3	4.5	4.7
204B	100	270	---	274	13	76.8	90.3	85.5	90.5	95.0	95.8	4.5	5.3
204B	100	270	370	259	377	78.7	94.3	87.8	94.1	98.7	98.5	4.6	4.4
OH-58A	---	90	---	82	5	81.2	94.8	86.1	89.7	91.4	90.8	1.7	1.1
OH-58A	---	90	120	87	144	76.8	89.1	83.1	86.1	87.6	88.4	1.5	2.3
OH-58A	---	270	---	284	64	73.1	86.9	81.1	84.5	86.5	86.4	2.0	1.9
OH-58A	---	270	370	300	329	68.5	81.6	77.8	80.7	81.3	81.8	0.6	1.1
OH-58A	---	90	---	97	36	79.1	93.7	85.4	89.2	90.5	90.9	1.3	1.7
OH-58A	---	90	120	71	27	82.3	96.0	86.9	90.4	92.0	92.9	1.6	2.5
OH-58A	---	270	---	274	4	70.7	83.9	80.0	83.2	84.9	85.3	1.7	2.1
OH-58A	---	270	370	277	311	68.3	80.2	77.4	80.0	80.8	81.4	0.8	1.4
OH-58A	---	90	---	85	7	80.9	94.3	85.4	89.1	90.3	90.0	1.2	0.9
OH-58A	---	90	120	88	111	76.8	90.2	83.0	85.8	86.7	87.4	0.9	1.6
OH-58A	---	270	---	284	0	72.8	85.8	80.4	83.4	85.1	84.7	1.7	1.3
OH-58A	---	270	370	286	366	69.5	81.6	76.2	78.5	79.6	80.7	1.1	2.2
T-28A	---	90	---	85	15	95.5	110.9	99.2	104.5	105.6	108.1	1.1	3.6
T-28A	---	90	120	73	128	94.1	109.1	98.6	103.1	105.9	107.3	2.8	4.2
T-28A	---	270	---	244	73	89.2	103.3	96.3	100.6	103.0	104.7	2.4	4.1
T-28A	---	270	370	279	404	84.3	97.5	91.3	94.3	97.5	97.6	3.2	3.3
T-28A	---	90	---	78	24	97.6	112.6	100.5	105.6	107.1	110.0	1.5	4.4
T-28A	---	90	120	76	126	95.4	110.1	99.2	103.5	106.6	108.8	3.1	5.3
T-28A	---	270	---	265	16	86.2	100.6	93.1	97.2	99.1	101.9	1.9	4.7
T-28A	---	270	370	278	419	82.8	96.6	89.3	92.3	94.9	95.4	2.6	3.1
T-28A	---	90	---	76	24	99.5	115.3	102.9	107.4	109.0	111.0	1.6	3.6
T-28A	---	90	120	67	135	95.8	110.5	99.9	104.6	107.4	108.9	2.8	4.3
T-28A	---	270	---	264	37	85.6	100.4	93.5	97.7	99.7	101.7	2.0	4.0
T-28A	---	270	370	261	432	84.5	96.5	91.3	94.0	97.5	98.2	3.5	4.2

TABLE V.- MEASURED NOISE LEVELS FOR SECOND EXPERIMENT

Aircraft	Nominal flight path		Measured flight path		L_A	PNLT	SEL	EPNL	$EPNL'_1$	$EPNL'_2$	ECF_1	ECF_2
	Descent angle, deg	Sideline distance, m	Altitude, m	Sideline distance, m								
204B	0	---	124	16	87.4	104.1	95.1	101.2	106.5	106.7	5.3	5.5
204B	0	120	76	121	90.8	105.5	95.0	100.2	105.6	106.5	5.4	6.3
204B	0	---	67	64	88.0	103.6	93.8	99.7	104.1	103.8	4.4	4.1
204B	0	120	87	110	86.2	101.3	91.8	96.9	101.8	101.8	4.9	4.9
204B	3	---	49	27	100.4	113.6	101.7	105.4	110.9	115.3	5.5	9.9
204B	3	120	58	108	85.5	100.4	93.1	98.2	103.0	103.4	4.8	5.2
204B	3	---	87	110	103.0	116.7	100.9	106.4	111.9	117.7	5.5	11.3
204B	3	120	76	130	87.8	102.5	94.4	99.4	104.6	107.4	5.2	8.0
204B	6	---	79	18	85.7	99.7	92.8	97.5	102.1	102.0	4.6	4.5
204B	6	120	46	126	81.6	95.9	90.3	95.7	99.0	98.0	3.3	2.8
204B	6	---	65	22	88.5	102.6	93.4	98.3	103.0	102.7	4.7	4.4
204B	6	120	50	100	81.6	96.2	89.8	94.5	97.9	97.9	3.4	3.4
OH-58A	0	---	81	0	81.9	95.0	85.3	88.9	90.3	91.8	1.4	2.9
OH-58A	0	120	84	128	77.3	90.3	83.7	86.8	88.4	89.5	1.6	2.7
OH-58A	0	---	76	36	80.7	94.1	85.6	89.2	90.7	91.0	1.5	1.8
OH-58A	0	120	88	137	76.2	89.4	83.5	86.6	88.6	89.2	2.0	2.6
OH-58A	3	---	123	0	80.7	95.0	86.9	90.6	94.3	96.4	3.7	5.8
OH-58A	3	120	125	119	73.7	88.2	81.9	85.5	87.5	89.5	2.0	4.0
OH-58A	3	---	70	22	80.5	94.5	86.1	89.8	93.9	97.1	4.1	7.3
OH-58A	3	120	80	126	74.5	88.6	82.5	86.1	89.4	93.3	3.3	7.2
OH-58A	6	---	61	16	85.3	97.8	88.4	91.8	95.7	97.0	3.9	5.2
OH-58A	6	120	48	126	-----	-----	-----	-----	-----	-----	---	---
OH-58A	6	---	76	63	81.1	94.5	86.7	90.3	93.6	94.5	3.3	4.2
OH-58A	6	120	79	132	73.4	86.7	81.8	85.2	86.4	87.4	1.2	2.2

TABLE VI.- SUBJECTIVE JUDGMENTS OF NOISINESS AND IMPULSIVENESS FOR FIRST EXPERIMENT

Aircraft	Rotor speed, percent max	Nominal flight path		Noisiness						Impulsiveness, SJI, percent
				Outdoor group		Indoor/brick		Indoor/frame		
		Altitude, m	Sideline distance, m	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	
204B	91	90	---	3.83	2.14	3.29	1.65	2.53	1.64	40
		90	120	3.59	1.47	2.42	1.19	3.84	2.36	10
		270	---	1.78	1.11	1.23	.58	1.51	1.27	5
		270	370	1.18	.83	1.14	.69	1.85	1.28	0
		90	---	6.12	1.79	4.42	2.18	2.77	1.74	50
		90	120	3.96	1.58	1.86	1.06	2.69	1.80	15
		270	---	2.36	1.50	1.98	.84	1.50	1.04	15
		270	370	1.46	1.00	.49	.56	1.09	.72	0
204B	96	90	---	6.22	1.93	4.10	1.50	3.63	1.71	70
		90	120	3.40	1.72	3.93	1.59	4.04	1.67	40
		270	---	2.14	.94	1.72	.92	2.68	1.79	15
		270	370	1.54	1.22	1.26	.95	1.90	.99	10
		90	---	5.30	1.87	3.33	1.15	4.14	1.99	50
		90	120	5.51	2.00	4.27	2.14	4.21	2.14	35
		270	---	2.36	1.43	2.33	1.08	1.38	.80	5
		270	370	1.46	.82	.72	.79	1.85	1.02	0
204B	100	90	---	6.21	1.84	4.81	2.05	4.01	2.27	70
		90	120	5.58	2.00	5.03	1.63	5.31	2.15	60
		270	---	3.02	1.45	2.49	1.33	2.19	1.27	20
		270	370	2.03	1.38	2.45	1.07	3.43	2.00	15
		90	---	7.40	1.98	5.18	2.05	5.40	2.08	85
		90	120	6.64	2.05	5.56	1.85	4.85	1.86	55
		270	---	2.71	1.45	1.76	1.04	1.83	.91	20
		270	370	3.56	1.95	3.01	1.76	2.33	1.81	20
OH-58A	---	90	---	3.00	1.45	2.71	1.42	3.26	1.96	5
		90	120	2.73	1.57	1.73	.90	4.08	2.01	0
		270	---	1.63	1.48	1.10	.94	1.51	1.13	0
		270	370	1.36	1.04	.73	.75	2.26	2.40	0
		90	---	3.80	1.55	3.66	1.10	3.22	1.92	0
		90	120	5.34	1.70	3.31	1.40	3.99	2.21	10
		270	---	1.74	1.15	.88	.65	1.43	.84	0
		270	370	1.55	1.08	.32	.36	1.10	.69	0
		90	---	3.91	1.84	2.53	1.26	2.40	1.34	10
		90	120	3.51	1.55	1.71	1.15	2.35	1.56	5
		270	---	1.81	1.31	1.46	1.00	1.39	.79	0
		270	370	1.38	1.03	.18	.32	.79	.56	0
T-28A	---	90	---	8.20	1.77	5.78	1.69	6.21	2.07	30
		90	120	7.91	1.58	5.52	1.42	6.23	2.14	55
		270	---	7.08	2.05	3.84	1.38	3.78	2.47	30
		270	370	3.80	1.88	2.47	.89	3.65	1.46	20
		90	---	9.10	1.80	5.80	1.72	6.65	2.29	30
		90	120	7.75	1.68	2.95	1.41	4.45	2.22	65
		270	---	5.94	1.85	3.49	1.70	4.14	2.09	10
		270	370	4.24	1.51	2.16	.93	3.03	1.54	20
		90	---	9.51	.86	6.64	1.66	6.27	2.23	45
		90	120	8.86	1.49	5.36	1.98	6.65	2.14	50
		270	---	6.19	1.68	2.66	1.13	3.90	1.51	5
		270	370	4.23	1.63	1.96	1.12	1.67	.83	15

TABLE VII.- SUBJECTIVE JUDGMENTS OF NOISINESS AND IMPULSIVENESS

FOR SECOND EXPERIMENT

Aircraft type	Nominal flight path		Noisiness		Impulsiveness, SJI, percent
	Descent angle, deg	Sideline distance, m	Mean	Standard deviation	
204B	0	---	7.96	1.73	83.7
	0	120	6.60	2.24	85.7
	0	---	7.38	1.91	77.5
	0	120	6.12	1.96	73.5
	3	---	8.11	2.05	89.8
	3	120	6.46	1.98	75.5
	3	---	9.33	1.49	93.9
	3	120	6.45	2.10	79.6
	6	---	6.49	1.95	61.2
	6	120	5.52	1.78	32.6
	6	---	6.97	2.01	55.1
	6	120	4.87	1.61	16.3
OH-58A	0	---	5.21	2.03	16.3
	0	120	3.50	1.54	4.1
	0	---	4.42	1.78	6.1
	0	120	3.98	1.95	8.2
	3	---	4.46	2.01	24.5
	3	120	2.87	1.21	12.2
	3	---	3.82	1.66	32.6
	3	120	3.15	1.74	30.6
	6	---	4.46	1.67	16.3
	6	120	2.76	1.35	8.2
	6	---	3.29	1.46	14.3
	6	120	2.70	1.44	6.1

TABLE VIII.- REGRESSION ANALYSES OF OUTDOOR SSV ON EPNL

Aircraft type	Number of stimuli	Intercept	Slope	Standard error of slope	Correlation coefficient	Standard error of estimate
First experiment						
204B	24	-33.17	0.398	0.034	0.928	0.735
OH-58A	12	-20.95	.277	.049	.874	.654
T-28A	12	-31.77	.385	.022	.984	.370
204B/OH-58A	36	-21.09	.271	.029	.849	.961
All aircraft	48	-24.93	.315	.018	.929	.898
Second experiment						
204B	12	-24.84	0.319	0.037	0.940	0.413
OH-58A	11	-16.14	.226	.086	.661	.619
204B/OH-58A	23	-20.65	.277	.017	.961	.521
First and second experiments combined						
204B	36	-34.20	0.411	0.022	0.955	0.684
OH-58A	23	-21.49	.285	.037	.861	.627
204B/OH-58A	59	-23.10	.297	.019	.896	.921
All aircraft	71	-24.16	.309	.015	.926	.866

TABLE IX.- CORRELATION MATRICES FOR FIRST EXPERIMENT

	SSV outdoor	SSV indoor/brick	SSV indoor/frame	L_A	PNLT	SEL	EPNL	$EPNL_1'$	$EPNL_2'$	ECF_1
204B										
SSV indoor/brick	0.928									
SSV indoor/frame	.814	0.853								
L_A	.933	.895	0.793							
PNLT	.938	.938	.797	0.976						
SEL	.952	.946	.820	.968	0.983					
EPNL	.928	.945	.815	.953	.984	0.992				
$EPNL_1'$	.923	.933	.775	.947	.977	.989	0.994			
$EPNL_2'$	.933	.921	.745	.955	.974	.985	.978	0.990		
ECF_1	.630	.549	.315	.646	.660	.690	.676	.752	0.779	
ECF_2	.441	.314	.045	.438	.398	.413	.350	.427	.536	0.770
OH-58A										
SSV indoor/brick	0.884									
SSV indoor/frame	.755	0.784								
L_A	.906	.924	0.783							
PNLT	.901	.946	.770	0.994						
SEL	.890	.946	.806	.979	0.987					
EPNL	.874	.949	.792	.970	.982	0.998				
$EPNL_1'$	.846	.936	.772	.961	.974	.992	0.996			
$EPNL_2'$	.889	.943	.813	.966	.976	.992	.991	0.992		
ECF_1	.130	.303	.166	.360	.377	.405	.423	.504	0.465	
ECF_2	.152	-.012	.193	.008	-.007	-.003	-.022	.013	.107	0.346
All Aircraft										
SSV indoor/brick	0.903									
SSV indoor/frame	.884	0.888								
L_A	.958	.868	0.869							
PNLT	.958	.898	.875	0.991						
SEL	.951	.879	.860	.979	0.988					
EPNL	.929	.898	.851	.952	.975	0.988				
$EPNL_1'$	.875	.874	.791	.897	.928	.952	0.983			
$EPNL_2'$	.891	.867	.794	.909	.937	.961	.985	0.995		
ECF_1	.055	.204	-.008	.056	.110	.171	.278	.447	0.411	
ECF_2	.354	.369	.210	.339	.379	.440	.512	.634	.651	0.833

TABLE X.- CORRELATION MATRICES FOR SECOND EXPERIMENT

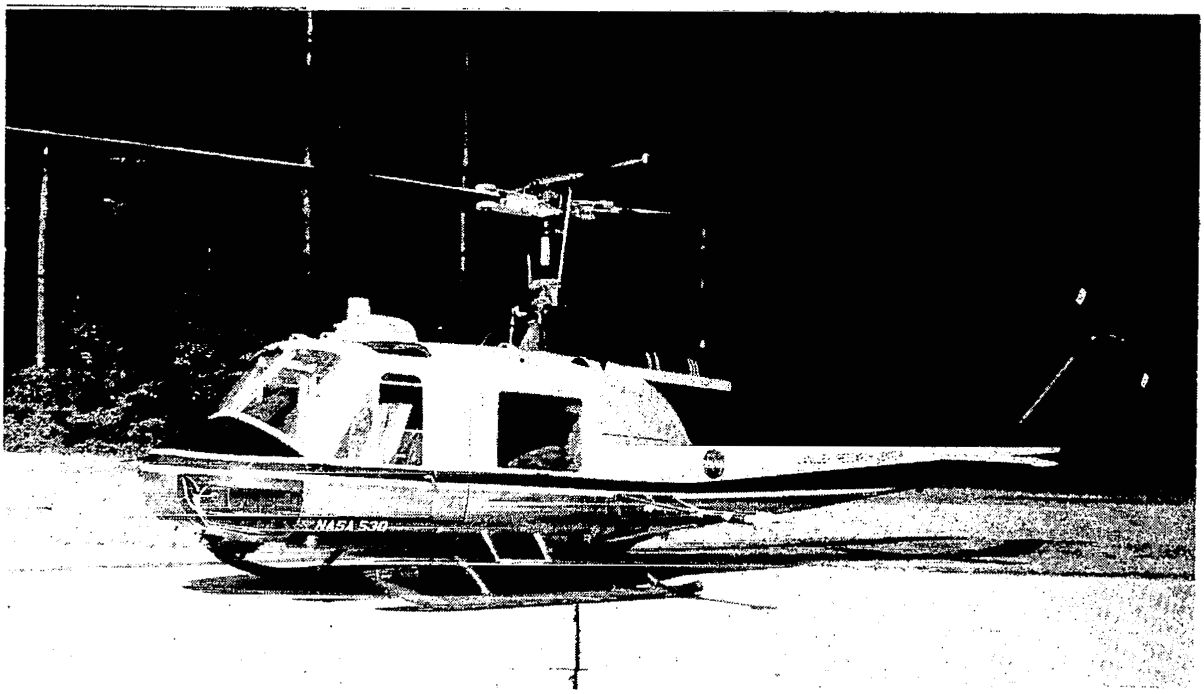
	SSV outdoor	L_A	PNLT	SEL	EPNL	$EPNL_1'$	$EPNL_2'$	ECF_1
204B								
L_A	0.870							
PNLT	.909	0.991						
SEL	.889	.973	0.974					
EPNL	.940	.959	.978	0.985				
$EPNL_1'$	.935	.950	.973	.980	0.994			
$EPNL_2'$	.887	.966	.975	.982	.983	0.982		
ECF_1	.747	.736	.777	.776	.788	.850	0.802	
ECF_2	.767	.923	.916	.924	.905	.911	.968	0.776
OH-58A								
L_A	0.773							
PNLT	.764	0.988						
SEL	.669	.966	0.974					
EPNL	.661	.959	.978	0.996				
$EPNL_1'$	.515	.867	.906	.950	0.960			
$EPNL_2'$	.403	.723	.787	.816	.841	0.949		
ECF_1	.083	.451	.522	.606	.627	.819	0.902	
ECF_2	-.061	.152	.243	.272	.312	.547	.776	0.886
All aircraft								
L_A	0.915							
PNLT	.944	0.992						
SEL	.952	.958	0.977					
EPNL	.961	.935	.965	0.994				
$EPNL_1'$	.947	.926	.958	.990	0.996			
$EPNL_2'$	.922	.948	.970	.978	.973	0.979		
ECF_1	.798	.791	.833	.870	.878	.918	0.911	
ECF_2	.557	.714	.709	.658	.625	.658	.789	0.739

TABLE XI.- CORRELATION MATRICES FOR FIRST AND SECOND EXPERIMENTS COMBINED

	SSV outdoor	L_A	PNLT	SEL	EPNL	$EPNL_1'$	$EPNL_2'$	ECF_1
				204B				
L_A	0.928							
PNLT	.942	0.989						
SEL	.959	.976	0.985					
EPNL	.955	.960	.980	0.992				
$EPNL_1'$	.948	.956	.977	.988	0.996			
$EPNL_2'$	.923	.971	.980	.979	.973	0.981		
ECF_1	.667	.694	.712	.718	.720	.780	0.790	
ECF_2	.515	.677	.648	.610	.566	.606	.738	0.731
				OH-58A				
L_A	0.883							
PNLT	.887	0.991						
SEL	.869	.974	0.985					
EPNL	.861	.964	.982	0.998				
$EPNL_1'$	.812	.932	.953	.977	0.981			
$EPNL_2'$	.800	.872	.899	.925	.931	0.975		
ECF_1	.353	.492	.514	.562	.568	.717	0.795	
ECF_2	.338	.320	.353	.385	.396	.547	.705	0.893
				All aircraft				
L_A	0.945							
PNLT	.952	0.991						
SEL	.944	.972	0.984					
EPNL	.927	.945	.970	0.990				
$EPNL_1'$	.886	.906	.936	.962	0.986			
$EPNL_2'$	.893	.922	.946	.964	.979	0.990		
ECF_1	.288	.308	.349	.390	.467	0.609	0.587	
ECF_2	.443	.499	.511	.515	.542	.636	.702	0.789

TABLE XII.- MULTIPLE REGRESSION ANALYSES

Impulsiveness factor	Number of stimuli	Intercept	Regression coefficient for EPNL	Standard error of regression coefficient for EPNL	Regression coefficient for impulsiveness factor	Standard error of regression coefficient for impulsiveness factor	Correlation coefficient	Standard error of estimate
First experiment								
ECF_1	24	-33.10	0.397	0.047	0.011	0.285	0.928	0.752
ECF_2	24	-32.45	.378	.035	.232	.143	.936	.710
SJI	24	-16.47	.206	.063	.038	.011	.954	.606
Second experiment								
ECF_1	12	-24.50	0.314	0.063	0.028	0.297	0.940	0.454
ECF_2	12	-37.74	.461	.074	-.215	.101	.960	.371
SJI	12	-22.50	.292	.064	.005	.009	.942	.448
First and second experiments combined								
ECF_1	36	-34.88	0.423	0.032	-0.120	0.217	0.955	0.691
ECF_2	36	-34.81	.420	.027	-.047	.080	.955	.691
SJI	36	-22.37	.275	.050	.025	.009	.964	.618



L-73-6372

Figure 1.- 204B helicopter.

L-73-6306

Figure 2.- OH-58A helicopter.

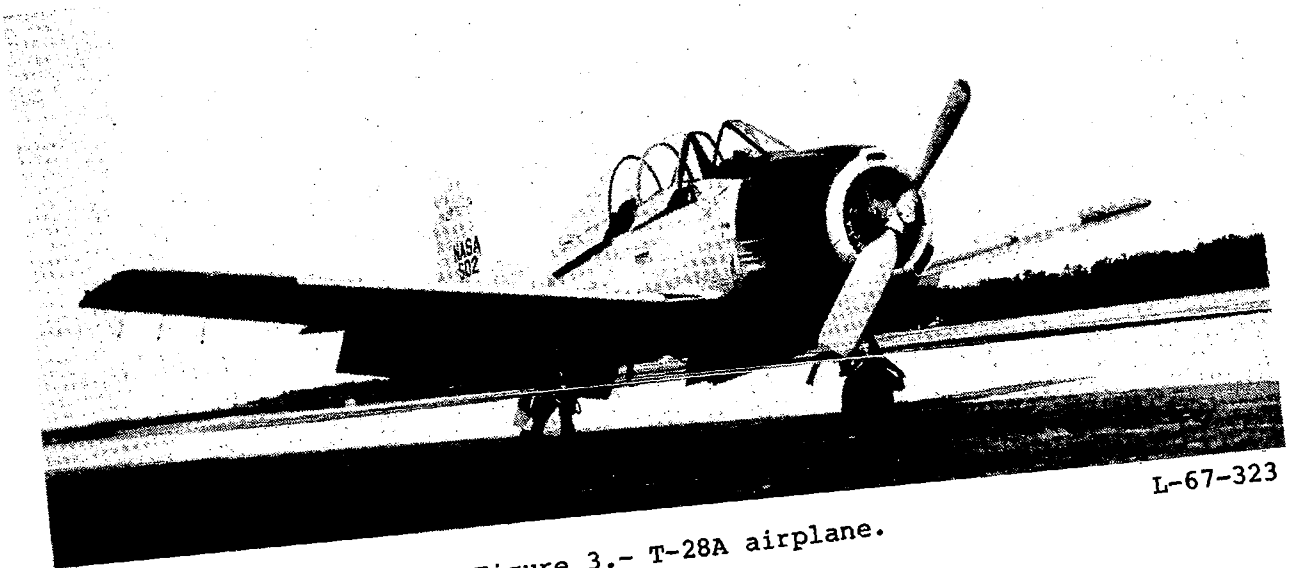


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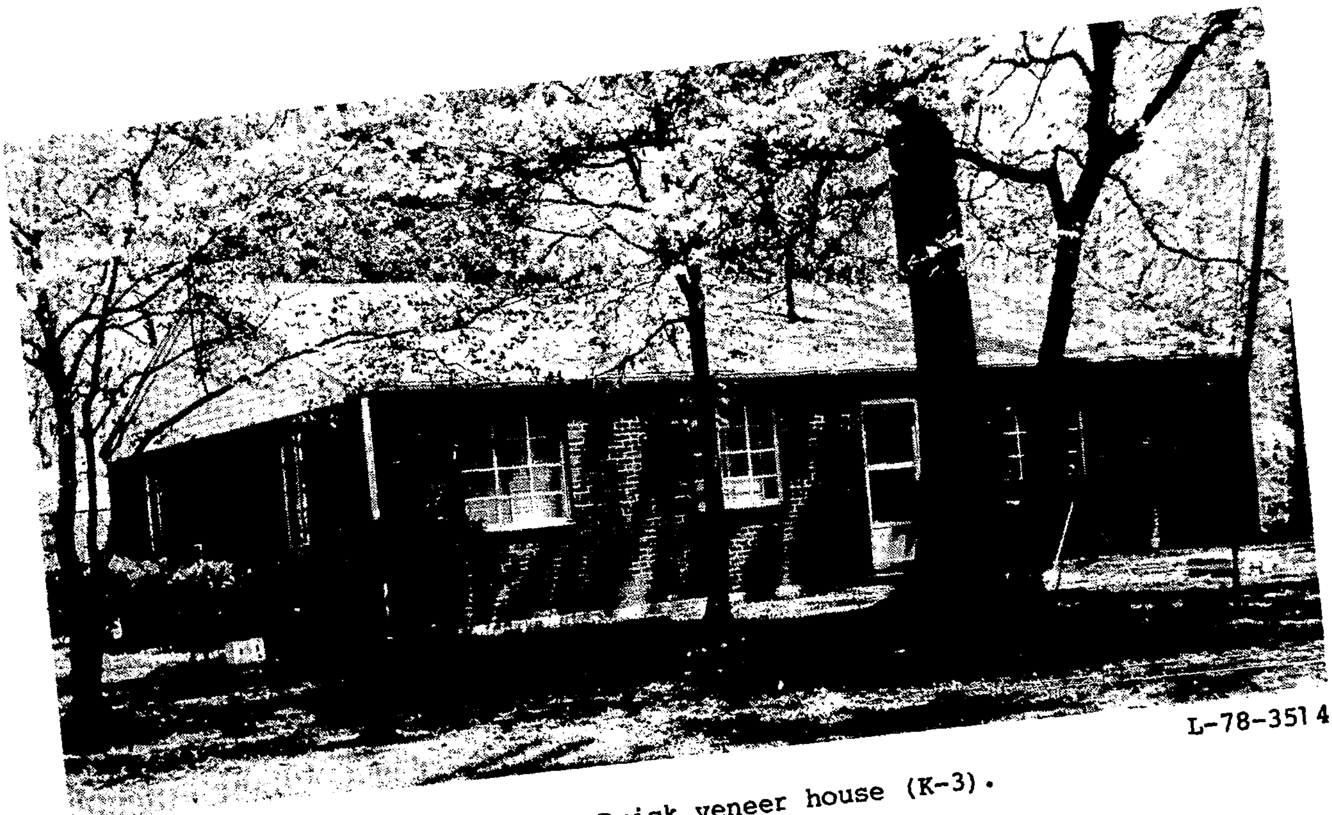
Figure 3.- T-28A airplane.



L-78-3514

Figure 4.- Brick veneer house (K-3).

L-78-3507

Figure 5.- Frame house (K-25).

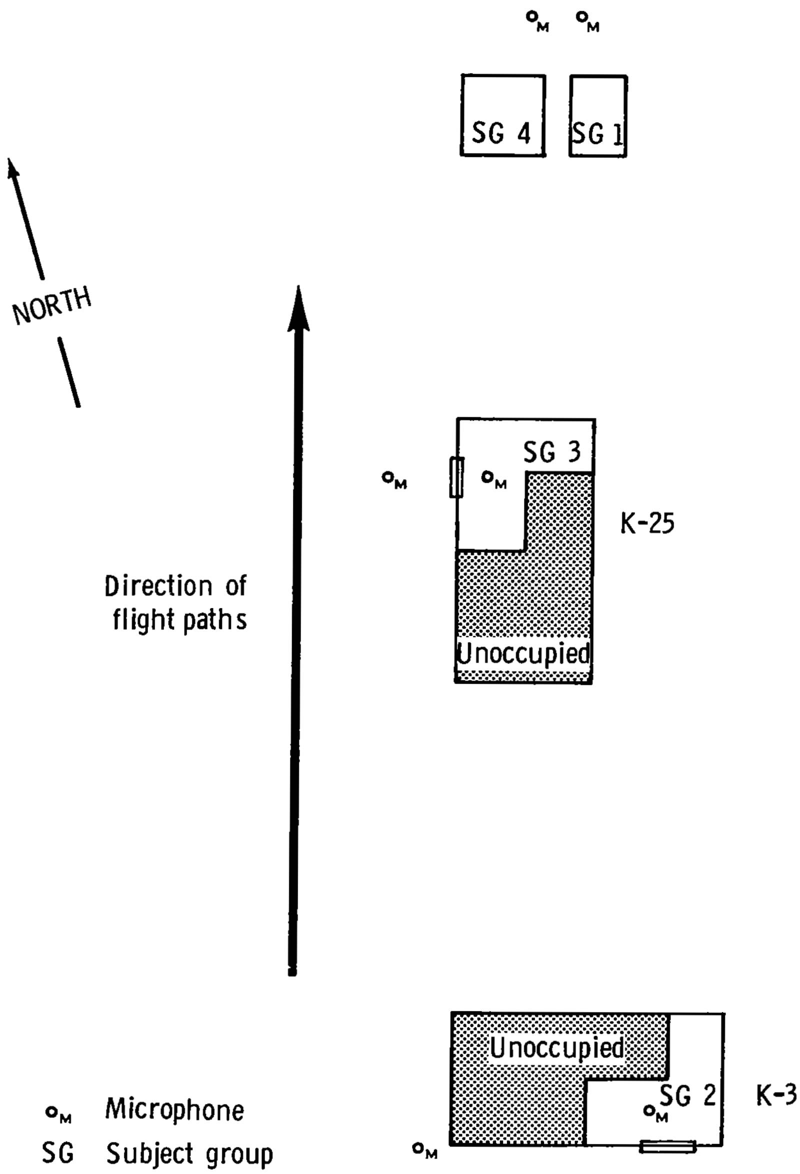


Figure 6.- Orientation of houses and outdoor subject groups to flight paths of first experiment.

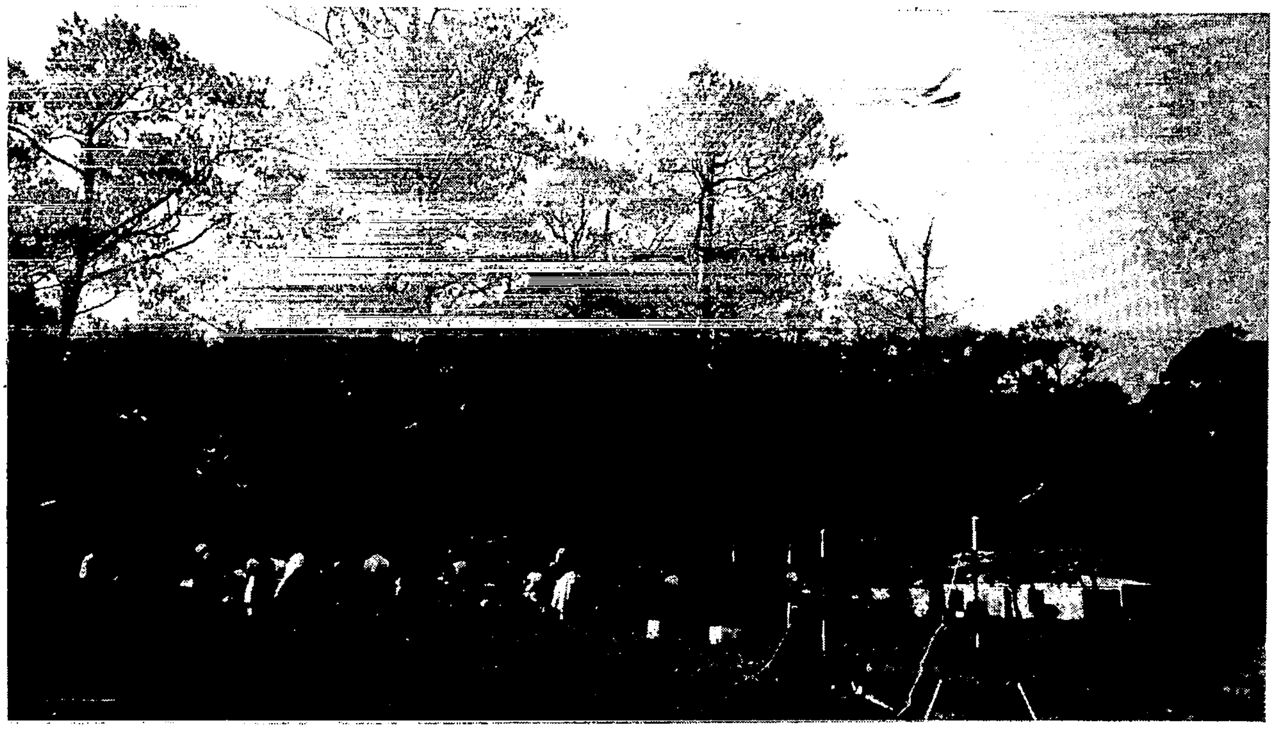


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Figure 7.- Outdoor test subjects and house K-25.

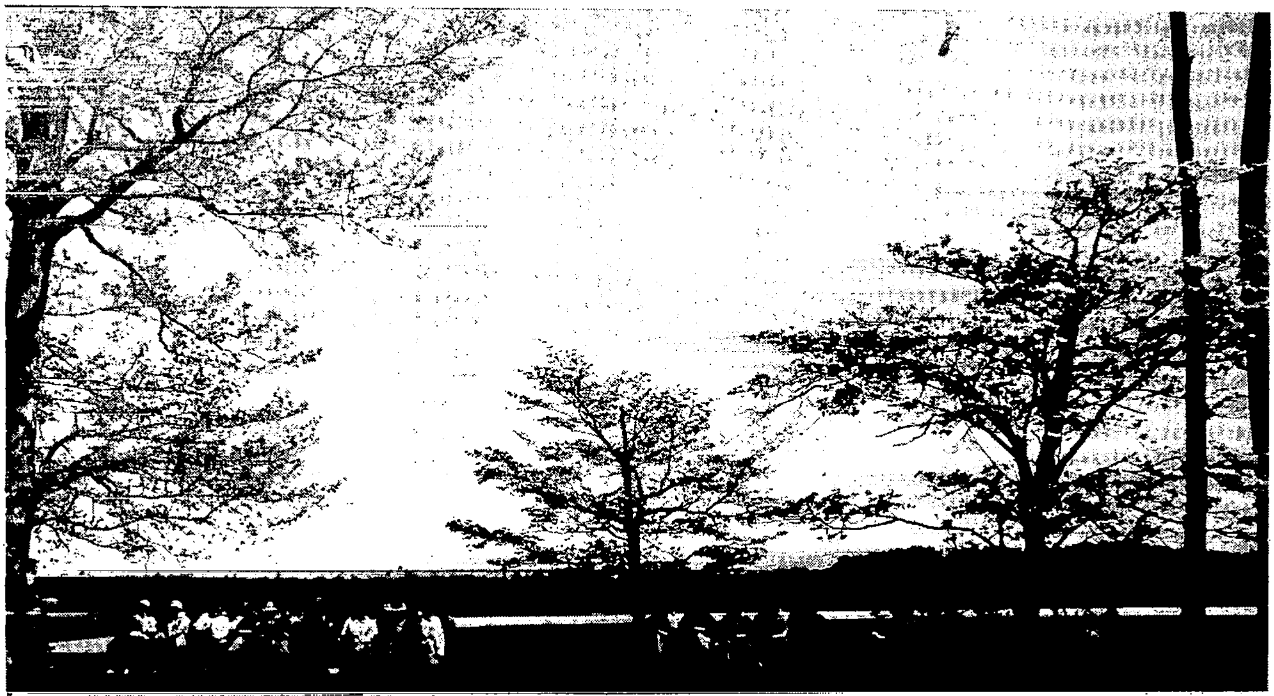

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Figure 8.- Outdoor test subjects and east-west runway.

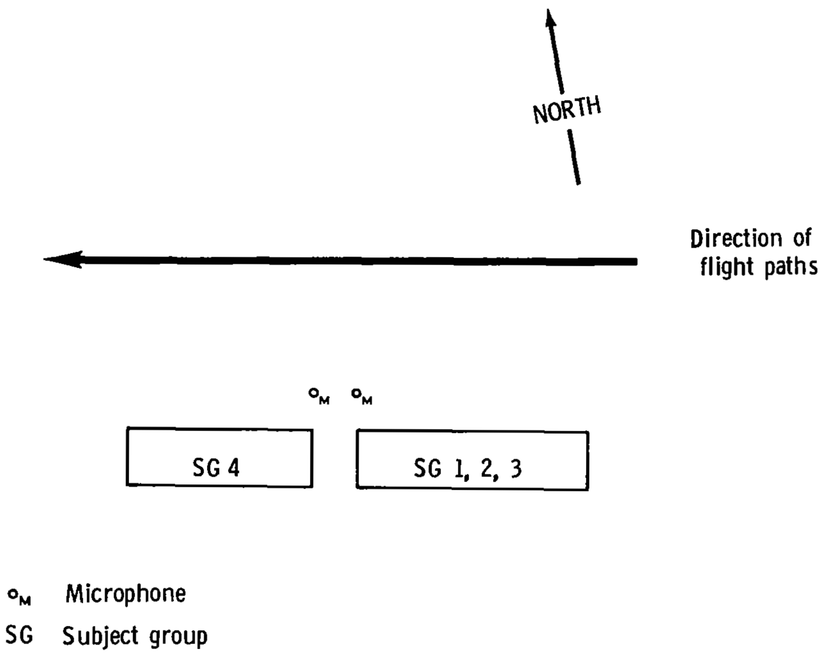

Figure 9.- Orientation of subject groups and flight paths for second experiment.

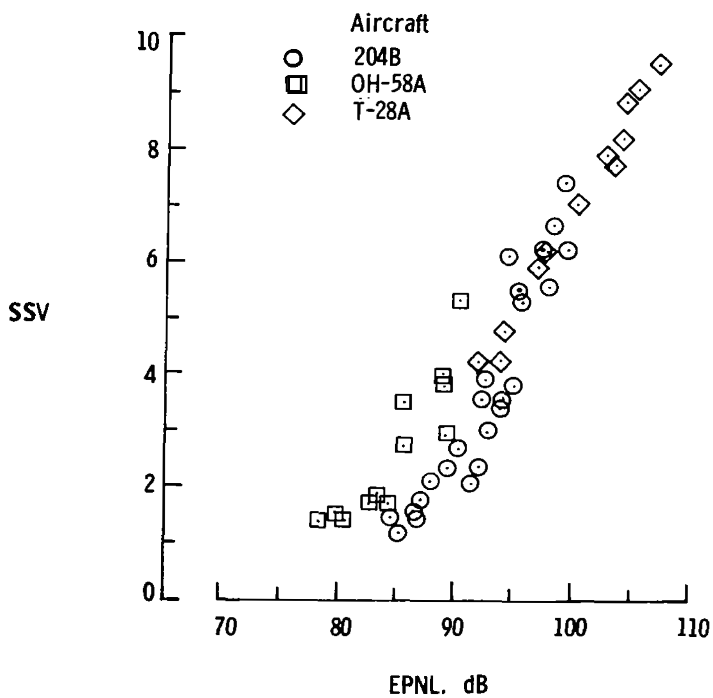

Figure 10.- Mean of subjective noisiness judgments (SSV) for outdoor subject group, first experiment.

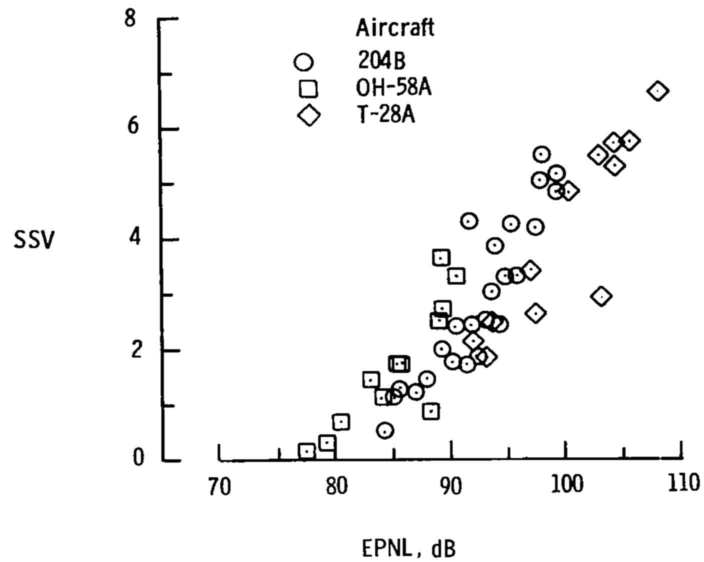

Figure 11.- Mean of subjective noisiness judgments (SSV) for subject group in brick house.

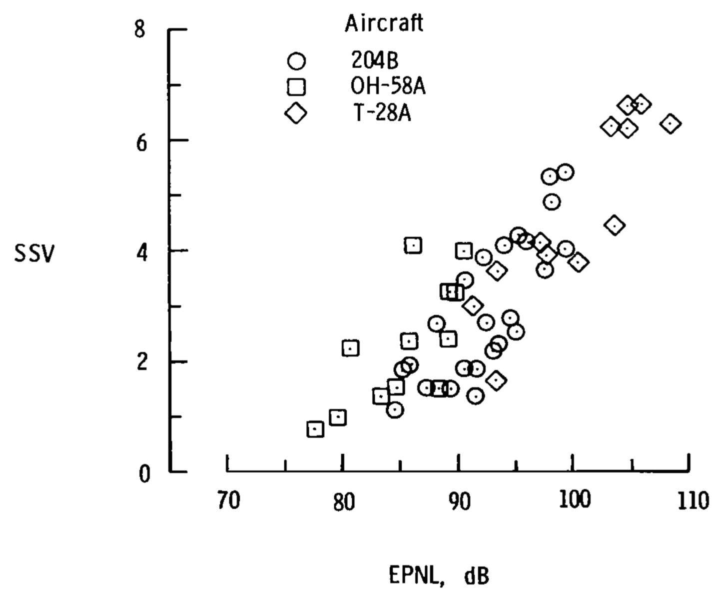

Figure 12.- Mean of subjective noisiness judgments (SSV) for subject group in frame house.

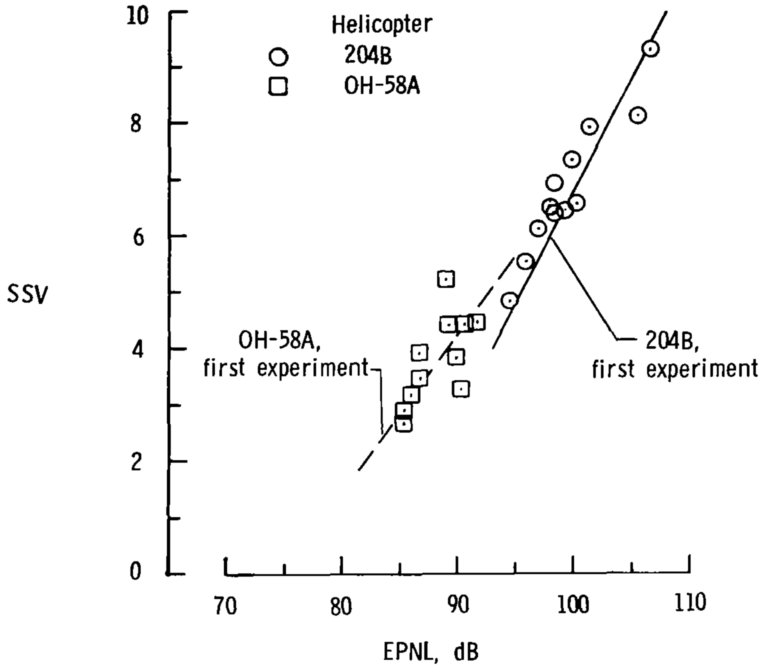

Figure 13.- Mean of subjective noisiness judgments (SSV) for second experiment.

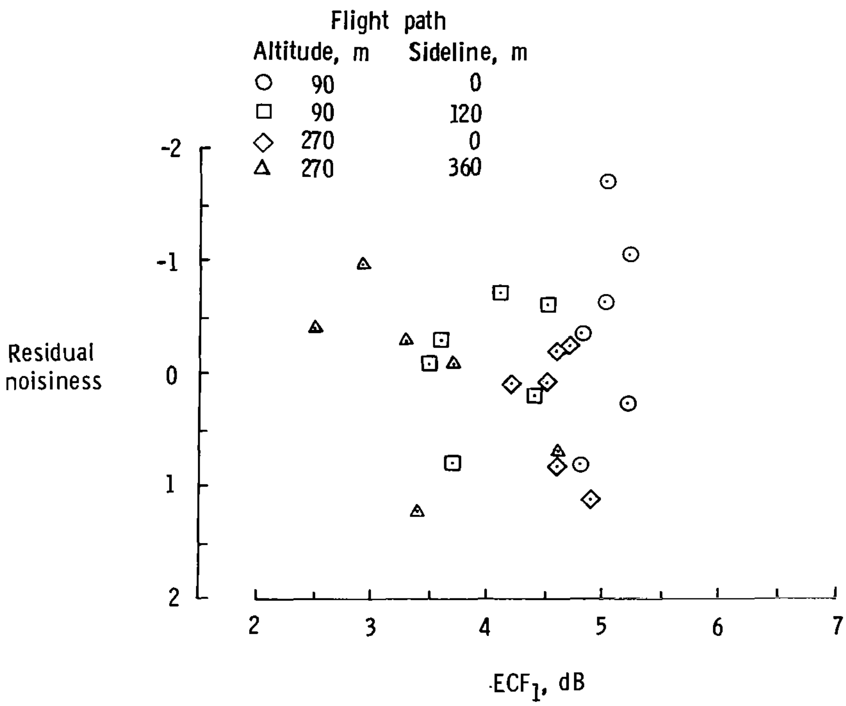

Figure 14.- Effect of impulsiveness, measured in ECF_1, on residual noisiness.

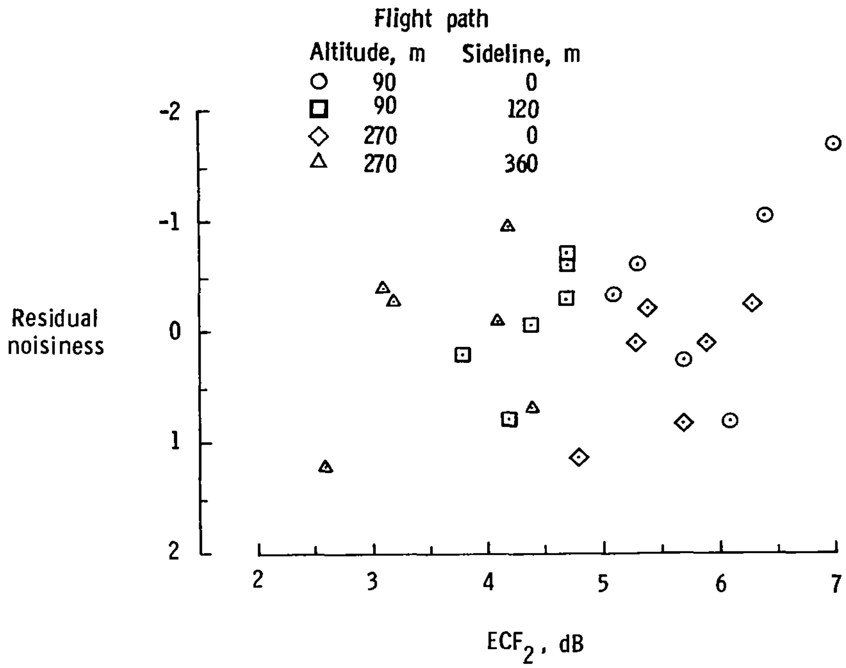

Figure 15.- Effect of impulsiveness, measured in ECF_2, on residual noisiness.

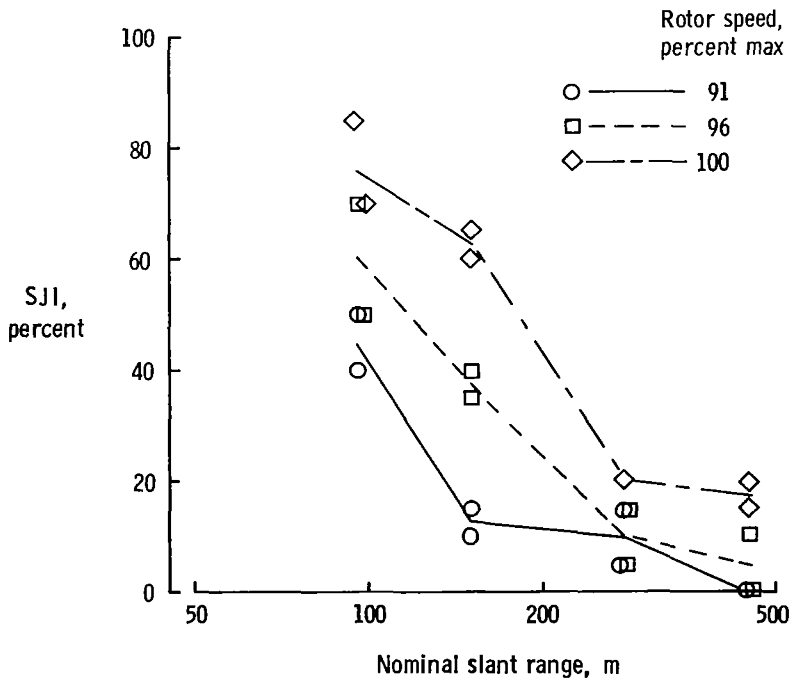

Figure 16.- Effect of flight conditions on subjective judgments of impulsiveness (SJI).

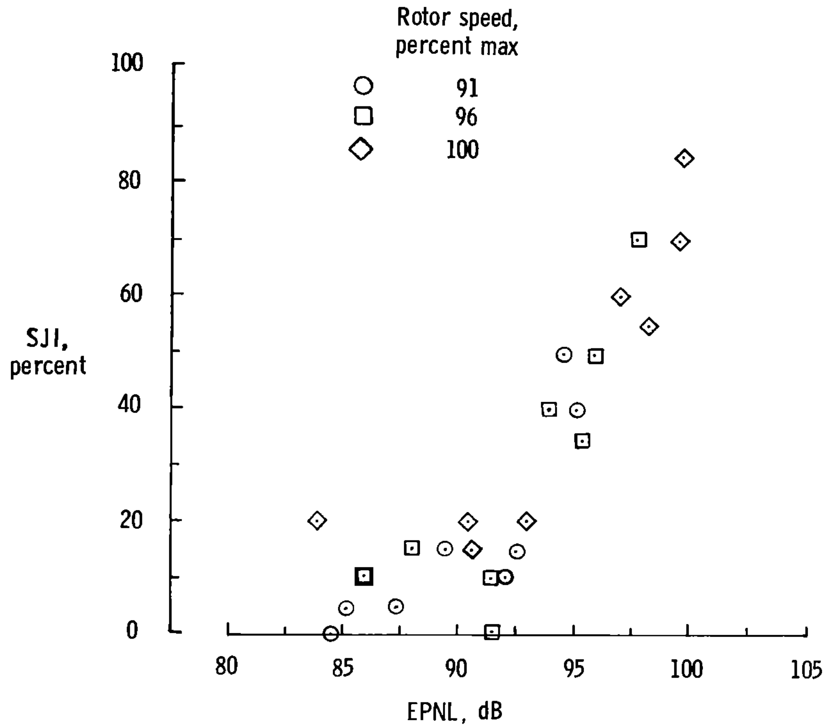

Figure 17.- Effect of noise level in EPNL on subjective judgments of impulsiveness (SJI).

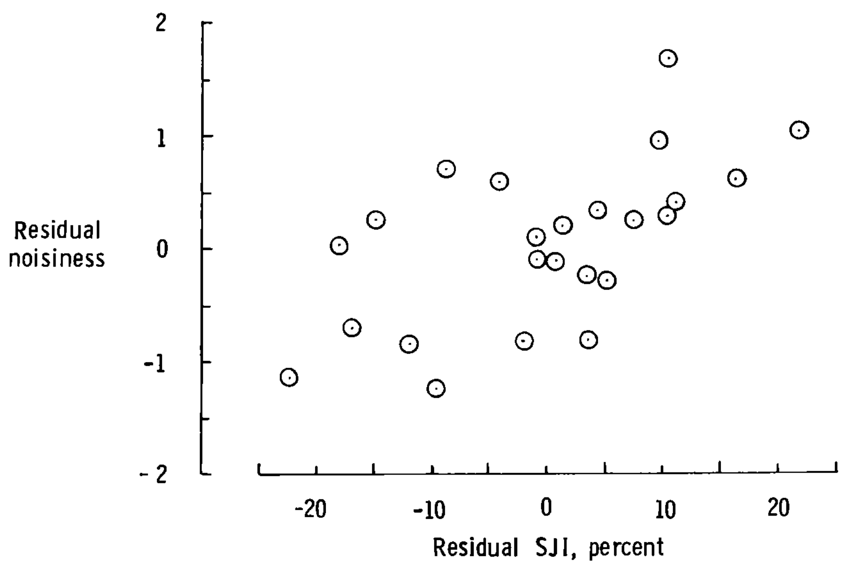

Figure 18.- Effect of residual judged impulsiveness on residual noisiness.

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15. Supplementary Notes

16. Abstract

Two experiments were conducted in which subjects, located outdoors and indoors, judged the noisiness and other subjective noise characteristics of flyovers of two helicopters and a propeller-driven airplane. The purpose of the study was to examine the effects of impulsiveness on the subjective response to helicopter noise. In the first experiment, the impulsive characteristics of one helicopter was controlled by varying the main rotor speed while maintaining a constant airspeed in level flight. The second experiment which utilized only the helicopters, included descent and level flight operations. The more impulsive helicopter was consistently judged less noisy than the less impulsive helicopter at equal effective perceived noise levels (EPNL). The ability of EPNL to predict noisiness was not improved by the addition of either of two proposed impulse corrections. A subjective measure of impulsiveness, however, which was not significantly related to the proposed impulse corrections, was found to improve the predictive ability of EPNL.

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