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SUMMARY

Two experiments were conducted in which subjects in a simulated living-room environment judged the annoyance of nine primary and two reference sessions of airplane noise which contained different noise levels and numbers of flyovers. For the primary sessions in the first experiment, 1, 2, or 4 high-noise-level flyovers occurred at the beginning, middle, or end of 30-minute test sessions containing a total of 8 flyovers. The reference sessions also contained 8 flyovers, but all flyovers in a session were either at the high or low noise level. For the primary sessions in the second experiment, 1, 4, or 16 flyover noises, all at fixed noise levels, occurred in 15-, 30-, or 60-minute test sessions. The reference sessions for this experiment were each of 15 minutes duration and contained 8 flyovers, with all flyovers in each session at either a higher or lower noise level than for the primary sessions. Results indicated that annoyance response was not dependent on when in the sessions high-noise-level flyover occurred, but annoyance response increased with the number of high-noise-level flyovers. Thus, neither an "annoyance decay model" nor the "dB(A) peak concept" could be supported. Results also indicated that annoyance was proportional to the rate of flyovers, in that annoyance decreased with session duration but increased with the total number of flyovers. Thus an "average energy model" rather than a "total energy model," or the dB(A) peak concept, could be supported. The number effect, however, was somewhat greater than the 3 dB per doubling of number trade-off predicted by an average energy model.

INTRODUCTION

Community annoyance due to aircraft flyover noise exposure is generally considered to depend on the number of flight operations in the community as well as the noise levels of the operations. Although numerous social survey studies have been conducted to determine the relationships of annoyance and noise exposure, the relationship of annoyance to the number of events has remained relatively unresolved.

A number of different models of annoyance to multiple events have been proposed. The U.S. Environmental Protection Agency (ref. 1) suggested that an "equivalent energy" method be used to account for noise level and number. (A doubling of the number of events equated to a 3-dB increase in level.) The "dB(A) peak concept" first proposed in reference 2 suggested that annoyance is proportional to the peak level of the noisiest aircraft, with provisos that the total number of aircraft and the number of the noisiest aircraft exceed certain minima. This model has been subsequently revised (refs. 3 through 5) into an interactive number and level model in which, for greater than 50 events per day, annoyance increases with peak noise level, but for lesser numbers of events, annoyance is proportional to the product of number and level.

In a reanalysis of several community surveys (ref. 6), the effects of number of aircraft and other noise events were examined for the possibility of a trading relationship between level and number. Annoyance was found in each survey investigated to increase with increased numbers of flyovers per unit of time; thus, the general trend does not support the dB(A) peak concept. The level and number trading relationships, however, varied from 0.2 to 7.2 dB per doubling of number of flyovers in the different surveys. Because of high correlation between noise level and number of events within each survey, and because of the possibility of error in the measurement or prediction of the noise exposure of respondents, the trading relationships could not in general be shown to be significantly different from the 3 dB per doubling of the energy model or other similar models.

Laboratory studies such as references 7 through 9 have not provided conclusive evidence of the validity of an equivalent energy model. In these studies, subjects made single annoyance or acceptability judgments to extended periods which contained different numbers of flyovers. In reference 8, a trading relationship between number and level could not be reliably established because of the design of the experiment. The trading relationship found between number and level in reference 7 generally supported an energy-type model. However, since no effect of number was found for the subjects' first condition of laboratory noise exposure it was concluded that the trading relationship was dependent on the annoyance judgment experience of the test subjects. The results of the series of experiments reported in reference 9 also generally supported an energy-type model. However, in the experiments in which the number of noises was a variable, only simulated flyovers were used. These simulated flyover noises were judged significantly less acceptable than actual aircraft flyover noises with equivalent energies.

In a study reported in reference 10, multiple bursts of broadband random noise, spectrally shaped to simulate the spectrum of a jet airplane flyover, were presented to subjects in differing background noise levels. The results of this study indicated a trade-off of noise level to number of 4 to 5 dB per doubling of number, which is somewhat greater than a strict equivalent energy model.

Although a number of the laboratory studies have produced results which do not disagree with an equivalent energy model, the studies have not completely addressed the nature or details of how subjects respond to the number and noise level of flyovers in the noise sessions. Several different response models have been hypothesized. One possible response model is that subjects respond to the total noise energy or integrate the energy over whatever period of time is available. Another possible response model is that the subjects respond to the average energy in the time available. Another possible response model, the "annoyance decay concept," is that the subjects' level of annoyance rises and falls with the noise level but with a long decay time. Therefore, the annoyance response would depend on the number and level of flyovers, the time between flyovers, and when the response was given.

To provide additional information on the effect of number and levels of aircraft flyover noises on annoyance and on the nature of how subjects respond to multiple noise exposure, a series of multiple-event studies were designed and conducted at the NASA Langley Research Center. In the first of these studies (ref. 11), different numbers of flyovers (amplitudes fixed during each half-hour test session) were judged by subjects in a simulated living-room environment. The increased annoyance produced by doubling the number of flyovers was found to be the equivalent of a 4- to 6-dB increase in noise level. It was also found that the sensitivity of subjects to changes in both noise level and number increased with laboratory experience. This latter finding supported the trend found in reference 7, but not the magnitude of effect of experience.

In the second of these studies (ref. 12), a fixed number of flyovers (nine per session) with differing peak noise levels were presented in half-hour test sessions. Because of high correlation between the maximum peak noise level and the energy average noise level of the sessions, it was not possible to statistically distinguish the equivalent energy model from the dB(A) peak concept, although the energy model was more highly correlated with the subjective responses. No support could be found for an annoyance decay concept for multiple-event annoyance over the relatively short (half-hour) test periods.

Two new multiple aircraft noise event annoyance studies are reported in this paper. The objective of the first experiment was to further study the dB(A) peak concept and the annoyance decay concept. The objective of the second study was to provide information as to whether annoyance to multiple events is more closely related to the average energy or the total energy of the events. In these studies, subjects in a simulated living-room environment made annoyance judgments on sessions with different durations and with differing numbers and levels of flyover noises. The details of the designs and the results of the experiments are reported herein.

SYMBOLS AND ABBREVIATIONS

F-ratio ratio of variances

L_A A-weighted maximum noise level, dB

L_{dn} day-night average sound level, dB

L_{eq} equivalent continuous sound level (energy-averaged), dB

NEF noise exposure forecast

NNI noise and number index

p probability of occurrence

r Pearson product-moment correlation coefficient

More details of the indices and scales for acoustical measurements can be found in a number of general noise references, including reference 13.

EXPERIMENTAL METHOD

Test Facility

The interior effects room in the Langley Aircraft Noise Reduction Laboratory (fig. 1) was used in the present experiment. This room was designed to resemble a typical living room and to allow controlled acoustical environments to be presented to subjects. The construction of the test room is typical of modern single-family dwellings.

The loudspeaker systems used to produce the airplane noise stimuli were located outside the test room to provide a realistic simulation of residential airplane noise. Reference 14 presents additional information on the facility.

Noise Stimuli

The noise stimuli used in both studies were recorded noises of a Boeing 727 airplane. The master recording used was made at a location approximately 6 km from brake release under the flight path. This sound was presented, under computer control, at different peak noise levels, for different numbers of occurrences, and at different times in noise test sessions as determined by the experimental designs described in the next section. For those test sessions containing multiple noise events, the noises were presented at equal time intervals plus or minus a random number of seconds between 0 and 45.

Experimental Design

The same basic design was chosen for both experiments. Each experiment contained 11 different conditions or test sessions. Two of the sessions served as reference conditions. The nine primary conditions were considered an incomplete block 3^2 factorial design with repeated measures. Subject groups served as the blocking factor. The design was incomplete because time considerations prevented each subject from experiencing all nine primary test conditions and because of difficulty in getting subjects to reliably return for additional testing. Differences in the two experiments are described in the sections which follow.

First experiment.- The primary variables of this experiment were the time of occurrence and the number of flyover noises with a noise level 12 dB greater than the generally more numerous low-noise-level flyovers. The total number of flyovers in the test sessions was 8 and all session durations were 30 minutes. In a given primary test session, the high-noise-level sounds occurred at the beginning, middle, or end of the series of flyover noises in the session. Either 1, 2, or 4 high-noise-level sounds were presented.

To provide a comparison of the effects of time of occurrence and number of high-noise-level flyovers with the effect of noise-level change, each subject group was presented a session with 8 of the low-noise-level flyovers and a session with 8 of the high-noise-level flyovers.

Each subject group was exposed to and judged five sessions of multiple-event airplane noise. Two of the sessions were the comparison (or reference) conditions, with constant-noise-level flyovers; the other three sessions were selected from the nine primary test conditions. The order of presentation of the sessions to the subject groups is given in table I. The reference conditions indicated by "H" and "L" occurred as the first or fourth of the series of conditions given to the subject groups. High noise levels are indicated by H, and low noise levels are indicated by L. Half of the groups were presented condition H first; half were presented condition L first. The order of the primary test conditions, which occurred as the second, third, or fifth sessions, was based on a Greco-Latin square for the time of occurrence and number condition. Although order of presentation or laboratory experience was shown in one previous study (ref. 11) to have only a small effect on subject response in a multiple-exposure experiment, the present design was balanced to keep possible effects of order from contaminating results attributable to the primary variables. Because the design was incomplete, it was realized that effects attributable to interaction between the primary factors (time of occurrence and number of high-noise-level flyovers) could not be completely separated from those attributable to differences in groups of subjects. Consequently, it was not considered necessary to balance the design for all possible combinations of time of occurrence and number of high-noise-level flyovers.

Acoustic measurements of the conditions presented to the subjects were taken, and descriptions of the noise exposures in terms of some commonly used noise metrics are given in table II. Maximum A-weighted sound levels L_A for the high- and low-noise-level flyovers were 79.2 dB and 67.2 dB. The various combinations of the high- and low-noise-level flyovers produced energy equivalent sound levels L_{eq} for the sessions from 50.8 dB to 62.8 dB. In terms of the computed metrics, noise exposure forecast NEF and noise and number index NNI, the exposures varied between 13.9 dB and 26.3 dB for NEF and between 38.1 dB and 50.5 dB for NNI. The L_A, L_{eq}, NEF, and NNI values reported were measured in the test facility. Outdoor noise exposures which would produce these indoor values would be approximately 20 dB greater than the indoor values reported. The highest exposures would, therefore, represent high community noise exposures similar to those close to major airports.

Second experiment.- The basic design for this experiment was identical to that of the first experiment except for a different set of variables. The primary variables were the duration of the test sessions and the number of flyover noises in the test sessions. Durations of sessions were 15, 30, and 60 minutes, and the sessions contained 1, 4, or 16 flyovers with a fixed peak noise level. The maximum rate is representative of maximum use rates for a runway system with two parallel runways.

To provide a comparison of the effects of the duration and number of flyover noises with the effect of noise level, each subject group was presented two reference test sessions of 15-minute duration which contained 8 flyover noises. The noise-level difference between these two sessions was 18 dB. As in the first experiment, the two noise levels are indicated by H and L. (See table III.)

As was the case in the first experiment, each subject group experienced and judged five sessions of multiple-event airplane noise. Two of the sessions were the reference conditions; the other three sessions were selected from the nine primary test conditions with factorial combinations of the test variables. The order of presentation of the sessions is given in table III. The same type of presentation scheme was used in this experiment as was used in the first experiment. However, the variables or test-session conditions were different, as shown in table III.

The noise exposures for the conditions of this experiment are given in table IV. The values of L_A for the high- and low-noise-level reference sessions were 79.3 dB and 61.3 dB, respectively; the L_A values for all other sessions were 76.3 dB. The values of L_{eq} ranged from 47.8 dB to 65.9 dB, a somewhat greater range than for the first experiment. Computed exposures in terms of NEF and NNI ranged from 10.8 dB to 29.4 dB and from 29.5 dB to 56.6 dB, respectively. Again, these values are the measured indoor exposure levels and would be approximately 20 dB less than outdoor exposure levels.

Subjects

The 60 subjects (12 groups of 5 subjects) used in each experiment were paid volunteers from the general population of the cities of Hampton and Newport News and of York County, Virginia. Approximately half of the subjects had previous experience in psychological judgment tests, but no subject participated in both experiments. The subjects were audiometrically screened to insure normal hearing ability.

Procedures

Upon arrival at the laboratory, each subject was given instructions for the experiments. After the subjects had read the instructions, the test conductor asked if there were any questions and verbally reinforced the use of the numerical category scale used for their annoyance responses. The instructions and scoring sheets are duplicated in the appendix. The subjects were first requested to judge the noise of each session with regard to their feelings of annoyance in the laboratory situation. They were then requested to judge the noise session in terms of how they would feel about the noise if they heard it in their homes. This home-projected annoyance question was divided into three time periods - day, evening, and night.

The subjects were also requested to indicate on the scoring sheets whether or not they were highly annoyed by the noise in the session. This was also divided into laboratory and day, evening, and night home-projected sections. A similar technique was used in references 7, 11, 12, and 15 for the comparison of laboratory annoyance studies with community survey results. The results of references 7, 11, 12, and 15 indicate relatively good agreement with community annoyance surveys such as those reported in reference 16.

After the instruction period, the subjects were escorted to the test facility, randomly assigned seats, and again asked if they had any questions. After each test session, the test conductor returned to the facility and gave the scoring sheets to the subjects for their judgments. A 15-minute rest break was given after the third session.

RESULTS AND DISCUSSION

First Experiment - Effects of Time of Occurrence and Number of High-Noise-Level Flyovers

Analyses of variance of annoyance responses.- The experimental design was not a common repeated-measures factorial design, in that each subject judged the two reference conditions and only one-third of the primary test conditions. As a consequence, modified analyses of variance were used to determine if the primary variables or main factors produced significant effects on subjects' annoyance responses. Summaries of these analyses for the four annoyance questions are presented in table V. The first step in the modified procedure for each question was to conduct a two-factor analysis of variance with subject groups and treatments (different noise conditions) as factors. The residual mean square from this analysis thereby provided an estimate of error variance to test for effects of the main factors, time of occurrence, and number of high-noise-level flyovers. The second step was to conduct a two-factor analysis of variance for time of occurrence and number of high-noise-level flyovers using only responses for these conditions (i.e., ignoring the reference conditions) to provide mean squares for the primary factors. As previously mentioned, the design was incomplete, and interaction between the primary factors could not be separated from subject group effects.

Results of these analyses revealed several interesting features. First, for all questions, subject groups and treatments were significant ($p < 0.05$). Second, for all questions, the time of occurrence was not significant. Third, the number of high-noise-level flyovers was significant for only the laboratory annoyance question. Because the error mean square was least for the laboratory question in both experiments, the comparisons for different conditions in subsequent sections of this report are primarily based on these responses. It is of interest to note, however, that the evening home-projected question had comparably small error and had the least mean-square variance due to subject groups.

Effects of time of occurrence.- The results of the analyses of variance indicated that the time of occurrence of the high-noise-level flyovers in the test sessions was not a significant factor in the annoyance responses. The annoyance response averaged over subjects and number of high-noise-level flyovers is shown on the left side of figure 2. Although a slight increase in annoyance was reported when the high-noise-level flyovers occurred at the end of the test sessions, there was no consistent trend indicated as the time of occurrence approached the end of the test session. Comparison of mean annoyance responses for all questions and for the various numbers of high-noise-level flyovers in table VI indicates that even this trend is not consistent. Consequently, these data are in good agreement with recent results in reference 12, which also did not support an annoyance decay hypothesis. Therefore, it appears that the feeling of annoyance towards individual noise events does not decrease appreciably over the short periods of time measurable in laboratory tests. As the experimental design was incomplete, it was not appropriate to test for interaction between time of occurrence and number of high-noise-level flyovers. Therefore, the experiment does not provide conclusive information to justify completely discounting any time-of-occurrence effect.

Effects of number of high-noise-level flyovers.- The analyses of variance indicated that the number of high-noise-level flyovers in the test sessions was a significant factor in the annoyance responses. Figure 2 indicates that the annoyance response increased with the number of flyovers. This trend was also found to be consistent for each of the home-projected responses based on the data of table VI. The relationship of annoyance to the number of high-noise-level flyovers (fig. 2) appears to be logarithmic. This trend is not supportive of the hypothesis of the db(A) peak concept of references 2 through 5, which is that above about two flyovers per hour only the noise level of the noisiest aircraft determines the annoyance. In the present test, the total number of flyovers per hour was fixed at 16, and the flyovers at the highest noise levels were at a fixed level; however, annoyance increased with the number of high-noise-level flyovers. These results are in good agreement with references 7, 11, and 12.

Second Experiment - Effects of Session Duration and Number of Flyovers

Analyses of variance of annoyance responses.- The same types of analyses of variance were performed for this experiment as were performed for the previous experiment. Summaries of these analyses for the four annoyance questions are presented in table VII. Mean squares for subject groups were approximately the same as in the previous experiment; however, mean squares for treatments were about twice as great as those for the first experiment. Both of these factors were significant ($p < 0.05$) for all questions. The number of flyovers in the test sessions were significant for all questions. The duration of the test sessions was significant for the laboratory annoyance question, but not for the projected questions. The error mean squares were comparable to those of the previous experiment.

Effects of session duration.- The overall effects of the duration of the test sessions are shown on the left side of figure 3 for the laboratory annoyance question. The annoyance response has been averaged over all subject groups and number of flyovers. The trend is for decreased annoyance for test sessions of longer duration. This is supportive of the hypothesis that annoyance is proportional to the average energy (equivalent continuous sound level) over the time period of interest. Annoyance therefore increases with the rate of noise events rather than with total energy. The change in annoyance from the 15-minute session to the 60-minute session was equivalent to approximately 8 dB in peak noise level, based on the change in mean annoyance response for the reference conditions. Although the 8-dB annoyance change is somewhat greater than the 6-dB change in equivalent continuous sound level between the 15-minute and 60-minute sessions, the difference between the experimental results and the equivalent energy model would not be significant.

Effects of number of flyovers.- A significant effect of number of flyovers on annoyance response was found for all questions. The trend for this effect on laboratory annoyance is also indicated in figure 3. The pattern of results was similar for the home-projected annoyance questions (table VIII). Annoyance response was approximately 2.8 units greater for 16 flyovers per session than for 1 flyover per session. This difference is equivalent to about a 19-dB change in peak noise level based on reference conditions. However, based on energy considerations, the difference in annoyance for these number conditions should be equivalent to a 12-dB difference in peak noise level. Although this result may be an artifact of the particular test, in that the most noticeable difference between conditions was number of flyovers, the result was consistent for the various annoyances and is in good agreement with results of a previous study (ref. 11), where both number and noise-level differences were quite apparent to the subjects. This effect of number of flyovers, which is greater than that predicted by energy-based metrics, is also in good agreement with the results of reference 10 and with the results of reference 7 for situations with more than about 15 events per hour. The results of this experiment in the present study are also not supportive of the dB(A) peak concept, since, for conditions greater than two flyovers per hour (i.e., one to four flyovers per session, depending on session duration), the number of flyovers was a significant factor in determining annoyance response.

Annoyance Prediction Ability of Noise Metrics

The variables of the two experiments covered a wide range of aircraft noise exposure conditions. Although different test subjects were used, the experimental test methods, instructions, and scaling procedures were the same. As a consequence, it was hoped that the mean response data could be pooled to provide a larger data base for investigating the effectiveness of a number of noise metrics for predicting annoyance. Before this could be done, however, it was necessary to reduce the effects that the different subject groups had on the mean annoyance response within each experiment.

Adjustments for subject groups.- As mentioned previously, it was possible for subject-group differences to affect the mean annoyance responses for the nine primary test conditions since each group experienced only three of the primary test conditions. This confounding of the effects of subject groups and experimental variables, however, did not affect the results of the trends of the main variable presented in the previous sections because of the particular combinations given to the groups. First-order effects of subject-group differences on the test conditions were determined by performing linear least-squares regression analyses using dummy variables for each subject group and treatment condition. The regression coefficient for each treatment dummy variable served as an adjustment to the grand mean for each treatment. This accounted for group differences. The adjusted annoyance responses are presented in tables IX and X for the first and second experiments, respectively. It should be noted that the adjusted responses for the reference conditions of each experiment (tables IX and X) are the same as the mean responses given in tables VI and VIII. This is because all subject groups experienced these conditions in each experiment. The adjustments for subject groups to the different conditions were in no case greater than 1.0 units on the annoyance scale.

Figures 4 and 5 present the adjusted annoyance responses for the first and second experiments, respectively, as related to noise exposure in terms of session L_{eq}. It is apparent from figure 4 that the annoyance responses to the primary test conditions are in reasonable agreement with the trend established by the reference constant-noise-level conditions. Examination of the data of the primary test conditions indicates no trends except increased annoyance with increased exposure, in this case the number of high-noise-level flyovers. It is apparent from figure 5 that the annoyance responses to the primary test conditions are not in as good agreement with the trend of the reference conditions as in figure 4. There is an indication of somewhat reduced annoyance for the lower-exposure conditions than for the reference conditions. No consistent evidence for interaction between session duration and number of flyover noises is immediately apparent.

It should be noted that conditions with comparable average energy or session L_{eq} also produced comparable annoyance. Those conditions for L_{eq} of about 54 dB, corresponding to one flyover in 15 minutes and four flyovers in 60 minutes, differed by less than 0.5 annoyance scale unit. Those conditions for L_{eq} of about 60 dB, corresponding to 4 flyovers in 15 minutes and 16 flyovers in 60 minutes, differed by only 0.2 annoyance scale unit. Whether these results were an indication of a "rate" effect or unqualified support for an equivalent energy model cannot be determined, because all flyovers were of the same peak noise level.

A further comparison of the data from both experiments is shown in figures 6 and 7. In figure 6 the pooled unadjusted mean annoyance responses are plotted against noise exposure in L_{eq}. Reasonably high correlation of annoyance with exposure ($r = 0.763$) is indicated. The data from both experiments, particularly for the reference conditions indicated by the solid symbols, are in good agreement. The annoyance data adjusted for subject groups are presented in figure 7. The improvement in correlation ($r = 0.887$) over the unadjusted data is obvious.

Annoyance prediction ability.- The annoyance prediction abilities of several multiple-event or cumulative noise exposure metrics were examined through linear least-squares regression analyses. A summary of the results for the laboratory annoyance response is presented in table XI for equivalent continuous sound level L_{eq}, noise exposure forecast NEF, and noise and number index NNI. From these analyses and figure 8 it can be seen that NNI provided slightly greater correlation than L_{eq} or NEF. Although the differences in correlation are not statistically significant, the results are consistent for the two experiments and are consistent with results presented in references 10 and 11. This slight improvement in prediction ability by NNI is consistent with the trend for effects of number of flyovers (figs. 2 and 3). It was previously mentioned that the effects of number of flyovers were greater than predicted based on energy considerations; NNI provides a greater weighting for number of events than does L_{eq} or NEF. It is also shown in table XI that the intercepts and slopes of any of the noise metrics are not significantly different for the analyses of the first experiment, the second experiment, or the combined experiments. Thus, the pooling of data from both experiments seems to be justified.

Percentage of Subjects Reporting High Annoyance

In addition to being asked to respond to how annoyed the subjects were in the laboratory or would be in their home, the subjects were also asked whether they were or would be highly annoyed by the noise exposures. The description "highly annoyed" was defined to the subjects as whether or not they would consider doing something about the noise, such as moving or complaining to authorities. This type of question has been used (refs. 7, 11, 12, and 15) to compare laboratory findings with community survey data such as in reference 16.

The percentage of subjects who reported they would be highly annoyed in their home during the various time periods of the day by the noise exposures experienced in the laboratory are presented in figure 9. The results for the separate day, evening, and night periods are compared with estimated outdoor L_{eq}. The three curves were derived from linear regressions on L_{eq} of unit normal deviates (Z-scores) which were associated with the values of percentage highly annoyed as areas under the normal probability distribution curve. The slope of the trend lines is the mean slope of the regression lines; the slopes of the individual regression lines were not found to be significantly different. Although the data have considerable scatter, more of the subjects thought they would be highly annoyed by the noises if they occurred at night rather than during the evening or day. Similarly, more subjects thought they would be highly annoyed during the evening than during the day.

Some cumulative exposure noise metrics incorporate penalties expressed as a number of decibels to be added to the level of events occurring during night and evening to account for possible increased annoyance relative to events occurring during the day. Based on the data of figure 9, an appropriate value for evening penalties would be approximately 5 dB, and an appropriate value for night penalties would be approximately 14 dB. Based on the annoyance judgments (tables VI and VIII), appropriate penalties would be approximately 5 dB for evening and 11 dB for night. The technique of "percentage highly annoyed" therefore emphasized the nighttime penalty. Although these values are in good agreement with the results of the study reported in reference 11, it should be realized that the night weighting could also be somewhat inflated by other factors. For instance, the subjects could have interpreted the nighttime question to mean, "Would you be highly annoyed if you were awakened by the noise?"

CONCLUSIONS

Two experiments were conducted in which subjects in a simulated living-room environment judged the annoyance of sessions of airplane noise which contained different noise levels and numbers of flyovers. In the first experiment, 1, 2, or 4 high-noise-level flyovers occurred at the beginning, middle, or end of half-hour test sessions. There were a total of 8 flyovers in each test session. In the second experiment, 1, 4, or 16 flyover noises occurred in 15-, 30-, or 60-minute test sessions. Findings of the study of importance to the assessment of community-noise annoyance are as follows:

1. In the first experiment, time of occurrence of the high-noise-level flyovers in the sessions was not a significant factor in annoyance response. Thus, subjective impressions of annoyance do not appear to decay over half-hour periods of time, and an "annoyance decay model" was not supported. It should be noted that it was not possible, because of the particular experimental design, to test for interaction effects between time of occurrence and number of high-noise-level flyovers.

Consequently, the experiment does not provide enough information to discount completely time-of-occurrence effects.

2. Also in the first experiment, annoyance increased with the number of high-noise-level flyovers in the test sessions. The "dB(A) peak concept" was therefore not supported.

3. In the second experiment, annoyance decreased with increased test-session duration for fixed numbers of flyovers per session. This finding is indicative that the rate of flyovers, or number per time period, is an important variable in community-noise annoyance. Thus, an "average energy model," rather than a "total energy model," was supported.

4. Also in the second experiment, annoyance increased with number of flyovers in the test sessions. Thus, the dB(A) peak concept was again not substantiated. The increase in annoyance was, however, somewhat greater than predictions based on the "equivalent energy" concept.

5. Based on analyses of data from both experiments, noise and number index NNI was found to predict annoyance response better than equivalent continuous sound level L_{eq} or noise exposure forecast NEF. This is attributed to a number effect greater than that based on the equivalent energy concept as mentioned in conclusion 4.

6. Based on the results of the responses of the subjects to the questions of annoyance projected in their home environments, appropriate time-of-day penalties were found to be 5 dB for evening events and 11 dB to 14 dB, for night events relative to day events.

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APPENDIX

INSTRUCTIONS AND SCORING SHEET

Instructions

The experiment in which you are participating today is to help us understand the reactions of people to various aircraft noise environments. There will be five sessions of aircraft noise, altogether lasting about $2\frac{1}{2}$ hours. At the end of each session, we would like you to make several different judgments on the noises you just heard.

You will be given a scoring sheet for each session which has four scales numbered "0 to 10," the end points of which are labeled "Not Annoying At All" and "Extremely Annoying." An example of these scoring sheets is on the final page of this instruction set. Your judgment in all cases should be indicated by circling one of the numbers on the scale. If you judge the noise to be very annoying then you should circle a number closer to the "Extremely Annoying" end of the scale. Similarly, if you judge the noise to be only slightly annoying you should circle a number closer to the "Not Annoying At All" end of the scale.

For the first question and scale, we would like to know how annoying you found the noise of the session. That is, your judgment should reflect your feelings of annoyance in our laboratory situation.

For the next question and the last three scales, we would like you to imagine how you would feel about the noise if you heard it in your home. The first of these last scales is for your judgment of how annoying the noise would be if you heard it during the day, say between 7 a.m. and 7 p.m. The second scale is for your judgment of how annoying the noise would be in the evening, say between 7 p.m. and 11 p.m. The third scale is for your judgment of how annoying the noise would be at night, say between 11 p.m. and 7 a.m. In making these last three judgments, we would like for you to consider all your home activities during each of the time periods and how you would feel about living with the noise day after day.

Also on each scoring sheet are two additional questions concerning your annoyance to the noises you just heard. On these questions you are to circle either the yes or no response if you were or would be highly annoyed by the noise. That is, whether or not you would consider doing something about the noise, such as moving or complaining to authorities. The first of these questions is for your feelings in our laboratory situation. The second is for your feelings if you heard the noise in your home during the day, evening or night periods.

There are no correct answers, we just want a measure of your own personal reaction to the noise in each session. For this reason, we request that you do not talk during the tests nor express any emotion which might influence the response of the other people in the room. During each of the sessions, we would like you to relax and read or do any needlework you may have brought with you.

Thank you for helping us with this investigation.

APPENDIX

Scoring Sheet

Subject No.________________ Group________________

Seat________________ Session________________

Code________________ Date________________

1. How annoying was the noise in the session?

Not Annoying at All 0 1 2 3 4 5 6 7 8 9 10 Extremely Annoying

2. How annoying would the noise be in your home?

(a) During the day

Not Annoying At All 0 1 2 3 4 5 6 7 8 9 10 Extremely Annoying

(b) During the evening

Not Annoying At All 0 1 2 3 4 5 6 7 8 9 10 Extremely Annoying

(c) During the night

Not Annoying At All 0 1 2 3 4 5 6 7 8 9 10 Extremely Annoying

3. Were you highly annoyed by the noise in the session?

Yes No

4. Would you be highly annoyed by the noise in your home?

(a) During the day

Yes No

(b) During the evening

Yes No

(c) During the night

Yes No

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TABLE I.- PRESENTATION ORDER OF EXPERIMENTAL CONDITIONS TO TEST SUBJECT GROUPS IN FIRST EXPERIMENT

Subject group	Order of experimental conditions				
	1	2	3	4	5
1	H	1B	2M	L	4E
2	H	2E	4B	L	1M
3	H	4M	1E	L	2B
4	H	4E	2M	L	1B
5	H	1M	4B	L	2E
6	H	2B	1E	L	4M
7	L	1B	2M	H	4E
8	L	2E	4B	H	1M
9	L	4M	1E	H	2B
10	L	4E	2M	H	1B
11	L	1M	4B	H	2E
12	L	2B	1E	H	4M

Note: 1, 2, and 4 indicate number of high-noise-level flyovers.
B, M, and E indicate that high-noise-level flyovers occurred at beginning, middle, or end of test sessions, respectively.
H and L indicate all flyovers at high or low noise levels, respectively. These are reference conditions.

TABLE II.- NOISE LEVELS OF SESSIONS PRESENTED TO SUBJECTS IN FIRST EXPERIMENT

Number of high-noise-level flyovers	Location of high-noise-level flyovers in session	Highest flyover noise level L_A, dB	L_{eq}, dB	NEF	NNI
0		67.2	50.8	13.9	38.1
8	Throughout	79.2	62.8	26.3	50.5
1	Beginning	79.2	55.4	18.7	42.9
1	Middle	79.2	55.4	18.7	42.9
1	End	79.2	55.4	18.7	42.9
2	Beginning	79.2	57.7	20.9	45.2
2	Middle	79.2	57.7	20.9	45.2
2	End	79.2	57.7	20.9	45.2
4	Beginning	79.2	60.0	23.5	47.7
4	Middle	79.2	60.0	23.5	47.7
4	End	79.2	60.0	23.5	45.7

TABLE III.- PRESENTATION ORDER OF EXPERIMENTAL CONDITIONS TO TEST SUBJECT GROUPS IN SECOND EXPERIMENT

Subject group	Order of experimental conditions				
	1	2	3	4	5
1	H	1A	4B	L	16C
2	H	16B	1C	L	4A
3	H	4C	16A	L	1B
4	H	16C	4B	L	1A
5	H	4A	1C	L	16B
6	H	1B	16A	L	4C
7	L	1A	4B	H	16C
8	L	16B	1C	H	4A
9	L	4C	16A	H	1B
10	L	16C	4B	H	1A
11	L	4A	1C	H	16B
12	L	1B	16A	H	4C

Note: 1, 4, and 16 indicate number of flyovers in session.
A, B, and C indicate session durations of 15, 30, and 60 minutes, respectively.
H and L indicate 8 high-noise-level or low-noise-level flyovers in 15-minute sessions, respectively. These are reference conditions.

TABLE IV.- NOISE LEVELS OF SESSIONS PRESENTED TO SUBJECTS IN SECOND EXPERIMENT

Number of flyovers	Session duration, min	Flyover rate, per hour	Highest flyover noise level L_A, dB	L_{eq}, dB	NEF	NNI
8	15	32	61.3	47.9	10.8	36.5
8	15	32	79.3	65.9	29.4	55.1
1	15	4	76.3	53.7	17.3	38.5
4	15	16	76.3	59.6	23.3	47.5
16	15	64	76.3	65.7	26.3	56.6
1	30	2	76.3	50.7	14.3	34.0
4	30	8	76.3	56.7	20.3	43.0
16	30	32	76.3	62.8	26.3	52.0
1	60	1	76.3	47.8	11.3	29.5
4	60	4	76.3	53.7	17.3	38.5
16	60	16	76.3	59.8	23.3	47.5

TABLE V.- SUMMARIES OF ANALYSES OF VARIANCE FOR ANNOYANCE RESPONSES FROM FIRST EXPERIMENT

Source of variation	Sum of squares	Degrees of freedom	Mean square	F-ratio	Level of significance
Laboratory					
Subject groups	164.460	11	14.951	2.821	0.002
Treatments	229.683	10	22.968	4.334	.001
Time of occurrence	21.011	2	10.506	1.982	.140
Number of occurrences	49.411	2	24.706	4.662	.010
Error	1473.357	278	5.300		
Total	1959.397	299	6.553		
Home projected for day					
Subject groups	169.287	11	15.390	2.555	0.004
Treatments	189.170	10	18.917	3.141	.001
Time of occurrence	12.311	2	6.156	1.022	.361
Number of occurrences	28.311	2	14.156	2.350	.097
Error	1674.430	278	6.023		
Total	2101.397	299	7.028		
Home projected for evening					
Subject groups	147.657	11	13.423	2.491	0.005
Treatments	212.923	10	21.292	3.951	.001
Time of occurrence	19.210	2	9.606	1.783	.170
Number of occurrences	17.678	2	8.839	1.640	.196
Error	1498.277	278	5.384		
Total	1924.000	299	6.435		
Home projected for night					
Subject groups	453.657	11	41.242	5.472	0.001
Treatments	163.190	10	16.319	2.165	.020
Time of occurrence	9.700	2	4.850	.643	.526
Number of occurrences	15.100	2	7.550	1.002	.369
Error	2095.210	278	7.537		
Total	2734.947	299	9.147		

TABLE VI.- MEAN ANNOYANCE RESPONSES FOR FIRST EXPERIMENT

Number of high-noise-level flyovers	Location of high-noise-level flyovers in session	Laboratory response	Home-projected response		
			Day	Evening	Night
0		3.53	3.68	4.62	5.07
8	Throughout	5.72	5.83	6.90	7.07
1	Beginning	4.55	4.75	5.45	4.95
1	Middle	3.05	3.25	4.30	4.95
1	End	4.40	4.30	5.75	6.05
2	Beginning	5.00	4.55	5.75	6.45
2	Middle	5.05	4.95	5.65	5.30
2	End	3.90	4.00	4.80	5.55
4	Beginning	4.25	4.80	4.80	5.45
4	Middle	4.65	4.60	5.65	6.15
4	End	6.95	6.40	7.30	6.45

TABLE VII.- SUMMARIES OF ANALYSES OF VARIANCE FOR ANNOYANCE RESPONSES FROM SECOND EXPERIMENT

Source of variation	Sum of squares	Degrees of freedom	Mean square	F-ratio	Level of significance
Laboratory					
Subject groups	151.410	11	13.765	2.327	0.010
Treatments	562.353	10	56.235	9.506	.001
Session duration	50.033	2	25.017	4.229	.016
Number of flyovers	243.633	2	121.817	20.591	.001
Error	1644.607	278	5.916		
Total	2474.250	299	8.275		
Home projected for day					
Subject groups	240.830	11	21.894	3.210	0.001
Treatments	496.623	10	49.662	7.280	.001
Session duration	35.744	2	17.872	2.620	.075
Number of flyovers	211.244	2	105.622	15.484	.001
Error	1896.337	278	6.821		
Total	2728.587	299	9.126		
Home projected for evening					
Subject groups	218.237	11	19.840	2.860	0.001
Treatments	615.910	10	61.591	8.877	.001
Session duration	37.878	2	18.939	2.730	.067
Number of flyovers	279.244	2	139.622	20.124	.001
Error	1928.730	278	6.938		
Total	2844.947	299	9.515		
Home projected for night					
Subject groups	250.417	11	22.765	3.106	0.001
Treatments	740.110	10	74.011	10.099	.001
Session duration	33.911	2	16.956	2.314	.101
Number of flyovers	393.011	2	196.506	26.816	.001
Error	2037.250	278	7.328		
Total	3172.320	299	10.610		

TABLE VIII.- MEAN ANNOYANCE RESPONSES FOR SECOND EXPERIMENT

Number of flyovers	Flyover noise level L_A, dB	Session duration, min	Laboratory response	Home-projected response		
				Day	Evening	Night
8	61.3	15	3.22	3.08	3.47	4.07
8	79.3	15	5.93	5.77	6.37	7.07
1	76.3	15	2.15	2.05	2.20	2.10
4	76.3	15	6.15	5.50	5.80	6.60
16	76.3	15	5.25	5.45	6.10	7.30
1	76.3	30	3.10	3.15	3.45	3.95
4	76.3	30	3.05	2.90	3.30	3.80
16	76.3	30	6.70	6.15	6.50	7.35
1	76.3	60	2.25	2.25	2.25	2.80
4	76.3	60	3.65	3.85	4.20	5.15
16	76.3	60	4.00	3.75	4.40	4.95

TABLE IX.- ANNOYANCE RESPONSES CORRECTED FOR SUBJECT-GROUP DIFFERENCES FOR FIRST EXPERIMENT

Number of high-noise-level flyovers	Location of high-noise-level flyovers in session	Laboratory response	Home-projected response		
			Day	Evening	Night
0		3.53	3.68	4.62	5.07
8	Throughout	5.72	5.83	6.90	7.07
1	Beginning	3.78	4.06	4.96	5.07
1	Middle	3.65	3.67	4.73	5.09
1	End	4.58	4.58	5.81	5.79
2	Beginning	5.18	4.83	5.81	6.19
2	Middle	4.28	4.26	5.16	5.42
2	End	4.50	4.41	5.23	5.69
4	Beginning	4.85	4.61	5.23	5.59
4	Middle	4.83	4.88	5.71	5.89
4	End	6.18	5.71	6.71	6.57

TABLE X.- ANNOYANCE RESPONSES CORRECTED FOR SUBJECT-GROUP DIFFERENCES FOR SECOND EXPERIMENT

Number of flyovers	Flyover noise level L_A, dB	Session duration, min	Laboratory response	Home-projected response		
				Day	Evening	Night
8	61.3	15	3.22	3.08	3.47	4.07
8	79.3	15	5.93	5.77	6.37	7.07
1	76.3	15	3.15	3.23	3.24	3.17
4	76.3	15	5.20	4.70	5.14	5.99
16	76.3	15	5.20	5.08	5.72	6.84
1	76.3	30	3.05	2.78	3.07	3.49
4	76.3	30	4.05	4.08	4.34	4.87
16	76.3	30	5.75	5.35	5.84	6.74
1	76.3	60	1.30	1.45	1.59	2.19
4	76.3	60	3.60	3.48	3.82	4.69
16	76.3	60	5.00	4.93	5.44	6.02

TABLE XI.- SUMMARY OF RESULTS FROM REGRESSION ANALYSES OF ADJUSTED LABORATORY RESPONSES FOR NOISE EXPOSURE DESCRIBED BY THREE NOISE METRICS

Noise metric	Intercept	Standard error of intercept	Slope	Standard error of slope	Correlation coefficient
First experiment					
L_{eq}	-7.42	2.90	0.210	0.050	0.811
NEF	.42	1.02	.202	.049	.812
NNI	-4.44	2.13	.202	.047	.819
Second experiment					
L_{eq}	-7.19	1.58	0.200	0.028	0.923
NEF	-.07	.56	.210	.027	.933
NNI	-2.44	.74	.151	.017	.949
Combined experiments					
L_{eq}	-7.29	1.36	0.204	0.024	0.887
NEF	.06	.49	.214	.023	.896
NNI	-2.70	.74	.160	.016	.908

L-78-603

Figure 1.- Photograph of test facility.

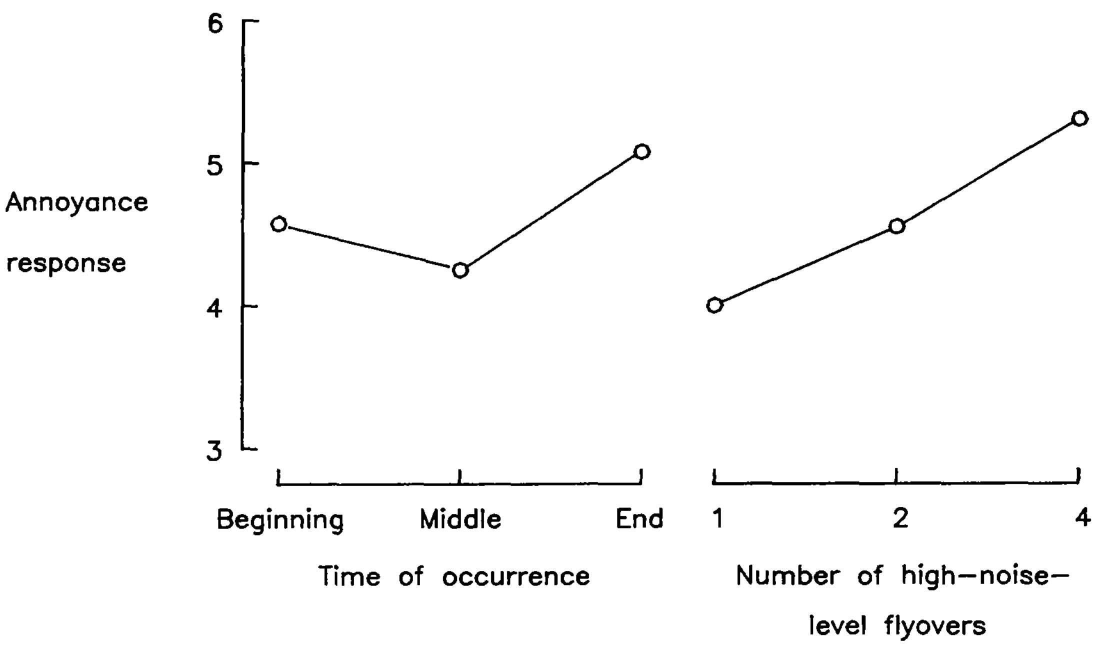

Figure 2.- Effects of time of occurrence and number of high-noise-level flyovers on laboratory annoyance response.

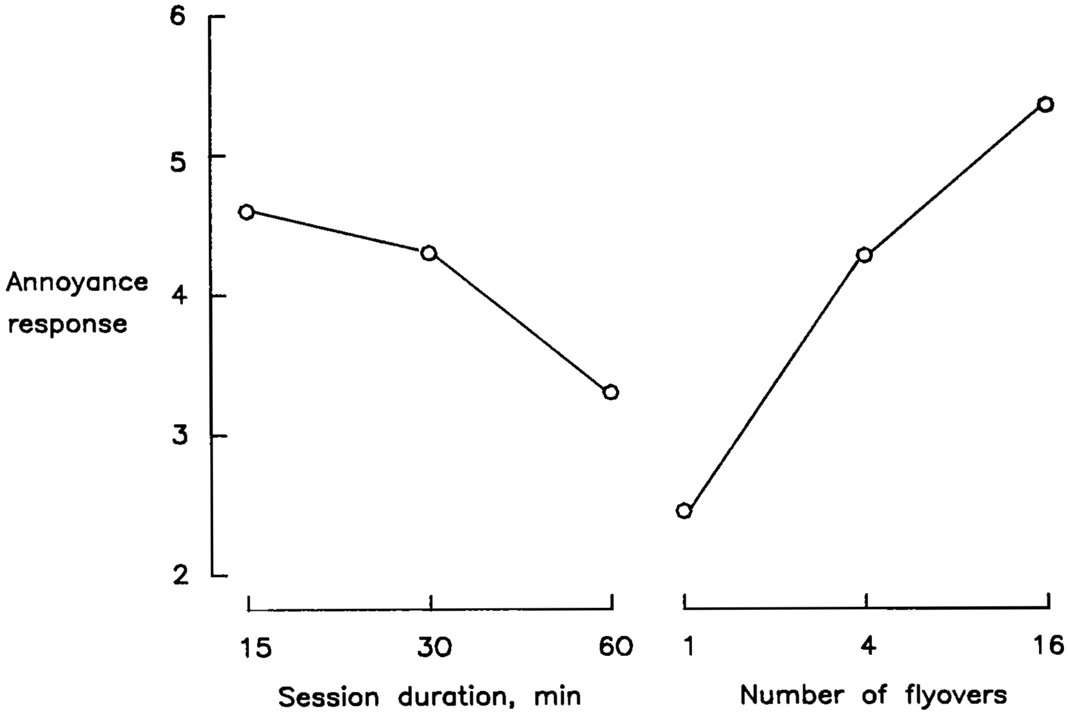

Figure 3.- Effects of session duration and number of flyovers on laboratory annoyance response.

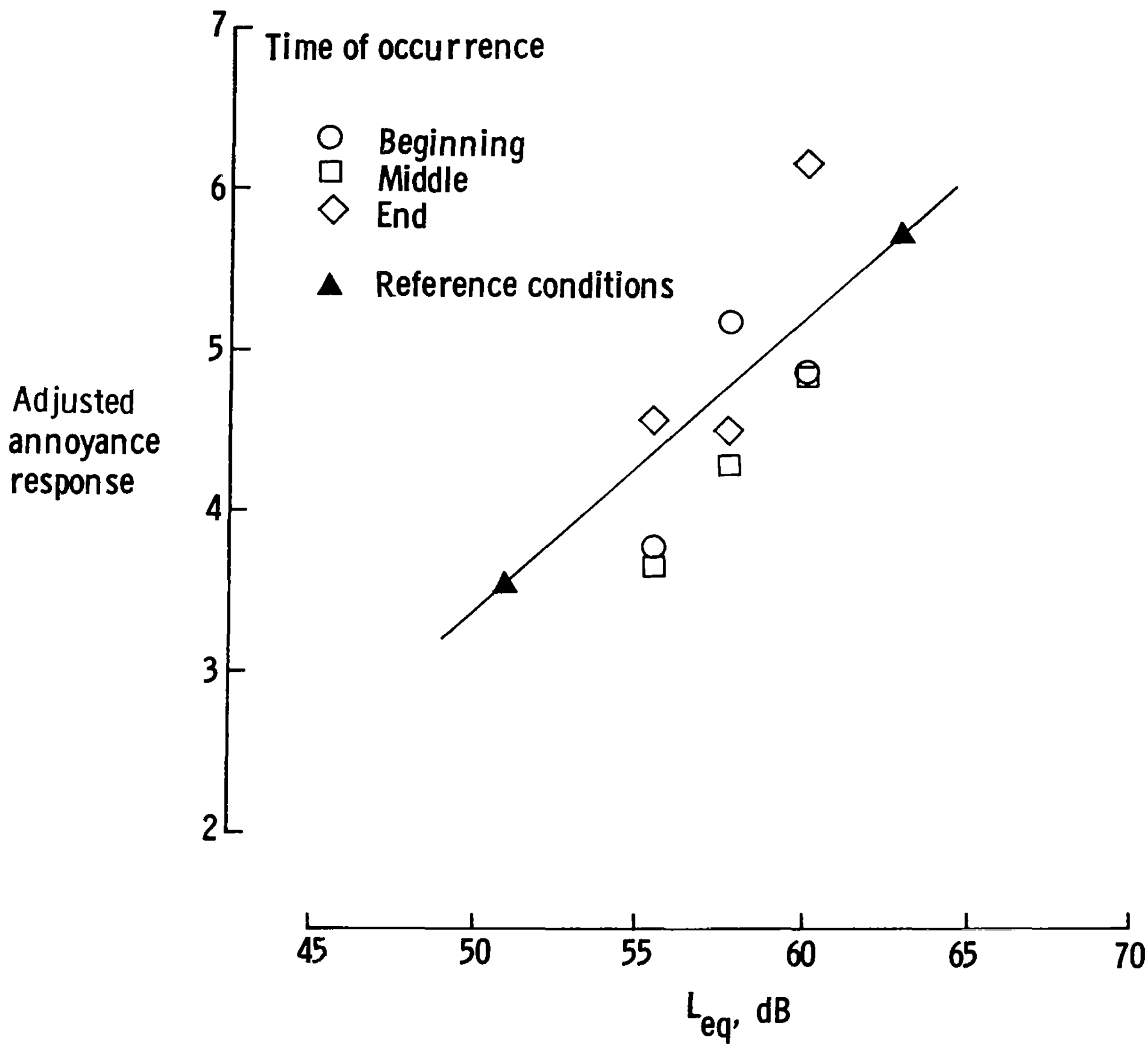

Figure 4.- Comparison of annoyance (adjusted for subject-group differences) with noise exposure in L_{eq} for high-noise-level flyovers occurring at different times within test sessions. First experiment.

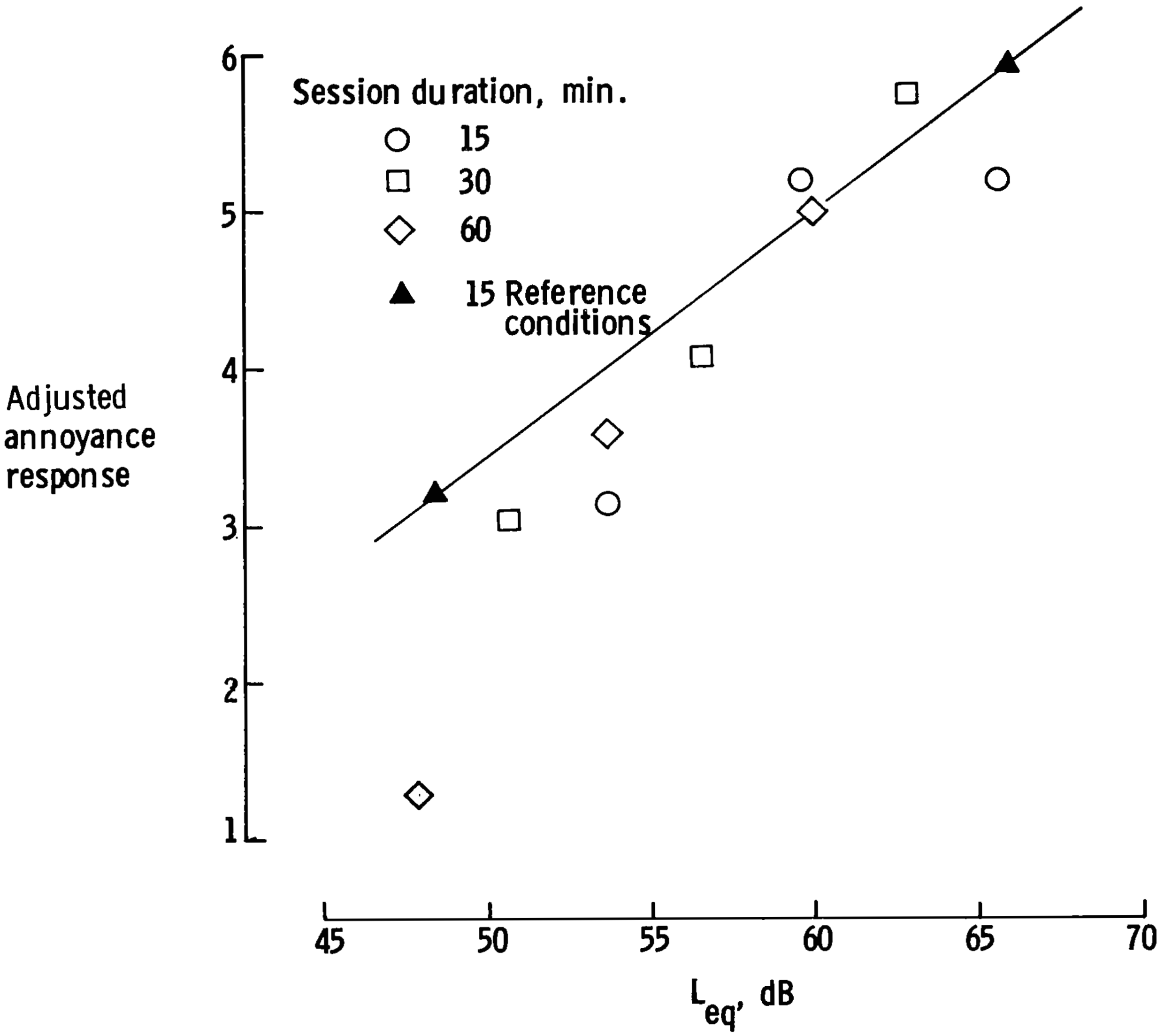

Figure 5.- Comparison of annoyance (adjusted for subject group differences) with exposure in L_{eq} for different session durations. Second experiment.

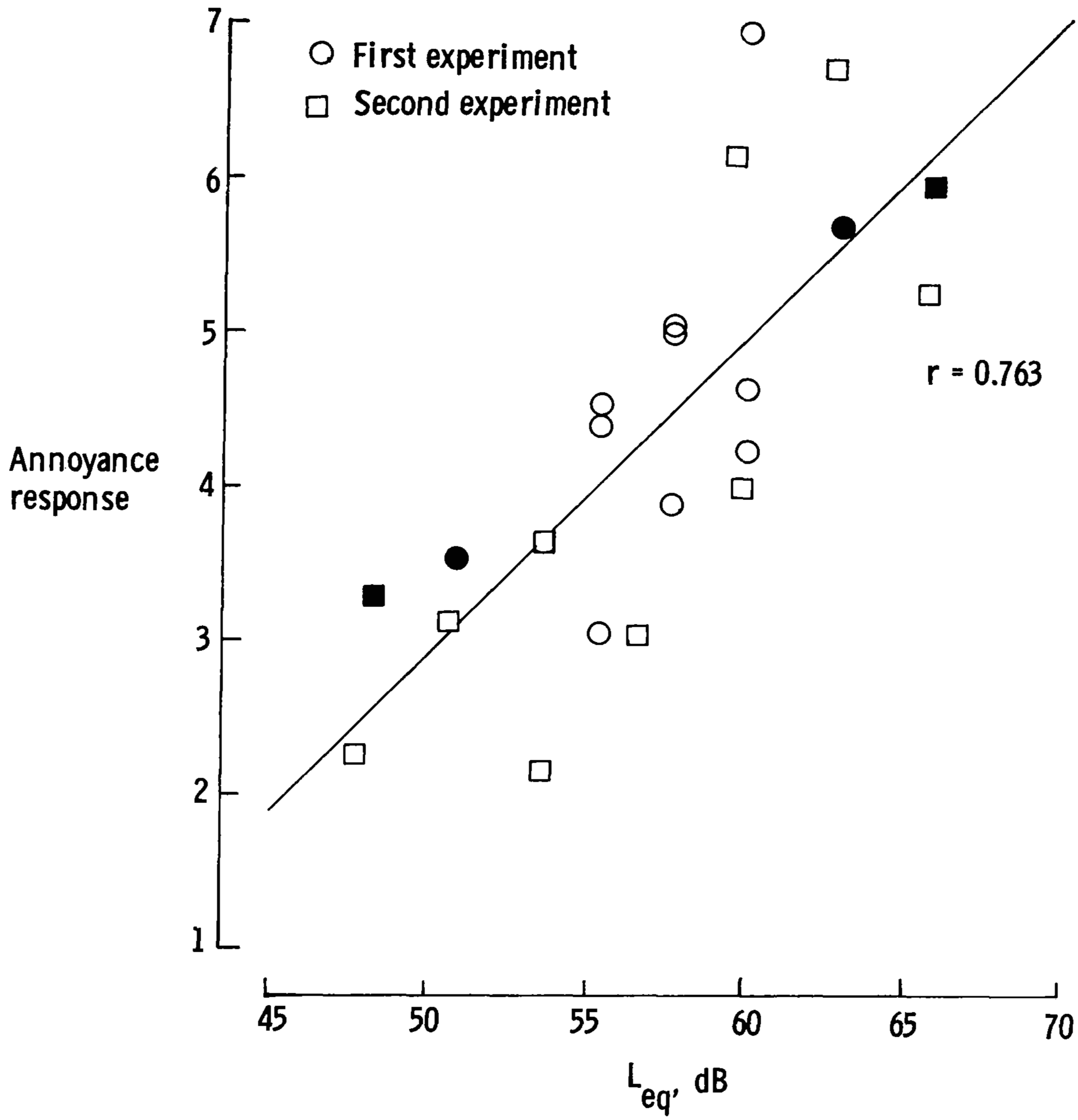

Figure 6.- Relationship of unadjusted annoyance response to exposure in L_{eq}. Solid symbols indicate reference conditions.

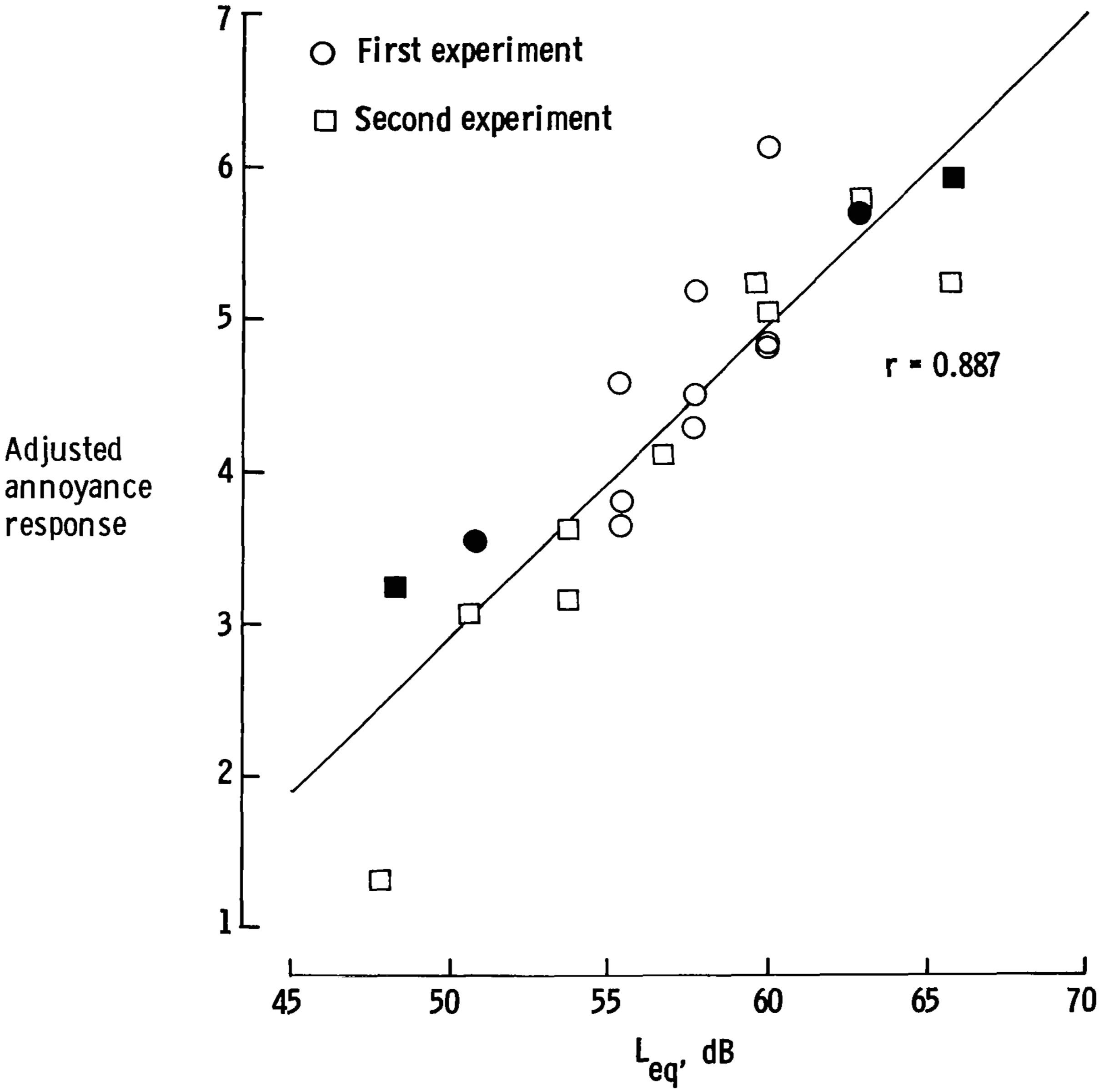

Figure 7.- Relationship of adjusted annoyance response to exposure in L_{eq}. Solid symbols indicate reference conditions.

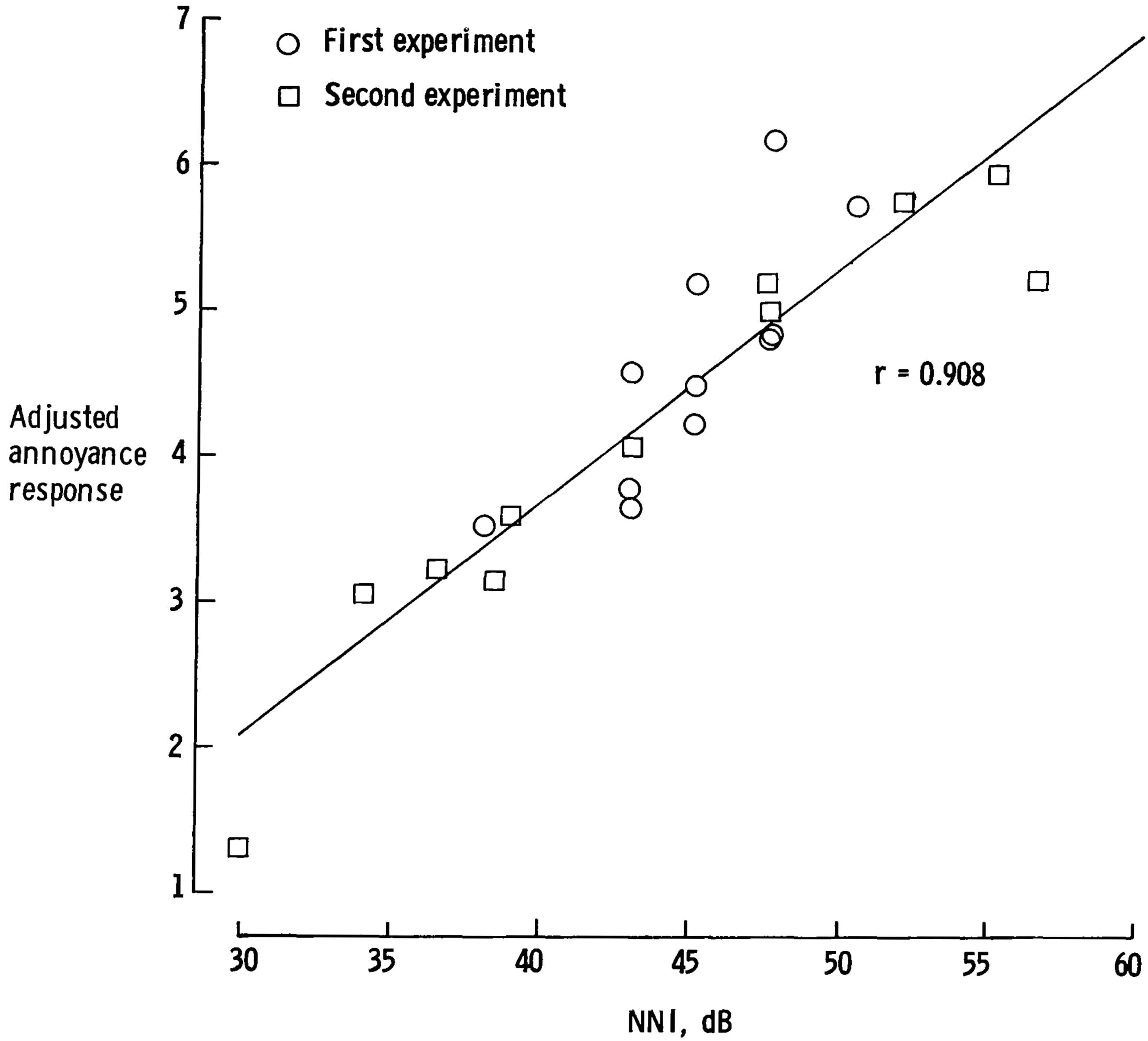

Figure 8.- Relationship of adjusted annoyance response to exposure in NNI.

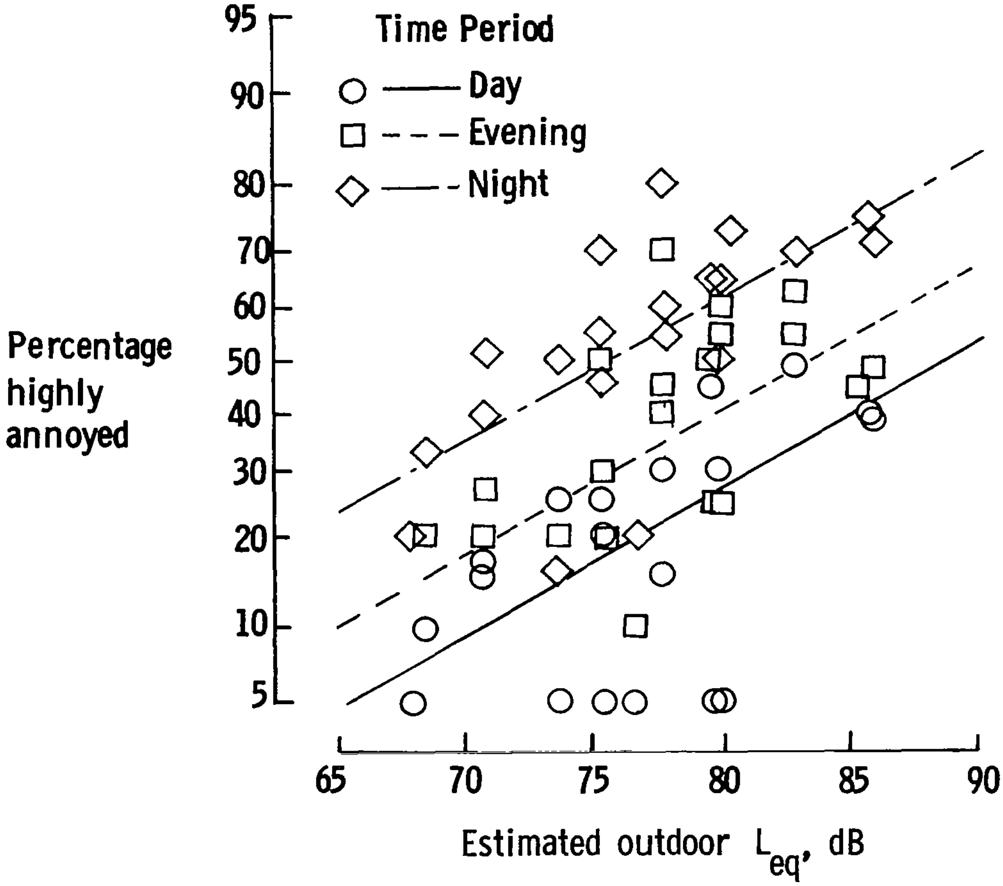

Figure 9.- Comparison of percentage of subjects highly annoyed for day, evening, and night periods.

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15. Supplementary Notes

16. Abstract

Two experiments were conducted in which subjects in a simulated living-room environment judged the annoyance of sessions of airplane noise which contained different noise levels and numbers of flyovers. In the first experiment, 1, 2, or 4 high-noise-level flyovers occurred at the beginning, middle, or end of 30-minute test sessions, each of which contained a total of 8 flyovers. In the second experiment, 1, 4, or 16 flyover noises occurred in 15-, 30-, or 60-minute test sessions. The time of occurrence of the high-noise-level flyovers in the sessions did not significantly affect annoyance, but annoyance increased with the number of such flyovers. Annoyance decreased with test-session duration but increased with the total number of flyovers in the test sessions. These results support an "average energy model" better than a "total energy model," the "annoyance decay model," or the "dB(A) peak concept."

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