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Effects of Background Noise on Total Noise Annoyance

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Summary

Two experiments were conducted to assess the effects of combined community noise sources on annoyance. The first experiment established baseline relationships between annoyance and noise level for three community noise sources (jet aircraft flyovers, traffic, and air conditioner) presented individually. Forty-eight subjects evaluated the annoyance of each noise source presented at four different noise levels. Results indicated that the slope of the linear relationship between annoyance and noise level for traffic noise was significantly different from that of aircraft and of air conditioner noise, which had equal slopes (i.e., traffic noise was more annoying than aircraft or air conditioner noise, which were about equally annoying).

The second experiment investigated annoyance response to combined noise sources for which jet aircraft noise was defined as the major noise source and traffic and air conditioner noise as background noise sources. Effects on annoyance of noise level differences between aircraft and background noise for three total noise levels and for both background noise sources were determined. A total of 216 subjects were required to make either total or source-specific annoyance judgments, or a combination of the two, for a wide range of combined noise conditions.

Both the background noise source and the type or combination of types of annoyance ratings requested had an effect on total annoyance. The results of this research have important implications for community noise criteria and for the application of community noise response prediction models, both of which should be designed to account for spectral, duration, and temporal differences between noise sources as well as noise levels.

Introduction

Historically, most research on human response to community noise has been focused on the effect of a particular noise source, especially aircraft noise, on annoyance. However, recently there has been an increasing awareness of the importance of considering multiple noise sources in the community. This is because noises rarely occur alone, so that more than one major noise source is common. It is possible that the individual noises which comprise the total noise environment may differentially influence the response to the combined noise environment. Thus, the specific effects of combined noises need to be understood in order to properly determine response to either individual noise sources or to total noise. Although several recent investigations of annoyance due to combined noise sources have been conducted (e.g., refs. 1 to 3), the relative contributions of various major noise sources to annoyance have not been clearly established. Specifically, the effects of background noise have not been defined well.

Prior to discussing the relevant literature, we need to define total annoyance and source-specific annoyance. Source-specific annoyance is the annoyance associated with a particular noise source and is usually determined by a question such as "How annoying is the aircraft noise?" Background noise annoyance is a type of source-specific annoyance when only one distinct background noise source other than the major noise source of interest is present. Total annoyance is the annoyance resulting from all noise sources present and is usually determined by a question such as "How annoying is the total noise environment?"

Several models of annoyance response to multiple noise sources have been used to explain the results of both laboratory and survey studies of combined noise effects. Many of these models are described in reference 4 and include the models of energy difference, independent effects, summation and inhibition, response summation, subjectively corrected L_{eq}, energy summation, and magnitude (or simple) summation. (These models are described in appendix A.) All these models are based on the noise levels of the individual noise sources or the subjective reactions to those sources or both. For the most part, researchers have investigated these models using noise sources which generally have equivalent source-specific annoyance function slopes (refs. 1 and 2). In general, annoyance effects due to combined noises have been primarily associated with the following sources: aircraft and traffic, aircraft and trains, or trains and traffic. When presented individually in the laboratory, these sources produce similar functions (i.e., slope) when annoyance rating scores are plotted against noise level, although the magnitude (as represented by the intercept) may vary. There are other community noises which may produce different annoyance response slopes. Such sources may include air conditioners, wind turbines, factories, power plants, and even children and barking dogs. The appropriateness of the existing total annoyance models in accounting for the effects of several noise sources with differing annoyance function slopes has not been determined.

A review of the relevant literature indicates inconclusive effects of multiple noise sources on annoyance were due to discrepancies and inconsistencies among the studies' approaches and results. Studies have examined either source-specific or total annoyance, or both, for the same subject so that the type of annoyance questions used across, and even within, investigations has been inconsistent. Both questions have been asked after the presentation of one noise (single-event studies) and after the presentation of several noises (multiple-event or session studies). These results have been either inconsistent or confounded for both source-specific and total annoyance. The effects of the subject's mind set or of cues from the experimental conditions or the rating approach are difficult to discern in the results. That is, for the same subjects in the same conditions, specific noise sources may lead to different responses for source-specific and total noise annoyance questions. These differences may be due to the subject's ability to separate these two types of annoyance when making judgments and thus are actual differences in response. On the other hand, the presence of one question may influence the other, so that the subjects may feel they should respond differently since there are two different questions. This could be either an order or a carryover type of effect. Interestingly, Fields and Walker (ref. 5) point out that different approaches may give various response magnitude differences between sources. In their railway survey they asked for parallel but separate ratings of railway and traffic noise, for forced ranking of the noises, and for total annoyance, but they did not provide the magnitude of differences for these approaches.

The present study was designed to obtain additional data for use in resolving the discrepancies discussed in the preceding paragraphs and to develop an improved understanding of human annoyance response to combined noise sources. To increase the generality of the results, an additional background noise source, having different temporal and spectral characteristics than the commonly studied aircraft and traffic sources, was included.

The following were specific objectives of this investigation. (1) Determine the relationships between annoyance response and noise level for each of the three noise sources. (2) Determine the effects of combined noise sources on total annoyance as a function of total noise level, type of background noise source, and difference between the background and aircraft noise levels. Included was a secondary objective of determining the relative contributions of aircraft annoyance and background noise annoyance to total annoyance. (3) Determine the effect of experimental set as represented by the type of annoyance questionnaire. (4) Determine the appropriateness of total annoyance models of community noise.

Symbols and Abbreviations

A	annoyance
A_{AC}	aircraft annoyance
A_{BG}	background noise annoyance
A_T	total annoyance
C_i	correction for difference in annoyance of a noise source in the subjectively corrected L_{eq} model
D	effective level increment associated with a noise source in the response summation model
D'	difference between values of R^2 of background sources from community response models
df	degrees of freedom
E	product of regression coefficient and source noise level, used to test independent effects model
E_{AC}	product E for aircraft noise source
E_{BG}	product E for background (traffic or air conditioner) noise source
F	ratio of variances
L_A	A-weighted sound pressure level, dB
L_{AC}	sound level for aircraft noise
L_{BG}	sound level for background (traffic or air conditioner noise)
L_{dn}	day-night average sound level, dB
L_{eq}	equivalent continuous sound level, dB
L_i	L_{eq} value of a noise source, dB
L_T	total noise level in L_{eq}, dB
M	mean of subjective magnitudes
MANOVA	multivariate analysis of variance, specifically for repeated measures
n	number of subjects
p	level of significance expressed as a percentage
Q	weighted ratio of sums of squares
R	Pearson product moment correlation coefficient
R^2	coefficient of multiple regression determination
S	background source type
S/N	signal-to-noise ratio, the difference between the L_{eq} values of aircraft (the signal) and background (the noise)
T	test or annoyance questionnaire type

z	test statistic for differences between means
α	level of significance, probability of rejecting the null hypothesis when it is true
β	unstandardized regression coefficient
Λ	Wilks' lambda statistic, a multivariate analog of F
ψ	subjective magnitude
ψ_{AC}	subjective magnitude of aircraft noise
ψ_d	inhibited subjective magnitude of dominant source
ψ_{BG}	subjective magnitude of background noise
$\psi_{e,T}$	equivalent subjective magnitude for combined noise sources
ψ_M	calculated subjective magnitude for dominant source
ψ_m	calculated subjective magnitude for subordinate source
ψ_s	inhibited subjective magnitude of subordinate source
ψ_T	total subjective magnitude of annoyance from combined noise sources

Method

Approach

To achieve the objectives of this study, two experiments were conducted. The purpose of the first experiment was to determine the slopes of the linear regression function relating annoyance response to noise level for three individual noise sources: jet aircraft flyover, traffic, and air conditioner. The air conditioner was used since it was expected that its noise annoyance function slope would be different from the slopes of the other two noise sources. The second experiment investigated the effects of combined noise sources on total annoyance. In this experiment, aircraft flyover noise was combined with either traffic noise or with air conditioner noise. These combinations were presented at different signal-to-noise ratios S/N, which were defined as the differences between the aircraft noise level and either the traffic noise or air conditioner noise levels. Total annoyance was predicted to differ for the two combinations and with increasing S/N.

Subjects

Experiment 1 used 48 paid subjects who were selected from a contractual pool of local community residents (from Hampton, Newport News, and York County in Virginia). There were 6 males and 42 females whose ages ranged from 20 to 76 years, with a combined average age of 40.5 years (standard deviation of 16.5 years). The median age was 39.5 years.

Experiment 2 used 216 subjects selected from the same local subject pool; none of these subjects had participated in experiment 1. The subjects' ages ranged from 18 to 66 years, with a combined average age of 35.9 years (standard deviation of 11.4 years). The median age was 34.8 years. All subjects from both experiments were given audiograms before and after participation to ensure normal hearing ability (within 20 dB of the average threshold for young adult males). Some of the subjects may have participated previously in similar experiments at this laboratory.

Test Facility

Both experiments took place in the Interior Effects Room (IER) in the Langley Aircraft Noise Reduction Laboratory. This room, shown in figure 1, 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 was typical of modern single-family dwellings.

Loudspeaker systems used to produce the noise stimuli were located outside the test room to provide a realistic simulation of residential outdoor noise. Aircraft noise stimuli were produced by four loudspeakers located above the test-room ceiling. Two loudspeakers used to produce traffic noise stimuli were mounted outside the room at window height 2 m from the test-room wall. A professional-quality, four-track tape recorder reproduced the noise stimuli through 200-W amplifiers in all loudspeaker channels. Reference 6 presents an additional description of the facility and the results of acoustic measurements which indicate that stimuli presented to test subjects in this facility were representative of those measured inside typical dwellings.

Stimulus Presentation System

The same stimulus presentation system was employed for both experiments. A computer-controlled tape recorder system was used to play back the aircraft flyover noise stimuli at the appropriate level and number of times during each session. (See fig. 2.) The stimuli were recorded on a four-track tape recorder. A microprocessor controlled the presentation times and noise levels of stimuli on each tape recorder channel and used four programmable attenuators. From the attenuators, the noise signal was passed through a noise reduction system and then was amplified by power amplifiers before entering the four overhead loudspeakers mentioned earlier. A separate tape recorder was used to reproduce the background noise stimuli, the appropriate levels of which were controlled manually with attenuators. These stimuli also passed through a dBX noise reduction system before being amplified through the two sidewall-mounted speakers. As a safety precaution, a power limiter system was in the circuit to ensure that the noise level in the test room did not exceed $L_A = 90$ dB while a test was in progress.

Questionnaire

Experiment 1. An 11-point, unipolar category rating scale with anchor labels was selected for use in this study. That is, the scale was 0 to 10 with the words "Not Annoying at All" and "Extremely Annoying" at the respective endpoints. An example of the rating scale is shown in appendix B. This questionnaire is also referred to as "test 1." A 10-point scale has been used in previous studies and was found to have test-retest reliabilities of 0.74 to 0.93 (ref. 7). The 11-point scale also was used in a previous study and had a reliability of 0.76 to 0.99 (ref. 8). The lower number represents the reliability coefficient across all conditions, and the higher number is the coefficient found within conditions. The current research included repeated test sessions so that reliability of the scale could be computed, this test-retest reliability (for sessions 1 and 13) was 0.75. However, the first and last sessions were the sessions that were always repeated, so that at least part of this lower reliability was due to practice or time effects.

An additional questionnaire in experiment 1 was administered to each subject upon completion of the last session of a test sequence. The purpose of this questionnaire was to obtain a reference point on the 11-point annoyance scale to allow comparisons between subjects. The question asked the subject to indicate at what point on the scale he or she would start to become highly annoyed. A copy of this questionnaire is also included in appendix B.

Experiment 2. In this experiment, three groups of subjects were asked to evaluate annoyance using three different questionnaires. The first questionnaire (test 2) asked subjects to rate total annoyance of the noise stimuli presented. The total annoyance was that resulting from both the background and the aircraft flyover noise, as was done in the first experiment. The second questionnaire (test 3) included two questions designed to measure source-specific annoyance due to the background noise and due to the aircraft noise. That is, one question asked "How annoying was the aircraft noise?" and the other question asked "How annoying was the background noise?" The third questionnaire (test 4) included ratings of both total annoyance and source-specific annoyance associated with the aircraft flyover and the background noise. At the end of the experiment, subjects were asked to indicate the point at which they became highly annoyed, as was done in experiment 1. The questionnaires for experiment 2 are in appendix C.

Noise Stimuli

Both experiments used three types of noise stimuli derived from audio recordings of jet aircraft flyovers, air conditioners, and traffic. The flyover and traffic noise stimuli were selected because of their similarity to those stimuli used in reference 1 and to allow comparison of results with that study. Because comparison of community noises that are not under the control of the resident was desired, outdoor air conditioner noise as heard indoors was used for comparison with traffic noise. The temporal and frequency characteristics of all three noise sources (shown in figs. 3 and 4, respectively) differed from one another as described below.

Aircraft flyover. The aircraft flyover noise stimulus was obtained from a tape recording made approximately 4.8 km from touchdown of a Boeing 727 landing. The flyover had a total duration of approximately 20 sec, 14 sec of which were 10 dB down from the peak. The time history of one flyover within a 3-minute sample is shown in figure 3(a). An average one-third-octave band spectrum was measured in the center of the test room and is reproduced in figure 4(a). The spectrum is the energy-averaged A-weighted sound pressure level over all 0.5-sec intervals of the flyover for one-third-octave band. The stimuli spectra were presented as L_A to allow the dominant frequencies to be examined in terms of human response. (A-weighting by an electronic network simulates the ear's response to sound over a wide range of frequencies.) Figure 4(a) indicates that energy of the frequency spectrum was concentrated at 4000 Hz.

Air Conditioner. The air conditioner noise stimulus was obtained from a recording of a typical home central air conditioning unit located outdoors. The recording was made at a height of 1 m and a distance of 1 m from the source. The noise was passed through a low-pass filter having a cutoff frequency of 800 Hz to eliminate high-frequency background tape hiss. The time history and spectrum as measured at the center of the test room from a 3-minute sample are illustrated in figures 3(b) and 4(b), respectively. The noise level was relatively constant with time, having a standard deviation from the mean noise level of about 0.5 dB.

Traffic. The traffic noise stimulus was obtained from a recording made approximately 100 m from the nearest lane of a limited-access, four-lane, divided highway during a period of moderate traffic flow. The noise had a standard deviation from the mean noise level of 3.6 dB. This stimulus was representative of freely flowing, high-speed road traffic with most truck and automobile events usually distinguishable. This is shown in the 3-minute time history given in figure 3(c), which was measured at the center of the test room. The energy-averaged L_A spectrum is shown in figure 4(c).

Comparison of noise sources. The three types of noise stimuli differed from one another in their spectral characteristics. Generally, the air conditioner noise energy was concentrated in the lower frequencies (63 to 900 Hz). (The roll-off of the skirt of the frequency filter applied to the air conditioner noise did not allow the noise to be cut off exactly at 800 Hz.) Traffic noise was more broadband and contained more energy in the moderate frequencies (63 to 4000 Hz) when averaged over a period of time. However, individual traffic noise spectra may have differed widely in content. The aircraft flyover noise, which contained more energy in the high frequencies than either of the other two noises, ranged between 63 and 8000 Hz and had the most energy between 2000 and 4000 Hz. Temporarily, both the traffic and the air conditioner noise were continuous, although the traffic noise level varied because of passing vehicles. The flyover noise was intermittent in that it occurred only for short durations.

For experiment 2 the stimuli were presented in combinations rather than separately. Examples of the time histories from combined noise sources are shown in figure 5. When presented together, the aircraft noise was considered the major noise source and the additional noise source was considered as background noise. This was assumed even though the level of the background noise was sometimes greater than that of the aircraft noise.

Design

Experiment 1. The experimental design for experiment 1 was a 3 × 4 complete-factorial repeated-measures design in which every subject received all 12 stimulus presentation combinations (see table 1). The two variables were noise source (aircraft flyovers, air conditioner, and traffic) and total indoor noise level (indoor L_{eq} values of 40, 48, 56, and 65 dB). The L_{eq} is the energy-averaged noise level integrated over a specific period of time; in this experiment, the time was 10 minutes and the L_{eq} was A-weighted. This range of noise levels was chosen as representative of those in residences near airports (see refs. 3 and 9, for example) for a variety of flight conditions.

Each session lasted for 10 minutes and consisted of one stimulus presentation condition. For each air conditioner or traffic noise condition, air conditioner or traffic noise was presented continuously throughout the 10-minute session. For each aircraft flyover condition, three identical flyovers were presented at equal intervals during each 10-minute aircraft session. In addition, the condition presented to each subject in the first session was repeated as the last session.

The stimulus presentation scheme was balanced by 6 orders derived from four 6 × 6 Latin squares, each containing 12 stimulus presentation combinations. These were combined to form one 12×12 Latin square. Each row of the Latin square represented a different presentation order for a group of four subjects. The actual presentation orders are listed in table 2.

Experiment 2. This experiment used a 3×3×2×6 split-plot repeated-measures design. The subjects were divided into three basic groups with each group receiving a different questionnaire or test. The design of experiment 2 within each test or questionnaire is given in table 3. Within each test, the subjects (in groups of 4) were blocked by total noise exposure (indoor L_{eq} values of 45, 55, or 65 dB) with 24 subjects in each block. Total noise exposure was the total L_{eq} of the combined L_{eq} of the three flyovers and the continuous background noise. The two variables within subject group were two background noise sources (air conditioner and traffic) and six signal-to-noise (S/N) ratios (±3, 9, and 15 dB). Signal-to-noise ratio was defined as the difference (in decibels) between the L_{eq} of the three aircraft flyovers and the L_{eq} of the background noise. The levels of the aircraft and the background noise were varied to achieve the desired S/N while maintaining a constant total L_{eq}. The background noise sources were distinguishable by their temporal characteristics and spectral content as shown in figures 3 and 4.

Each subject, in groups of four, received all combinations of background noise and S/N for a given total L_{eq}. Each combination was presented over one 10-minute session. The aircraft and background noise levels needed to achieve the desired overall levels and S/N are given in table 4. In addition to the 12 conditions, 2 anchor conditions were presented to allow comparison of the aircraft flyovers as an individual noise source across both experiments. Each anchor condition was one 10-minute session of either the three highest level ($L_{eq} = 65$ dB) or lowest level ($L_{eq} = 40$ dB) aircraft flyovers used in experiment 1. This was done as an attempt to compare the subject samples.

One-half the subjects received all the air conditioner stimulus conditions first while the other half received all the traffic stimulus conditions first. These subjects were split evenly among the three total L_{eq} blocks. In addition, presentation order within each of the blocks was counterbalanced by six orders derived from a 6×6 Latin square, one order for each group of four subjects. Six additional orders were created by reversing the first six orders. The presentation orders were the same for each block. The actual presentation orders are listed in table 5. In total, each group of subjects received 14 different 10-minute sessions.

Procedure

The procedure for experiments 1 and 2 was identical. Upon arrival at the laboratory, each subject was assigned to sit in one of the four chairs illustrated in figure 1 and were given a set of instructions and questionnaires. After reading the instructions, the subjects completed a consent form required of all participants in subjective experiments. Copies of the instructions, questionnaires, and consent forms are in appendix B. The test conductor reviewed the instructions and questionnaires and answered any questions that the subjects had. The subjects were instructed to sit during all sessions and were requested not to talk, although reading was permitted. For all sessions, subjects were instructed to respond to the questionnaire after the end of each session. The intersession interval was approximately 1 minute, and a 15-minute break was provided after the seventh session.

Analysis

The data analyzed for both experiments were the annoyance ratings, which were assumed to be interval data. The major analyses conducted were multivariate analysis of variance (MANOVA) and multiple regression analysis. Unless otherwise stated, all analyses were performed using current revisions of packaged software analysis programs.

Designs for both experiments involved split-plot repeated measures. In experiment 1, subjects were blocked by groups for presentation order, and in experiment 2 they were blocked by questionnaire type (test) and total noise exposure level total L_{eq}). Subject group or presentation order were not considered as factors in the second experiment because of the nonsignificant effects of these factors found in experiment 1. The blocking or grouping variables were the between-subjects variables. Each subject in a particular group was observed under all levels of the within-subjects stimulus presentation combinations, which resulted in repeated measures. The within-subjects variables were noise source and total noise exposure level for experiment 1 and background noise source and signal-to-noise ratio for experiment 2.

Details of MANOVA computation can be found in references 10 and 11. All MANOVA's performed for this research were for repeated measures. Wilks' lambda statistic Λ and the corresponding approximate ratio of variances F were used as the test statistics in MANOVA. Wilks' lambda is a multivariate analog of the univariate F-test.

Multiple regression analyses were conducted with either individual ratings or the means of the stimulus presentation conditions, depending upon the purpose of the analysis. For example, in some cases, in order to allow comparisons with results obtained from other studies, the same types of analyses had to be used (e.g., comparing community response models). These were usually regressions using the mean annoyance ratings. For other situations, regressions using the individual observations were performed (e.g., examining the relationship between variables). Regression functions derived from the means generally account for more of the variance than do those based on individual observations. However, the latter provides better control of individual differences.

Experiment 1

The major data used in the analyses were the annoyance ratings from the session questionnaires. Session 1, which had the same experimental conditions as session 13, was treated as a practice session, so that the responses to session 1 were excluded in the analyses. The responses to the last annoyance questionnaire, which asked for the point at which subjects estimated they became highly annoyed, were analyzed separately from the session annoyance ratings.

Experiment 2

The data were analyzed by type of annoyance rated within and between questionnaire type. For example, both tests 2 and 4 (the first and third questionnaires) contained total annoyance questions so that data for total annoyance could be examined for the two tests separately or combined. Furthermore, sessions 1 to 6 and 9 to 14, the sessions containing combined background and flyover noise, were analyzed separately from sessions 7 and 8, which had only flyover noise. As in experiment 1, the questionnaire results giving the point at which subjects became highly annoyed were analyzed separately from the session annoyance ratings.

Results

Experiment 1

For convenience the results of this study are discussed in terms of the four response tests that were conducted. Recall that test 1 refers to experiment 1. Tests 2, 3, and 4 refer to the three parts of experiment 2. Specifically, test 2 relates to the portion of experiment 2 involving the total annoyance questionnaire, test 3 relates to the part using the source-specific questionnaire, and test 4 relates to the part involving both total and source-specific questionnaires.

The main objective of experiment 1 was to determine the relationship between annoyance and noise level for three noise sources presented separately. These sources were aircraft flyovers, air conditioner, and traffic. Of specific interest was whether the slopes of the linear regression function for each noise source differed. (For all statistical decisions within this paper the probability of rejecting a null hypothesis when it was actually true was set at $\alpha = 0.05$ ($p \leq 0.05$).)

The means of the annoyance ratings for each noise source and noise level of experiment 1 are given in table 6. These data are also shown in figure 6 together with the best-fit linear regression lines through the means for each noise source. The results presented in figure 6 imply that, for equal L_{eq}, traffic noise was much more annoying than either air conditioner or aircraft flyover noise, which were equally annoying. This effect was statistically significant. (See table 7.) In addition, application of statistical tests for differences in regression line slopes confirmed that the slope associated with traffic noise was significantly different from that of both air conditioner noise ($z = 4.64$) and aircraft flyover noise ($z = 2.58$). The slopes for air conditioner and aircraft flyover noise did not differ from each other ($z = 1.13$). These results must be kept in mind when interpreting annoyance data obtained when aircraft flyover noise is combined with either of the two background noise sources.

Inspection of figure 6 also implies that the aircraft flyover annoyance data may be best fit by a quadratic regression function. To investigate this, regression analyses in which a model with a quadratic term was used were formed for each source. The difference between the percentage of variance (R^2) explained by the linear model and the percentage explained by the quadratic model was calculated from a model comparison test described in reference 12 for each noise source. The regression equations and results of the model comparisons are given in table 8, which shows that the quadratic regression models did not significantly explain more variance than the linear regression models. Particularly, the quadratic regression coefficient for aircraft flyovers was not significantly better than the linear regression coefficient. However, this conclusion is based upon analysis using the mean annoyance ratings as opposed to individual ratings.

A MANOVA for repeated measures (described in ref. 9) was performed to determine the significance of each variable of this study, including subject group. The results of this analysis are given in table 7. As indicated in the table, subject group, or presentation order, was not significant. This was expected given the assumption of random selection of subjects. The main effects of noise source and total noise level were significant ($p \leq 0.05$). More importantly, significance for the interaction of noise source with noise level provided additional support for the results of the regression analyses presented previously.

Although the results presented thus far have been statistically significant, their practical significance has not been considered. That is, the relative differences in annoyance for sources may not really matter if the most annoying source is not very annoying in an absolute sense. To help determine the practical significance of the data, the annoyance responses were recorded according to each subject's specification of the value on the rating scale at which that subject was highly annoyed. This value was the rating response to the overall questionnaire presented at the end of test session 13. If the subject's annoyance response for a session was greater than or equal to the subject's rating for being highly annoyed, the session response was scored as a 1. Otherwise, it was scored a 0.

A MANOVA was conducted with the reduced data. A Q-test was used for dichotomous data, as described by reference 9. These results are shown in table 9. The data for the within-subjects portion of the analyses were pooled across groups after the group variable was found to be a nonsignificant between-subjects factor. The Q-test results supported results of the previous analyses. Both main effects of noise source and noise level and the interaction of noise source with level were significant.

These results confirm that the regression lines for the different noise sources were different and also that at least one of these sources was highly annoying at certain levels. A frequency analysis of the recorded data indicated that traffic noise at an L_{eq} of 65 dB was the most highly annoying experimental condition. Thirty out of the forty-eight subjects rated this condition as highly annoying. Aircraft flyovers at an L_{eq} of 65 dB, air conditioner at an L_{eq} of 65 dB, and traffic at an L_{eq} of 56 dB were rated highly annoying by nine or fewer subjects. The mean value associated with high annoyance was 7.35. The median and mode were 7.30 and 7.00, respectively.

Experiment 2

The objective of experiment 2 was to investigate the annoyance effects of two different background noises combined with aircraft flyover noise through the use of different combinations of annoyance questionnaires. Recall that test 2 measured only total annoyance, test 3 measured only source-specific annoyance, and test 4 measured both total and source-specific annoyance.

Total annoyance. One purpose of this experiment was to determine the effect of combined noise sources on total annoyance as a function of the total noise level, the type of background source, and the difference between the background and aircraft flyover noise levels (S/N). Specifically, total annoyance was predicted to differ with background noise source in such a way that this difference varied with increasing S/N.

A MANOVA was performed for the total annoyance responses for tests 2 and 4 separately. These results are presented in tables 10 and 11. The means and standard deviations for each type of annoyance rating for each test and experimental condition are presented in tables D1 to D6 in appendix D. As shown in table 10, there was a significant interaction of background noise source with S/N for test 2, which used the total annoyance questionnaire. This is illustrated in figure 7, which shows that total annoyance decreased with increased S/N for traffic background noise but remained relatively unchanged for air conditioner background noise. Given the high annoyance for traffic noise found in experiment 1, total annoyance could be expected to decrease as traffic background noise decreased. The air conditioner and aircraft flyover noises were equally annoying when presented separately, so that any changes in S/N when they were presented in combination may have cancelled one another. However, the data of test 4, which required both total and source-specific annoyance responses, indicated no significant interaction of background source with S/N, although both the main effects of background source and S/N were significant. These results are given in table 11 and figure 8, which shows that total annoyance was greater for traffic noise and decreased with increased S/N at the same rate for both traffic and air conditioner noise. The cancellation effect of air conditioner and aircraft noise were not present for test 4. Discussion of differences between the results of each test is presented in a subsequent section.

A second purpose of experiment 2 was to determine the relative contributions of aircraft annoyance and background noise annoyance to total annoyance. It was anticipated that total annoyance would be influenced more by background noise annoyance than by aircraft annoyance. Only test 4 results were used in the analysis since this was the only questionnaire that measured directly all three types of annoyance. Stepwise multiple linear regression analysis was performed with the following model:

$$A_T = \beta_0 + \beta_1 A_{AC} + \beta_2 A_{BG}$$

where A_T is the total annoyance, A_{AC} is the aircraft annoyance, and A_{BG} is the background noise annoyance for both background noise sources. The terms were entered in a stepwise fashion, which meant that the variable with the largest squared partial correlation was entered first. That is, the first variable entered into the equation was the one that shared with total annoyance the greatest amount of variation.

The results of this analysis are given in table 12. This equation explained 74.8 percent of the variation in total annoyance from the combined linear influence of aircraft and background noise annoyance. Background noise annoyance accounted for 64.9 percent of the shared total variation, and aircraft annoyance accounted for an additional 9.9 percent of the shared total variance after background noise annoyance had already been entered into the equation. Thus, this analysis confirmed that background noise annoyance exerted the most influence on total annoyance.

This influence is illustrated in figure 9, which presents the mean annoyance responses obtained in test 4 as a function of S/N. The three curves shown in the figure represent data obtained for each type of annoyance, that is, total, aircraft flyover, and background noise. Each curve represents data averaged over total L_{eq} and background noise condition for test 4. These results show that both background noise and total annoyance ratings decreased with increased S/N whereas aircraft annoyance responses slightly increased as S/N increased. To investigate this further, the aircraft annoyance responses for each of the two background noise sources were examined separately. Figure 10 shows the mean aircraft annoyance responses as a function of S/N for air conditioner and traffic noise averaged over total noise level. These results indicate that annoyance to aircraft noise, when in the presence of background traffic noise, was rated more annoying than when air conditioner noise was used as the background noise source. Furthermore, aircraft annoyance remained relatively constant with S/N for traffic background noise but increased with S/N for air conditioner noise. At lower values of S/N where the background noise dominated, aircraft noise annoyance seemed to be influenced by the background noise, that is, traffic noise was more annoying than air conditioner noise. But at the higher values of S/N, where aircraft noise was more easily discernible, aircraft annoyance did not differ by background noise type. This interaction of sources and S/N for aircraft annoyance was statistically significant, as indicated in table 13.

Types of questionnaires. Determination of the effect of experimental set as represented by the type of annoyance questionnaire was another goal of the present study. Thus, differences in responses between tests were anticipated for the same type of annoyance and experimental conditions. This hypothesis was tested by performing a MANOVA over combined tests for each type of annoyance rated. This is, total annoyance was examined for tests 2 and 4 combined, aircraft flyover annoyance was examined for tests 3 and 4 combined, and background noise annoyance was examined for tests 3 and 4 combined. Although the effects on total annoyance were of major interest, the two source-specific annoyances were examined as factors comprising total annoyance. The results of these analyses are presented in tables 14, 15, and 16, respectively.

Figure 11 illustrates how mean total annoyance varied with S/N for the two background noise sources of tests 2 and 4. This figure shows the interaction of a test (i.e., questionnaire type) with S/N with source for total annoyance. This interaction was statistically significant. (See table 14.) Annoyance responses for test 4 generally decreased as S/N increased, whereas the responses for test 2 traffic background noise decreased slightly and those for test 2 air conditioner background noise remained fairly constant. These results indicate that experimental set is a factor to be considered when eliciting total annoyance responses from subjects.

A significant interaction of test with S/N was also obtained for aircraft annoyance responses of tests 3 and 4. (See table 15.) This interaction is illustrated in figure 12. Although the interaction was statistically significant, the slight differences in aircraft annoyance response were probably not of practical significance. Thus, experimental set does not appear to be important when the subjects are asked to evaluate aircraft annoyance.

Ratings of background noise annoyance obtained in tests 3 and 4 showed a significant interaction of test with source as well as a significant main effect for test. (See table 16.) These are illustrated in figure 13. Mean background annoyance response in test 3 was much higher for traffic than for air conditioner noise and was also much higher than both the traffic and air conditioner annoyance responses obtained in test 4. In test 4 background annoyance responses to traffic and air conditioner noise were approximately equal. These data indicate that experimental set is also important in the evaluation of background noise annoyance.

Additional insight into the effect of type of question upon annoyance response to identical noise conditions was obtained by comparing results of experiments 1 and 2 for the aircraft flyover noise only. Thus, in experiment 2 only data from sessions 7 and 8 were considered. This comparison was justified on the basis of analysis of each subject group's evaluations of the point of high annoyance on the 11-point rating scale. The average points of high annoyance for tests 1, 2, 3, and 4 were 7.35, 6.58, 6.79, and 7.12, respectively, with standard deviations ranging from 1.94 to 1.96. This provides a "rough calibration" of differences between the four subject groups. Since the maximum difference between groups was 0.77 scale units, and this difference is less than 0.40 standard deviations, the comparisons are deemed justified.

The comparisons are presented in figure 14. These data show that the total annoyance questions with a single scale (tests 1 and 2) gave similar results. However, when both total and source-specific annoyance questions were asked at the same time for the same conditions (test 4, open and closed triangles), the results were inconsistent. The source-specific annoyance responses (closed triangles) gave results comparable to the single-scale total annoyance responses whereas the responses to the companion total annoyance question (open triangles) were much lower. One would have expected the open triangles to be near the open circles and squares, all representing total annoyance of aircraft flyovers presented with a quiet background. Although the reasons for the inconsistency cannot be determined from these experiments, it is possible that the subjects treated the question of source-specific aircraft flyover annoyance as the one really of interest to the test conductor, since they perceived only the single source, and were confused by the total annoyance question.

Models. Another objective involved assessment of several models of community annoyance to determine which model best fit the data from this experiment. The comparisons were based on separate analyses of the total annoyance ratings from test 2 (the total annoyance questionnaire) and test 4 (the combined total and source-specific annoyance questionnaire). Seven models were compared: energy summation, independent effects, energy difference, response summation, subjectively corrected L_{eq}, magnitude summation, and summation and inhibition. A description of each model is included in appendix A. For each model, the necessary data transformations and computations on the mean annoyance ratings were calculated for each of the 36 stimulus presentation combinations (6 levels of S/N, 3 L_{eq} levels, and 2 types of background noise). For details of these steps, see appendix A. Multiple regressions were then performed according to each model's specifications. The resulting prediction equations for each model are shown in table 17. The results were compared through use of the percentage of total variance accounted for by each model and are presented in table 18 for tests 2 and 4. The ranks assigned to each model, from the largest to smallest average squared multiple correlation coefficient R^2, were used only as a guide for comparison. The average R^2 was used because each model had a separate R^2 for each background source.

The results in table 18 indicate that no one model stood out as best both within a test or across tests. Overall, the simple energy summation model, in which annoyance is a function of the total noise level, did not account for the total variance of total annoyance as well as some of the other models. As shown in table 17, the correction factor for differences between noise source levels in the energy difference model was not significant, which means that accounting for absolute differences between separate noise source levels did not account for any additional variance. This result agreed with that in reference 4. Therefore, there was really no difference between results for the energy summation and energy difference models for either test after the correction factor was removed.

The energy difference model implies that annoyance decreases symmetrically with the difference between the noise source levels, regardless of whether that difference, the S/N, is positive or negative. However, examination of the data from this study indicated that the effect of S/N was asymmetrical.

The actual difference model, a new model suggested by the author which accounts for the actual difference in source levels, is represented by the following:

$$A_T = f_1(L_T) - f_2(L_1 - L_2)$$

where A_T is total annoyance, L_T is the total noise level in terms of L_{eq}, L_1 and L_2 are the L_{eq} values of the separate background sources and aircraft, respectively, and f_1 and f_2 are annoyance functions. In this model, total annoyance is a function of both the total noise level and the actual difference between the source noise levels rather than the absolute difference in the energy difference model. The multiple regression equation corresponding to this model is:

$$A_T = \beta_0 + \beta_1 L_T + \beta_2(S/N)$$

Statistical analysis indicated that the S/N term in the above equation was significant, that is, it contributed significantly to the explained variance. Results for this model are given in table 18.

The worst fitting models for test 4 were the best fitting models for test 2 (i.e., the magnitude summation model and the summation and inhibition model). Also, for test 4 the models accounted for more variance in the traffic conditions, whereas for test 2 the models generally accounted for more variance in the air conditioner conditions.

In addition to differences between tests for the various models, there were also differences between background noise sources within the tests. These models did not explain the same amount of variance for each background noise source as would be expected if all sources had the same annoyance function slopes or if the models' correction factors for differences between sources were adequate. In table 18, D' was the difference between values of R^2 for the background noise sources. As D' became smaller, the model better accounted for differences between the background sources. For test 2 the subjectively corrected L_{eq} model had the smallest D', whereas for test 4 the actual difference model had the smallest D'. The implications of these results are discussed in the next section.

Discussion

The results of experiment 1 showed that subjects did not respond in the same manner to each source, as indicated by differences between the linear annoyance-noise level function slopes. The slope associated with traffic noise was greater than that of either air conditioner or aircraft flyover noise, which were equal, and traffic noise was significantly more annoying. Reasons for this were likely related to both the temporal (intermittency and duration) and frequency characteristics of the different sources. For example, the air conditioner noise was continuous, with no discernible discrete events and with the primary energy in the mid-frequency (300 to 700 Hz) region. Aircraft flyover noise, on the other hand, was brief (i.e., not continuous), with its energy concentrated at higher frequencies. Traffic noise, however, was continuous, with well-defined discrete events. The noise energy for traffic was distributed over a wider range of frequencies (100 to 2000 Hz). Thus, possible reasons for the increased annoyance of traffic noise may include one or more of the following:

1. Higher frequency noise is generally more annoying than lower frequency noise at the same noise levels (ref. 13). Thus, in addition to the temporal variations, the traffic noise may have been more annoying than the air conditioner noise because the traffic noise contained higher frequency components than the predominantly low-frequency air conditioner noise. The difference in slope between these two sources indicated that the temporal or frequency characteristics or both interacted in such a way that not only was traffic noise more annoying than air conditioner noise, but it also increased at a greater rate over the same range of noise levels. Although the noise levels were equated on the basis of A-weighting, it is possible that A-weighting was not sufficient to correct for frequency effects.

2. Duration of each noise source is another factor that may have influenced the subjective annoyance reactions. For example, each flyover lasted 20 sec, for a total noise duration of 1 minute out of a 10-minute session. In contrast, both air conditioner and traffic noise were present throughout their 10-minute sessions.

For the same total noise level, noises of longer durations (i.e., noises that are "on" more of the time) are more annoying (refs. 14 and 15). Duration in those studies was defined as the amount of time the sound was within 10 dB of the maximum level. Based upon this definition, air conditioner noise had the longest duration because it was always within 10 dB of its maximum level. Therefore, if duration had been the sole consideration, air conditioner noise would have been the most annoying noise, followed by traffic noise. Least annoying would have been aircraft flyover noise. However, energy averaging of the noise source levels with L_{eq} should have accounted for annoyance differences resulting from duration but not necessarily for intermittences and frequency characteristics. Consequently, the fact that traffic noise was judged most annoying was most likely because of its temporal or frequency characteristics or both.

3. It is possible that cognitive associations of the noises might have accounted for differences in annoyance of the three sources. Subjects may have associated air conditioner noise with comfort and therefore may have had a favorable bias to this source. Conversely, subjects may have had a negative bias toward traffic noise because of its intrusive nature in the context of the "home" environment as well as its association with feelings of dislike for being "in traffic."

Similarly, the same characteristics that made traffic noise more annoying than air conditioner noise could also explain why traffic was more annoying than the aircraft noise. Even though the aircraft flyover noise was of higher frequency than the traffic noise, the aircraft noise was present only one-tenth of the time that traffic noise was present. Thus, for aircraft noise, the effect of shorter duration could have interacted with the effect of higher frequency to produce a less annoying noise. In much the same way the characteristics of air conditioner noise probably interacted to make it as annoying as aircraft noise rather than more annoying, as would be expected if only duration were considered. The characteristics of low frequency and continuity both lead to lower annoyance. However, the characteristic of longer duration leads to higher annoyance. The net effect of these three characteristics combined leads to overall annoyance lower than that for traffic noise but equal to that for aircraft noise.

4. The effects of frequency were supposedly accounted for by A-weighting, and the effects of duration were controlled by the use of L_{eq}. However, there was a temporal characteristic for which there was no control, and that was the temporal variation in noise levels within a session for a given L_{eq}. Intermittent or fluctuating noises, such as the traffic noise, are more annoying than steady-state (continuous) noise. For example, Öhrström, Bjorkman, and Rylander (ref. 16) found less annoyance for session judgments of separately presented transportation noise sources which had the fewest rapid variations in octave band level. This would explain why annoyance was greater for traffic noise (which fluctuated rapidly in noise level) than for air conditioner noise (which remained relatively constant with time). They also noted that their own previous research had found fluctuating industrial noise to be more annoying than a steady-state noise of the same L_{eq}. These findings were supported by reference 17, in which increased annoyance was observed for increased fluctuations of traffic noise (because of truck passages), although a constant L_{eq} was maintained. Further support was reported in the findings of reference 18. The noisiness of steady-state noises seemed to be determined by the level of total noise energy, whereas the noisiness of intermittent noises was determined by other

factors such as their rate of intermittency in addition to total noise level. Therefore, annoyance would be expected to be lower for air conditioner background noise than for traffic background noise. Similarly, annoyance for aircraft noise would be expected to be less than that for traffic noise because of the greatly reduced intermittency of the aircraft noise compared with the traffic noise. It is therefore likely that the rate of intermittency for each noise was responsible for the higher annoyance produced by traffic noise.

The results of experiment 1 justified experiment 2 on the effect on total annoyance resulting from combinations of these noise sources. The difference between annoyance responses to traffic and air conditioner noise sources made them of special interest for comparison of background noise sources in combination with aircraft noise.

In experiment 2, aircraft noise was combined with either traffic noise or air conditioner noise for a range of S/N and total noise exposure levels. Three different annoyance questions were used to measure total annoyance (test 2), source-specific annoyance (test 3), or both (test 4). Although source-specific annoyance was measured, the effect of background noise (traffic and air conditioner) on total annoyance for these different noise conditions was of the most interest. For the cases in which only total annoyance responses were requested it was seen that, for all values of S/N, combined aircraft noise and traffic background noise was more annoying than combined aircraft noise and air conditioner noise. Further, total annoyance for combined aircraft and traffic noise decreased with increasing S/N, whereas it remained constant with increasing S/N for combined aircraft and air conditioner noise. The decrease in total annoyance with increasing S/N for traffic background noise is not surprising in light of the fact that traffic noise was the single most annoying noise source, and as S/N increased, the traffic noise level decreased. If one considers the continuous nature of the traffic noise with multiple discrete events, its high annoyance factor, and the brief duration of the aircraft flyover noise, it is reasonable to expect that the total annoyance evaluations would reflect the traffic noise level versus S/N trend. Similar reasoning can be applied to assist in understanding the lack of a trend associated with total annoyance data for air conditioner background noise. Since total annoyance responses to aircraft and air conditioner noise were equal (experiment 1), it is possible that increased annoyance resulting from increasing aircraft noise with increasing S/N was balanced by decreased annoyance resulting from decreasing air conditioner noise with increasing S/N. The resulting annoyance responses would remain relatively constant, as was found in this study. Total annoyance responses depended upon the type of background source as well as the type of annoyance rating requested. When only total annoyance ratings were requested for traffic background noise, annoyance increased as S/N decreased (i.e., as traffic background noise increased and aircraft flyover noise decreased) for a constant total L_{eq}. However, for air conditioner background noise, total annoyance remained constant across all values of S/N. In contrast, when both total and source-specific annoyance ratings were requested, total annoyance increased with decreasing S/N for both traffic and air conditioner background noises. For both questionnaires, total annoyance was influenced more by background noise than by aircraft noise.

The differences in annoyance responses obtained when combinations of annoyance questions were used (as compared with single questions) may be attributed to task interference and selective attention. (See ref. 19.) The results presented in this paper indicate that subjects could effectively rate either total annoyance only or source-specific annoyance only. When asked to do both, as has been done in previous studies (e.g., ref. 13), the ratings were affected in such a way that the rated total annoyance was reduced and followed background noise annoyance. Apparently, the subjects were not capable of either attending, registering, or recalling their annoyance to both the individual noise sources as well as to the entire noise environment.

The differences in responses help explain, in terms of questionnaire type, the results of comparisons between several community response models. The data across background noise sources were best fit with the magnitude summation model and the summation and inhibition model for the questionnaire dealing with total annoyance only. These results agree with a laboratory study (ref. 1) in which only total annoyance ratings were requested. These models also provided the worst fit for the questionnaire dealing with combined annoyance. The models giving the best fit for the combined annoyance questionnaire were the independent effects model and the actual difference model. Similar results were obtained from analysis of survey responses to a questionnaire for combined annoyance (ref. 3).

The actual difference model is a new model proposed as a result of this research. This model includes a correction factor for the effect of the actual difference between noise source levels that is added to the effect of the total noise level. For the limited range of S/N and total L_{eq} values studied, this model produced very good results in terms of the questionnaire for combined annoyance.

For all models, data from the questionnaire for total annoyance only were better fit for the air conditioner background noise condition whereas those from the questionnaire for combined annoyance were better fit for the traffic background condition. Furthermore, the models differed in their ability to account for differences in total annoyance resulting from the different background sources, that is, the difference in annoyance function slopes between the background noise sources found in experiment 1. Again, this difference depended on the type of questionnaire. For the questionnaire for total annoyance only, which was the same one used in experiment 1, the subjectively corrected L_{eq} model best accounted for the slope differences. This model includes a correction factor based on the difference in annoyance between noise sources for the noise level of each source. For the questionnaire for combined annoyance, the smallest difference between the fits of the model for the two background sources was found for the actual difference model, which assumes equal slopes. The data from this questionnaire resulted in significant main effects of source and S/N but not of an interaction between them, which implies the two background sources had equal slopes for their annoyance functions.

An implication of the findings of this research is that care must be taken to use an appropriate community response model for the particular situation of interest (e.g., types of background noise sources) and the annoyance questionnaire used. Furthermore, to account for the background noise source differences accurately, a unifying metric or model must also include corrections for differences in spectra, intermittency, and duration as well as in noise level. Use of L_{eq} alone is not sufficient to adequately account for these differences.

Although the use of different models is permissible in the interpretation of research results, the use of only one model is desirable for prediction of community annoyance response. The results of this research, however, do not identify a single model that is generally applicable for all situations. Further research in this area is needed.

These findings have implications for the noise criteria and metrics which are less restrictive for those situations with higher background noise levels. These criteria include the day-night average sound level known as L_{dn}, Noise Exposure Forecast, and ISO R-1996 (ref. 20). Contained within them is the implication that, if the background noise level is already high, any additional noise sources will not be very intrusive and so will not produce additional annoyance. However, as shown from the results of this experiment, the type of background noise source is important. The influence of background noise sources depends on the noise source characteristics. As shown in experiment 1, all sources are not equally annoying at the same L_{eq}. Therefore, more information about background sources should be incorporated into the noise criteria or metrics.

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Appendix A

Descriptions and Test Steps of Community Response Models

Model Descriptions

The oldest and simplest model is what has been called the *energy summation model.* In this model, annoyance is a function of the total noise level L_T computed as an energy summation of the levels of the separate sources in L_{eq} (Taylor, ref. 4). Energy summation is performed according to the formula

$$L_T = 10 \log \sum_{i=1}^{n} 10^{L_i/10}$$

so that

$$A_T = f(L_T)$$

where A_T is the total annoyance, L_T is the total noise level in L_{eq}, and L_i is the L_{eq} of each source.

According to Taylor, this model depends on two assumptions. The first is that annoyance does not depend on the relative contributions of the separate-source noise levels to the total noise level, what Taylor calls the effective levels. That is, total noise exposure is important rather than the noise exposure from a particular source. Second, the model assumes that the relationship between overall annoyance and the separate-source L_{eq} is the same for all sources. Taylor refers to this as independence of absolute level differences between sources. The model as it stands now assumes that individuals mentally integrate separate source noise levels before making an overall annoyance judgment.

From the results of Powell's studies (ref. 21), this assumption seems invalid. However, Powell's studies were not a sufficient test of this assumption because of the confounding of instructional sets or annoyance questions. That is, for most experiments he asked the same people to judge the same sounds for both total and source-specific annoyance.

Another model described by Taylor (ref. 4) is called the *independent effects model.* Annoyance is equal to the sum of the functions of the separate source levels. That is, separate sources make independent but additive contributions to total annoyance as follows:

$$A_T = f_1(L_1) + f_2(L_2) + \ldots + f_n(L_n)$$

where A_T is the total annoyance, L_i is the total noise level of each source for n sources, and f_i is the annoyance function determined for each source separately for n sources. No allowance is made for interactions between sources. In other words, no variations in response to one source due to the presence of other sources are allowed. This model assumes that annoyance responses are made to each source first and then these responses are summed to provide an overall annoyance judgment. The energy summation model assumes that the actual noise levels are integrated before any annoyance judgment is made.

Taylor described yet another model, which is called the *energy difference model.* According to this model, annoyance is a function of the total annoyance with the absolute difference between the source values of L_{eq} subtracted. Total annoyance increases as the difference between the source levels nears zero. Taylor described the model with the following formula:

$$A_T = f_1(L_T) - f_2(|L_1 - L_2|)$$

where A_T is the total annoyance, L_T is the total noise level, L_1 and L_2 are the separate noise source levels, and f_1 and f_2 are annoyance functions which cannot be determined for each source separately.

This model assumes that the direction of difference between the source values of L_{eq} is of no importance. Also, the effect of the difference in values of L_{eq} is assumed to be independent of total L_{eq}.

A fourth model was proposed by Ollerhead (refs. 22 and 23), which he called the overall effective level L_{eff} but which is generally referred to as the *response summation model.* The model is described by the following:

$$A_T = f\left(L_T + \sum_{i=1}^{n} D\ 10^{(L_i - L_T)/10}\right)$$

where L_T is the total L_{eq} of all sources, D is the effective level increment associated with the ith source, and L_i is the contribution of each independent source. This model is meant to account for the differences in annoyance between sources, as described in Fields and Walker (ref. 5). The term D can be calculated from multiple regression analysis of annoyance responses to various combinations of sources. The model assumes that the relative effective levels of sources are not level dependent, that is, the source slope coefficients are equal.

Rice (ref. 24) has proposed a similar model, based on differences in annoyance between sources, which he calls *subjectively corrected* L_{eq}:

$$A_T = 10 \log \sum_{i=1}^{n} 10^{(L_D + C_i)/10}$$

where L_D is the level of the subjectively dominant source and C_i is the correction for differences in annoyance between L_D and the separate sources. This C_i can be empirically derived by having the same people judge the separate sources for annoyance, and it can be level dependent, that is, annoyance slopes may differ. (This C_i and the D in Ollerhead's model response summation are not necessarily equal.)

Powell (refs. 1 and 21) described a simpler model which he called the *magnitude summation* (or simple summation) model:

$$\psi_T = \psi_1 + \psi_2$$

where ψ_T is the total subjective magnitude of annoyance resulting from combined noise sources and ψ_1 and ψ_2 are the subjective annoyance magnitudes of the individual sources (ψ_1 and ψ_2 are determined by presenting each source separately). The assumption of this simple model is that people add their separate annoyance responses to each source to provide a total annoyance response. This model is similar to the independent effects model but uses subjective magnitudes rather than the annoyance ratings themselves.

Powell proposed another model called the *summation and inhibition model*. This model is based on Stevens' (ref. 25) power law and theory of power-group transformation of stimulus inhibition. This theory proposes that the sensation magnitude of a stimulus is inhibited by the presence of another stimulus. Powell's model is represented as

$$\psi_T = \psi_d + \psi_s$$

where ψ_T is the total subjective magnitude of annoyance resulting from combined noise sources and ψ_d and ψ_s are the inhibited subjective magnitudes of the dominant and subordinate sources, respectively. Thus, annoyance is due to the sum of the inhibited subjective magnitudes. The basic assumption underlying this model is the validity of Stevens' theory. The assumption that annoyance is doubled for every 10-dB increase in sound level is not necessary. However, unless subjective magnitudes are acquired in a different manner, this assumption can be used to estimate the subjective magnitudes for application of the model. This assumption implies that the rate of increase in annoyance with noise level is the same for both sources. This model does account for both relative level differences between sources and absolute source levels.

Steps Involved in Testing the Models

The steps involved in testing the community response models are listed below.

Energy summation model:

$$A_T = f(L_T) = f\left(10 \log \sum_{i=1}^{n} 10^{L_i/10}\right)$$

The sum of L_i, where i represented the aircraft flyover noise and either the traffic or air conditioner noise, had already been incorporated into the experimental design as L_T. Therefore, for each background noise source, a standard linear regression of mean total annoyance ratings was performed with the following regression model:

$$A_T = \beta_0 + \beta_1 L_T$$

Independent effects model:

$$A_T = f_1(L_1) + f_2(L_2) + \cdots + f_n(L_n)$$

Regression coefficients were obtained for each noise source (aircraft, traffic, and air conditioner) by performing a separate standard linear regression of the mean annoyance ratings for each source from experiment 1 on the total noise level for that source (e.g., 40, 48, 56, or 65 dB). Then the regression coefficient for each source was multiplied by its respective noise level in experiment 2. For example, $\beta = 0.1533$ for the air conditioner noise and the noise level of the air conditioner was 45 dB at the 15-dB S/N and 45-dB total L_{eq} condition. Therefore, $E = \beta_i L_i = 0.1533(45) = 6.8985$. This was done for each S/N and total L_{eq} value for each source. For each background source, separate standard linear regressions of the mean total annoyance ratings from experiment 2 were performed on the appropriate E values with the following model:

$$A_T = \beta_0 + \beta_1 E_{BG} + \beta_2 E_{AC}$$

where E_{BG} is the product E for either traffic or air conditioner noise and E_{AC} is E for aircraft flyover noise.

Energy difference model:

$$A_T = f_1(L_T) - f_2(|L_1 - L_2|)$$

The absolute difference between the source noise levels was computed for each S/N and total L_{eq} condition; for example, aircraft L_{eq} was 50 dB and the air conditioner L_{eq} was 65 dB for the −15-dB S/N and 65-dB total L_{eq} condition. Therefore, the absolute difference value was 15. For each background noise source, standard linear regressions of the mean total annoyance ratings from experiment 2 were performed on the total L_{eq} and the absolute difference between background and aircraft levels:

$$A_T = \beta_0 + \beta_1 L_T = \beta_2 |L_{AC} - L_{BG}|$$

where L_{BG} is the sound level for either the traffic or air conditioner noise and L_{AC} is the sound level for the aircraft flyover noise.

Response summation model:

$$A_T = f\left(L_T + \sum_{i=1}^{n} D \; 10^{(L_i - L_T)/10}\right)$$

The values of D were solved from

$$A_T = \beta_0 + \beta_1 L_T + \beta_2 10^{(L_i - L_T)/10}$$

and $D = \beta_2/\beta_1$, so that

$$A_T = \beta_0 + \beta_1 \left(L_T + D_i 10^{(L_i - L_T)/10}\right)$$

where L_i represents each noise source including aircraft flyover. Standard linear regression of the mean total annoyance ratings from experiment 2 was performed on total L_{eq} and $10^{(L_i - L_T)/10}$ for each noise source separately:

$$A = \beta_0 + \beta_1 L_T + \beta_2 10^{(L_i - L_T)/10}$$

For each source, $D_i = \beta_2/\beta_1$ was computed from these regression results. Then the response summation value (RS) was computed for each source, where

$$\mathrm{RS} = L_T + D_i 10^{(L_i - L_T)/10}$$

For each background noise source and including aircraft noise, standard linear regressions of the mean total annoyance ratings from experiment 2 were performed on RS:

$$A_T = \beta_0 + \beta_1 \mathrm{RS}$$

Subjectively corrected L_{eq} model:

$$A_T = f\left(10 \log \sum_{i=1}^{n} 10^{(L_D + C_i)/10}\right)$$

The subjective magnitude ψ for each individual noise source and L_{eq} was calculated in a manner described subsequently in this appendix. These subjective magnitudes were then converted to equivalent energy levels $L_{e,i}$, where $L_{e,i} = 40 + 32.22 \log \psi_i$. Energy summation of the aircraft and background noise sources were performed through use of

$$L_{e,T} = 10 \log 10^{L_{e,1}/10} + 10^{L_{e,2}/10}$$

From this the equivalent subjective magnitude for the combined sources was determined as follows:

$$\psi_{e,T} = 10[L_{e,T} - (40/33.22)]$$

Finally, standard linear regressions of mean total annoyance ratings were performed on $\psi_{e,T}$:

$$A_T = \beta_0 + \beta_1 \psi_{e,T}$$

Magnitude summation model:

$$\psi_T = \psi_1 + \psi_2$$

The subjective magnitudes of each separate noise source from experiment 1 for each L_{eq} value in experiment 2 were calculated. The subjective magnitudes for each background noise source and for aircraft flyover noise were summed, that is, traffic plus aircraft and air conditioner plus aircraft. For each background noise source, standard linear regressions of the mean total annoyance ratings from experiment 2 were performed on the summed subjective magnitudes:

$$A_T = \beta_0 + \beta_1 (\psi_{BG} + \psi_{AC})$$

Summation and inhibition model:

$$\psi_T = \psi_d + \psi_s$$

The subjective magnitudes for each source were calculated from experiment 1 for the L_{eq} values in experiment 2. The term ψ_T was computed for each condition with either of the following two equations:

$$\begin{aligned} \psi_T = {} & \left[(1/g)^f (\psi_M/\psi_m)^f \psi_M\right] \\ & + \left[(1/g)^f (\psi_m/\psi_M)^c \psi_m\right] \qquad (\psi_M/\psi_m < g) \quad (1) \end{aligned}$$

$$\psi_T = \psi_M + \left[(1/g)^f (\psi_m/\psi_M)^c \psi_m\right] \quad (\psi_M/\psi_m > g) \quad (2)$$

where $g = 2.56$, $f = 0.17$, and $c = 1.34$, which were the same values that Powell (ref. 21) used for his data. The dominant source was ψ_M, the highest calculated subjective magnitude in the combination of aircraft plus background noise. The subordinate source was ψ_m, the lower calculated subjective magnitude in a combination. For example, for the −15-dB S/N and 45-dB total L_{eq} condition, traffic noise was dominant, with a calculated subjective magnitude of 1.40, and aircraft noise was subordinate, with a calculated subjective magnitude of 0.35. Therefore, $\psi_M/\psi_m = 4.00$ which is greater than g (or 2.56), so that equation (2) was used to calculate ψ_T. For each background source, standard linear regressions of mean total annoyance ratings from experiment 2 were performed on ψ_T

$$A_T = \beta_0 + \beta_1 \psi_T$$

Actual difference model:

$$A_T = f_1(L_T) - f_2(L_1 - L_2)$$

The actual difference between aircraft and background noise levels was computed for each S/N condition. For each background noise source, standard linear regressions of the mean total annoyance ratings from experiment 2 were performed on total L_{eq} and the actual difference between noise source levels (i.e., S/N):

$$A_T = \beta_0 + \beta_1 L_T + \beta_2 (S/N)$$

Subjective magnitude calculation:

Subjective magnitudes ψ were used in the subjectively corrected L_{eq}, magnitude summation, and summation and inhibition models. The means for each traffic condition in experiment 1 were calculated (L_{eq} values of 40, 48, 56, and 65 dB). The subjective magnitude of each mean was calculated based on doubling of subjective magnitude for every 10-dB increase in noise level. The 40-dB condition was given the subjective magnitude of 1, 50 dB was equivalent to 2, and so forth. A second-order polynomial regression of the subjective magnitudes was performed on the means M as follows:

$$A_T = \beta_0 + \beta_1 M + \beta_2 M^2$$

The resulting regression equation was used to predict the subjective magnitudes for aircraft and air conditioner noise as separate sources and to predict traffic noise from the appropriate means in experiment 1. The predicted values for traffic noise were slightly different from those for which the equation was calculated. The subjective magnitudes for the other L_{eq} values used in experiment 2 for each source were found by interpolation and extrapolation. The calculated subjective magnitudes for each combined condition within tests 2 and 4 were found through use of their means for the combined conditions and the same regression equation that was used from experiment 1.

Appendix B

Instructions and Questionnaires for Experiment 1

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 several sessions of noises during which you may hear traffic, air conditioner, or aircraft flyover noise. Each session will last about 10 minutes. There will be a break after half of the sessions.

During all the sessions, we request that you stay seated, but feel free to read. We ask that you talk as little as possible and do not do any handwork (e.g., knitting). There will be a short beep at the end of every session. At that time we would like you to make a judgment about the noises you just heard.

A set of response sheets, one for each session, will be given to you at the start of the test. Please be sure that you record your judgments on the appropriate sheet for the session concerned. The session number will be written on each response sheet. The response sheet will have one scale numbered horizontally "0 to 10" for each session. The end points are labeled "NOT ANNOYING AT ALL" and "EXTREMELY ANNOYING." Your judgment in all cases should be indicated by circling one of the numbers on the scale with the pencil provided. For example, 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. The first response sheet will serve as an example. Remember to make a judgment at the end of each session when you hear a single beep. The beginning of the next session will be signaled by two short beeps.

There are not correct answers; we just want a measure of your own personal reaction to the noises in each session. For this reason, we request that you do not talk about the noise, especially while responding to questions on the response sheets and do not attempt to compare judgments.

Thank you for participating in this investigation.

Voluntary Consent Form for Subjects for Human Response to Aircraft Noise and Vibration

I understand the purpose of the research and the technique to be used, including my participation in the research, as explained to me by the Principal Investigator (or qualified designee).

I do voluntarily consent to participate as a subject in the human response to aircraft noise experiment to be conducted at NASA Langley Research Center on ____________.
date

I understand that AUDIO/VIDEO recordings are to be made of my response to the AIRCRAFT NOISE AND/OR VIBRATION experiment to be conducted at NASA Langley Research Center on ____________, and that these recordings are to be held in strictest confidence.

I have been informed of the purpose of such recordings and do voluntarily consent to their use.

I further understand that I may withdraw my approval of such recordings at any time before or during the actual recording.

I understand that I may at any time withdraw from the experiment and that I am under no obligation to give reasons for withdrawal or to attend again for experimentation.

I undertake to obey the regulations of the laboratory and instruction of the Principal Investigator regarding safety, subject only to my right to withdraw declared above.

I affirm that, to my knowledge, my state of health has not changed since the time at which I completed and signed the medical report form required for my participation as a test subject.

____
Print Name

____

Session Questionnaire for Test 1 of Experiment 1

Session Questionnaire

Group ____________ Test ____________ Session ____________

Subject No. ____________ Date ____________

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

Questionnaire for Point of High Annoyance for Experiment 1

Questionnaire

Group ____________ Test ____________ Session ____________

Subject No. ____________ Date ____________

At what point on your scale would you start to become highly annoyed? In other words, at what point on the scale would you consider doing something about the noise, such as moving or complaining to authorities?

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

Appendix C

Instructions and Questionnaires for Experiment 2

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 several sessions of noises during which you may hear traffic, air conditioner, and/or aircraft flyover noise. Each session will last about 10 minutes. There will be a break after half of the sessions.

During all the sessions, we request that you stay seated, but feel free to read. We ask that you talk as little as possible and do not do any handwork (e.g., knitting). There will be a short beep at the end of every session. At that time we would like you to make a judgment about the noises you just heard.

A set of response sheets, one for each session, will be given to you at the start of the test. Please be sure that you record your judgments on the appropriate sheet for the session concerned. The session number will be written on each response sheet. The response sheet will have one scale numbered horizontally "0 to 10" for each session. The end points are labeled "NOT ANNOYING AT ALL" and "EXTREMELY ANNOYING." Your judgment in all cases should be indicated by circling one of the numbers on the scale with the pencil provided. For example, 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. The first response sheet will serve as an example. Remember to make a judgment at the end of each session when you hear a single beep. The beginning of the next session will be signaled by two short beeps.

There are not correct answers; we just want a measure of your own personal reaction to the noises in each session. For this reason, we request that you do not talk about the noise, especially while responding to questions on the response sheets and do not attempt to compare judgments.

Thank you for participating in this investigation.

Session Questionnaire for Test 2 of Experiment 2

Session Questionnaire

Group ______________ Test ______________ Session ______________

Subject No. ________________ Date ________________

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

Session Questionnaire for Test 3 of Experiment 2

Session Questionnaire

Group ________________ Test ________________ Session ________________

Subject No. ________________ Date ________________

1. How annoying was the aircraft noise?

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

2. How annoying was the background noise?

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

Session Questionnaire for Test 4 of Experiment 2

Session Questionnaire

Group ____________ Test ____________ Session ____________

Subject No. ______________ 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. Specifically, how annoying was the aircraft noise?

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

3. Specifically, how annoying was the background noise?

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

Questionnaire for Point of High Annoyance for Experiment 2

Questionnaire

Group ________________ Test ________________ Session ________________

Subject No. ________________ Date ________________

At what point on your scale would you start to become highly annoyed? In other words, at what point on the scale would you consider doing something about the noise, such as moving or complaining to authorities?

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

Appendix D

Means and Standard Deviations for Annoyance for Experiment 2

Table D1. Means and Standard Deviations for Total Annoyance Ratings for Experiment 2

[Excluding sessions 7 and 8]

Background source		Mean ratings and standard deviations[a] for S/N, dB, of—					
Test	Total noise level, L_{eq}, dB	−15	−9	−3	3	9	15
Air conditioner background noise							
2	45	2.667 (2.461)	2.125 (1.541)	3.083 (1.998)	2.417 (1.863)	2.750 (2.027)	2.958 (1.805)
	55	3.417 (2.185)	3.667 (2.297)	3.125 (2.153)	3.417 (2.569)	3.333 (2.408)	3.208 (2.637)
	65	4.833 (2.160)	5.625 (1.884)	5.708 (2.404)	4.917 (2.701)	5.542 (2.828)	5.167 (3.371)
4	45	2.833 (2.297)	2.750 (2.400)	2.250 (2.111)	2.333 (2.200)	1.833 (1.971)	1.833 (1.551)
	55	3.833 (2.681)	4.333 (2.599)	3.125 (2.346)	3.292 (2.116)	3.000 (2.187)	2.708 (2.196)
	65	7.750 (2.251)	6.875 (2.290)	5.417 (1.909)	5.208 (1.865)	4.958 (1.654)	3.542 (1.911)
Traffic background noise							
2	45	4.667 (2.278)	4.500 (2.359)	4.292 (1.601)	4.000 (1.642)	3.208 (2.043)	3.333 (1.834)
	55	4.208 (2.484)	4.417 (2.842)	4.458 (2.431)	4.292 (2.662)	3.792 (2.449)	3.833 (2.777)
	65	5.958 (2.528)	7.458 (2.064)	6.792 (1.719)	6.625 (2.446)	6.583 (2.125)	5.875 (2.133)
4	45	3.292 (2.493)	3.292 (2.678)	2.792 (1.793)	2.958 (2.136)	2.333 (1.736)	1.833 (1.494)
	55	4.750 (3.025)	4.917 (2.903)	4.292 (2.510)	4.000 (2.519)	4.250 (2.642)	2.875 (2.173)
	65	6.708 (2.758)	6.750 (2.270)	6.500 (2.147)	6.125 (2.007)	6.083 (1.954)	4.833 (1.810)

[a] Numbers in parentheses are the standard deviations.

Table D2. Means and Standard Deviations for Aircraft Annoyance Ratings for Experiment 2

[Excluding sessions 7 and 8]

Background source		Mean ratings and standard deviations[a] for S/N, dB, of—					
Test	Total noise level, L_{eq}, dB	−15	−9	−3	3	9	15
Air conditioner background noise							
3	45	2.083 (1.886)	2.417 (1.692)	2.833 (2.316)	3.083 (2.062)	3.042 (2.032)	3.500 (2.554)
	55	3.375 (2.428)	3.583 (2.466)	4.750 (2.345)	4.750 (2.674)	5.833 (2.426)	5.125 (2.833)
	65	4.583 (1.954)	4.958 (2.312)	5.708 (2.404)	6.250 (3.110)	7.417 (2.466)	6.458 (2.859)
4	45	1.917 (1.472)	2.500 (2.187)	2.042 (1.829)	2.542 (2.105)	2.458 (1.841)	2.875 (2.050)
	55	2.625 (2.242)	3.917 (2.466)	3.583 (2.685)	4.667 (2.036)	3.792 (2.322)	4.458 (2.621)
	65	4.250 (2.541)	5.958 (2.293)	5.958 (2.440)	7.458 (1.978)	7.792 (1.769)	7.125 (2.309)
Traffic background noise							
3	45	3.917 (2.430)	4.125 (2.383)	3.625 (2.039)	3.333 (1.810)	3.667 (2.014)	3.292 (2.274)
	55	5.917 (2.145)	5.750 (2.707)	6.542 (2.105)	6.083 (2.225)	5.375 (2.841)	6.208 (1.978)
	65	6.583 (2.205)	6.500 (2.571)	6.833 (2.057)	7.042 (2.216)	7.708 (2.331)	7.042 (2.236)
4	45	3.667 (2.648)	4.083 (2.586)	3.625 (2.356)	3.250 (1.894)	3.458 (1.978)	3.250 (2.327)
	55	4.208 (2.377)	4.750 (3.025)	4.708 (2.545)	4.625 (2.466)	4.917 (2.781)	4.500 (2.687)
	65	6.250 (3.040)	6.625 (2.551)	6.583 (2.466)	7.292 (2.032)	7.000 (2.396)	7.000 (2.265)

[a] Numbers in parentheses are the standard deviations.

Table D3. Means and Standard Deviations for Background Annoyance Ratings for Experiment 2

[Excluding sessions 7 and 8]

Background source		Mean ratings and standard deviations[a] for S/N, dB, of—					
Test	Total noise level, L_{eq}, dB	−15	−9	−3	3	9	15
Air conditioner background noise							
3	45	2.583 (1.692)	3.000 (2.167)	2.417 (1.767)	2.458 (1.817)	1.917 (1.472)	1.917 (1.558)
	55	3.708 (2.596)	4.125 (2.724)	3.625 (2.464)	3.250 (2.558)	2.958 (2.236)	2.458 (2.431)
	65	5.375 (1.974)	5.333 (2.200)	5.458 (1.865)	4.708 (1.781)	3.875 (2.193)	3.208 (2.303)
4	45	2.250 (2.418)	2.542 (2.621)	2.000 (2.341)	1.708 (2.255)	1.375 (2.018)	0.750 (1.032)
	55	3.792 (2.766)	4.417 (2.733)	3.167 (2.479)	3.167 (2.200)	2.875 (2.173)	2.083 (1.767)
	65	5.667 (2.839)	5.958 (2.645)	4.917 (2.448)	4.583 (2.586)	3.917 (2.394)	2.958 (2.095)
Traffic background noise							
3	45	3.708 (2.293)	4.083 (2.339)	3.333 (2.371)	3.333 (2.160)	2.667 (1.903)	2.542 (2.340)
	55	6.333 (2.220)	6.000 (2.467)	6.292 (2.136)	6.000 (1.934)	4.292 (1.967)	4.583 (2.283)
	65	6.292 (2.312)	7.333 (2.496)	6.250 (2.090)	5.958 (2.645)	5.958 (2.293)	4.333 (2.426)
4	45	2.833 (2.444)	2.250 (2.289)	2.208 (1.587)	2.083 (1.442)	1.458 (1.062)	1.292 (1.083)
	55	4.500 (3.148)	4.875 (3.111)	4.208 (2.587)	4.167 (2.665)	3.917 (2.781)	2.167 (2.582)
	65	5.667 (3.226)	6.417 (2.685)	5.750 (2.524)	5.417 (2.552)	5.042 (2.116)	3.333 (2.390)

[a] Numbers in parentheses are the standard deviations.

Table D4. Means and Standard Deviations for Total Annoyance Ratings for Experiment 2

[Sessions 7 and 8, aircraft noise only]

Test	Total noise level, L_{eq}, dB	Mean ratings and standard deviations[a] for aircraft L_{eq}, dB, of— 40	65
2	45	2.083 (1.954)	7.833 (2.496)
	55	2.333 (2.823)	4.375 (3.118)
	65	.958 (1.301)	4.375 (3.076)
3	45	0.875 (.992)	3.333 (3.409)
	55	1.000 (1.142)	4.333 (3.818)
	65	.583 (.717)	2.375 (1.813)

[a] Numbers in parentheses are the standard deviations.

Table D5. Means and Standard Deviations for Aircraft Annoyance Ratings for Experiment 2

[Sessions 7 and 8, aircraft noise only]

Test	Total noise level, L_{eq}, dB	Mean ratings and standard deviations[a] for aircraft L_{eq}, dB, of— 40	65
3	45	2.208 (1.911)	7.458 (3.078)
	55	3.083 (2.165)	8.458 (1.817)
	65	1.792 (1.719)	6.500 (3.135)
4	45	1.958 (1.805)	7.125 (2.643)
	55	2.000 (1.560)	8.167 (1.971)
	65	1.333 (1.049)	6.125 (3.158)

[a] Numbers in parentheses are the standard deviations.

Table D6. Means and Standard Deviations for Background Annoyance Ratings for Experiment 2

[Sessions 7 and 8, aircraft noise only]

Test	Total noise level, L_{eq}, dB	Mean ratings and standard deviations[a] for aircraft L_{eq}, dB of—	
		40	65
3	45	0.667 (1.523)	0.833 (2.180)
	55	1.000 (2.207)	1.042 (2.881)
	65	.333 (.917)	1.042 (2.440)
4	45	0.125 (.448)	0.833 (2.160)
	55	.042 (.204)	.625 (1.996)
	65	.250 (.532)	.500 (1.911)

[a] Numbers in parentheses are the standard deviations.

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Table 1. Experimental Design for Experiment 1[a]

Noise source	Indoor noise level, L_{eq}, dB			
	40	48	56	65
Aircraft flyover				
Traffic				
Air conditioner				

[a] Every subject received every stimulus presentation combination, $n = 48$.

Table 2. Presentation Orders of Conditions for Experiment 1[a]

Presentation order	Stimulus presentation conditions [b] for session—												
	1	2	3	4	5	6	7	8	9	10	11	12	13 (repeat)
1	T2	02	A4	04	A2	T1	A3	T3	T4	A1	01	03	T2
2	A4	T2	A2	02	A3	04	T4	T1	01	T3	03	A1	A4
3	A2	A4	A3	T2	T4	02	01	04	03	T1	A1	T3	A2
4	A3	A2	T4	A4	01	T2	03	02	A1	04	T3	T1	A3
5	T4	A3	01	A2	03	A4	A1	T2	T3	02	T1	04	T4
6	01	T4	03	A3	A1	A2	T3	A4	T1	T2	04	02	01
7	03	01	A1	T4	T3	A3	T1	A2	04	A4	02	T2	03
8	A1	03	T3	01	T1	T4	04	A3	02	A2	T2	A4	A1
9	T3	A1	T1	03	04	01	02	T4	T2	A3	A4	A2	T3
10	T1	T3	04	A1	02	03	T2	01	A4	T4	A2	A3	T1
11	04	T1	02	T3	T2	A1	A4	03	A2	01	A3	T4	04
12	02	04	T2	T1	A4	T3	A2	A1	A3	03	T4	01	02

[a] Each group of four different subjects received stimuli in one order.

[b] Stimuli key: A—air conditioner; T—traffic; 0—aircraft flyover; 1— 40-dB noise level; 2—48-dB noise level; 3—56-dB noise level; 4—65-dB noise level.

Table 3. Experimental Design for Experiment 2[a]

Total indoor noise level, L_{eq}, dB	Group	Subject	Air conditioner background noise source						Traffic background noise source					
			S/N, dB						S/N, dB					
			-15	-9	-3	3	9	15	-15	-9	-3	3	9	15
45	1	1–4												
	2	5–8												
	3	9–12												
	4	13–16												
	5	17–20												
	6	21–24												
55	7	25–28												
	8	29–32												
	9	33–36												
	10	37–40												
	11	41–44												
	12	45–48												
65	13	49–52												
	14	53–56												
	15	57–60												
	16	61–64												
	17	65–68												
	18	69–72												

[a] This design was used for each questionnaire or test.

Table 4. Noise Level Combinations for Experiment 2[a]

Total noise exposure, L_{eq}, dB	S/N, dB	Background level, L_{eq}, dB	Aircraft flyover level, L_{eq}, dB
45	-15	45	30
	-9	45	36
	-3	43	40
	3	40	43
	9	36	45
	15	30	45
55	-15	55	40
	-9	55	46
	-3	53	50
	3	50	53
	9	46	55
	15	40	55
65	-15	65	50
	-9	65	56
	-3	63	60
	3	60	63
	9	56	65
	15	50	65

[a] All levels given as measured in center of test room.

Table 5. Presentation Orders of Conditions For Experiment 2

Total noise exposure, L_{eq}, dB	Group	Stimulus presentation conditions[a] for session—													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
45	1	13	15	14	12	16	11	Hi	Lo	21	26	22	24	25	23
	2	24	23	26	25	21	22	Lo	Hi	12	11	15	16	13	14
	3	16	14	11	13	12	15	Hi	Lo	25	22	23	21	24	26
	4	21	26	22	24	25	23	Lo	Hi	13	15	14	12	16	11
	5	12	11	15	16	13	14	Hi	Lo	24	23	26	25	21	22
	6	25	22	23	21	24	26	Lo	Hi	16	14	11	13	12	15
55	7	13	15	14	12	16	11	Hi	Lo	21	26	22	24	25	23
	8	24	23	26	25	21	22	Lo	Hi	12	11	15	16	13	14
	9	16	14	11	13	12	15	Hi	Lo	25	22	23	21	24	26
	10	21	26	22	24	25	23	Lo	Hi	13	15	14	12	16	11
	11	12	11	15	16	13	14	Hi	Lo	24	23	26	25	21	22
	12	25	22	23	21	24	26	Lo	Hi	16	14	11	13	12	15
65	13	13	15	14	12	16	11	Hi	Lo	21	26	22	24	25	23
	14	24	23	26	25	21	22	Lo	Hi	12	11	15	16	13	14
	15	16	14	11	13	12	15	Hi	Lo	25	22	23	21	24	26
	16	21	26	22	24	25	23	Lo	Hi	13	15	14	12	16	11
	17	12	11	15	16	13	14	Hi	Lo	24	23	26	25	21	22
	18	25	22	23	21	24	26	Lo	Hi	16	14	11	13	12	15

[a] Stimuli key: First digit—1 = Air conditioner, 2 = Traffic. Second digit—1 = −15-dB S/N, 2 = −9-dB S/N, 3 = −3-dB S/N, 4 = 3-dB S/N, 5 = 9-dB S/N, 6 = 15-dB S/N; Hi = Flyover only (65 dB), Lo = Flyover only (40 dB).

Table 6. Means and Standard Deviations of Annoyance Ratings for Individual Sources for Experiment 1

Noise source	Mean annoyance rating and standard deviation[a] for total noise level L_{eq}, dB, of—			
	40	48	56	65
Aircraft flyover	1.521 (1.544)	2.042 (2.010)	3.146 (2.617)	5.917 (2.967)
Traffic	2.188 (1.684)	3.417 (2.061)	5.333 (2.660)	7.479 (2.449)
Air conditioner	1.479 (1.557)	2.542 (2.388)	3.813 (2.574)	5.292 (2.440)

[a] Numbers in parentheses are the standard deviations.

Table 7. Summary of MANOVA for Annoyance for Experiment 1

Source of variation	Hypothesis df	Error df	Mean square	Wilks' lambda	F
Between subjects:					
Group	11	36	28.88		0.99
Within subjects:					
Noise source	2	35		0.3510	[a]32.36
Source × group	22	70		.5710	1.03
Noise level	3	34		.1006	[a]101.32
Level × group	33	101		.4978	.82
Source × level	6	31		.4395	[a]6.59
Source × level × group	66	171		.1782	.99

[a]Significant at $p \leq 0.05$.

Table 8. Regression Analyses for Individual Noise Sources for Experiment 1

Noise source	Quadratic regression			Linear regression			F-comparison
	Equation (a)	df	R^2	Equation (b)	df	R^2	
Aircraft flyover	$14.042 - 0.611\ L_T + 0.007\ L_T^2$	1	0.9977	$-5.926 + 0.174\ L_T$	2	0.9029	[c]9.44
Traffic	$-0.022 - 0.044\ L_T + 0.002\ L_T^2$	1	.9983	$-6.616 + 0.215\ L_T$	2	.9909	[c]4.35
Air conditioner	$-2.246 + 0.056\ L_T + 0.001\ L_T^2$	1	.9998	$-4.728 + 0.153\ L_T$	2	.9977	[c]10.50

[a]Full model.
[b]Restricted model.
[c]Not significant at $p \leq 0.05$.

Table 9. Summary of Analysis of Variance of Responses Corrected for High Annoyance for Experiment 1

Source variation	df	Sum of squares	Q
Between subjects:	47		
Group	11	6.98	14.77
Group × subjects within groups	36	20.79	
Within subjects[a]:	528		
Noise source	2	2.01	[b]17.29
Source × subjects within groups	94	11.16	
Noise level	3	18.08	[b]150.84
Level × subjects within groups	141	17.26	
Source × level	6	1.02	[b]13.89
Source × level × subjects within groups	282	21.15	

[a] Subjects were pooled across groups for the within-subjects variables.
[b] Significant at $p \leq 0.05$.

Table 10. Summary of MANOVA for Total Annoyance for Test 2 of Experiment 2

Source of variation	Hypothesis df	Error df	Mean square	Wilks' lambda	F
Between subjects:					
Total noise level L_T	2	69	625.07		[a]17.60
Within subjects:					
Background source S	1	69	326.34		[a]37.72
$S \times L_T$	2	69	10.52		1.22
Signal-to-noise ratio S/N	5	65		0.8264	[a]2.73
$S/N \times L_T$	10	130		.8141	1.41
$S \times S/N$	5	65		.7646	[a]4.00
$S \times S/N \times L_T$	10	130		.7693	1.82

[a] Significant at $p \leq 0.05$.

Table 11. Summary of MANOVA for Total Annoyance for Test 4 of Experiment 2

Source of variation	Hypothesis df	Error df	Mean square	Wilks' lambda	F
Between subjects:					
Total noise level L_T	2	69	758.11		[a]25.59
Within subjects:					
Background source S	1	69	104.17		[a]9.67
$S \times L_T$	2	69	3.41		.32
Signal-to-noise ratio S/N	5	65		0.5066	[a]12.66
$S/N \times L_T$	10	130		.8310	1.26
$S \times S/N$	5	65		.8878	1.64
$S \times S/N \times L_T$	10	130		.8847	.82

[a] Significant at $p \leq 0.05$.

Table 12. Stepwise Multiple Regression of Total Annoyance on Aircraft and Background Noise Annoyance for Test 4 of Experiment 2

Variable	Coefficient, β	F to enter equation	R	Change in R^2
A_{BG}	0.6154	1997.59	0.8059	0.6495
A_{AC}	.3350	423.85	.8652	.0990
Constant	.3085			

Table 13. Summary of MANOVA for Aircraft Annoyance for Test 4 of Experiment 2

Source of variation	Hypothesis df	Error df	Mean square	Wilks' lambda	F
Between subjects:					
Total noise level L_T	2	69	981.76		[a]30.24
Within subjects:					
Background source S	1	69	128.34		[a]14.84
$S \times L_T$	2	69	11.48		1.33
Signal-to-noise S/N	5	65		0.6012	[a]8.62
$S/N \times L_T$	10	130		.7244	[a]2.27
$S \times S/N$	5	65		.7195	[a]5.07
$S \times S/N \times L_T$	10	130		.8784	.87

[a] Significant at $p \leq 0.05$.

Table 14. Summary of MANOVA for Total Annoyance for Tests 2 and 4 of Experiment 2

Source of variation	Hypothesis df	Error df	Mean square	Wilks' lambda	F
Between subjects:					
Test T	1	138	59.63		1.83
Total noise level L_T	2	138	1358.58		^{a}41.71
$T \times L_T$	2	138	24.60		.76
Within subjects:					
Background source S	1	138	399.63		^{a}41.15
$S \times T$	1	138	30.88		3.18
$S \times L_T$	2	138	6.12		.63
$S \times T \times L_T$	2	138	7.81		.80
Signal-to-noise ratio S/N	5	134		0.6494	^{a}14.79
$S/N \times T$	5	134		.8441	^{a}4.95
$S/N \times L_T$	10	268		.8506	^{a}2.26
$S/N \times T \times L_T$	10	268		.9620	.52
$S \times S/N$	5	134		.9113	^{a}2.61
$S \times S/N \times T$	5	134		.8704	^{a}3.99
$S \times S/N \times L_T$	10	268		.8923	1.57
$S \times S/N \times T \times L_T$	10	268		.9259	1.05

^{a}Significant at $p \leq 0.05$.

Table 15. Summary of MANOVA for Aircraft Flyover Annoyance for Tests 3 and 4 of Experiment 2

Source of variation	Hypothesis df	Error df	Mean square	Wilks' lambda	F
Between subjects:					
Test T	1	138	61.50		1.86
Total noise level L_T	2	138	1673.16		[a]50.72
$T \times L_T$	2	138	55.62		1.69
Within subjects:					
Background source S	1	138	377.81		[a]43.27
$S \times T$	1	138	11.67		1.34
$S \times L_T$	2	138	5.71		.65
$S \times T \times L_T$	2	138	11.86		1.36
Signal-to-noise ratio S/N	5	134		0.6843	[a]12.37
$S/N \times T$	5	134		.9004	[a]2.96
$S/N \times L_T$	10	268		.7478	[a]4.19
$S/N \times T \times L_T$	10	268		.9603	.55
$S \times S/N$	5	134		.6953	[a]11.75
$S \times S/N \times T$	5	134		.9550	[a]1.26
$S \times S/N \times L_T$	10	268		.9614	.53
$S \times S/N \times T \times L_T$	10	268		.9086	1.32

[a] Significant at $p \leq 0.05$.

Table 16. Summary of MANOVA for Background Noise Annoyance for Tests 3 and 4 of Experiment 2

Source of variation	Hypothesis df	Error df	Mean square	Wilks' lambda	F
Between subjects:					
Test T	1	138	224.61		^{a}7.15
Total noise level L_T	2	138	1137.44		^{a}36.19
$T \times L_T$	2	138	13.41		.43
Within subjects:					
Background source S	1	138	441.05		^{a}40.66
$S \times T$	1	138	101.60		^{a}9.37
$S \times L_T$	2	138	29.42		2.71
$S \times T \times L_T$	2	138	7.90		.73
Signal-to-noise ratio S/N	5	134		0.4414	^{a}33.91
$S/N \times T$	5	134		.9395	^{a}1.73
$S/N \times L_T$	10	268		.8796	^{a}1.78
$S/N \times T \times L_T$	10	268		.9079	1.33
$S \times S/N$	5	134		.9799	.55
$S \times S/N \times T$	5	134		.9735	.73
$S \times S/N \times L_T$	10	268		.8768	1.82
$S \times S/N \times T \times L_T$	10	268		.9317	.96

[a] Significant at $p \leq 0.05$.

Table 17. Total Annoyance as Predicted With Regression Equations of Community Response Models for Experiment 2

(a) Test 2

Community response model	Regression equation for total annoyance, A_T, for—	
	Air conditioner background noise	Traffic background noise
Energy summation	$-3.4625 + 0.1316\ L_T$	$-2.8251 + 0.1424\ L_T$
Independent effects	$-2.5589 + 0.3986\ E_{BG} + 0.3819\ E_{AC}$	$-1.4375 + 0.4911\ E_{BG} + 0.1427\ E_{AC}$
Energy difference	[a] $-3.4104 + 0.1316\ L_T - 0.0058 \lvert L_{AC} - L_{BG} \rvert$	[a] $-2.6111 + 0.1424\ L_T - 0.0229 \lvert L_{AC} - L_{BG} \rvert$
Response summation	$-2.7742 + 0.1299(L_T + D_i\ 10^{(L_i - L_T)/10})$	$-2.8259 + 0.1350(L_T + D_i 10^{(L_i - L_T)/10})$
Subjectively corrected L_{eq}	$0.6533 + 0.4807\ \psi_{e,T}$	$0.9299 + 0.7008\ \psi_{e,T}$
Magnitude summation	$0.4007 + 0.5338(\psi_{BG} + \psi_{AC})$	$0.7574 + 0.5372(\psi_{BG} + \psi_{AC})$
Summation and inhibition	$0.3946 + 0.6923\psi_T$	$0.8247 + 0.6529\psi_T$
Actual difference	[a] $-3.4625 + 0.1316\ L_T + 0.0024\ S/N$	$-2.8106 + 0.1424\ L_T - 0.0434\ S/N$

[a] Not significant at $p \leq 0.05$.

Table 17. Concluded

(b) Test 4

Community response model	Regression equation for total annoyance, A_T, for—	
	Air conditioner background noise	Traffic background noise
Energy summation	$-4.6366 + 0.1511\ L_T$	$-5.0297 + 0.1708\ L_T$
Independent effects	$-3.6851 + 0.8456\ E_{BG} + 0.1041\ E_{AC}$	$-3.6099 + 0.6207\ E_{BG} + 0.1610\ E_{AC}$
Energy difference	$^{a}- 4.5218 + 0.1510\ L_T - 0.0128\lvert L_{AC} - L_{BG}\rvert$	$^{a}- 4.6400 + 0.1708\ L_T - 0.0418\lvert L_{AC} - L_{BG}\rvert$
Response summation	$-2.4335 + 0.1178(L_T + D_i\ 10^{(L_i - L_T)/10})$	$-3.5096 + 0.1431(L_T + D_i 10^{(L_i - L_T)/10})$
Subjectively corrected L_{eq}	$-0.0482 + 0.7814\ \psi_{e,T}$	$0.4075 + 0.7619\ \psi_{e,T}$
Magnitude summation	$0.2413 + 0.6309(\psi_{BG} + \psi_{AC})$	$0.3011 + 0.5633(\psi_{BG} + \psi_{AC})$
Summation and inhibition	$0.2233 + 0.8230\psi_T$	$0.3547 + 0.6902\psi_T$
Actual difference	$^{a}- 4.6366 + 0.1511\ L_T + 0.0558\ S/N$	$-5.0122 + 0.1708\ L_T - 0.0523\ S/N$

[a] Not significant at $p \leq 0.05$.

Table 18. Comparisons of Community Response Models for Experiment 2

Model	Test 2 values for—					Test 4 values for—				
	Air conditioner R^2	Traffic R^2	Average R^2	D'	Rank	Air conditioner R^2	Traffic R^2	Average R^2	D'	Rank
Energy summation	0.8717	0.6916	0.7817	0.1801	7	0.7404	0.8313	0.7859	0.0909	5
Independent effects	.8490	.7454	.7972	.1036	5	.8970	.9678	.9324	.0708	1
Energy difference	.8723	.6975	.7849	.1748	6	.7423	.8476	.7950	.1053	4
Response summation	.6228	.6969	.6599	.0741	8	.6112	.8098	.7105	.1986	6
Subjectively corrected L_{eq}	.8448	.8357	.8403	.0091	3	.8230	.9666	.8948	.1436	3
Magnitude summation	.9046	.8661	.8854	.0385	1	.4660	.9320	.6990	.4660	8
Summation and inhibition	.8944	.8532	.8738	.0412	2	.4660	.9328	.6994	.4668	7
Actual difference	.8717	.7965	.8341	.0752	4	.8996	.9584	.9290	.0588	2

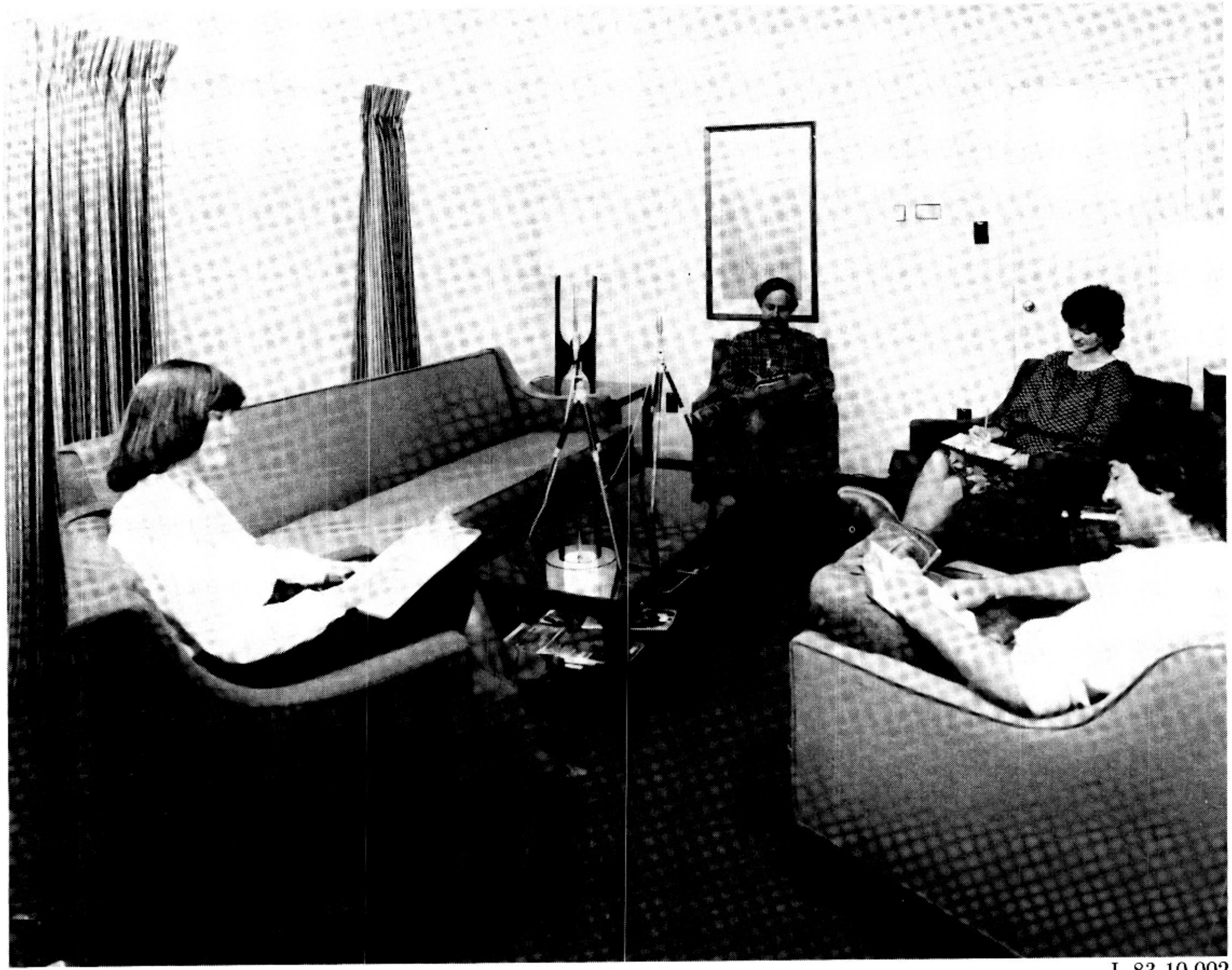

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Figure 1. Subjects in the Interior Effects Room in the Langley Aircraft Noise Reduction Laboratory.

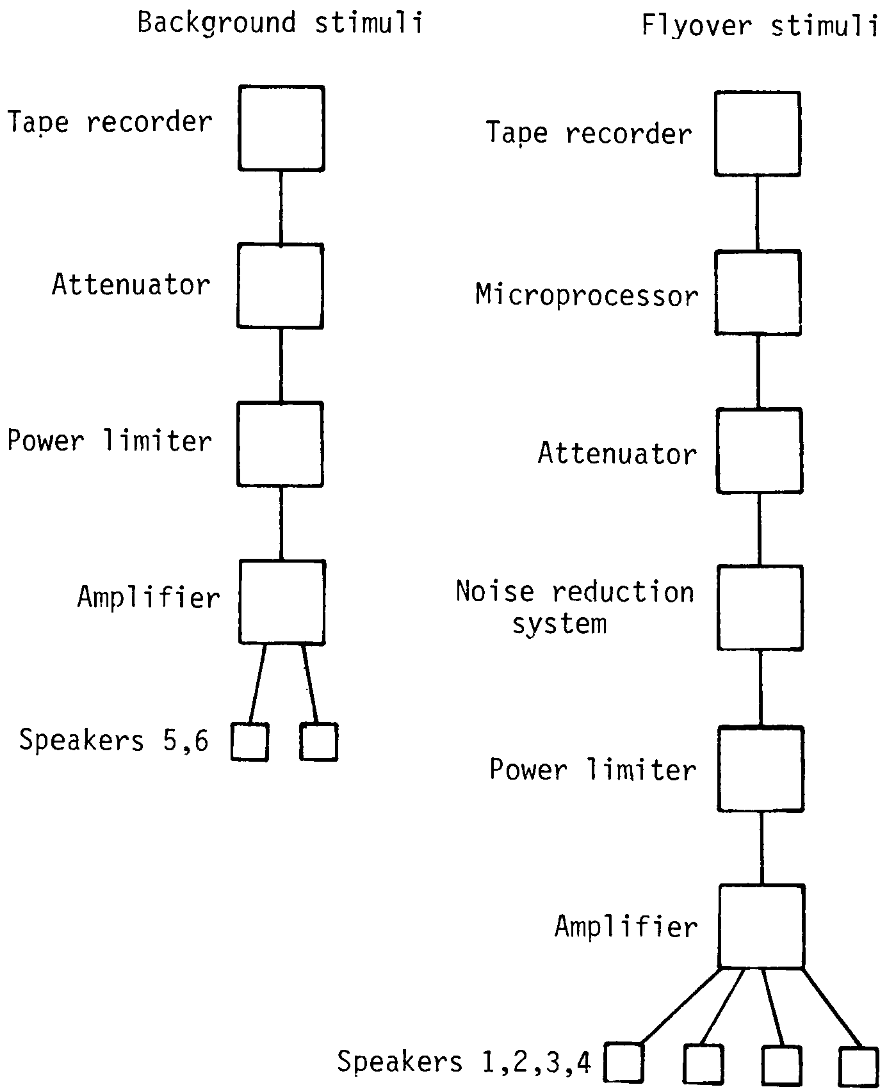
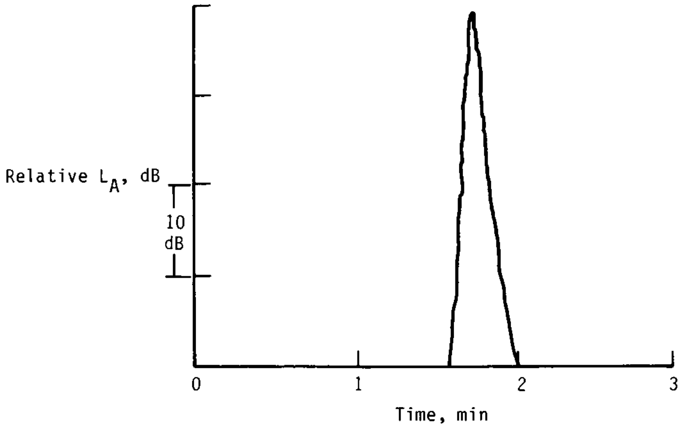
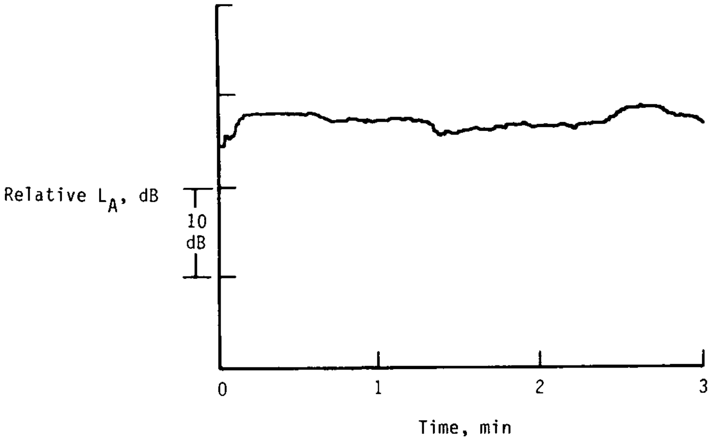


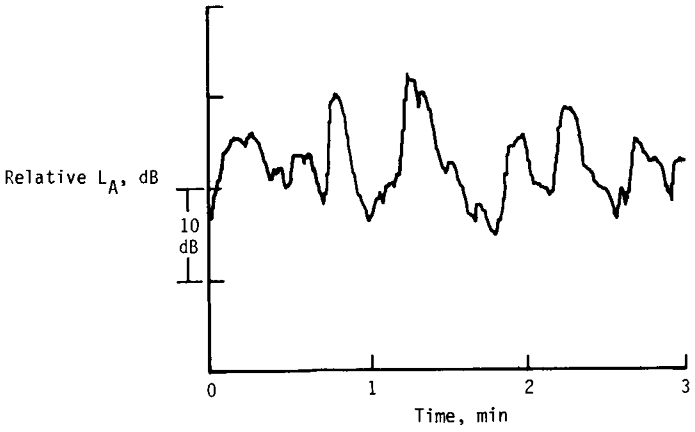
Figure 2. Diagram of the noise stimuli presentation system.



(a) Aircraft flyover.

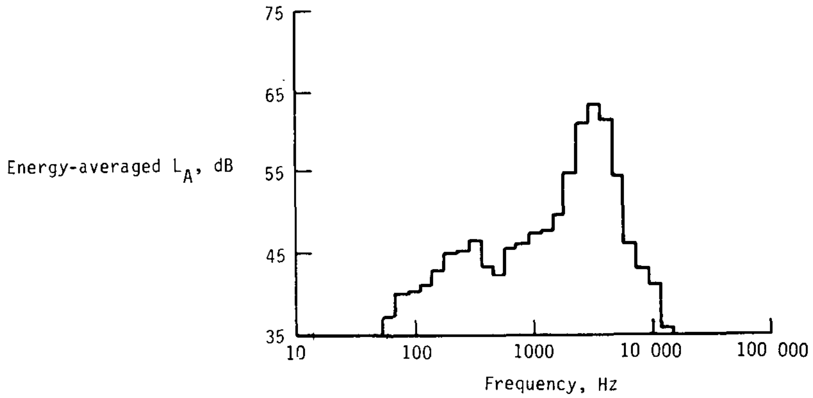


(b) Air conditioner.

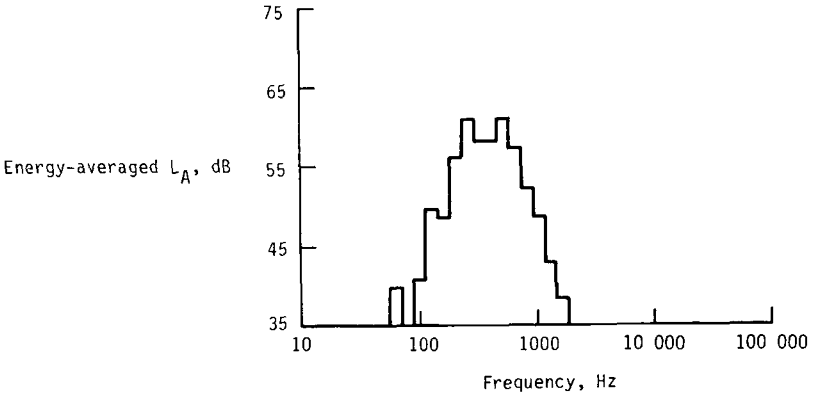


(c) Traffic.

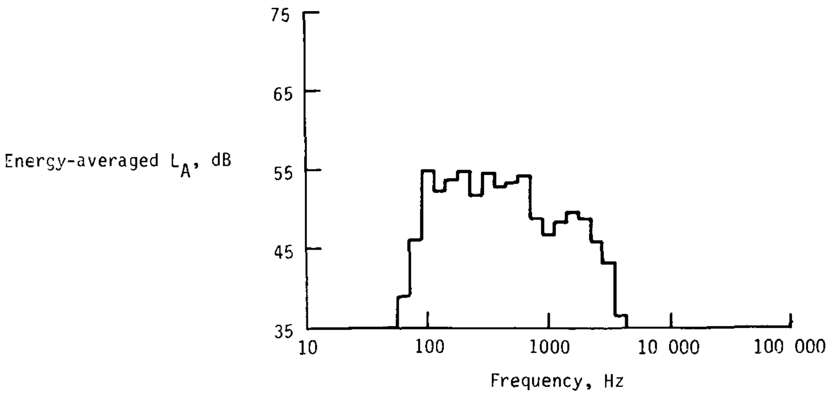
Figure 3. Time histories of noise stimuli over a 3-minute sample period.



(a) Aircraft flyover noise spectrum.

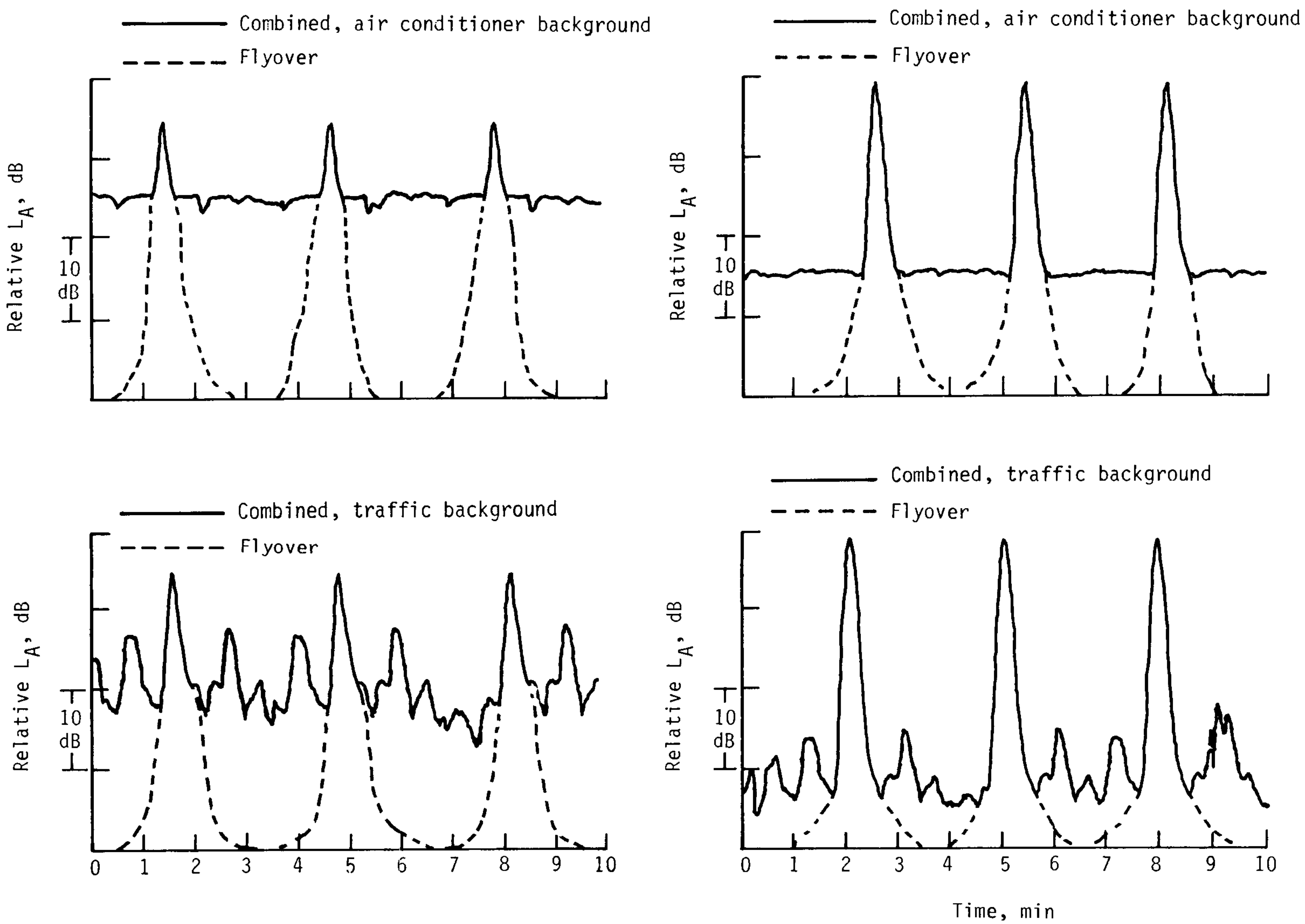


(b) Air conditioner noise spectrum.



(c) Traffic noise spectrum.

Figure 4. Average one-third-octave band spectra of noise stimuli.



(a) $S/N = -3$ dB.

(b) $S/N = 15$ dB.

Figure 5. Examples of combined time histories of three flyovers and background noise.

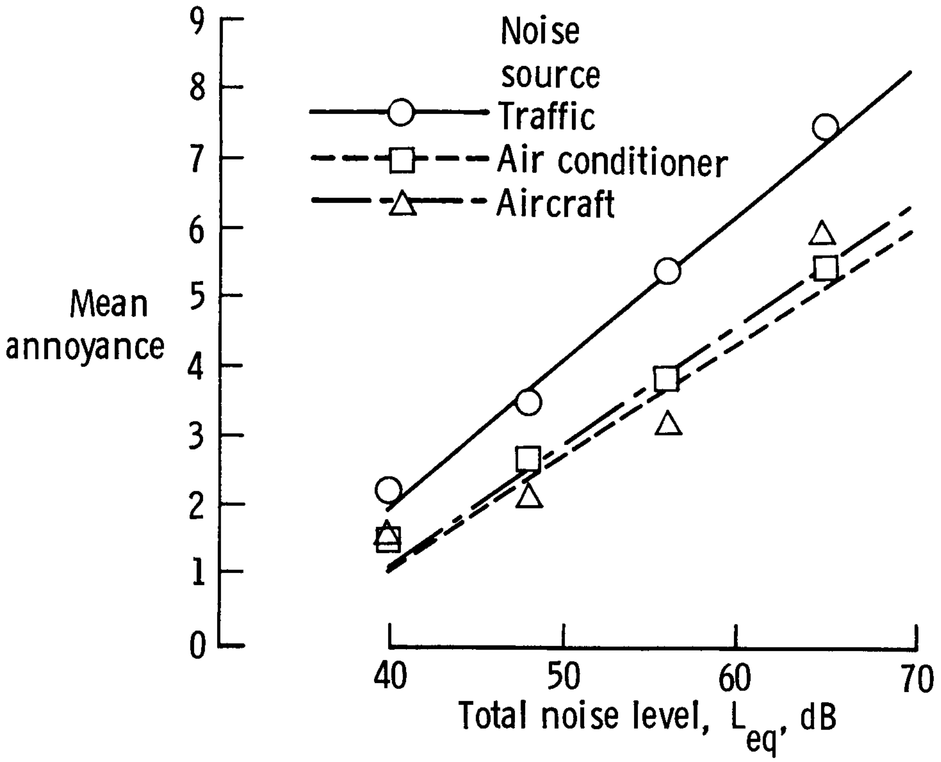


Figure 6. Mean annoyance ratings and linear regression lines for individual noise sources.

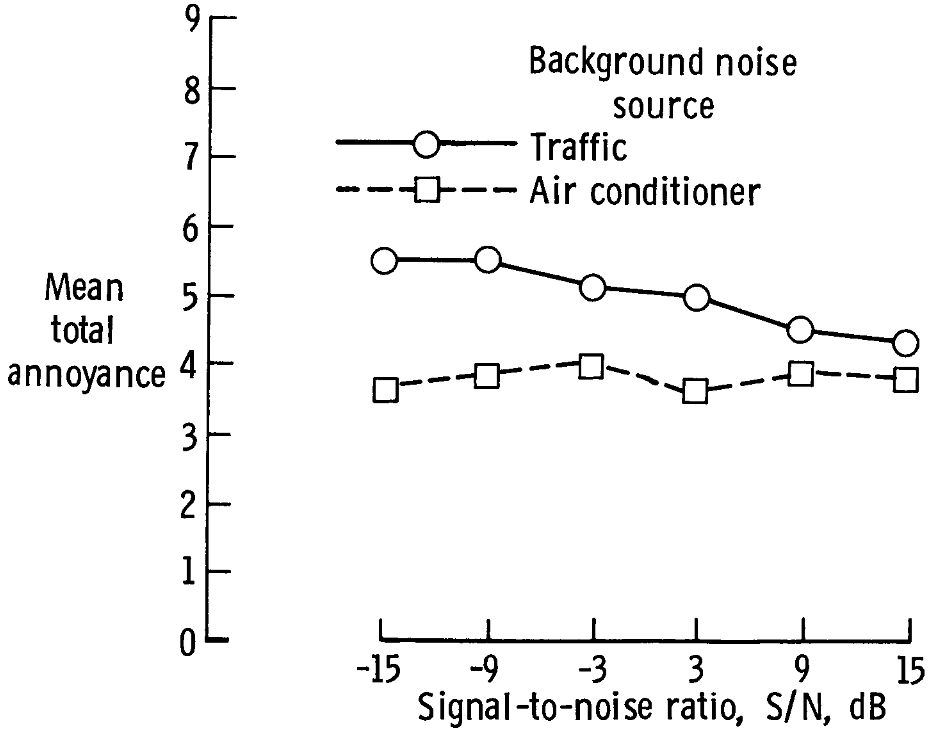


Figure 7. Effects of S/N on total annoyance in test 2 for different background noise sources.

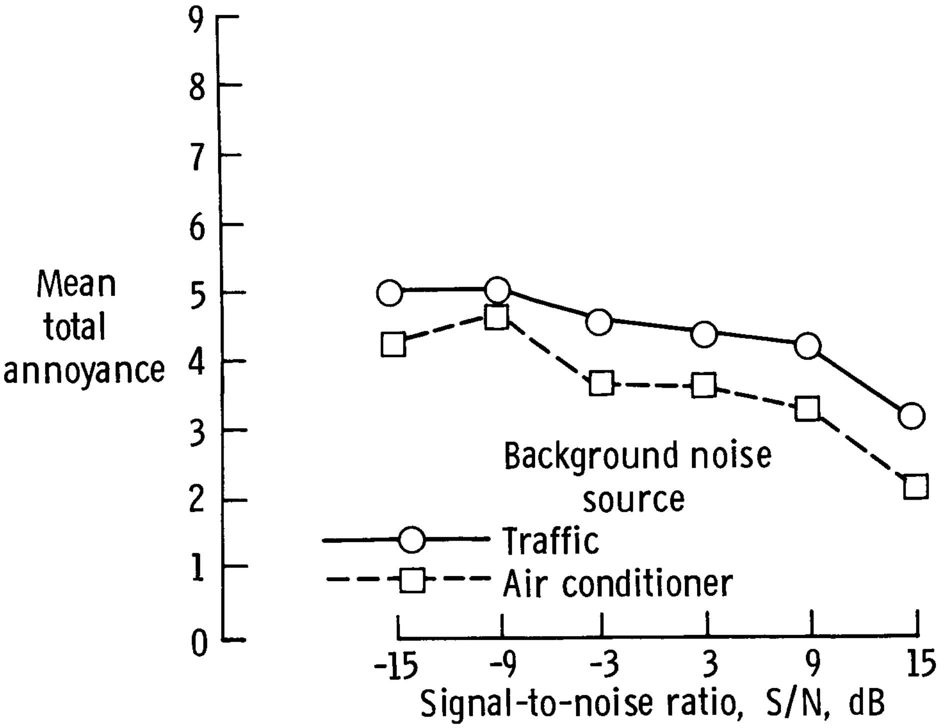


Figure 8. Effects of S/N on total annoyance in test 4 for different background noise sources. This interaction is not statistically significant.

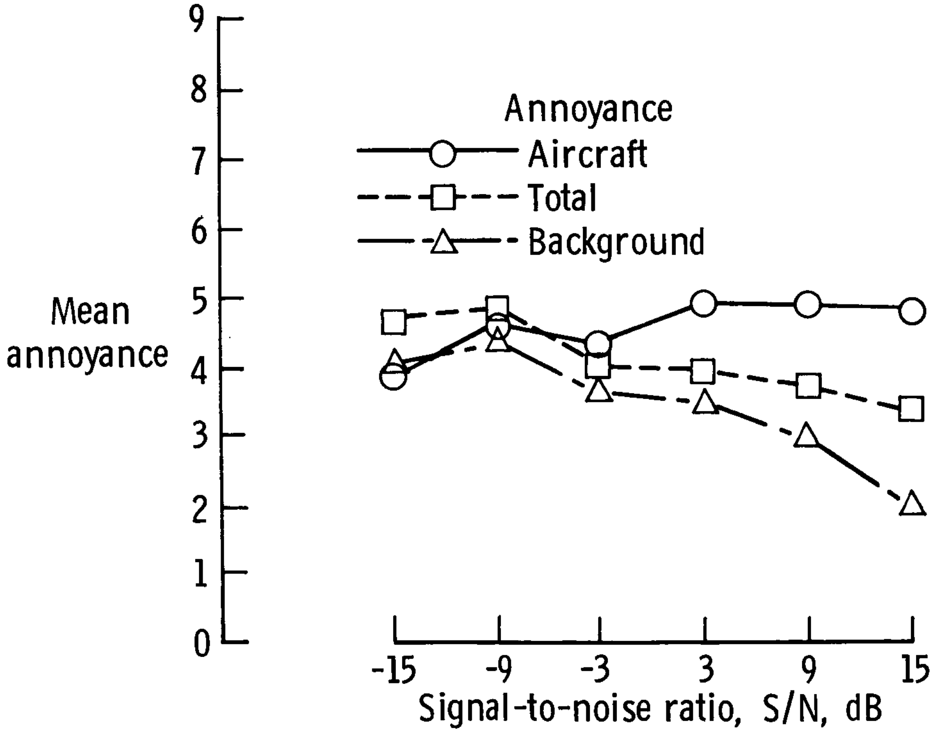


Figure 9. Mean annoyance for different annoyance questions in test 4 as a function of S/N.

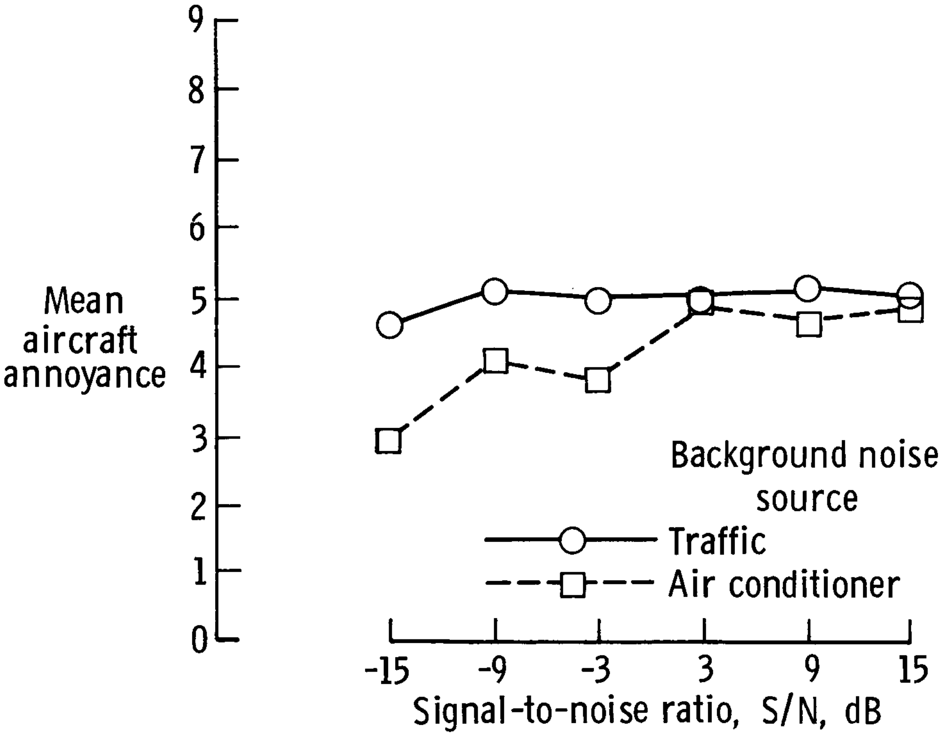


Figure 10. Effect of S/N on aircraft annoyance in test 4 for different background noise sources.

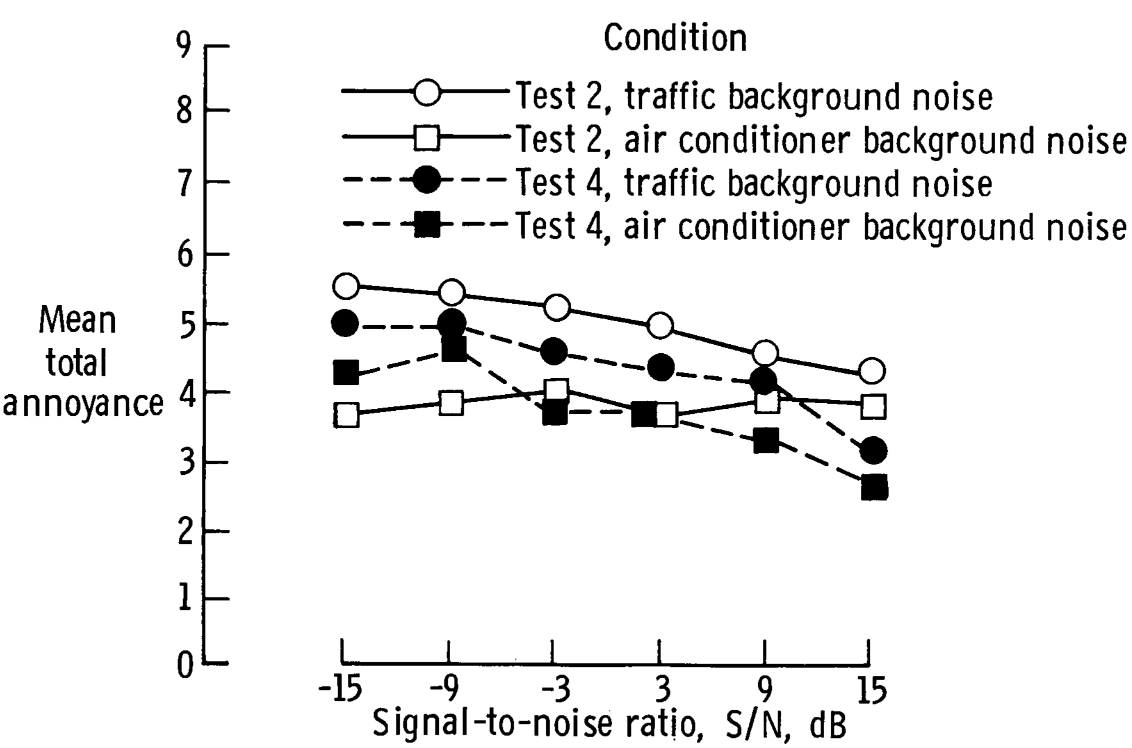


Figure 11. Relationship of total annoyance and S/N for tests 2 and 4 for different background noise sources.

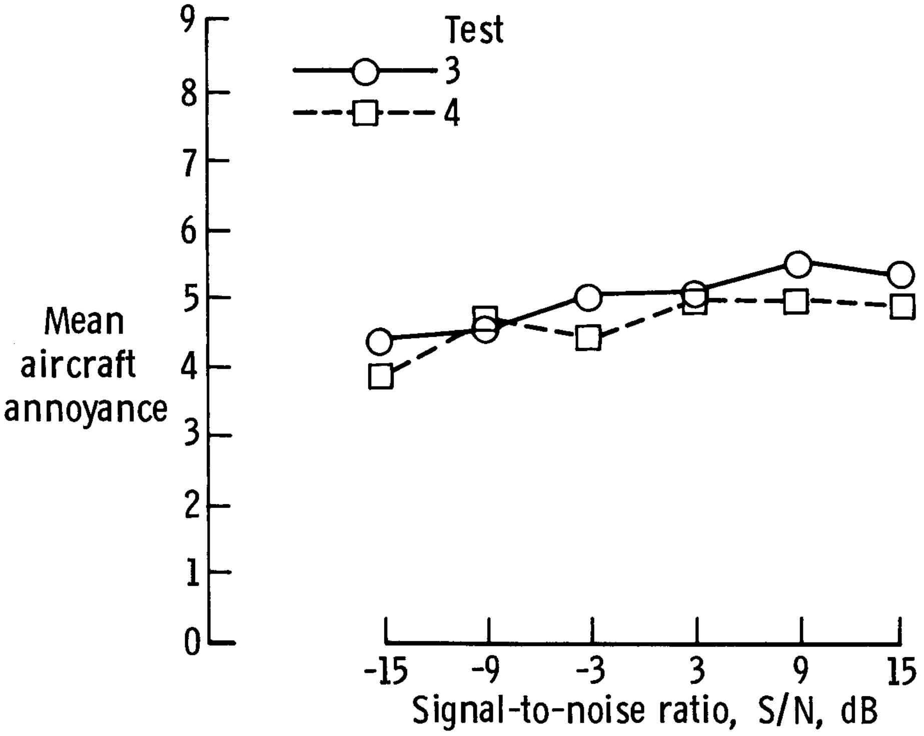


Figure 12. Illustration of small but significant interaction of test with S/N for aircraft annoyance.

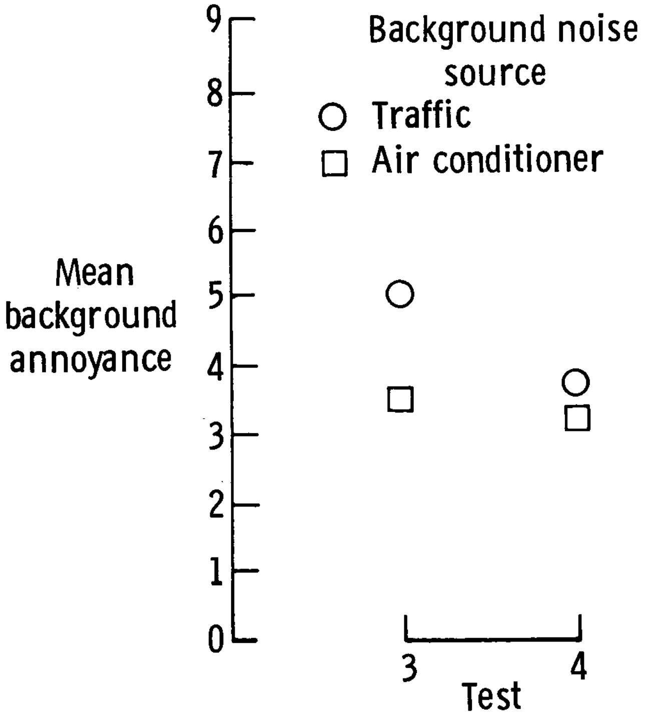


Figure 13. Mean background annoyance for different background noise sources as function of test.

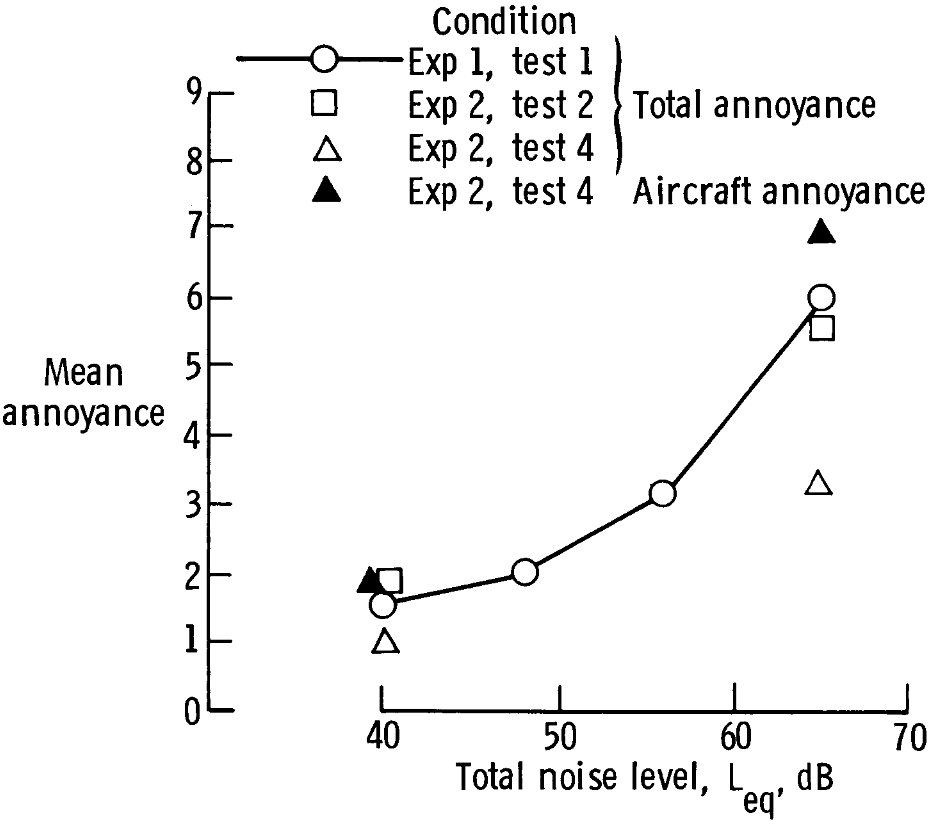


Figure 14. Comparisons of annoyance between experiments 1 and 2 (sessions 7 and 8).

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16. Abstract

Two experiments were conducted to assess the effects of combined community noise sources on annoyance. The first experiment established baseline relationships between annoyance and noise level for three community noise sources (jet aircraft flyovers, traffic, and air conditioner) presented individually. Forty-eight subjects evaluated the annoyance of each noise source presented at four different noise levels. Results indicated the slope of the linear relationship between annoyance and noise level for the traffic noise was significantly different from that of aircraft and of air conditioner noise, which had equal slopes. The second experiment investigated annoyance response to combined noise sources, with aircraft noise defined as the major noise source and traffic and air conditioner noise as background noise sources. Effects on annoyance of noise level differences between aircraft and background noise for three total noise levels and for both background noise sources were determined. A total of 216 subjects were required to make either total or source-specific annoyance judgments, or a combination of the two, for a wide range of combined noise conditions.

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