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Laboratory Study of Annoyance to Combined Airplane and Road-Traffic Noise

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SUMMARY

A laboratory study was conducted in which 64 subjects judged the annoyance of 15-minute sessions of noise. The sessions consisted of both separate and combined exposures to airplane noise and road-traffic noise. The subjects were asked to judge each session as to how annoyed they were in the simulated living-room environment of the laboratory and as to how annoyed they would be if they heard the noise in their home during day, evening, and night periods.

The airplane noises, for equal-session L_{eq} levels (where L_{eq} represents the equivalent continuous sound level), were judged significantly more annoying than the road-traffic noises for the separate sessions. For the combined sessions, a significant interaction was found between the airplane-noise and traffic-noise levels which was not adequately assessed by the total energy concept of L_{eq}. Differences were found between the projected home responses for the day, evening, and night periods. Based on these results appropriate penalties for the different time periods were determined. Generally good agreement was found between the laboratory results and community surveys for the percentage of people highly annoyed by the separate noise conditions. However, the percentages of people highly annoyed by some of the combined noise conditions were considerably greater than those found for the separate noise conditions at equal L_{eq} levels.

INTRODUCTION

During the past 20 years considerable information has been generated concerning annoyance due to aircraft noise in both laboratory studies and in surveys of community response to noise. Most laboratory studies have centered around the annoyance or unpleasantness of individual aircraft events. Although this information is of great importance for determining the relative effects of different types of aircraft, very little insight is provided as to how various mixes or numbers of aircraft and noises from other sources combine over periods of time to affect the quality of the community-noise environment. It is this problem area that is of concern in this paper.

Social surveys or community-noise annoyance surveys, although providing information on annoyance under real environmental conditions, suffer from a lack of precision in noise measurements. Respondents are usually grouped into broad categories of noise exposure. Although these gross estimates of exposure provide relatively good correlation with grouped or mean annoyance data, the true nature of the effects and interactions of factors such as the number and mix of aircraft as well as the influence of other noise sources is obscured.

Laboratory studies, such as those reported in references 1 to 4, have agreed that individual aircraft-noise events are judged less annoying in the presence of background noise. Results of recent social surveys, however, have not been as consistent. For example, in two surveys (refs. 5 and 6) which considered background noise, less aircraft annoyance was reported under conditions of high levels of road-traffic noise than under low levels of road-traffic noise. On the other hand, in two other surveys which considered background noise (reported in ref. 7), greater railroad-noise annoyance was reported under conditions of high levels of road-traffic noise than under low levels of road-traffic noise.

In one of the aircraft-noise surveys (ref. 5), the respondents were also asked to give their feelings of general noise dissatisfaction. For conditions of high aircraft-noise exposure, less general noise dissatisfaction was found for high levels of road-traffic noise than for low levels of road-traffic noise. For conditions of low aircraft-noise exposure, greater general noise dissatisfaction was found for high levels of road-traffic noise than for low levels of road-traffic noise. The authors of reference 5 considered these results to be strong qualitative support for a noise-pollution-level model for community-noise annoyance which considers the fluctuation in noise level as well as the energy average noise level (ref. 8). A more recent report (ref. 9), however, considered the same data as support for a response summation model. In this model, the energy average level is augmented by a factor which depends on the differences in noise levels of the separate sources which produce equal annoyance responses.

References 1 to 9 indicate a need for additional research in several areas of community-noise annoyance which involve exposure to more than one source of intrusive noise. Consequently, the Langley Research Center began a research program to investigate the nature of multiple-noise-source annoyance. Two experiments conducted within this program examined the effects of road-traffic background noise on annoyance to individual aircraft-noise events and were reported in reference 10. Two additional experiments were conducted (ref. 11) to examine the effects of road-traffic noise on sessions of multiple aircraft noise and the nature of total annoyance due to combined noise sources. The latter study indicated an interaction between noise sources for the case of total annoyance which could not be satisfactorily explained by any of the previously mentioned models.

Based on the results of the studies reported in references 10 and 11, a model of annoyance to combined noise sources was developed and reported in reference 12. The model provides for the summation of annoyance due to the separate sources and the inhibition of annoyance of each source as a result of the presence of the other source. An additional experiment was then conducted to provide the necessary information to verify the model, that is, separate and combined annoyance judgments for aircraft and traffic noise.

Additional objectives of the verification experiment were as follows:

(1) Provide additional information on the nature of the interactions between noise sources which affect annoyance response.

(2) Provide information on the appropriateness of weightings or penalties used in current noise-exposure indices for evening and night exposures.

(3) Provide comparisons between annoyance responses obtained in laboratory situations for typical community indoor-noise exposures with responses obtained from community-noise annoyance surveys.

The details of the experimental design and results of the experiment relevant to these objectives are reported herein.

SYMBOLS AND ABBREVIATIONS

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

EPL — effective perceived level (according to the Stevens Mark VII procedure with duration correction), dB

EPNL — effective perceived noise level, dB

F — ratio of variances

L_A — A-weighted peak noise level, dB

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

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

L_{np} — noise pollution level, dB

L_{10} — level exceeded 10 percent of a time period, dB

L_{90} — level exceeded 90 percent of a time period, dB

PL — perceived level (according to the Stevens Mark VII procedure), dB

PNL — perceived noise level, dB

TCPNL — tone-corrected perceived noise level, dB

TNI — traffic-noise index, dB

σ — standard deviation of instantaneous A-weighted noise level, dB

EXPERIMENTAL METHOD

Test Facility

The interior effects room of the Langley aircraft noise reduction laboratory was used in the present experiment. This room was designed to resemble a typical living room and to allow controlled acoustical environments to be presented to subjects. The construction of the test room is typical of modern single-family dwellings. The floor plan and a photograph of the facility are shown in figures 1 and 2, respectively. The loudspeaker systems used to produce the airplane- and road-traffic noise stimuli were located outside the test room to provide a more realistic simulation of residential environmental noise. The locations of the loudspeaker systems are indicated in figure 1 by the dashed rectangular areas. Loudspeaker systems 1 to 4 were mounted above the ceiling of the test room and were used to reproduce the airplane-noise stimuli. Systems 5 and 6, which were used to reproduce the traffic-noise stimuli, were mounted at window height approximately 2 m from the test room across an open area to the basement.

Careful attention was given to the acoustics of the test room and surrounding area so that a realistic acoustical environment could be provided. A detailed description of the facility and results of acoustic measurements are given in reference 10. These measurements indicated that the airplane and traffic noises presented to test subjects would be representative of those experienced inside typical dwellings.

Noise Stimuli

One of the primary concerns of the experiment was to provide an ample number of observations for each noise condition in order that good statistical estimations of the mean response at each condition could be obtained. Consequently, only airplanes and road-traffic noise were considered in this study in order to allow a relatively wide range of noise levels to be investigated for each type. Complete details of the noise stimuli are given in appendix A.

A total of 17 noise conditions were used in the experiment. These consisted of four levels each of airplane and traffic noise and nine combinations of mixed airplane and traffic noise (three levels of each type). The airplane noises consisted of eight flyover recordings presented in a 15-minute noise session. The traffic noise consisted of recordings of freely flowing road traffic characterized by relatively small variation in noise level. Results of acoustical analyses of each of the 17 noise conditions are presented in table I in terms of several cumulative noise indices. Both the airplane and traffic-alone conditions were included at the level of L_{eq} = 30 dB so that additional information on the shape of the response-level relationship could be obtained.

EXPERIMENTAL DESIGN

The chosen design was based on the combination of a replicated 8 × 6 Youden square design (ref. 14) with repeated measures for the eight separate noise conditions and an incomplete block 3^2 factorial design with repeated measures for the combined noise conditions. Subject groups served as the blocking factor. Additional blocks of conditions for the combined noises were added because of the number of subject groups required for the design for the separate noise conditions.

The order of presentation of the design is given in table II. Each of the 16 subject groups (4 subjects per group) made judgments on 6 sessions of airplane or traffic noise alone and 3 sessions of combined airplane and traffic noise. The combined noises were always presented as sessions three, five, and seven. The particular blocks of combined noises presented to subject groups 1 to 6 and 9 to 14 were selected so that at least partial information was available for determining interaction effects of airplane and traffic (ref. 15). The remaining four blocks (or subject groups) provided one additional replication of all combined conditions and another replication of the conditions with equal airplane- and traffic-noise levels. The total number of judgments for each separate airplane- and traffic-noise condition was 48. The total for all combined noise conditions, except those at equal noise levels, was 20; the total for the equal noise level conditions was 24.

Subjects

The 64 subjects for this experiment were paid volunteers from the general population of the cities of Hampton and Newport News and from York County in Virginia. Approximately one-half had previous experience in judging sessions of noise. Twenty-two of the subjects were male. The subjects were randomly assigned to the 16 groups.

Procedure

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

The subjects were then escorted into the test facility, randomly assigned seats, and again asked if they had any questions. After each test session, the test conductor returned to the facility and gave the scoring sheets to the subjects for their judgment. A 15-minute break was given to the subjects following the fifth test session. After indicating their judgments for the final session, the subjects were requested to indicate at what point on the rating scale they would start to become highly annoyed. This question was used to provide information for the conversion of the subjects' judgments into the percentage of subjects highly annoyed. This technique had been used in references 16 and 17 for the comparison of laboratory-annoyance studies with community-survey results. Although the validity of the techniques of home projection and conversion to percentage of subjects highly annoyed has not been universally established, the results of references 16 and 17 indicate relatively good agreement with community-annoyance surveys such as those reported in reference 7. Consequently, with further testing and perhaps modification, these techniques may provide a vital link between laboratory-noise annoyance research and the prediction of community-noise annoyance.

RESULTS AND DISCUSSION

Analysis of Variance

The subjective-response data for the laboratory annoyance and three cases of projected home annoyance were analyzed separately by using the same analysis of variance technique. The analysis for the subjects' annoyance in the laboratory to the different noise sessions is presented in table III. The first step in the analysis was to test whether significant differences existed between the 17 different noise conditions (treatments). A two-way cross-classification model for treatment and subject effects was fitted. Since the subjects did not judge each of the 17 treatments, it was necessary to adjust treatment means for subject differences. This was done by using the linear-model techniques described in reference 18. The prime reason for the portion of the analysis listed in table III under "All conditions," which indicated that significant treatment differences were found, was to furnish an estimate of experimental error to be used for further tests on the different treatments. The residual mean square (2.25 for 496 degrees of freedom) supplied the needed estimate.

The first set of treatment comparisons of interest was the nine combinations of airplane and traffic noises. The effects of airplane noise, traffic noise, and their interaction, appropriately adjusted for subject differences, were tested by using the preceding error estimate. As indicated, airplane noise, traffic noise, and their interaction were found significant at the 1-percent level. These effects will be discussed in greater detail in a later section. The other treatment comparison of interest was for the eight separate airplane and traffic-noise conditions. For this analysis the effects of noise type (either airplane or traffic), noise level (four L_{eq} levels for each type), and the interaction of type and level were tested by using the same error estimate. Noise type was found significant at the 5-percent level, and noise level was significant at the 1-percent level. The interaction was not found to be significant.

Similar analyses were performed for the three cases of the home-projected annoyance question. These are presented in tables IV, V, and VI for the three time periods - day, evening, and night, respectively. The only important differences found between the results of the analyses for the four questions were related to noise type for the separate airplane and traffic conditions. For the laboratory question, this effect was found significant at the 5-percent level; whereas for the day and evening home-projected questions no significance was found. The analysis for the night home-projected question, however, indicated an effect of noise type significant at the 1-percent level. These differences will also be discussed in a later section. It should be noted from the analyses of variance that there was a greater between-subject variance and a greater residual variance for each of the home-projected questions than for the laboratory question.

Laboratory-Annoyance Responses

The major results of the annoyance response are presented in table VII. The mean annoyance responses to the laboratory-annoyance questions and the three cases of the home-projected questions are given for each noise condition presented to the subjects. In addition, the adjusted means as estimated by the linear-model technique are also given. In general, the adjusted means were not very different from the unadjusted means; however, in some cases the difference was as much as 0.5 unit of the subjective scale. In the following discussions the adjusted means will be used since the experimental design was incomplete and the adjustments compensated for subject differences. The following paragraphs of this section will consider, in turn, the topics of the airplane and traffic noises separately and the airplane and traffic noise in combination.

Airplane and traffic noises separately.- As indicated in the analysis of variance (table III) there was a difference (significant at the 5-percent level) in the judgments of the airplane and traffic noises when presented as separate sessions for judgment. This result is presented in figure 3 where the adjusted mean response for the laboratory conditions is plotted against the session noise level in L_{eq}. Both the airplane- and traffic-noise data follow the same type of relationship with level except for a small shift in intercept or mean value. This was evidenced by the lack of a significant interaction between noise type and level in the analysis of variance. As shown, the adjusted airplane-noise judgments were approximately 0.3 unit greater than the traffic judgments. The difference in annoyance response at equal levels of exposure, although relatively small for these two sources, is indicative of the inability of the energy-equivalent A-weighted sound level to assess annoyance adequately to all types of community-noise sources.

Airplane and traffic noises combined.- In the analysis of variance (table III) for the combined airplane- and traffic-noise conditions it was found that both the airplane-noise level and traffic-noise level as well as their interaction was significant at the 1-percent level. The nature of these effects is shown in figures 4 and 5. In figure 4 the adjusted mean response data are presented as a function of the airplane-noise level with the traffic-noise level as a parameter. The judgments of the airplane noises separately are indicated by cross-shaped symbols.

For the lowest traffic-noise level (circular symbols where L_{eq} = 40 dB) as the airplane-noise level was increased, there was a slight decrease in annoyance followed by a substantial increase as the airplane level was further increased. For the middle traffic level (square symbols where L_{eq} = 50 dB) as the airplane-noise level was increased, there was a substantial increase in annoyance followed by a very slight decrease in annoyance. For the highest traffic level (diamond symbols where L_{eq} = 60 dB), there was a decrease in annoyance followed by a substantial increase as the airplane level was increased. As can be seen there were several conditions for which the combined noises were judged less annoying than the airplane noise alone, thus indicating that some type of inhibition or masking had occurred. The same results are plotted in figure 5; however, in this case the adjusted mean response is presented as a function of the traffic level with airplane-noise level as the parameter. With few exceptions, the same trends occurred with increasing traffic-noise level as was shown in figure 4 for increasing airplane-noise level.

Linear least-squares regression analyses were performed with the adjusted mean responses as the dependent variables and various measures of noise exposure as the independent variables. Results of these analyses are presented in table VIII. The highest correlation was provided by TNI and L_{eq}. However, in each case only about 75 percent of the variability in response is accounted for by the measured noise index. The residual variability and results of a previous study (ref. 11) in which the total energy L_{eq} was held fixed for different combinations of airplane and traffic noise are indicative that for combined noise situations the resultant responses are complex functions of the component exposures. Therefore, for combined exposure situations, community-noise annoyance may not be adequately assessed by the total energy concept.

Comparison Between Annoyance Questions

As was mentioned in a previous section, an important difference was found in the analyses of variance between the results of the laboratory question and the three home-projected questions. This difference was that a significant effect of noise type was found only for the laboratory question and the night-projected question. Another difference between the responses obtained for the various questions was evident when the mean adjusted responses were compared across the questions for the separate airplane and traffic conditions. This is discussed in the following section.

Separate airplane and traffic conditions.- Figure 6 presents the overall adjusted mean response for all separate airplane and traffic conditions for each annoyance question. It can be seen, in general, that the response for each of the home-projected questions was greater than that for the laboratory question. This indicates that the subjects at least thought they would be more annoyed when engaged in activities at home than when they were in the laboratory situation. The subjects, however, also made distinctions between the three time periods. This was evidenced by the monotonic increase in annoyance for the day-to-evening-to-night questions. It is also apparent that the subjects were generally more annoyed by the airplane noises than by the traffic noises. For the laboratory, day, and evening questions, the differences between the overall means of the airplane and traffic responses were nearly constant. However, these differences were significant at the 5-percent level for only the laboratory question. For the night question the subjects indicated a much greater anticipated annoyance due to the airplane noise (significant at the 1-percent level). One possible explanation is that the subjects thought the intermittent nature of the airplane flyovers would perhaps cause more sleep disturbance than the steady traffic noise.

Figure 7 presents the adjusted mean airplane-noise response for each of the questions as a function of the airplane-noise level. The difference in annoyance between the questions was consistent across the airplane-noise levels. The differences between the means (over levels) for the day and evening questions, the day and night questions, and the evening and night questions were each found to be significant at the 1-percent level based on t-tests. A topic of great current interest in the field of community response concerns the validity of the penalties which have been applied to various community-noise indices for night or evening noise events. If such penalties are warranted then, based on the results shown in figure 7 for an equivalent annoyance of day and night airplaneıoise events, a penalty of 6 dB to 10 dB for night events would be reasonable. For equivalent day and evening events a penalty of 3 dB to 6 dB would be reasonable for evening events.

Figure 8 presents the adjusted mean traffic response for each of the questions as a function of the traffic-noise level. In these cases the differences between the questions are not as distinct as they were for the airplane responses (fig. 7); however, a consistent difference was found between the laboratory or day questions and the evening or night questions. The differences between the means (over levels) for the day and evening questions and the day and night questions were found to be significant at the 1-percent level; however, no significant difference was found between the evening and night questions. Based on these results, for an equivalent annoyance for day and evening or for day and night a penalty of about 5 dB for the evening and night period appears reasonable.

Combined airplane and traffic conditions.- A comparison of the adjusted mean response data in table VII for the combined noise conditions indicates a very consistent trend across the annoyance questions from laboratory to day to evening to night. Data for the conditions of equal airplane- and traffic-noise levels are presented in figure 9 as a function of the total noise level. The separation between the four questions is clearly evident although some closing of the separation occurred at the highest level. The t-tests for these data indicate that the differences between the day and evening questions and the day and night questions were significant at the 1-percent level, and the difference between the evening and night questions was significant at the 5-percent level. For equivalent annoyance for the day and evening questions, a 2-dB to 4-dB penalty for the evening is suggested by these results. For equivalent annoyance for day and night a 6-dB to 8-dB penalty seems reasonable for the night period.

The indications from the results of both the combined and separate conditions for the need of a night penalty are in general agreement with the 10-dB penalties associated with cumulative noise indices, such as L_{dn}. Most noise indices, however, do not provide any penalty during the evening time period. The indication from this study is that a penalty of approximatley 5 dB for the evening period may also be necessary.

Percentage of Subjects Highly Annoyed

A problem which has plagued the interpretation of results of community-annoyance surveys has been the difficulty of comparing results across surveys. One technique which has found some favor in recent years for unifying the reporting of annoyance (refs. 16 and 17) is the description of annoyance in terms of the percentage of people highly annoyed. The description "highly annoyed" has been interpreted in references 16 and 17 as being the point at which the respondent would find the noise unacceptable enough to consider doing something about the noise such as moving or complaining to authorities. The following technique, which had been used in references 16 and 17, was used to convert the subjects' responses to the noise conditions of the present experiment into the percentage of people highly annoyed.

At the conclusion of the experiment the subjects were requested to indicate at what point on the rating scale they would consider doing something about the noises they heard. The exact question is replicated in appendix B. The responses given to the day, evening, and night home-projected questions were then individually scored on a basis of 0 to 1/2 to 1 depending on whether the response was less than, equal to, or greater than their self-determined highly annoyed point. The total of these scores for each noise condition was thereby converted to the percentage of subjects highly annoyed. These results are presented in table IX for each noise condition and home-projected question. Also included is the pooled percentage of subjects highly annoyed, i.e., the percentage of subjects responding that they would be highly annoyed by the given noise conditions for one or more of the time periods.

The pooled data for the separate airplane and traffic conditions are plotted in figure 10. In the figure the circular symbols represent the airplane-noise conditions and the square symbols represent the traffic-noise conditions. To account for wall attenuation the abscissa has been converted to estimated outdoor-noise levels by the addition of 20 dB to the measured indoor levels used in the tests. Trend lines of data from two referenced reports are also presented in the figure. The first is based on the "Levels Document" of the Environmental Protection Agency (EPA). (See ref. 19.) The second is based on a more recent report (ref. 7) in which comparisons were made across many different community surveys of airplane, road-traffic, and railway noise. For presentation in figure 10, the original noise levels of the referenced data in L_{dn} have been equated to L_{eq}. The data for the separate airplane and traffic conditions are, in general, bracketed by the referenced trend lines. This indicates that the technique of projection and conversion to a percentage of people highly annoyed does provide results comparable to community surveys for separate noise conditions and thereby provides a measure of validity for the technique.

Figure 11 presents the percentage of subjects highly annoyed for the combined airplane- and traffic-noise conditions. Although most of the data points are bounded by the trend lines, as was the case for the separate airplane- and traffic-noise conditions, almost half of the conditions fall out of the bounded region. From the spread of these data it is possible that differences as large as 20 to 30 percentage points could be expected in communities of equal total exposure but with different combinations or mixtures of noise sources.

Based on the assumed validity of the data for separate noise conditions, the implications of the results for the combined noise conditions take on an added significance. For example, the conclusion of reference 7, that a single valid relationship exists between noise exposure in L_{dn} and annoyance for all kinds of noise, may be incorrect. This implication is further reinforced by the results of the laboratory study reported in reference 17. Another implication with regard to community-survey work is that extreme care should be taken in the measurement and description of the primary and secondary noise sources which make up actual noise environments experienced by the respondents. Gross categorizations of noise exposures into rather broad ranges of noise levels could lead to great variability in response at seemingly equivalent exposures. This type of variability could, at least in part, be responsible for the poor correlation of annoyance and noise exposure which has been found in most community surveys.

CONCLUSIONS

A laboratory study was conducted in which subjects judged the annoyance of sessions of multiple airplane noise and road-traffic noise presented separately and combined. Subjects were also asked to project their feelings about the noise sessions to their home situation for day, evening, and night periods. Findings of the study of importance to the assessment of community-noise annoyance are as follows:

1. Significant and consistent differences were found in judgments of the same L_{eq} levels of separate airplane and road-traffic noise (where L_{eq} represents the equivalent continuous sound level). The airplane noises were found to be more annoying than the traffic noises.

2. Airplane-noise level, traffic-noise level, and their interactions were found to be significant for judgments of the combined noise conditions. This and the finding of the first conclusion are indicative that community-noise annoyance may not be adequately assessed by the total energy concept.

3. Penalties for evening and night noise exposures were indicated based on the results of responses to questions of how annoying the test noise conditions would be if heard in the subjects' home during day, evening, and night periods. Although these results were in general agreement with the 10-dB penalty provided by cumulative noise indices such as L_{dn} (where L_{dn} represents the day-night average sound level), the study also indicated the possible need of a 5-dB penalty for evening noise exposures.

4. Generally good quantitative agreement was found between the percentage of the subjects highly annoyed by the separate airplane- and traffic-noise conditions and the percentage of people highly annoyed by similar noises as reported in community surveys. This agreement indicates a measure of validity to the laboratory techniques. However, the percentage of subjects highly annoyed by some of the combined noise conditions in the laboratory was as much as 20 percent greater than for the separate noise conditions at equal noise levels. This finding is an important consideration for modeling community-noise annoyance when exposures contain more than one noise source.

5. The results of the study for combined noise conditions also indicate the care which should be taken in the measurement and description of the separate noise sources which make up combined exposures experienced by respondents in community surveys. Gross categorizations of exposures into broad ranges of noise levels could lead to great variability in response at seemingly equivalent exposures.

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APPENDIX A

NOISE STIMULI

Airplane-Noise Recordings

Four different airplane types were used and one recorded approach noise of each was selected from a library of recordings as being representative of the airplane type and as having the best signal-to-noise ratio. The four types were the 747, 707, DC-10, and 727. Each of these airplanes had turbofan engines with various bypass ratios and represent a wide range of gross weights. The noise of each type was characterized by high-frequency fan noise of distinct tonal quality. This characteristic was deliberately chosen for these tests in an effort to reduce confusion among the test subjects between the sources of the noise stimuli. All of the recordings were made at a location approximately 1400 m from touchdown directly under flight paths at Dulles International Airport.

The original monophonic recordings for each airplane type were rerecorded to simulate motion and directionality for a pseudo stereophonic effect in the room. This was accomplished by manually fading the monophonic signal into two channels to provide a realistic amplitude time history. When reproduced in the test facility, the flyover noises appeared to pass overhead.

Table AI gives the results of acoustical analyses of the airplane-noise stimuli as recorded on the presentation tapes. These values are presented only to point out the relative differences between several different scales for quantifying airplane noises. As pointed out earlier each airplane noise had distinct tonal qualities. Corrections for these tones ranged from 0.7 dB to 3.1 dB over the airplane types. Since the recordings were made for approach conditions close to the touchdown point, the noises were quite short in duration as evidenced by negative duration corrections between 6.6 dB and 8.7 dB.

Time histories of these noises are shown in figure A1 in terms of the A-weighted noise level. As shown, the duration of 10 dB down from peak was very short, typically 4 to 5 seconds. The dynamic range for each of the noises was at least 40 dB(A).

Traffic-Noise Recording

A single type of road-traffic noise was used in the experiment. This noise had a low standard deviation in noise level ($\sigma = 1.36$ dB) and was representative of high-density, freely flowing, high-speed road traffic. This condition was recorded stereophonically by using the coincident directional microphone technique at a location approximately 200 meters from the near lane of a limited-access four-lane divided highway at a near peak-flow condition. For presentation to the test subjects, this recording was copied and then repeatedly mixed with its copies until the traffic-flow rate simulated a condition eight times the flow rate of the original recording. During each rerecording process the start times of the recordings were staggered so that given noise events were not overlayed with the same events from another recording. The final product of this process was a recording in which single events could rarely be distinguished. An A-weighted time history of a segment of this recording is shown in figure A2. The actual levels of this noise presented to the test subjects will be described in the following section.

Test-Session Noise Stimuli

The stereophonic-recorded airplane noises previously described were rerecorded on the final presentation tapes to serve as noise stimuli during the test sessions. Two session tapes were prepared upon which each airplane type was recorded twice at the appropriate relative levels given in table A1. The order of the airplanes on each tape was random. Two different orders were used solely to provide some measure of variety for the test subjects. The time period between peak noise levels of adjacent flyovers varied from approximately 100 seconds to 130 seconds. The road-traffic noise was then rerecorded on the final presentation tapes. The total period for each presentation tape was 15 minutes.

TABLE A1.- SELECTED ACOUSTICAL ANALYSES OF

AIRPLANE NOISE STIMULI

Airplane type	L_A, dB	PNL, dB	TCPNL, dB	EPNL, dB	PL (Mark VII), dB	EPL (Mark VII), dB
747	98.8	114.0	115.2	106.5	105.7	96.5
707	104.8	119.8	122.9	116.3	110.7	104.3
DC-10	89.8	107.3	109.0	100.8	98.0	90.1
727	97.5	112.8	113.5	106.5	103.4	95.7

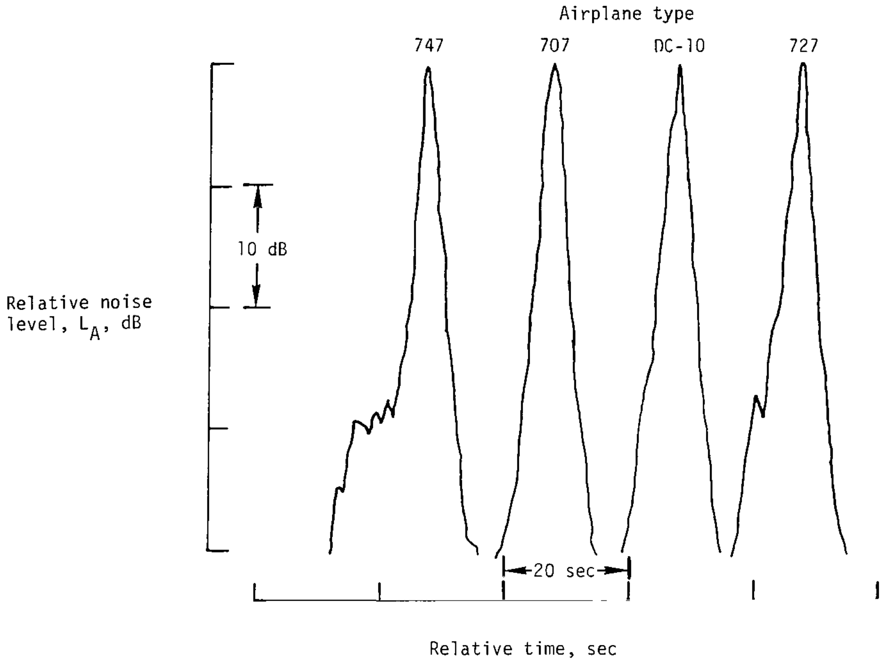

Figure A1.- Time histories of airplane-noise stimuli.

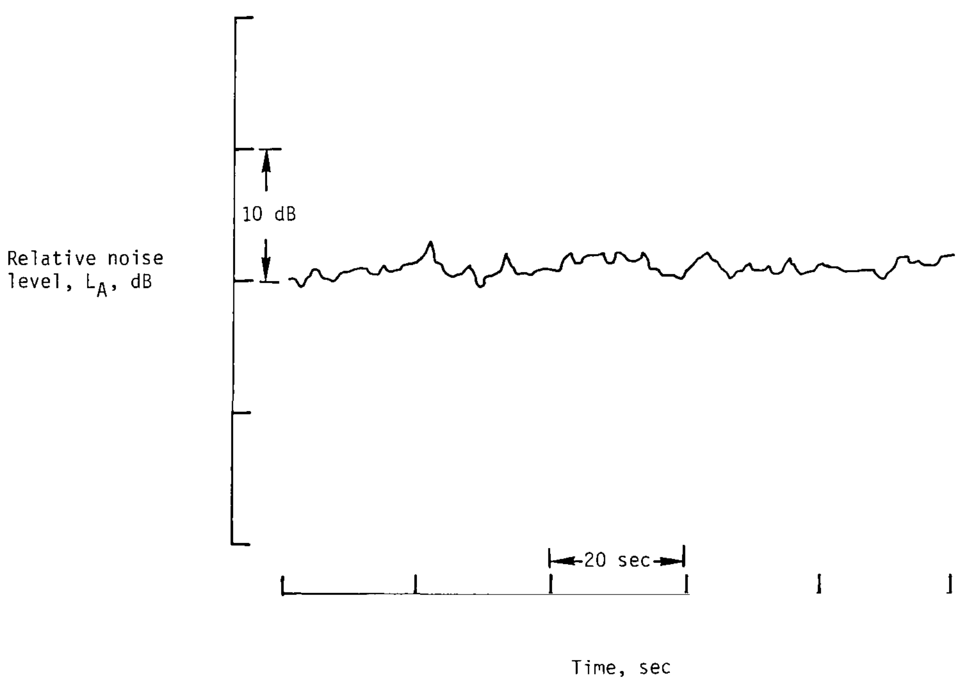

Figure A2.- Time history of road-traffic noise with low standard deviation (σ = 1.3 dB.)

APPENDIX B

INSTRUCTIONS AND SCORING SHEETS

General Instructions

Thank you for volunteering to participate in a research program being carried out at the NASA Langley Research Center. We are studying peoples' reactions to aircraft noises in order to contribute towards the development of a cumulative noise index for the prediction of general noise annoyance.

During the study you will hear various aircraft and other noises. None of these noises will be greater than those experienced on a daily basis by many community residents. As such, we anticipate that you will experience no undue physiological or psychological discomfort as a result of the noises. However, if at any time you feel indisposed to the extent that you cannot continue your role in the study, you will be free to leave.

If you would kindly sign the attached voluntary consent form, it will signify that you understand the purpose of the research and the technique to be used.

Specific Instructions

The experiment in which you are participating today is to help us understand reactions of people to various noise environments. There will be nine sessions altogether, each lasting 15 minutes, in which you will hear various types of aircraft and traffic noise. At the end of each session, we would like you to make four different judgments on the noises you just heard.

You will be given a scoring sheet for each session which has four scales numbered "0" to "9", the end points of which are labeled "Not Annoying At All" and "Extremely Annoying." An example of these scoring sheets is shown on the final page of this instruction set. Your judgments in all cases should be indicated by circling one of the numbers on the scales. If you judge the noise to be very annoying, then you should circle a number closer to the "Extremely Annoying" end of the scale and similarly if you judge the noise to be only slightly annoying you should circle a number closer to the "Not Annoying at All" end of the scale.

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

For the next question and the last three scales, we would like you to <u>imagine</u> how you would feel about the noise if you heard it in <u>your home</u>. The first of these last scales is for your judgment of how annoying the noise would be if you heard it during the day, say between 7 a.m. and 6 p.m. The second is for your judgment of how annoying the noise would be in the evening, say between 6 p.m. and 10 p.m. The third scale is for your judgment of how annoying the noise would be at night, say between 10 p.m. and 7 a.m. In making these last three judgments, we would like for you to consider all your home activities during each of the time periods and how you would feel about living with the noise day after day.

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

Thank you for helping us with this investigation.

APPENDIX B

Scoring Sheet

Group ______________ Tape ______________

Seat ______________ 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 Extremely Annoying

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

(a) During the day

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

(b) During the evening

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

(c) During the night

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

APPENDIX B

Questionnaire

Subject Name ____________________

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 Extremely Annoying

Group ______________ Tape ____________________

Seat ______________ Session ______________

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TABLE I.- ACOUSTICAL ANALYSIS OF NOISE CONDITIONS

[All values are given in decibels]

Nominal levels, L_{eq}		Measured levels					
Airplane	Traffic	L_{eq}	L_{np}	σ	L_{90}	L_{10}	TNI
Airplane alone							
30		30.5	41.5	4.29	20.1	21.0	----
40		40.2	57.0	6.58	20.1	22.4	----
50		50.1	74.0	9.32	20.1	32.4	39.2
60		60.1	90.8	11.97	21.1	42.4	76.2
Traffic alone							
	30	30.2	33.7	1.36	28.3	32.1	13.5
	40	40.2	43.7	1.36	38.3	42.1	23.5
	50	50.2	53.7	1.36	48.3	52.1	33.5
	60	60.2	63.7	1.36	58.3	62.1	43.2
Airplane and traffic combined							
40	40	43.2	50.4	2.81	38.3	42.7	25.9
40	50	50.6	55.0	1.72	48.3	52.4	34.7
40	60	60.2	63.8	1.39	58.3	62.2	43.6
50	40	50.5	62.2	4.54	38.4	43.2	27.6
50	50	53.2	60.4	2.81	48.3	52.7	35.9
50	60	60.6	65.0	1.72	58.3	62.4	44.7
60	40	60.2	77.4	6.73	38.4	44.7	33.5
60	50	60.5	72.2	4.54	48.4	53.2	37.6
60	60	63.2	70.4	2.81	58.3	62.7	45.9

TABLE II.- PRESENTATION ORDER OF CONDITIONS

Subject group	Stimuli[a] for presentation order -								
	1	2	3	4	5	6	7	8	9
1	02	30	43	03	34	40	22	01	04
2	30	40	32	02	23	04	44	03	10
3	40	04	24	30	42	10	33	02	20
4	04	10	44	40	33	20	22	30	01
5	10	20	32	04	24	01	43	40	03
6	20	01	23	10	42	03	34	04	02
7	01	03	34	20	23	02	42	10	30
8	03	02	22	01	44	30	33	20	40
9	02	30	22	03	34	40	43	01	04
10	30	40	44	02	23	04	32	03	10
11	40	04	33	30	42	10	24	02	20
12	04	10	22	40	33	20	44	30	01
13	10	20	43	04	24	01	32	40	03
14	20	01	34	10	42	03	23	04	02
15	01	03	43	20	32	02	24	10	30
16	03	02	33	01	22	30	44	20	40

[a]First digit represents airplane-noise level L_{eq} and second digit represents traffic-noise level L_{eq} as follows:

0	0 dB	2	40 dB
1	30 dB	3	50 dB
		4	60 dB

TABLE III.- ANALYSIS OF VARIANCE FOR LABORATORY ANNOYANCE

Source	Degrees of freedom	Sum of squares	Mean square	F-ratio (a)
All conditions				
Treatments	16	1500.04	93.75	41.67[++]
Subjects	63	963.11	15.29	
Residual	496	1118.15	2.25	
Total	575	3581.30		
Combined conditions				
Airplane noise . .	2	88.27	44.14	19.62[++]
Traffic noise . .	2	231.20	115.60	51.38[++]
Interaction . . .	4	42.77	10.69	4.75[++]
Separate conditions				
Noise type	1	9.00	9.00	4.00[+]
Level	3	661.32	220.44	97.97[++]
Interaction . . .	3	3.70	1.23	0.55[ns]

[a]Superscript ++ indicates significant at 1 percent; + indicates significant at 5 percent; and ns indicates not significant.

TABLE IV.- ANALYSIS OF VARIANCE FOR PROJECTED HOME DAY ANNOYANCE

Source	Degrees of freedom	Sum of squares	Mean square	F-ratio (a)
All conditions				
Treatments . . .	16	1654.79	103.44	
Subjects	63	1001.13	15.89	
Residual	496	1215.28	2.45	
Total	575	3871.16		
Combined conditions				
Airplane	2	76.33	38.17	15.58^{++}
Traffic	2	251.54	125.77	51.33^{++}
Interaction . .	4	69.57	17.39	7.10^{++}
Separate conditions				
Noise type . . .	1	8.99	8.99	3.67^{++}
Level	3	738.53	246.18	100.48^{++}
Interaction . .	3	4.31	1.44	0.59^{ns}

[a]Superscript ++ indicates significant at 1 percent, and ns indicates not significant.

TABLE V.- ANALYSIS OF VARIANCE FOR PROJECTED HOME EVENING ANNOYANCE

Source	Degrees of freedom	Sum of squares	Mean square	F-ratio (a)
		All conditions		
Treatments . . .	16	1768.20	110.50	
Subjects	63	1323.13	21.00	
Residual	496	1262.00	2.54	
Total	575	4353.33		
		Combined conditions		
Airplane	2	65.67	32.84	12.93++
Traffic	2	223.55	111.78	44.01++
Interaction . .	4	60.50	15.13	5.96++
		Separate conditions		
Noise type . . .	1	6.63	6.63	2.61ns
Level	3	873.87	291.29	114.68++
Interaction . .	3	3.73	0.24	0.48ns

[a]Superscript ++ indicates significant at 1 percent, and ns indicates not significant.

TABLE VI.- ANALYSIS OF VARIANCE FOR PROJECTED HOME NIGHT ANNOYANCE

Source	Degrees of freedom	Sum of squares	Mean square	F-ratio (a)
All conditions				
Treatments . . .	16	2014.15	125.88	
Subjects	63	1694.95	26.90	
Residual	496	1776.39	3.58	
Total	575	5485.49		
Combined conditions				
Airplane	2	50.54	25.27	7.06++
Traffic	2	200.65	100.33	28.03++
Interaction . .	4	81.78	20.45	5.71++
Separate conditions				
Noise type . . .	1	43.53	43.53	12.16++
Level	3	1010.53	336.84	94.09++
Interaction . .	3	3.05	1.02	0.28ns

[a]Superscript ++ indicates significant at 1 percent, and ns indicates not significant.

TABLE VII.- ANNOYANCE RESPONSE

Noise level, L_{eq}, dB		Laboratory		Home projection					
				Day		Evening		Night	
Airplane	Traffic	Mean	Adjusted	Mean	Adjusted	Mean	Adjusted	Mean	Adjusted
Airplane noise alone									
30		0.90	0.84	0.98	0.93	1.42	1.25	1.63	1.60
40		1.92	1.88	2.06	1.99	2.52	2.43	2.71	2.70
50		2.54	2.51	2.69	2.73	3.27	3.24	3.90	3.84
60		4.52	4.51	4.71	4.68	5.38	5.34	6.10	6.02
Traffic noise alone									
	30	0.52	0.68	0.64	0.73	0.88	1.03	0.88	0.96
	40	1.33	1.23	1.46	1.47	1.77	1.83	1.68	1.72
	50	2.29	2.35	2.17	2.22	2.88	3.04	3.29	3.36
	60	4.23	4.24	4.67	4.65	5.31	5.28	5.35	5.37
Airplane and traffic noise combined									
40	40	2.29	2.56	2.54	2.70	3.42	3.59	4.33	4.28
40	50	2.40	2.29	2.45	2.45	2.95	2.83	3.25	3.19
40	60	5.80	5.59	6.20	6.02	6.65	6.56	6.80	6.94
50	40	2.35	2.42	2.55	2.53	3.25	3.23	3.60	3.58
50	50	4.42	4.29	5.04	4.91	5.54	5.23	6.29	6.04
50	60	4.85	4.93	4.90	5.09	5.50	5.91	6.00	6.33
60	40	4.85	4.47	4.80	4.64	5.45	5.27	5.45	5.55
60	50	4.00	4.26	4.10	4.27	4.50	5.00	5.05	5.42
60	60	6.42	6.52	6.79	6.79	7.21	6.95	7.58	7.21

TABLE VIII.- REGRESSION ANALYSES FOR COMBINED

NOISE CONDITIONS

Noise index	Intercept	Slope	Correlation coefficient
L_{eq}	-6.422	0.189	0.860
L_{np}	-2.793	.108	.620
L_{90}	-1.997	.127	.744
L_{10}	-2.512	.125	.750
TNI	-2.399	.179	.869

TABLE IX.- PERCENTAGE OF SUBJECTS HIGHLY ANNOYED FOR THE PROJECTED ANNOYANCE QUESTIONS

Noise level, L_{eq}, dB		Percentage of subjects highly annoyed during -			
Airplane	Traffic	Day	Evening	Night	Pooled
Airplane and traffic separately					
30		0	2	3	5
40		2	5	8	10
50		15	21	31	33
60		35	46	66	69
	30	3	4	6	6
	40	9	11	11	17
	50	7	15	29	30
	60	39	51	50	56
Airplane and traffic combined					
40	40	6	19	42	46
40	50	0	8	23	28
40	60	68	75	78	78
50	40	15	25	53	43
50	50	38	38	65	67
50	60	38	43	58	58
60	40	40	53	53	60
60	50	30	43	43	53
60	60	65	73	83	83

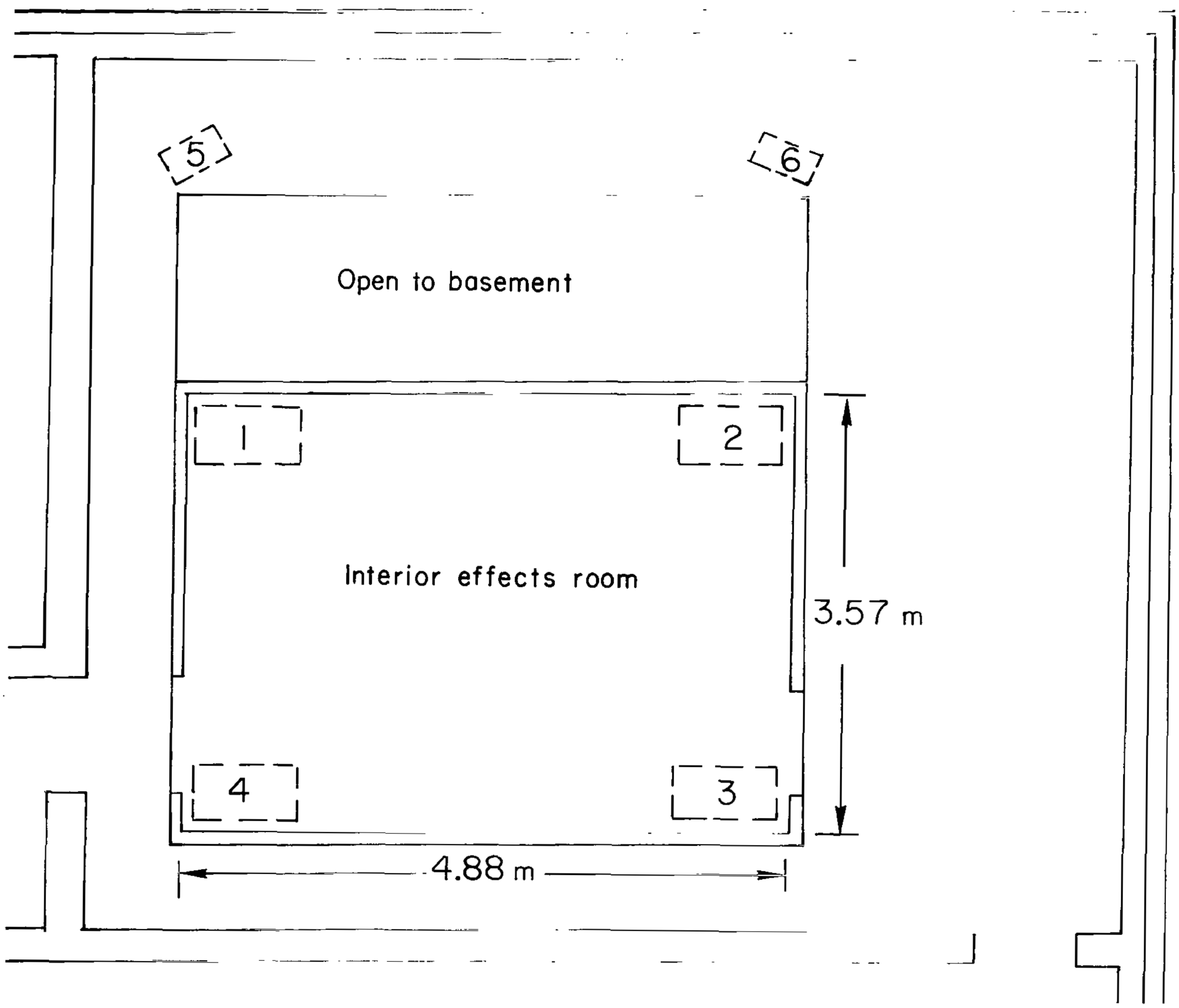

Figure 1.- Floor plan of test facility.

L-76-3945

Figure 2.- Photograph of test facility.

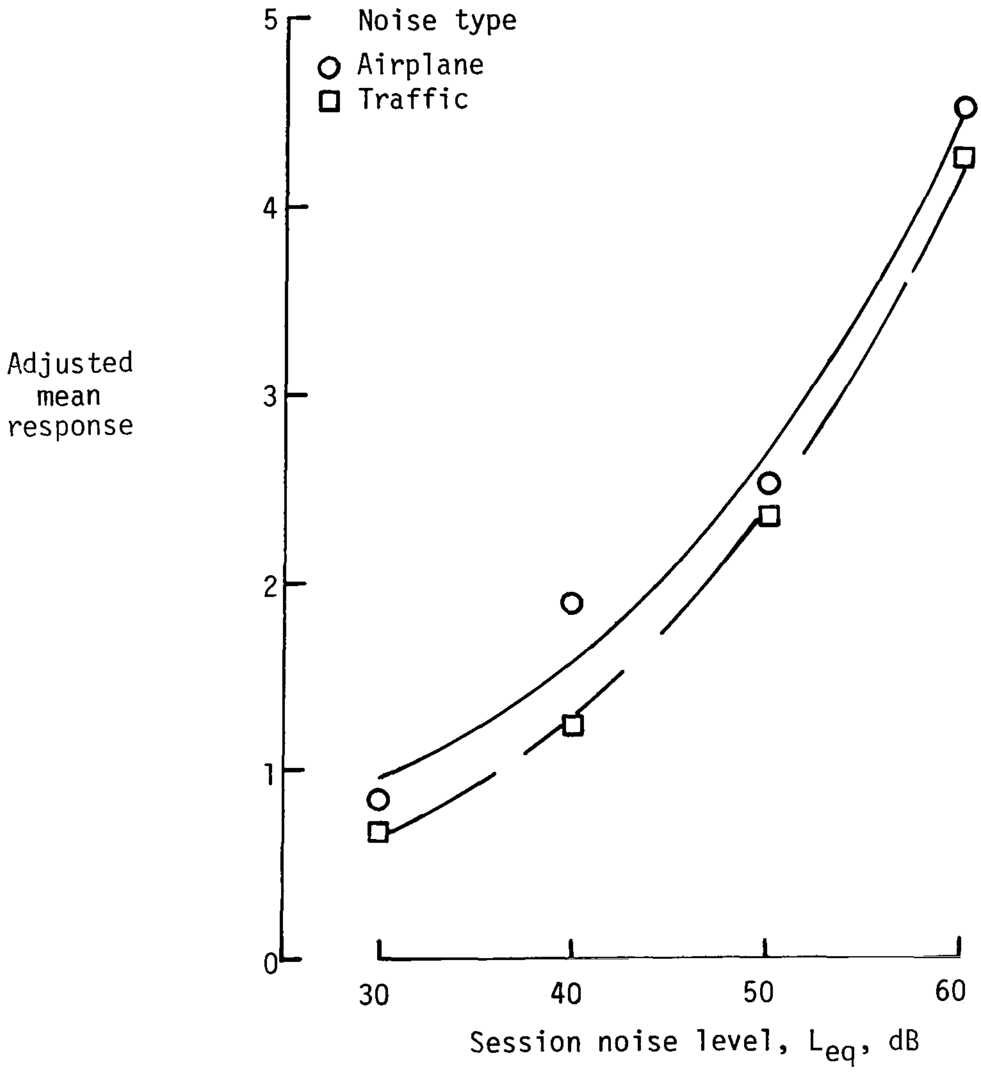

Figure 3.- Relationships of laboratory-adjusted mean response for separate airplane and traffic noise with noise level.

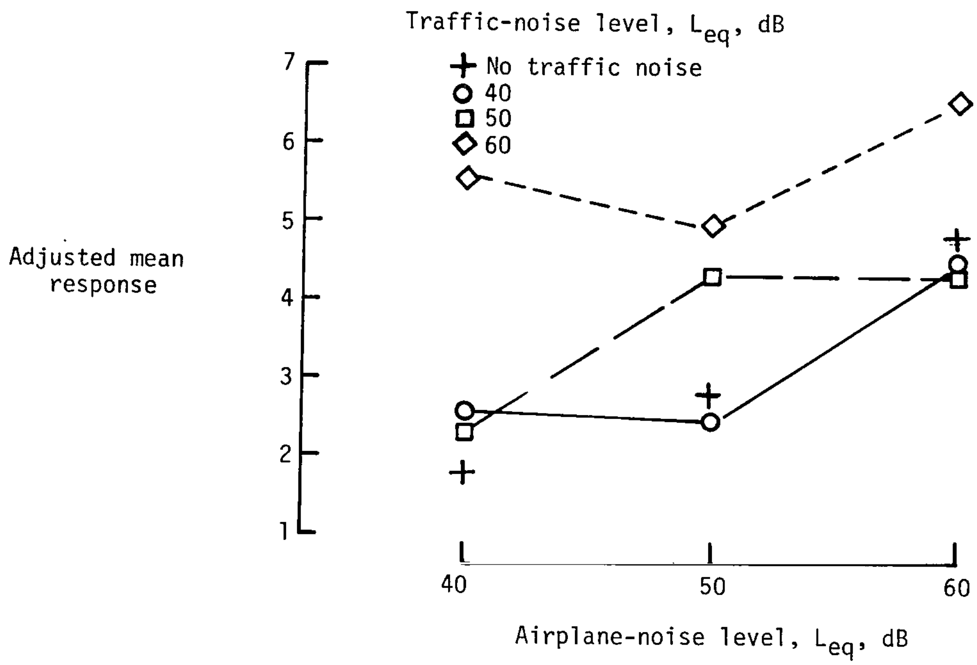

Figure 4.- Relationship of laboratory-adjusted mean response to combined noise with airplane-noise level.

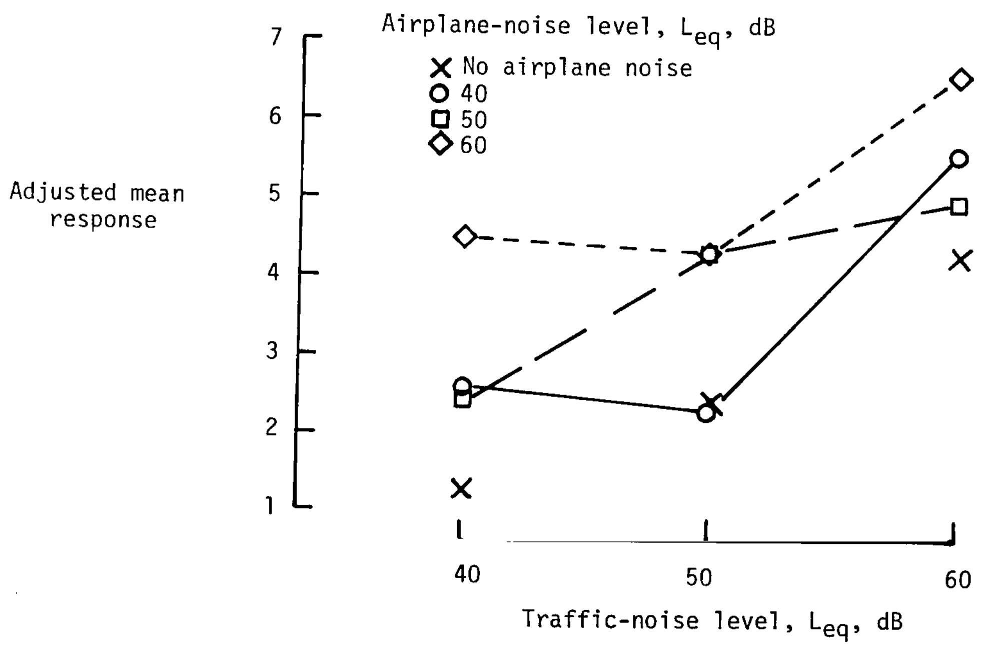

Figure 5.- Relationship of laboratory-adjusted mean response to combined noise with traffic-noise level.

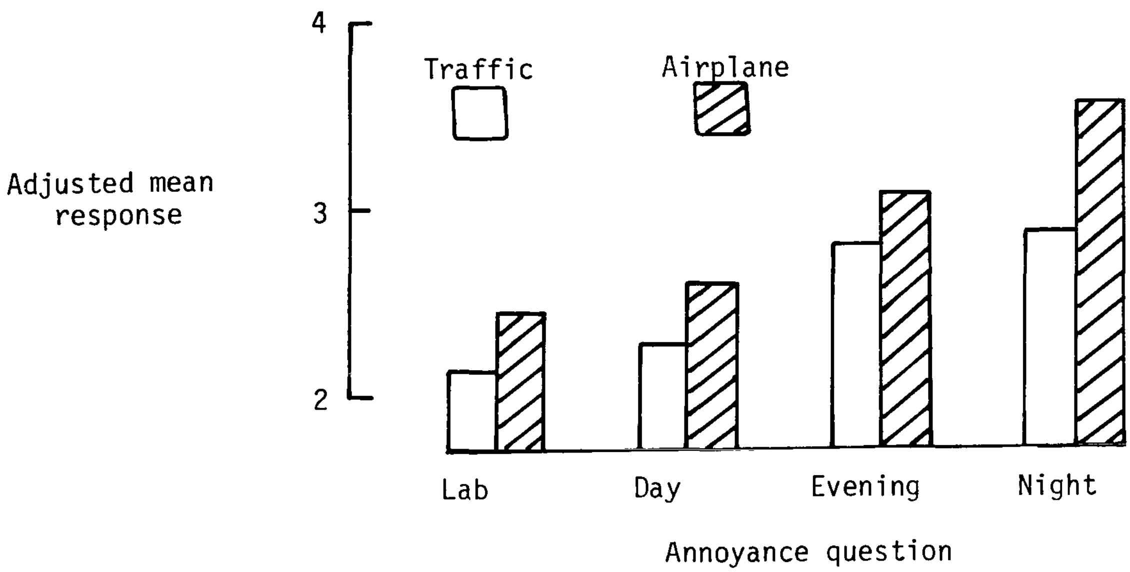

Figure 6.- Overall adjusted mean response for the separate airplane and traffic conditions for each annoyance question.

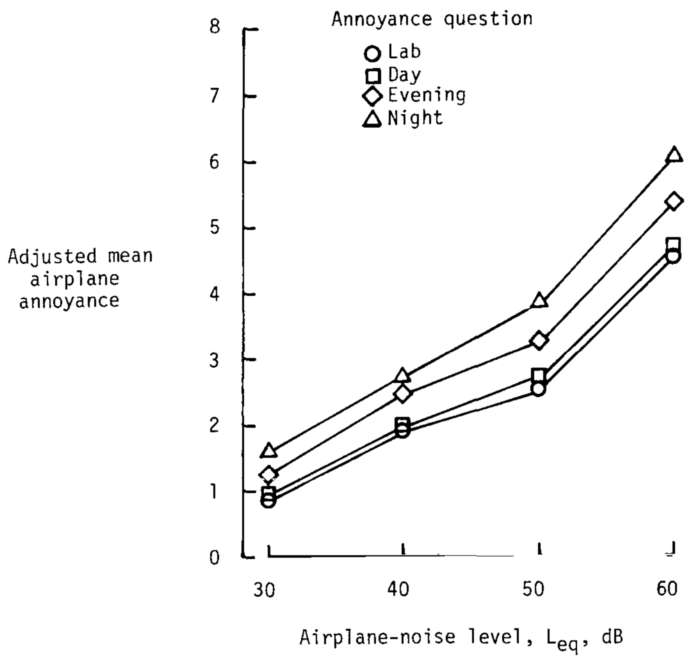

Figure 7.- Adjusted mean airplane annoyance for the different annoyance questions as a function of airplane-noise level.

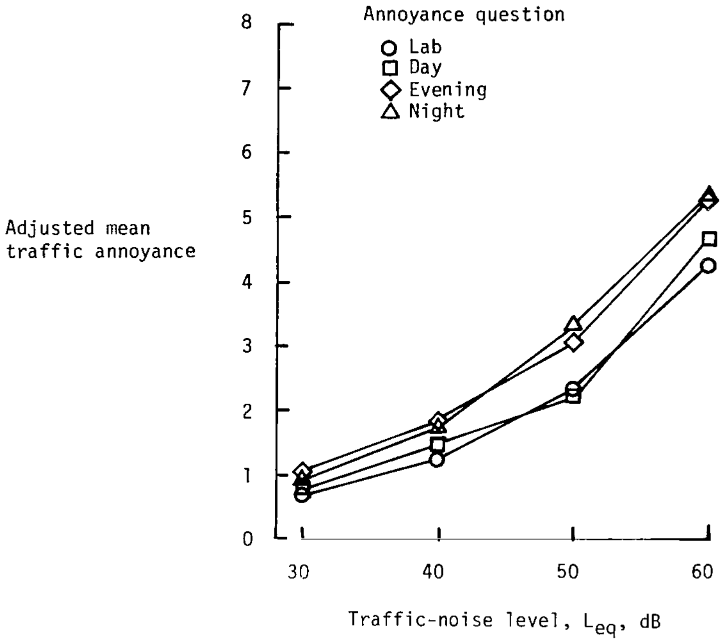

Figure 8.- Adjusted mean traffic annoyance for the different annoyance questions as a function of traffic-noise level.

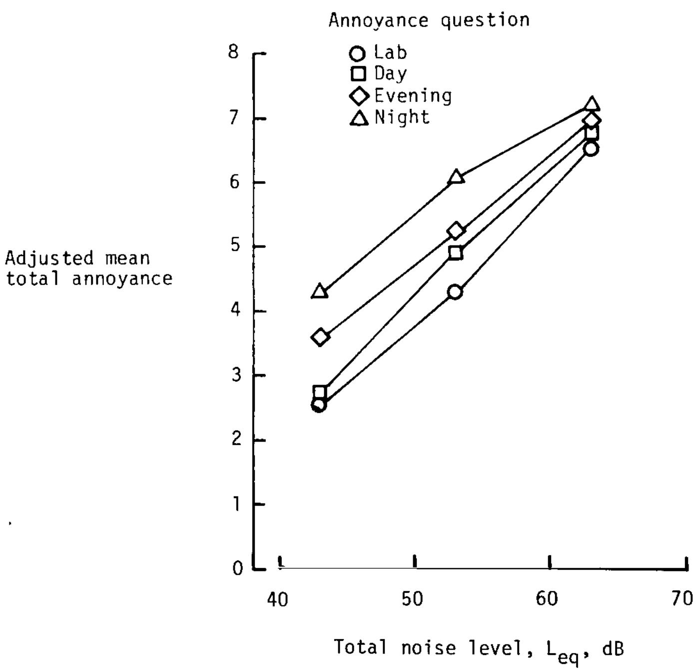

Figure 9.- Adjusted mean total annoyance for combined equal levels of airplane and traffic noise for the different annoyance questions as a function of the total noise level.

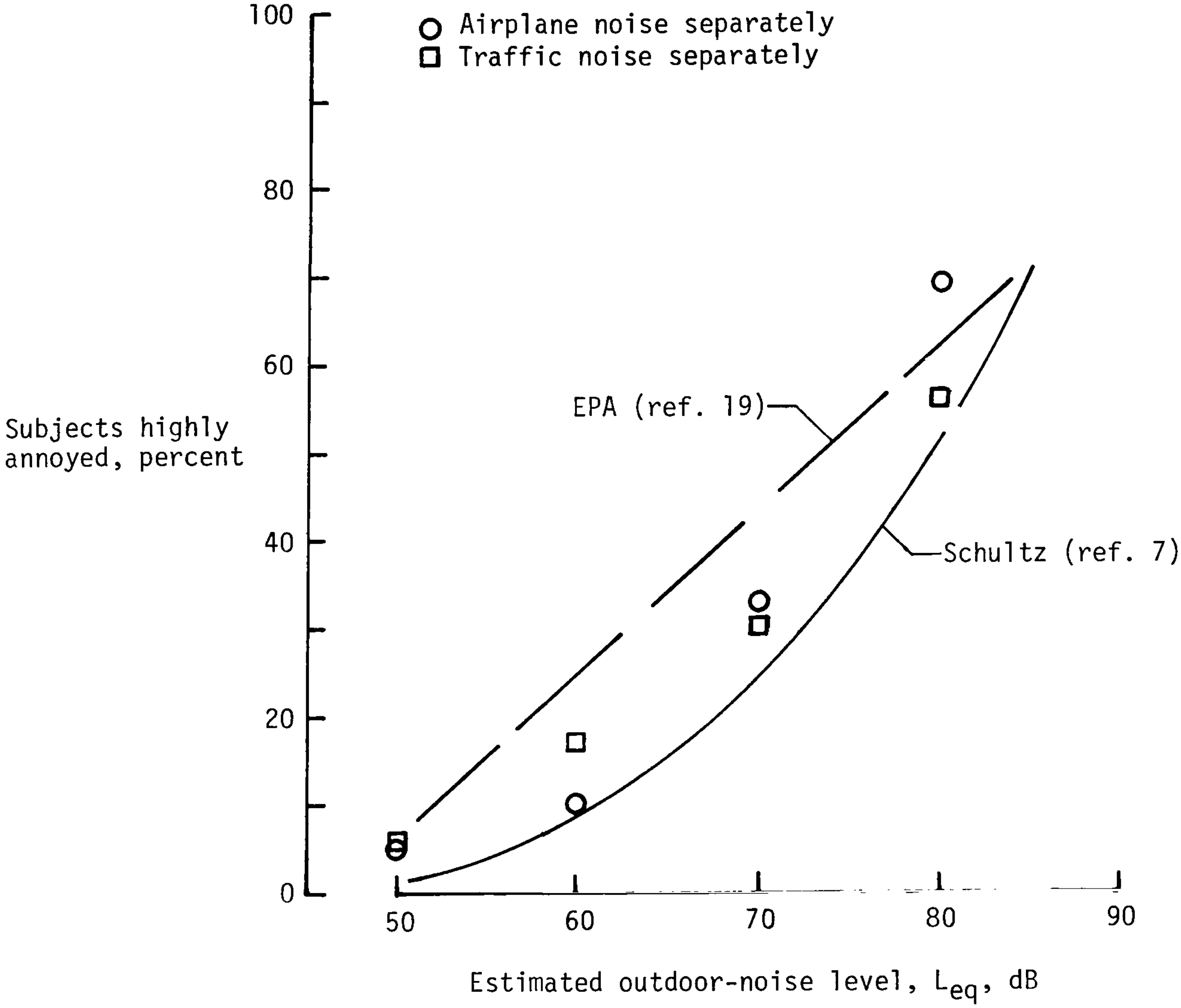

Figure 10.- Percentage of subjects highly annoyed as a function of estimated outdoor-noise level for separate airplane and traffic conditions.

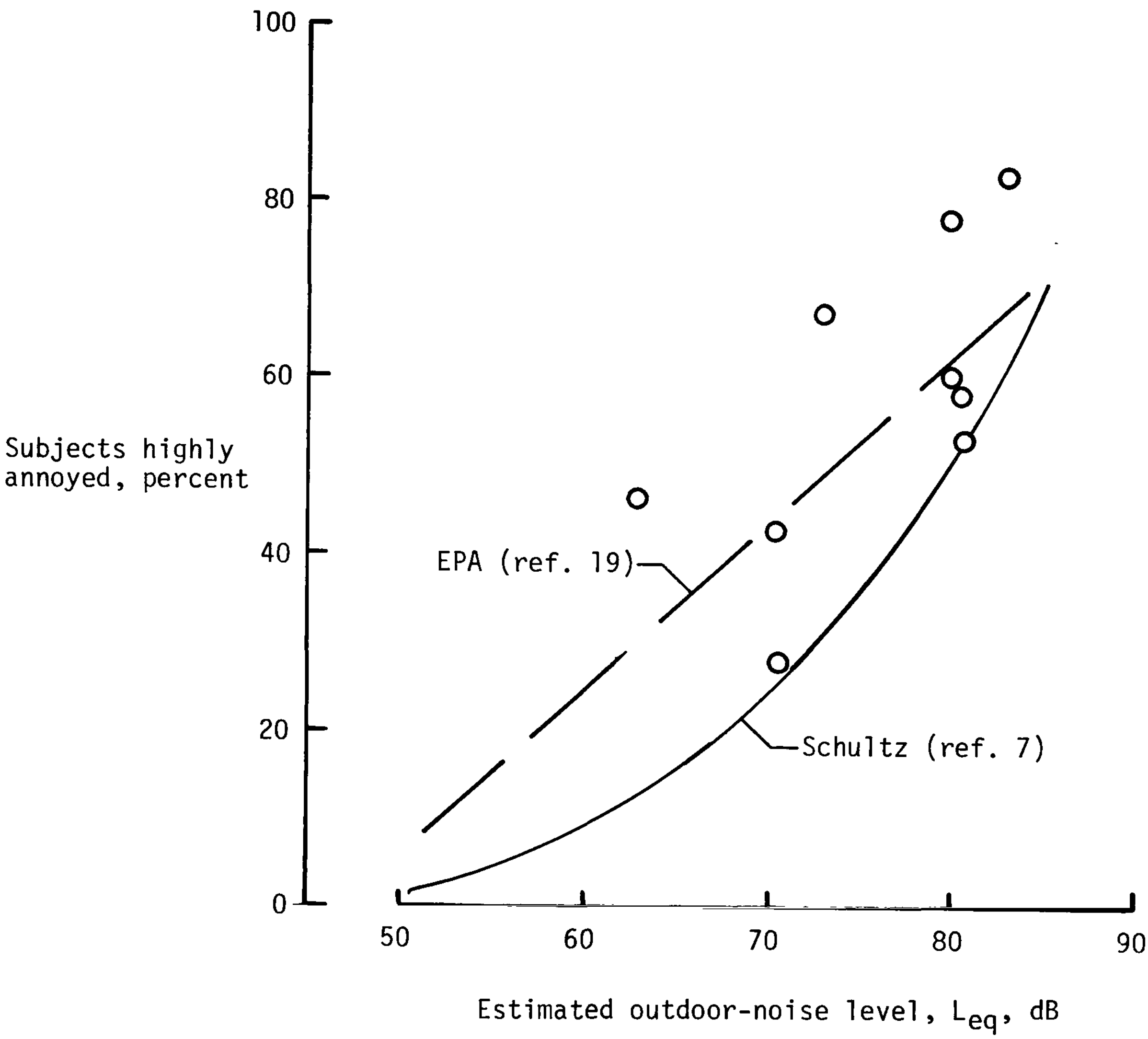

Figure 11.- Percentage of subjects highly annoyed as a function of estimated outdoor-noise level for combined airplane and traffic conditions.

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15. Supplementary Notes

16. Abstract

A laboratory study was conducted in which subjects judged the annoyance of sessions of noise which consisted of both separate and combined airplane and road-traffic noises. The subjects judged each session as to how annoyed they were in the simulated living-room laboratory environment and as to how annoyed they would be if they heard the noise in their home during day, evening, and night periods.

The airplane noises, for equal-session L_{eq} levels (where L_{eq} represents the equivalent continuous sound level), were judged significantly more annoying than the road-traffic noises for the separate sessions. For the combined sessions, an interaction was found between the airplane-noise and traffic-noise levels which was not adequately assessed by the total energy concept of L_{eq}. Significant differences were found between the projected home responses for the day, evening, and night periods.

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