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SUMMARY

Two laboratory experiments were conducted to provide information on quantifying the annoyance response of people to propeller airplane noise. The specific items of interest were (1) the annoyance prediction ability of current noise metrics; (2) the effects on annoyance prediction ability of tone corrections, duration corrections, and critical band corrections; and (3) the effects of type of engine, type of operation, maximum takeoff weight, blade passage frequency, and blade tip speed on prediction ability. This report presents analyses of the data obtained from the two experiments.

The first experiment examined propeller airplanes with maximum takeoff weights greater than or equal to 5700 kg. The second experiment examined propeller airplanes weighing 5700 kg or less. Included in the first experiment were recordings of 11 different propeller airplanes ranging in weight from 5700 to 70 300 kg. Operations included both takeoffs and landings. The second experiment included recordings of 14 different propeller airplanes weighing from 800 to 5700 kg. Operations included takeoffs, takeoffs with power cutbacks, landings, and constant altitude flyovers. As a comparison, recordings of takeoff and landing operations of five different commercial service jet airplanes were also included in each experiment. Each recording was presented at D-weighted sound pressure levels of 70, 80, and 90 dB to subjects in a testing room which simulates the outdoor acoustic environment. In each experiment, the annoyance of each recording at each of the three levels was judged by 64 test subjects using a unipolar, 11-point scale from 0 to 10.

For both the heavy and the light propeller airplanes, perceived noise level and perceived level (Stevens Mark VII procedure) predicted annoyance better than other commonly used noise metrics. Duration corrections and corrections for tones greater than or equal to 500 Hz generally improved prediction ability for the heavy propeller airplanes. Duration corrections and tone corrections generally degraded prediction ability for the light propeller airplanes. The effect on prediction ability of critical band corrections to perceived noise level varied. Takeoffs of the heavy propeller airplanes were less annoying than landings. Annoyance to the light propeller airplanes was not affected by the type of operation. No consistent effects of type of engine, maximum takeoff weight, blade passage frequency, or blade tip speed on annoyance were found for either class of propeller airplanes.

INTRODUCTION

Much attention has been directed towards understanding and quantifying the annoyance caused by aircraft flyover noise. Research in this area has concentrated primarily on the noise of jet airplanes and more recently on the noise of helicopters. Relatively little research has been conducted on annoyance caused by propeller airplanes. Because of the increased interest in propeller airplanes for general aviation, commuter, and energy-efficient long-haul operations, the need to understand and quantify annoyance caused by propeller airplanes has also increased. The research reported herein addresses that need.

One of the primary concerns in quantifying the annoyance caused by the noise of propeller airplanes arises because of the somewhat unusual spectral characteristics of the noise. Propeller noise, which can dominate the noise produced by such airplanes, typically consists of a number of harmonically related pure-tone components. The fundamental frequency of these tones, which occurs at the propeller blade passage frequency, ranges from about 50 Hz to about 150 Hz for existing airplanes and may go as high as 300 Hz for proposed advanced turboprop airplanes. The number of higher harmonics and their strength relative to the fundamental depend primarily on propeller tip shape and tip Mach number. The annoyance caused by noise sources with strong tonal components has historically been more difficult to quantify than broadband noise. In the case of propeller noise, the uncertainty in accounting for tonal content is increased because less psychoacoustic research has been conducted in the lower frequency range than in the higher frequency range of tones from jet airplanes.

Another uncertainty in quantification of the low-frequency content of propeller airplane noise is whether or not consideration should be given to the "critical band" concept (ref. 1). Annoyance metrics such as perceived noise level (PNL) are formulated around the summation of annoyance components based on 1/3-octave bands of noise. The critical band concept suggests that below 500 Hz the summation of annoyance components should be based on bands which are considerably wider than 1/3-octave bands. Although this concept has been considered by a number of researchers (refs. 1 and 2, for example), no definitive conclusions have been reached.

The purpose of the research described in this report was to provide information on the quantification of annoyance caused by propeller airplane noise. The specific objectives were (1) to determine the ability of current noise metrics to assess or quantify annoyance caused by propeller airplane noise; (2) to determine whether tone corrections improve or degrade the annoyance prediction ability of the metrics; (3) to determine whether duration corrections improve or degrade the annoyance prediction ability of the metrics; (4) to determine if correction of PNL to account for critical band auditory theory offers any improvement in annoyance prediction ability; and (5) to determine if type of engine, type of operation, maximum takeoff weight, blade passage frequency, and blade tip speed could be used to improve annoyance prediction ability.

To accomplish these objectives, two laboratory annoyance judgment experiments were conducted. In the first experiment, the annoyance to recorded sounds of propeller airplanes with maximum takeoff weights greater than or equal to 5700 kg was judged along with sounds of a number of commercial service jet airplanes. In the second experiment, the annoyance to recorded sounds of propeller airplanes with maximum takeoff weights less than or equal to 5700 kg was judged along with the sounds of the same jet airplanes. The experiments were separated at 5700 kg because current and proposed noise certification regulations use a maximum takeoff weight of 5700 kg as the break point to determine in which of two classes a propeller airplane will be certified. This report presents analyses of the data obtained from the two experiments, which are directly applicable to the previously stated objectives.

NOISE METRICS, SYMBOLS, AND ABBREVIATIONS

Noise Metrics

EPNL effective perceived noise level, dB

L_A A-weighted sound pressure level, dB

L_D D-weighted sound pressure level, dB

L_E E-weighted sound pressure level, dB

L_1 weighted sound pressure level based on modified frequency weighting from reference 3 and energy summation (see "Acoustic Data Analyses"), dB

L_2 weighted sound pressure level based on modified frequency weighting from reference 3 and masked-band summation (see "Acoustic Data Analyses"), dB

LL loudness level (Stevens Mark VI procedure), dB

PL perceived level (Stevens Mark VII procedure), dB

PNL perceived noise level, dB

PNL_K, PNL_M, PNL_W perceived noise level with critical band corrections (see "Acoustic Data Analyses"), dB

Detailed descriptions of the noise metrics used in this report can be found in references 3, 4, and 5.

Symbols and Abbreviations

FAR Federal Aviation Regulation

F_{oc} calculated blade passage (fundamental) frequency, Hz

F_{om} measured blade passage (fundamental) frequency at peak L_A, Hz

L_S subjective noise level, dB

T_1 EPNL tone correction method (ref. 5)

T_2 tone correction method identical to T_1 except that no corrections are applied for tones below the 500-Hz 1/3-octave band

V_T blade tip speed, m/sec

W maximum takeoff weight, kg

EXPERIMENTAL METHOD

Test Facility

The exterior effects room in the Langley Aircraft Noise Reduction Laboratory (see fig. 1) was used as the test facility in both experiments. This room, which has a volume of approximately 340 m^3 and a reverberation time of approximately 0.25 sec at 1000 Hz, simulates the outdoor acoustic environment. The subjects pictured in figure 1 occupy the seats used during testing by each group of four subjects. The monophonic recordings of the airplane-noise stimuli were played on a studio-quality tape recorder and presented to the subjects by means of four overhead loudspeakers. A commercially available noise reduction system which provided a nominal 30-dB increase in signal-to-noise ratio was used to reduce tape hiss to inaudible levels.

Test Subjects

One hundred twenty-eight subjects, 64 for each experiment, were randomly selected from a pool of local residents with a wide range of socioeconomic backgrounds and were paid to participate in the experiments. All test subjects were given audiograms prior to the experiment to verify normal hearing. Table I gives the sex and age data for the subjects in each experiment.

Noise Stimuli

The noise stimuli for both experiments consisted of loudspeaker-reproduced recordings of actual flight operations. The recordings of commercial service jet airplanes were made on the runway centerline approximately 5000 m from the brake release point. The propeller airplane recordings were made at several different airports, and the distances from brake release and touchdown varied. At each location, the propeller airplane recordings were made on or near the runway centerline. Because of the higher flight profiles and lower source noise levels of the propeller airplanes, the recording sites for propeller airplanes were located closer to the brake release or touchdown points than those for the commercial service jet airplanes. Microphones were located approximately 1.2 m above ground level over dirt or grass.

First experiment stimuli.- The first experiment examined propeller airplanes with maximum takeoff weights greater than or equal to 5700 kg. One hundred and eight stimuli were presented to the subjects. Of these 108 stimuli, 96 served as the basic data set, 7 were included for converting subjective responses to subjective decibel levels, 3 were included as a common reference with another study (ref. 6), and 2 were repeats of stimuli included to provide an equal number of stimuli per session. (The data for the common reference stimuli and the repeated stimuli were not used in the following analyses and are not discussed in this report.) The 96 basic stimuli consisted of takeoff and landing operations of 11 propeller and 5 jet airplanes presented at nominal peak L_D values of 70, 80, and 90 dB. The types of airplanes included in the basic data set and some specifications of each are given in table II. The L_A time histories and the 1/3-octave-band spectra at peak L_A for the highest level presentations of the takeoffs and landings of the 11 propeller airplanes are given in figure A1 of appendix A. Figure A2 of appendix A gives similar data for the five jet airplanes.

Second experiment stimuli.- The second experiment examined propeller airplanes with maximum takeoff weights less than or equal to 5700 kg. One hundred and thirty-two stimuli were presented to the subjects. Of the 132 stimuli, 108 served as the basic data set, 7 were included for converting subjective responses to subjective decibel levels, 3 were included as a common reference with another study (ref. 6), 12 were a pilot study of microphone height effects, and 2 were repeats of stimuli included to provide an equal number of stimuli per session. (The data for the common reference stimuli, the pilot study stimuli, and the repeated stimuli were not used in the following analyses and are not discussed in this report.) Fourteen propeller and 5 jet airplanes were included in the 108 basic stimuli. Operations included takeoff, landing, takeoff with power cutback at 152-m altitude, and constant altitude flyover at 305 m. However, not every airplane was represented by every operation. Each combination of airplane and operation that was included was presented at nominal peak L_D values of 70, 80, and 90 dB. A summary of the types of airplanes in the basic data set, some specifications of each, and the type of operations included are given in table III. The L_A time histories and the 1/3-octave-band spectra at peak L_A

for the highest level presentations of the operations of the 14 propeller airplanes are given in figure A3 of appendix A. The commercial service jet stimuli were identical for both experiments. Also the Swearingen Metro II takeoff and landing were included in the basic data set in both experiments for comparison purposes.

Experiment Design

Numerical category scaling was chosen as the psychophysical method for both experiments. The choice was made to maximize the number of stimuli that could be judged in the fixed amount of time available. The scale selected was a unipolar, 11 point scale from 0 to 10. The end points of the scale were labeled "EXTREMELY ANNOYING" and "NOT ANNOYING AT ALL." The term "ANNOYING" was defined in the subject instructions as "UNWANTED, OBJECTIONABLE, DISTURBING, OR UNPLEASANT."

For each experiment, the stimuli were divided into two sets of four groups (tapes). The first set of four tapes contained all the stimuli in the experiment. The second set contained the same stimuli as the first but in reverse order. There were 27 stimuli per tape in the first experiment and 33 per tape in the second experiment. The stimuli were divided among the tapes, so that airplanes, levels, and operations were about equally represented on each tape. The order of the stimuli on the tape was then randomly selected. The orders for each tape are given in tables IV and V. A period of approximately 10 sec was provided after each stimulus for the subjects to make and record their judgments. Each tape served as one of four test sessions for the subjects and required approximately 20 min for playback in the first experiment and 25 min in the second experiment.

The 64 test subjects in each experiment were divided into 16 groups of 4 subjects. The first four tapes were presented to eight groups of subjects, and the second four tapes were presented to the other eight groups of subjects. To prevent subject fatigue and other temporal effects from unduly influencing the results, the order in which the tapes were presented was varied to provide a balanced presentation. Table VI gives the order of presentation used for the tapes in both experiments.

Procedure

Upon arrival at the laboratory, the subjects were seated in a conference room, and each was given a set of instructions and a consent form. Copies of these items for the first experiment are given in appendix B. In the second experiment, these items were identical except that the length of the session was changed from 20 min to 25 min, and the number of aircraft sounds was changed from 27 to 33. After reading the instructions and completing the consent form, the subjects were given a brief verbal explanation of the cards used for recording judgments and were asked if they had any questions. The subjects were then taken into the test facility and randomly assigned to the four seat locations. Three practice stimuli were presented to the subjects while the test conductor remained in the test facility. In order for the subjects to gain experience in scoring the sounds, they were instructed to make and record judgments of the practice stimuli. After asking again for any questions about the test, the test conductor issued scoring cards for the first session and left the facility. Then, the first of four test sessions began. After the conclusion of each session, the test conductor reentered the test facility, collected the scoring cards, and issued new scoring cards for the next session. Between the second and third sessions, the subjects were given a 15-min rest period outside the test facility.

RESULTS AND DISCUSSION

Acoustic Data Analyses

Each noise stimulus was analyzed to provide 1/3-octave-band sound pressure levels from 20 Hz to 20 kHz for use in computing a selected group of noise metrics. The measurements were made with a 1.27-cm-diameter condenser microphone and a real-time 1/3-octave analysis system, which used digital filtering. The microphone was located at a subject's head position (third subject from the reader's left in fig. 1). No subjects were present during the measurements. To account for spectral differences in the noise stimuli for this analysis, a total of 11 noise metrics were considered. They included the simple weighting procedures L_A, L_D, L_E, L_1, and L_2 and the more complex calculation procedures LL, PL, and PNL. In addition, three types of critical band corrections were applied to PNL.

The noise metrics L_1 and L_2 are based on a modified frequency weighting developed in a study of annoyance to simulated helicopter rotor noise reported in reference 3. That study found that annoyance prediction error was more correlated with the logarithm of the subjectively dominant frequency (approximated by the 1/3-octave band center frequency with the greatest D-weighted energy) than with impulsiveness measures. From these data, a modified frequency weighting was developed which provided improved annoyance prediction when implemented as the L_1 and L_2 noise metrics. Figure 2 compares the modified weighting with A-weighting and D-weighting for 1/3-octave bands with center frequencies less than or equal to 1000 Hz. D-weighting values are used for bands above 1000 Hz. The L_1 metric uses the energy summation method commonly used for L_A, L_D, and L_E. The L_2 metric uses the summation method used in the PNL calculation procedure, which considers the possibility of masking by the dominant band.

The first critical band correction procedure applied to PNL was suggested in reference 7. In this procedure, the increased bandwidths of critical bands below 400 Hz are approximated by groups of 1/3-octave bands. The three groups are composed of the bands with center frequencies (1) 315 and 250 Hz, (2) 200, 160, and 125 Hz, and (3) 100, 80, 63, and 50 Hz. Within each group, the band levels are summed on an energy basis. The summed band levels are assigned to the band center frequency having the greatest intensity within the group. The PNL calculation procedure then uses these "critical bands" instead of the 1/3-octave bands below 400 Hz. The metric using this procedure is designated as PNL_K in further discussions in this report.

The second critical band correction procedure used the same groups for summing the 1/3-octave bands. The summed band levels, however, were assigned to the band center frequency responsible for the greatest "noy" value within the group before summing. The metric using this procedure is designated as PNL_M.

The third critical band correction procedure also used the same groups of 1/3-octave bands. In this case, the noy values of the 1/3-octave-band levels were added on an energy basis within each group. The resultant noy values for all critical bands were then summed using the PNL procedure. The metric using this procedure is designated as PNL_W.

Six different variations of each of the 11 previously described noise metrics were calculated. The first was the peak or maximum level occurring during the fly-over noise. Two other variations were calculated by applying two different tone corrections. Three more variations were attained by applying duration corrections to the non-tone-corrected level and the two tone-corrected levels. The duration correction and the first tone correction T_1 are identical to those used in the effective perceived noise level procedure defined in the Federal Aviation Administration FAR 36 regulation (ref. 5). The second tone correction T_2 is identical to the first, except that no corrections are applied for tones identified in bands with center frequencies less than 500 Hz.

Subjective Data Analyses

The means (across subjects) of the judgments were calculated for each stimulus. These mean annoyance scores were converted to "subjective noise levels" L_S having decibel-like properties through the following process: Included in each experiment for the purpose of converting the mean annoyance scores to L_S values were seven presentations of the Boeing 727 takeoff recording ranging in values of L_D from 65 to 95 dB in 5-dB increments. Three additional presentations of the recording, at 70, 80, and 90 dB, were included in the basic data set for each experiment. Third-order polynomial regression analyses were performed separately for each experiment on data obtained for these 10 stimuli. The dependent variable was the calculated PNL, and the independent variable was the mean annoyance score for each of the 10 stimuli. Figure 3 presents the two sets of data and the resulting best fit curves. The regression equations thusly determined were subsequently used to predict the level of the Boeing 727 takeoff noise which would produce the same mean annoyance score as each of the other noise stimuli in the separate experiments. These levels were then considered as the subjective noise level for each stimulus.

Comparison of Results for Propeller and Jet Airplanes

In both experiments, some differences in results were found between propeller airplanes and jet airplanes. This section presents specific results for the two noise metrics most commonly used for aircraft noise assessment, peak L_A and EPNL.

First experiment.- Figure 4 presents the relationships between the subjective noise level L_S and the measured noise levels peak L_A and EPNL for the heavy propeller airplanes and the jet airplanes. Results for linear least squares regression analyses of these data are presented in table VII. No significant differences in slopes between the two airplane types were found for either metric. For a given peak L_A, jet airplanes were judged, on the average, 2.4 dB more annoying than the propeller airplanes. For a given EPNL, on the average, no differences in judged annoyance were found between the jet and propeller airplane noises. The regression analyses indicated more scatter in the data for propeller airplanes than for jets for peak L_A but less scatter for propeller airplanes for EPNL.

In general, for all 11 metrics examined, the addition of the duration correction to a metric resulted in no differences in judged annoyance between the jet and propeller noises, whereas the lack of the duration correction resulted in the jet airplanes being judged more annoying than the propeller airplanes. This result is indicative of the fact that the propeller airplane noises were of shorter durations than the jet airplane noises. The difference in average duration correction between the propeller and jet noises was about 3 dB.

Second experiment.- Comparisons of the results obtained for the light propeller airplanes and the jet airplanes of the second experiment are presented in figure 5. A summary of the regression analyses for these data is presented in table VIII. No significant differences were found between the slopes for the two airplane types for either metric. There were differences, however, on the average between the two airplane types for both metrics. The light propeller airplanes were found to be, on the average, 6.3 dB less annoying than the jet airplanes for peak L_A and 4.4 dB less annoying for EPNL. The regression results of this experiment also indicated more scatter in the data for propeller airplanes than for jets for peak L_A but less scatter for propeller airplanes for EPNL.

In general, for all 11 metrics examined, the addition of the duration correction to a metric resulted in a decrease in the differences in judged annoyance between the jet and propeller noises. However, despite the decrease, substantial differences remain. As in the first experiment, this decrease is indicative of the shorter durations of the propeller airplane noises. The difference in average duration correction between the propeller and jet noises was a little over 2 dB.

Between experiments.- The results of the two experiments for the jet airplanes were remarkably consistent. No significant differences were found in the regression analyses (tables VII and VIII) between the two experiments for either peak L_A or EPNL. Although the original recorded airplane noises were identical, the noises presented to the completely different sets of subjects of the two experiments were from different copies of the originals. The implications of these findings are that the two sets of subjects were providing very consistent judgments of the noise relative to the Boeing 727 takeoff noise used as a reference for converting judgments to subjective noise levels.

The results of the two experiments for the propeller airplanes were not as consistent. The slopes for the two experiments were slightly different; the slopes for the light propeller airplanes were less than the slopes for the heavy propeller airplanes for both peak L_A and EPNL. The annoyance to the light propeller airplanes was also on the average less than that to the heavy propeller airplanes for both peak L_A and EPNL.

Comparison of Noise Metrics for Propeller Airplanes

In determining how to most accurately predict the annoyance caused by propeller airplane noise, the questions that must be answered are which noise metric procedure should be used and which corrections, if any, should be applied to the metric. In order to investigate annoyance prediction ability in detail, the differences between the subjective noise level L_S and the calculated noise level for each of the six variations of each noise metric were determined for each stimulus in each experiment. These differences were considered to be the "prediction error" for each stimulus and noise metric variation. The standard deviation of the prediction errors for each noise metric variation is a measurement of how accurately the variation predicts annoyance. The smaller the standard deviation is, the greater the prediction accuracy.

Tables IX and X give the standard deviations of prediction error for each noise metric and correction combination examined for the propeller airplane noises in the first and second experiments, respectively. To facilitate comparisons, each table divides the 11 noise metrics into three groups consisting of the 6 metrics in conventional usage, the 3 metrics resulting from the application of critical band corrections to PNL, and the 2 recently developed metrics based on the modified frequency weighting. The standard deviations for each group are averaged in three ways: (1) across the six variations of tone and duration corrections, (2) across the noise metrics, and (3) across the noise metrics and across the three tone-correction variations. The information in these tables is used in the following discussions.

It should be noted that because of interrelationship among the data cases, statistical tests for significance of differences in the standard deviations of prediction error are not straightforward. As a consequence, the following results are based primarily on general trends found in the data that were usually consistent across the different cases examined. Approximate statistical tests indicate that differences on the order of 0.15 to 0.20 in standard deviations could be significant.

First experiment.- Comparisons of the conventional noise metrics in the first group in table IX indicate that PNL consistently had the smallest standard deviation of prediction error for each combination of tone and duration corrections. PL usually had the next smallest standard deviation. The T_2 tone correction improved prediction ability, and the T_1 tone correction generally degraded prediction ability. The addition of duration corrections tended to improve prediction ability. PNL with duration corrections and T_2 tone corrections had the smallest standard deviation of prediction error.

Second experiment.- Comparisons of the conventional noise metrics in the first group in table X indicate that PL consistently had the smallest standard deviation of prediction error for each combination of tone and duration corrections. The standard deviation for PNL without tone and duration corrections equalled that of PL, and PNL had the next smallest standard deviation for each of the other five correction combinations. Both T_1 and T_2 tended to degrade prediction ability, T_1 more so than T_2. Duration corrections also generally degraded prediction ability. Peak PL and peak PNL (i.e., PL and PNL without tone and duration corrections) had the smallest standard deviation of prediction error.

Duration.- A word of caution is in order concerning the duration correction results for both experiments discussed in the preceding paragraphs. Research on annoyance to commercial service jet airplane noise showed that different studies often yielded widely varying conclusions on the need for duration corrections. One of the reasons for this variation was the inability to independently vary duration and other noise characteristics such as spectral content when using recordings of real aircraft (ref. 8). This problem may also affect the results of propeller noise studies. In addition, the propeller airplane recordings used in the study, particularly those for the light propeller airplanes, were made at locations relatively close to lift-off and touchdown points and may not adequately represent the range of durations to which the surrounding communities are exposed. A definitive answer to the question of the need for duration corrections in assessing propeller airplane noise will require an experiment designed specifically to study duration with carefully selected stimuli in which other noise characteristics are controlled over a wide range of durations.

Critical band corrections.- In the first experiment, critical band corrections generally improved the prediction ability of PNL. However, the critical band correction which provided the most improvement depended on the particular combination of tone and duration corrections used. Also, the difference between the smallest standard deviation of prediction error for conventional PNL (duration-corrected PNL with T_2 tone corrections) and the smallest standard deviation for PNL with critical band corrections (duration-corrected PNL_W with T_2 tone corrections) is not significant. Critical band corrections did not significantly improve the prediction ability of PNL in the second experiment.

Modified frequency weighting.- In both experiments, L_1 was consistently a better predictor of annoyance than L_2. In the first experiment, L_1 predicted annoyance better than any other noise metric for each combination of tone and duration corrections. In the second experiment, L_1 did not surpass PL and PNL but did predict annoyance better than the other simple weighting procedures, L_A, L_D, and L_E. These results and those from the helicopter studies of reference 3 indicate that the L_1 noise metric merits further examination.

Regrouping of Propeller Airplanes

During the design of the two experiments, it could not be determined in which weight category three 5700-kg airplanes (Beechcraft Super King Air 200, Embraer EMB-110 Bandeirante, and Swearingen Metro II) would be classified. It was decided to include them in the first experiment with the airplanes greater than 5700 kg. (The Metro II was already included in the second experiment as a comparison). Subsequent to conducting the two experiments, it was learned that the three airplanes would be certified in the class below 5700 kg.

As a check to determine if the location of the three airplanes within the two experiments would affect the results, the data for the three airplanes were transferred from the first experiment data set to the second experiment data set and the analyses repeated. This regrouping was possible because the L_S values in both experiments were referenced to the same noise, and the L_S values for the 54 stimuli presented in both experiments are highly correlated. The analyses of the regrouped propeller data sets yielded the same results and conclusions as the original analyses. This was true for both comparisons with jet airplanes and comparisons among the standard deviations of prediction error for the different combinations of noise metrics and corrections.

Influence of Other Variables

In addition to the metrics, five physical parameters were considered as possible predictors of annoyance response. They were engine type, operation type, blade passage frequency, blade tip speed, and maximum takeoff weight. The effects of these parameters in conjunction with four commonly used metrics L_A, duration-corrected L_A, PNL, and EPNL (duration-corrected PNL with T_1 tone corrections) were studied using multiple regression analyses with L_S as the dependent variable.

Engine type and operation type are qualitative variables and therefore are represented as indicator (dummy) variables in the regressions. For simplicity of presentation, each is considered separately in the following discussions. Combining both in the same regression yielded similar results. Reference 9 provides a detailed discussion of indicator variable analysis.

For each of the four metrics, regression models including the metric and each combination of one or more of the quantitative variables blade passage frequency, blade tip speed, and maximum takeoff weight were determined and compared by using the models comparison approach detailed in reference 10.

Engine type.- The experiments contained two types of propeller engines, turboprop and piston. The first experiment had only turboprop airplanes, and no comparison was possible. The second experiment included five turboprop airplanes and nine piston airplanes. Regression analyses of L_S on each metric with the engine indicator variable and the metric and engine interaction variable found no significant differences in the regression slopes between the turboprop and the piston cases. Neither were any significant differences found in the regression intercepts for the two engine types when the regressions were repeated without the interaction term. Therefore, no effect of engine type on annoyance is indicated.

Operation type.- The first experiment included two types of operations, takeoffs and landings, in equal numbers. Regression analyses of L_S on each metric and the operation indicator variable and the metric and operation interaction variable found no significant differences in the regression slopes. Regression equations with the interaction term eliminated did indicate significant differences (at the 0.01 level) between the regression intercepts for takeoffs and landings for each metric. Table XI gives the regression results for each metric both with and without the operation indicator variable. The differences in intercepts between takeoffs and landings (i.e., the operation coefficient) were fairly consistent across metrics. Takeoffs were, on average, 2.4 dB less annoying than landings in the first experiment.

The second experiment included four types of operations: takeoffs, landings, takeoffs with power cutback at 152-m altitude, and constant altitude flyovers at 305 m. The numbers of airplanes included in each type of operation were 14, 2, 7, and 3, respectively. The four classes of operation were modeled by three operation indicator variables and three metric and operation interaction variables. Regression analyses of L_S on each metric and the six variables found no significant differences in the regression slopes. Regression equations with the interaction terms eliminated found no significant differences in intercepts for peak L_A and peak PNL. However, the regressions for duration-corrected L_A and EPNL did indicate significant differences (at the 0.1 level) between intercepts for takeoffs, landings, and the combination of takeoffs with power cutbacks and flyovers. Additional analyses showed that the indicated variation in intercepts was caused by differences in the duration corrections applied to the different operations and was not a real effect of operation type. If duration has little or no effect on the annoyance response to the propeller airplanes in the second experiment (as is indicated by the degradation of prediction ability generally found when duration corrections were applied), then differences between the average duration corrections applied to the different operation types would cause an incorrect indication of different intercepts for different operation types. The average duration corrections of the operation types were different, and the differences corresponded to the indicated differences in intercept. Therefore, the results do not indicate an effect of operation type on annoyance response in the second experiment.

Other variables.- The other variables considered as possible indicators of annoyance response were blade passage frequency, blade tip speed, and maximum takeoff weight. The blade passage frequency is the frequency of the fundamental pure tone in the harmonic content of propeller noise (assuming no Doppler shift) and is determined by the number of blades and the propeller rotational speed. The blade tip speed determines the shape of the harmonic envelope (i.e., the levels of the harmonics relative to the fundamental frequency) and is a function of the blade length and the propeller rotational speed. Maximum takeoff weight is not directly related to any specific noise characteristic but, if found to be significant, could indicate the existence of some other important, but undetermined, parameter. Blade tip speed (V_T) and maximum takeoff weight (W) for the airplanes in both experiments were determined from specifications in various issues of reference publications such as Jane's All The World's Aircraft and Aviation Week & Space Technology. Four measures of blade passage frequency were used. First, it was calculated from the same specifications used for tip speed and weight (F_{oc}). Second, it was measured at peak L_A with a narrowband analyzer (F_{om}). Since the fundamental frequency changes throughout the flyover as a result of Doppler shift, peak L_A was chosen as a repeatable point in time to make the measurement. Past experience with other studies (such as ref. 3) has shown that the common logarithm of frequency can be a better variable to use than frequency. Therefore, $\log_{10} F_{oc}$ and $\log_{10} F_{om}$ were also considered.

To determine which of the six parameters W, V_T, F_{oc}, F_{om}, $\log_{10} F_{oc}$, and $\log_{10} F_{om}$, to include in the regression models, correlations between the parameters and the annoyance prediction errors for the four metrics considered were calculated. Since almost all the correlation coefficients were very low and no consistent trends were apparent, it was decided to include both W and V_T and choose $\log_{10} F_{om}$ as the frequency parameter in the regression models.

For each experiment and each metric, multiple linear regression equations were calculated for L_S on eight different models. The models consisted of the metric alone and the metric combined with each of the seven possible groupings of one or more of the three parameters W, V_T, and $\log_{10} F_{om}$. A models comparison approach using an F-test to test the significance of sets of predictor variables (ref. 10) was then used to compare the models and select the optimum regression model for each metric in each experiment.

The addition of the W, V_T, and $\log_{10} F_{om}$ terms did not improve the regression models in any consistent manner in either experiment. Therefore, no effect on annoyance of blade passage frequency, blade tip speed, or maximum takeoff weight is indicated.

CONCLUSIONS

Two laboratory experiments were conducted to provide information on the quantification of annoyance caused by propeller airplane noise. The first experiment examined 11 heavy propeller airplanes with maximum takeoff weights greater than or equal to 5700 kg. Operations included both takeoffs and landings. The second experiment examined 14 light propeller airplanes weighing 5700 kg or less. Operations included takeoffs, takeoffs with power cutbacks, landings, and constant altitude flyovers. Also included in each experiment were takeoff and landing operations of five commercial service jet airplanes. In each experiment, 64 subjects made annoyance judgments of the stimuli presented at different sound pressure levels in a testing room which simulates the outdoor acoustic environment. Analyses of these annoyance responses were conducted in terms of several variations of six conventional noise metrics (A-, D-, and E-weighted sound pressure level, loudness level (Stevens Mark VI procedure), perceived level (Stevens Mark VII procedure), and perceived noise level) and two other recently developed noise metrics (L_1 and L_2) based on a modified frequency weighting.

Based on the results presented in this paper, the following conclusions were noted:

1. The heavy propeller airplanes and the jet airplanes were judged equally annoying when differences in duration between the two types of airplanes were accounted for by corrections to the noise metrics.

2. The light propeller airplanes were judged approximately 4 dB less annoying than the jet airplanes, even when differences in duration between the two types of airplanes were accounted for by corrections to the noise metrics.

3. As can be inferred from the first two conclusions, the annoyance to the light propeller airplanes was less than that to the heavy propeller airplanes.

4. Of the six conventional noise metrics considered, the perceived noise level (PNL) procedure most accurately predicted the annoyance caused by heavy propeller airplanes. The next most accurate procedure was perceived level (PL).

5. Of the six conventional noise metrics considered, the procedure that most accurately predicted the annoyance caused by light propeller airplanes was perceived level (PL). Perceived noise level (PNL) was the next most accurate procedure.

6. For the heavy propeller airplanes, the annoyance prediction ability of the noise metrics was improved by the addition of a duration correction and the addition of a tone correction similar to the one used in effective perceived noise level (EPNL) but limited to tones in 1/3-octave bands with center frequencies greater than or equal to 500 Hz.

7. For the light propeller airplanes, annoyance prediction was degraded by the addition of a duration correction or the addition of a tone correction to the noise metrics.

8. Critical band corrections to perceived noise level (PNL) did not consistently improve annoyance prediction for either the heavy or the light propeller airplanes.

9. A recently developed noise metric L_1, which uses a simple frequency weighting with low-frequency characteristics between the current A- and D-weightings, merits further consideration for usage in predicting annoyance to airplane flyover noise. The L_1 procedure predicted annoyance better than any of the conventional noise metrics for the heavy propeller airplanes and better than any of the other simple weighting procedures for the light propeller airplanes.

10. For a given level of the noise metric variations examined, takeoffs of the heavy propeller airplanes were judged about 2.4 dB less annoying than landings. No effect of operation type on annoyance was found for the light propeller airplanes.

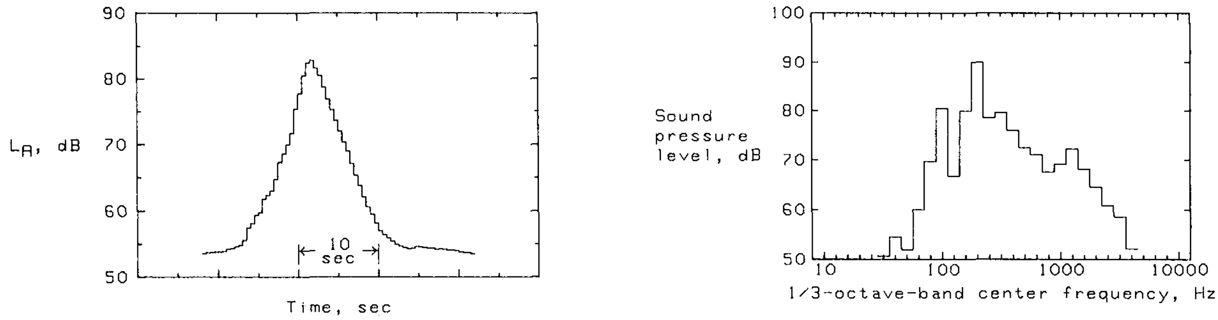
11. Piston and turboprop airplanes were judged equally annoying.

12. No consistent effects of blade passage frequency, blade tip speed, or maximum takeoff weight on judged annoyance were found for either the heavy or the light propeller airplanes.

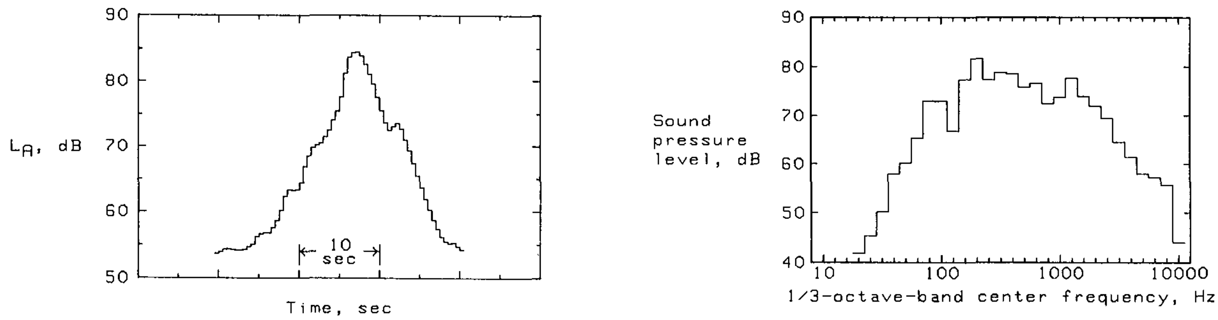
Langley Research Center
National Aeronautics and Space Administration
Hampton, VA 23665
July 17, 1984

APPENDIX A

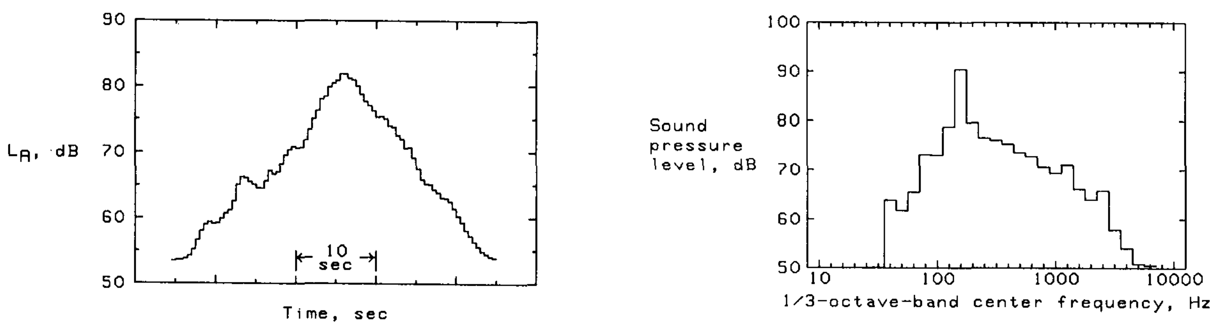
TIME HISTORIES AND SPECTRA OF AIRPLANES INCLUDED IN BASIC DATA SETS OF EXPERIMENTS



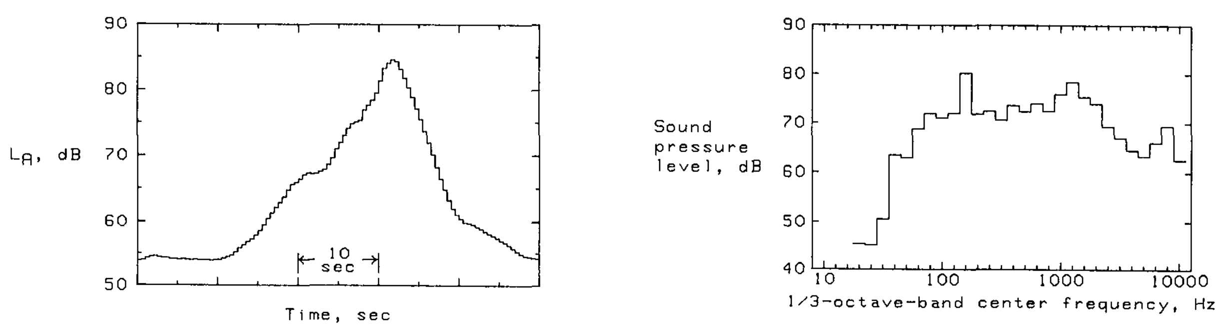
(a) Beechcraft Super King Air 200 takeoff.



(b) Beechcraft Super King Air 200 landing.

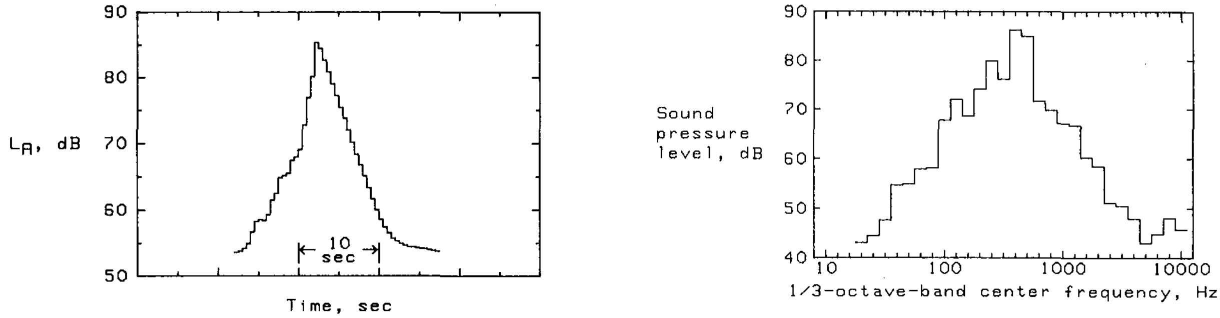


(c) de Havilland Canada DHC-7 Dash 7 takeoff.

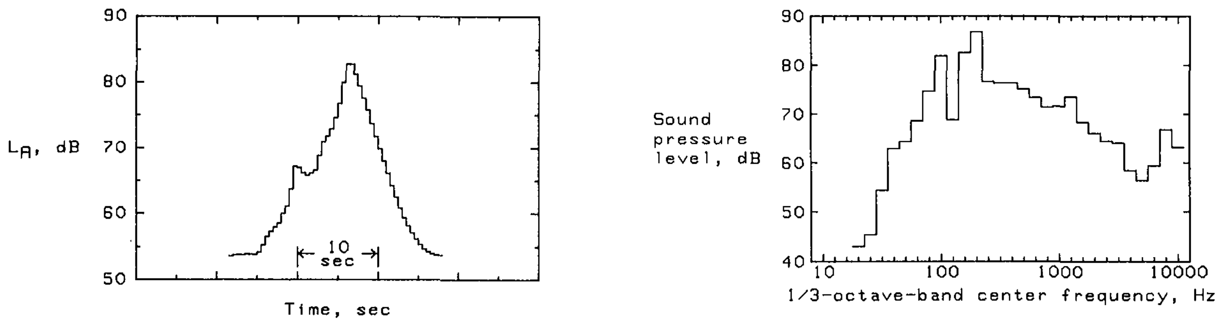


(d) de Havilland Canada DHC-7 Dash 7 landing.

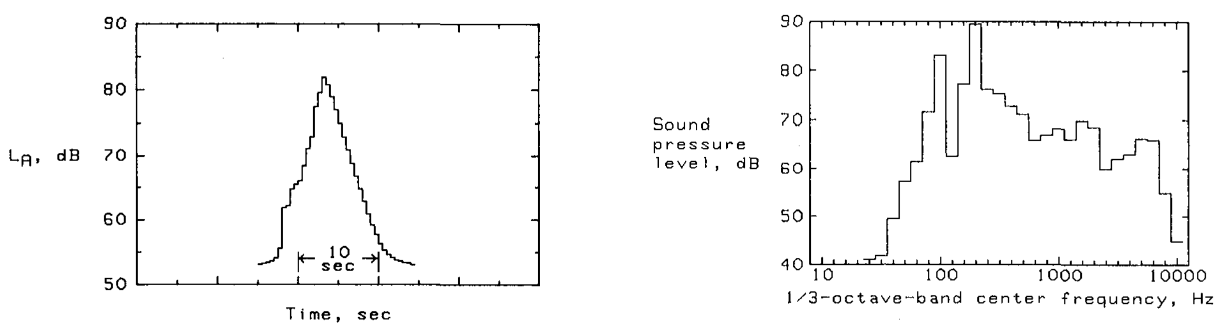
Figure A1.- L_A time histories and 1/3-octave-band spectra at peak L_A of takeoffs and landings of propeller airplanes included in basic data set of first experiment.



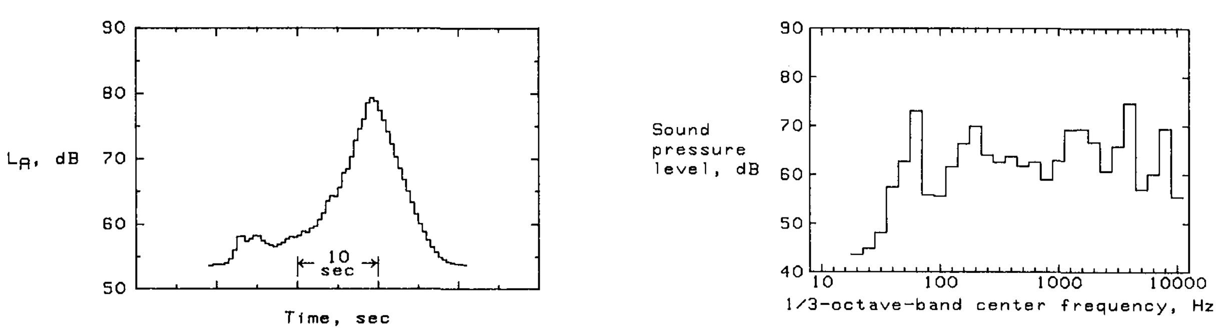
(e) Embraer EMB-110 Bandeirante takeoff.



(f) Embraer EMB-110 Bandeirante landing.

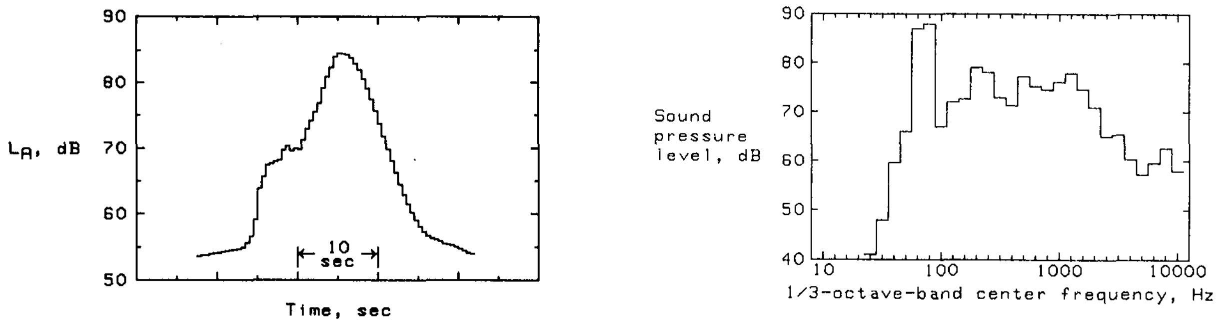


(g) Gulfstream American Gulfstream I takeoff.

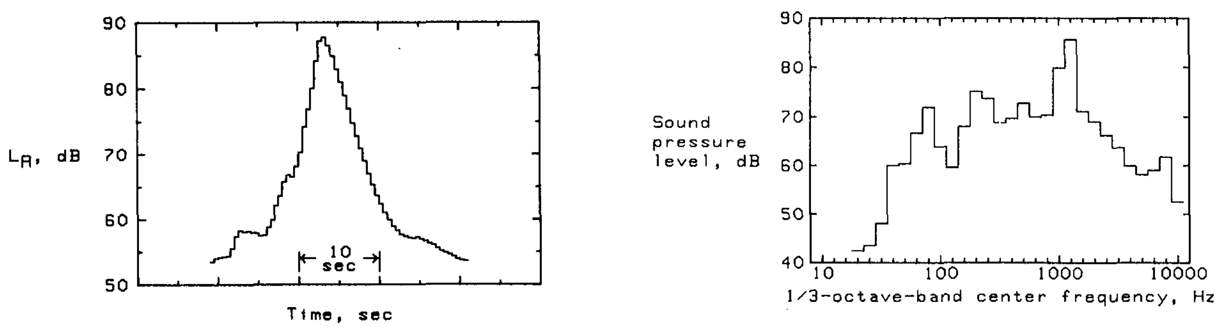


(h) Gulfstream American Gulfstream I landing.

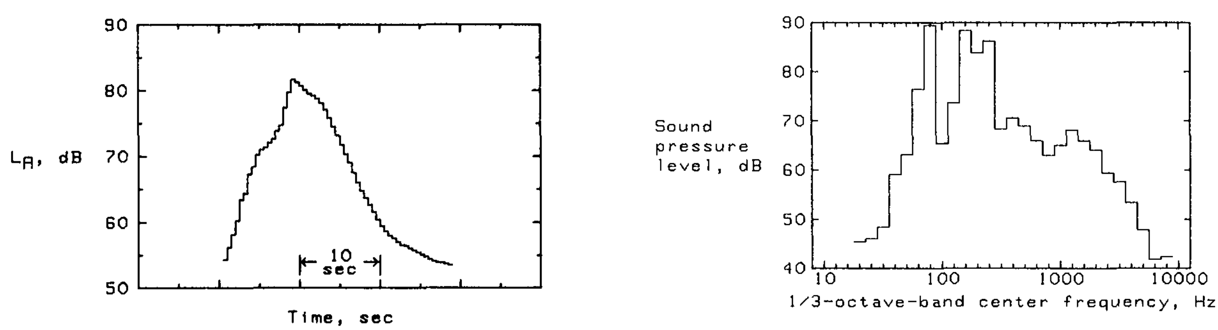
Figure A1.- Continued.



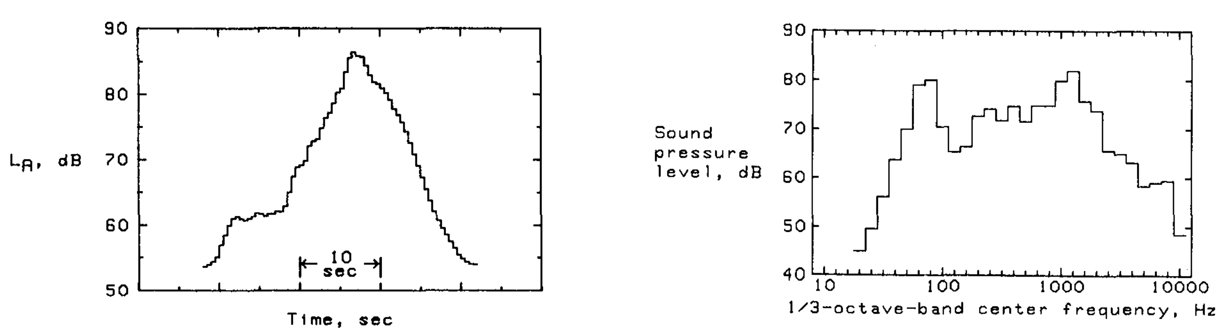
(i) Lockheed C-130 takeoff.



(j) Lockheed C-130 landing.

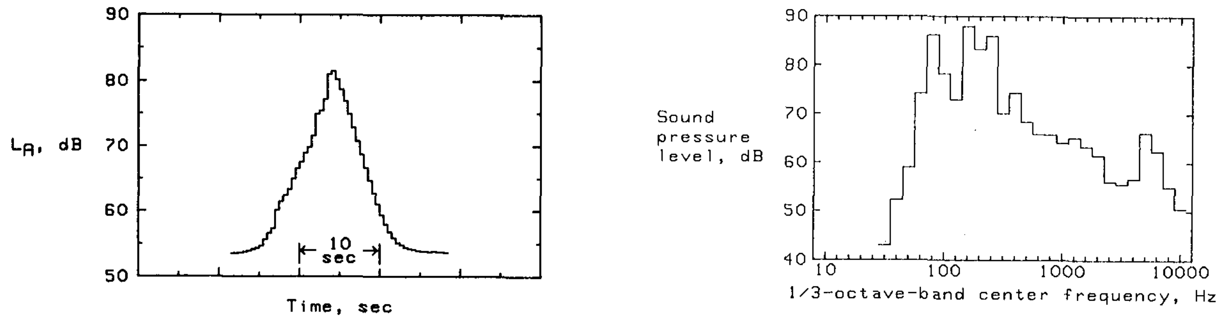


(k) Lockheed P-3 takeoff.

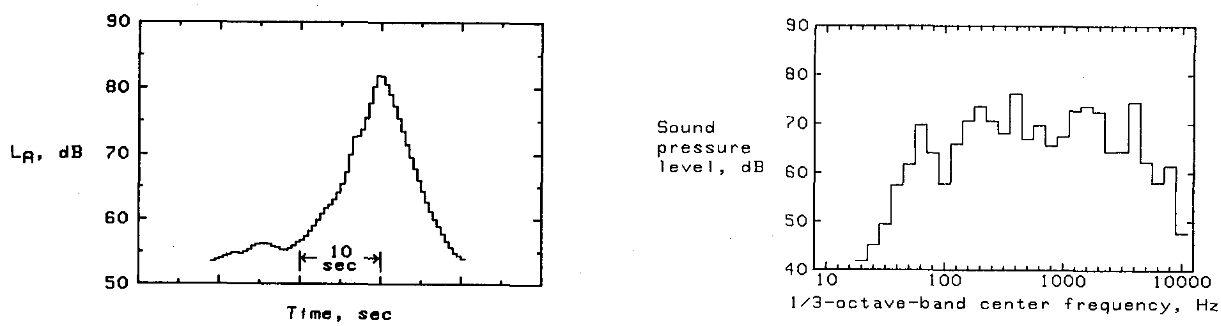


(l) Lockheed P-3 landing.

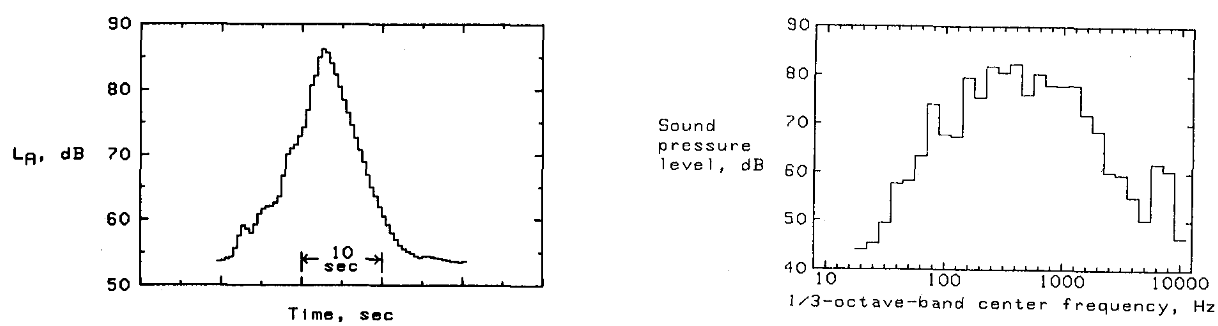
Figure A1.- Continued.



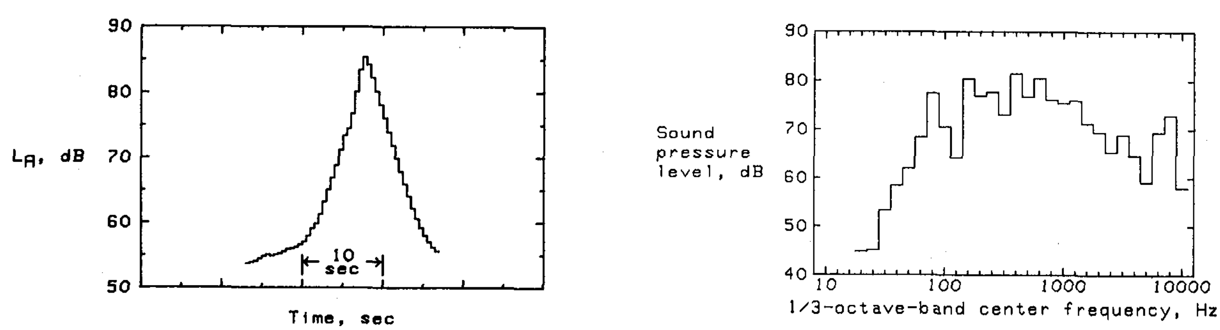
(m) NAMC YS-11 takeoff.



(n) NAMC YS-11 landing.

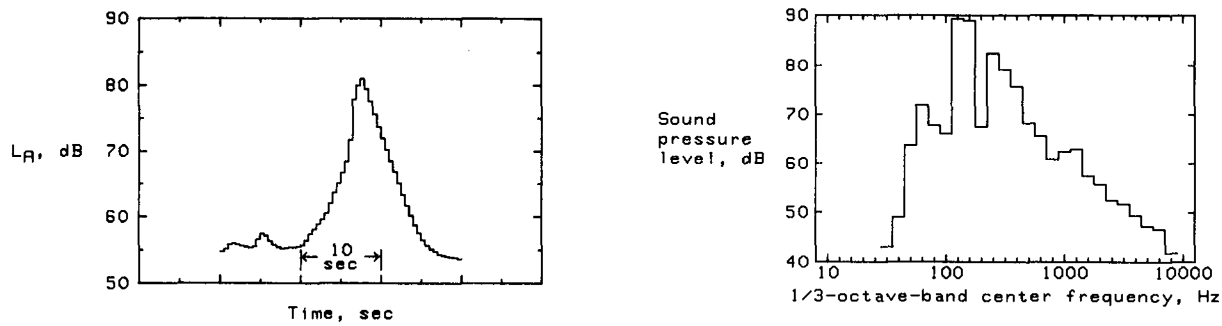


(o) Nord 262 takeoff.

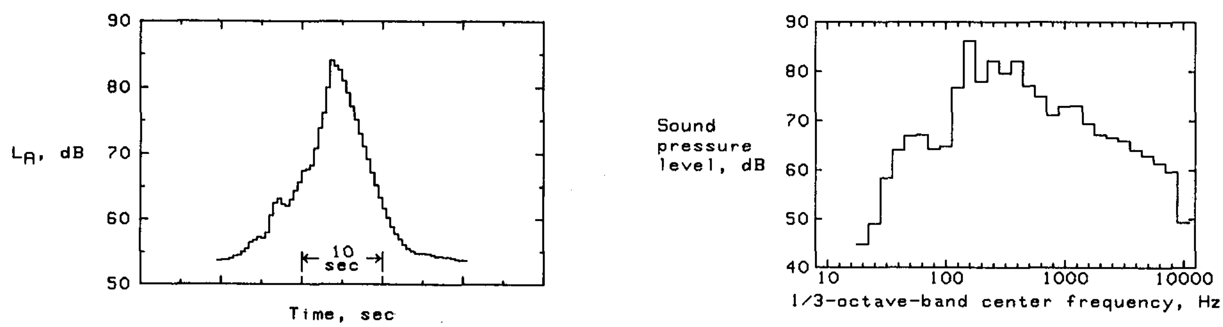


(p) Nord 262 landing.

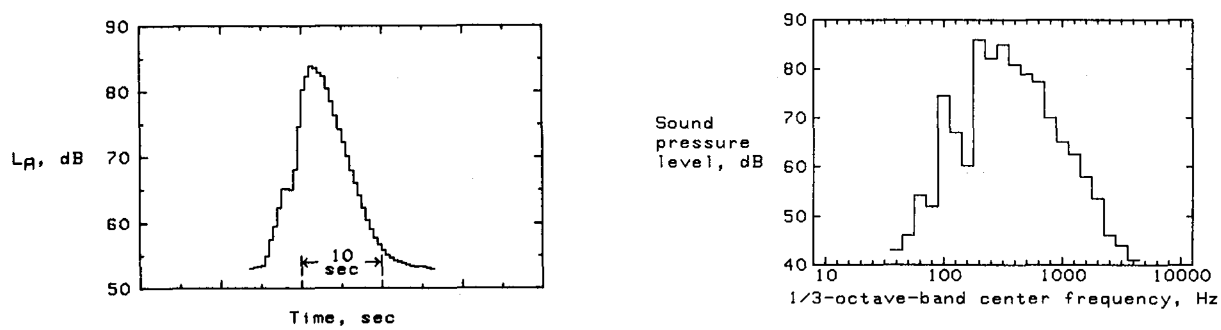
Figure A1.- Continued.



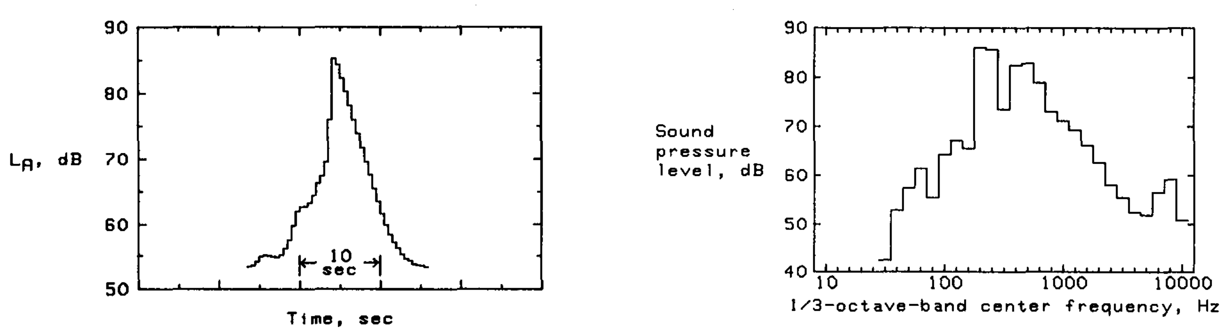
(q) Shorts 330 takeoff.



(r) Shorts 330 landing.

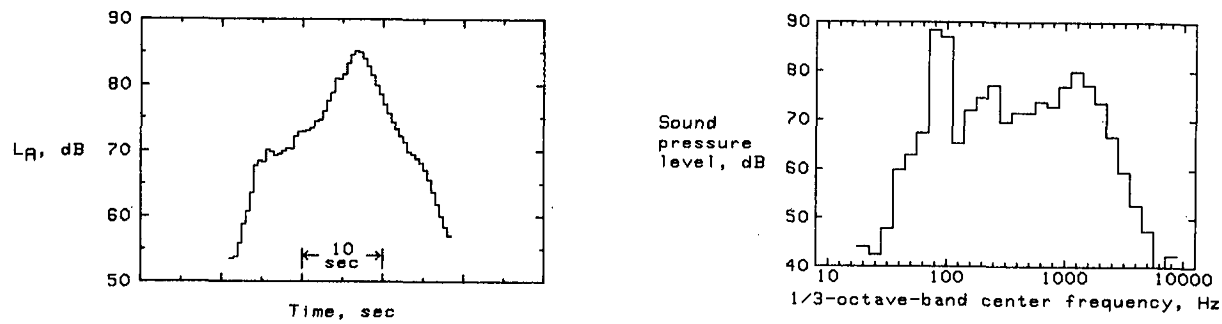


(s) Swearingen Metro II takeoff.

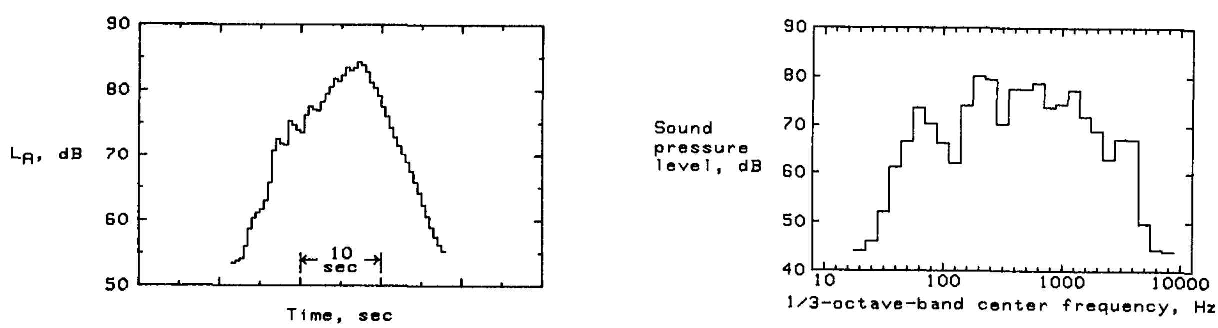


(t) Swearingen Metro II landing.

Figure A1.- Continued.

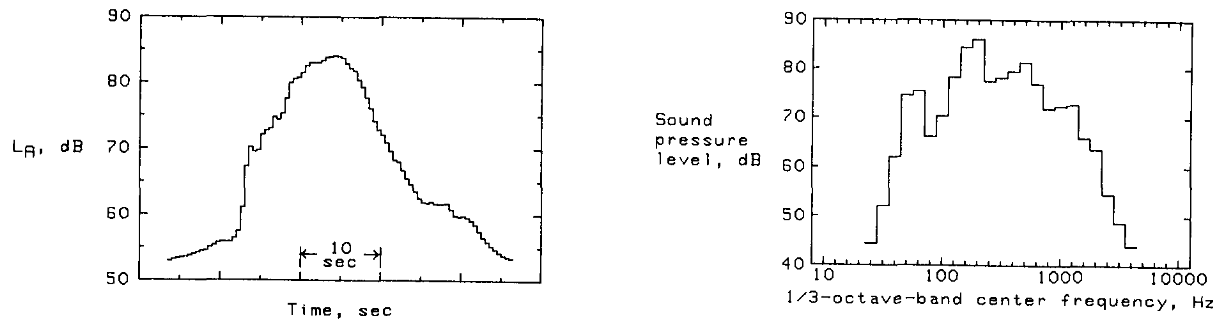


(u) Vickers Viscount takeoff.

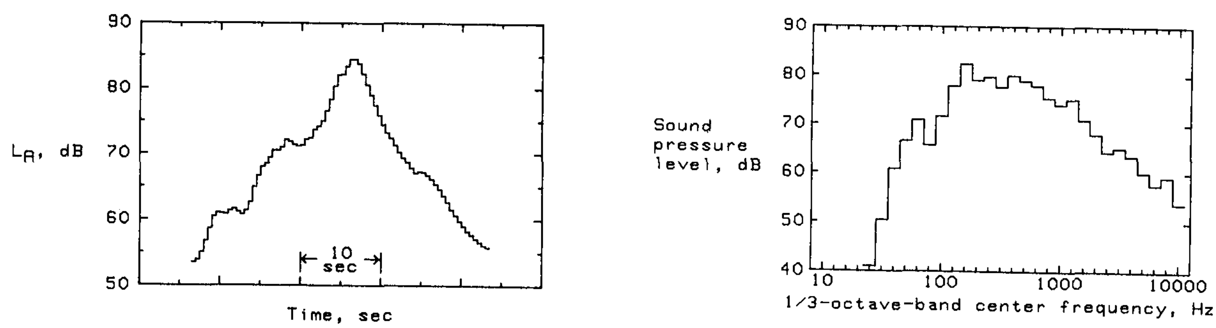


(v) Vickers Viscount landing.

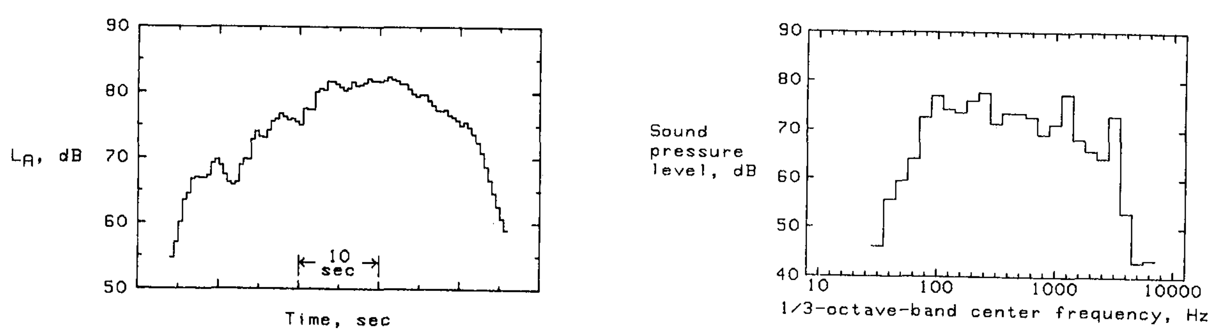
Figure A1.- Concluded.



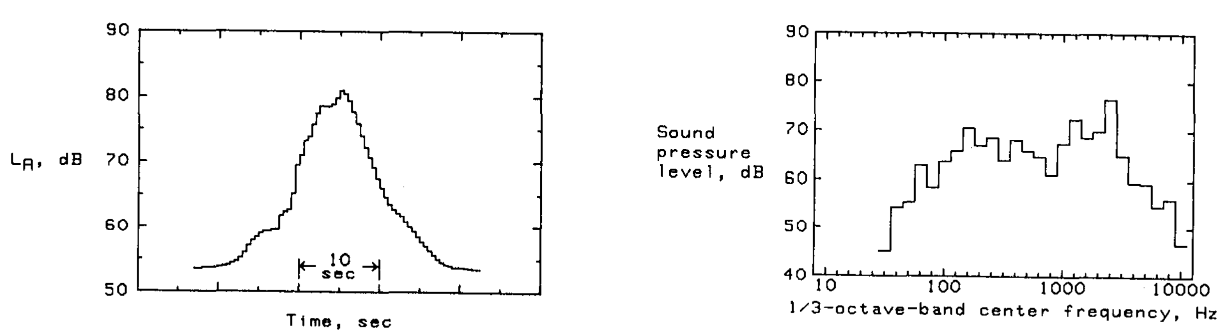
(a) Airbus Industrie A-300 takeoff.



(b) Airbus Industrie A-300 landing.

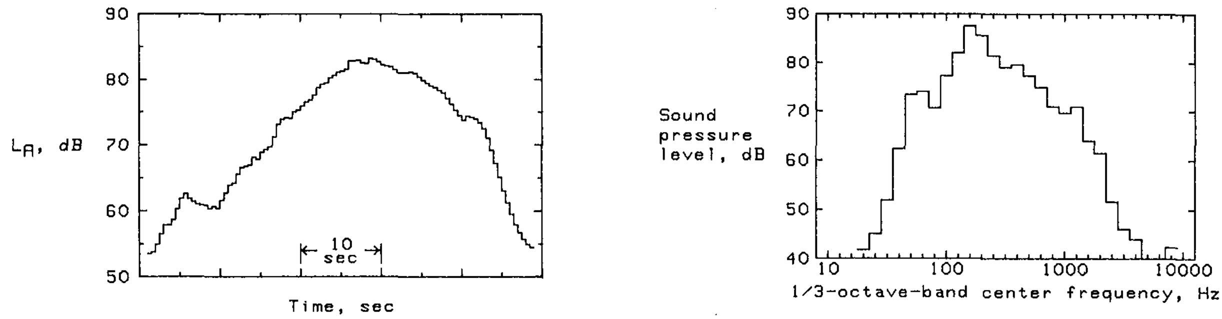


(c) Boeing 707 takeoff.

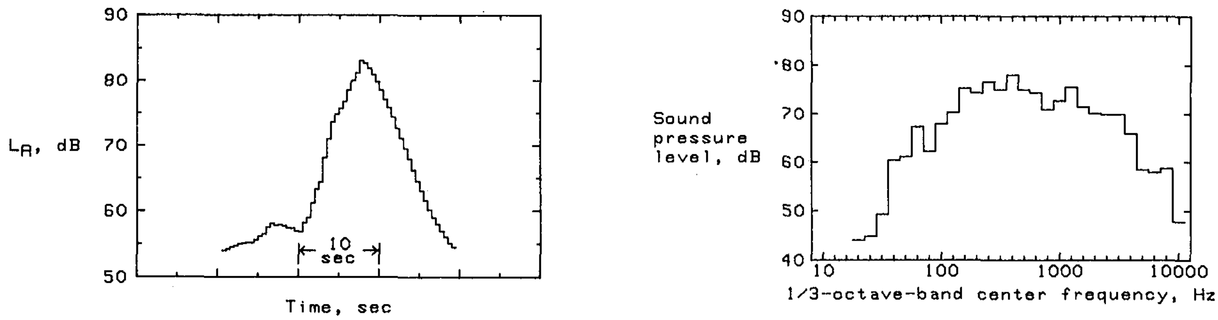


(d) Boeing 707 landing.

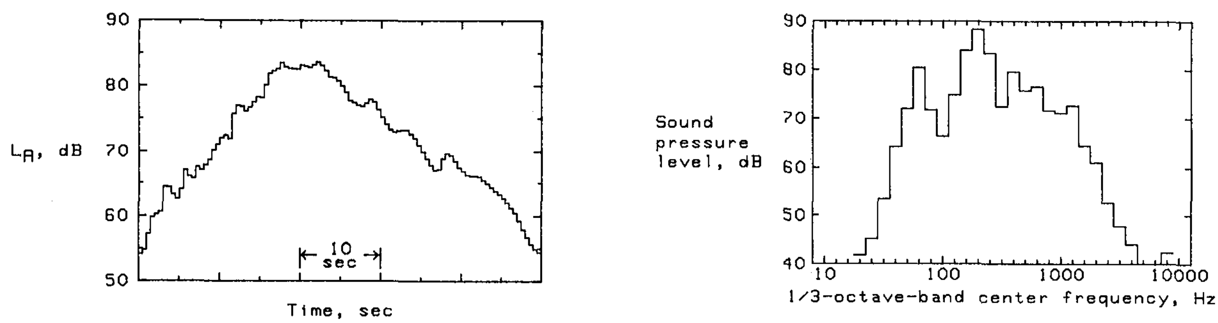
Figure A2.- L_A time histories and 1/3-octave-band spectra at peak L_A of takeoffs and landings of jet airplanes included in basic data sets of both experiments.



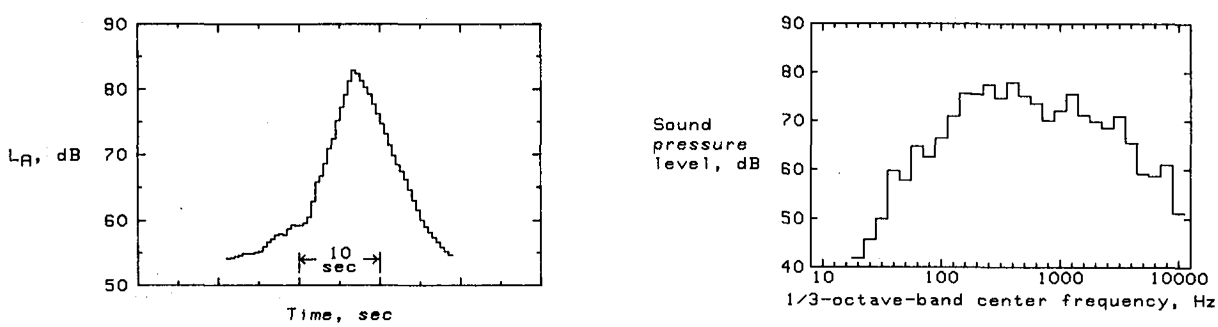
(e) Boeing 727-200 takeoff.



(f) Boeing 727-200 landing.

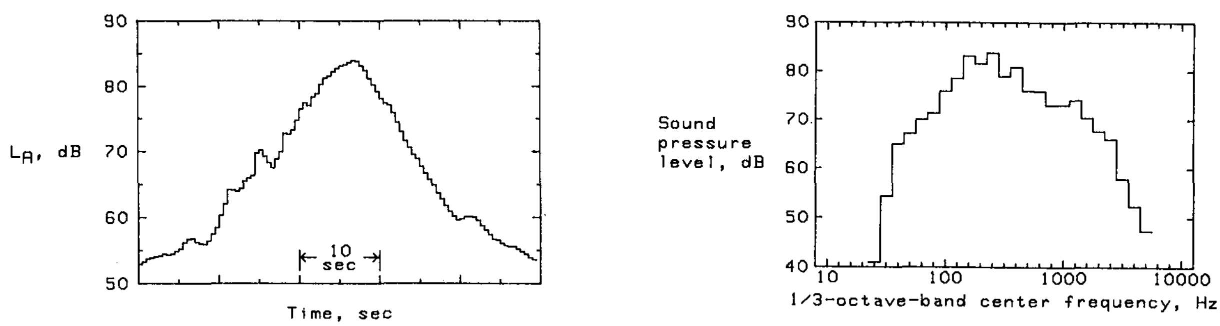


(g) McDonnell Douglas DC-9 takeoff.

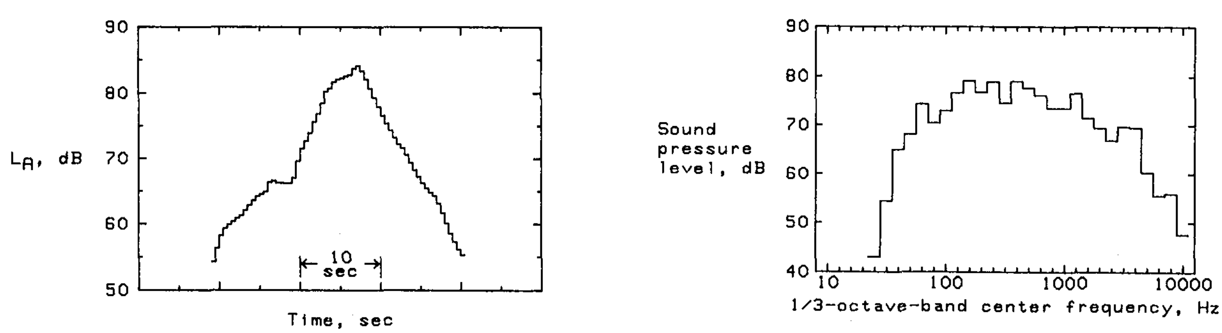


(h) McDonnell Douglas DC-9 landing.

Figure A2.- Continued.

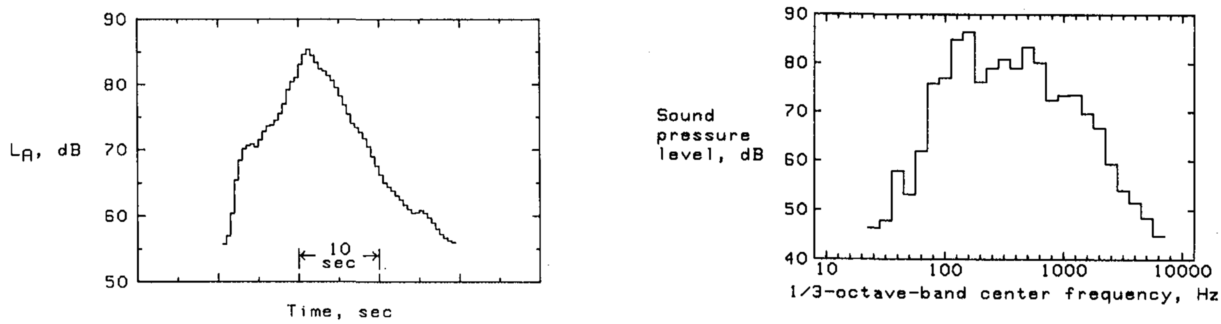


(i) McDonnell Douglas DC-10 takeoff.

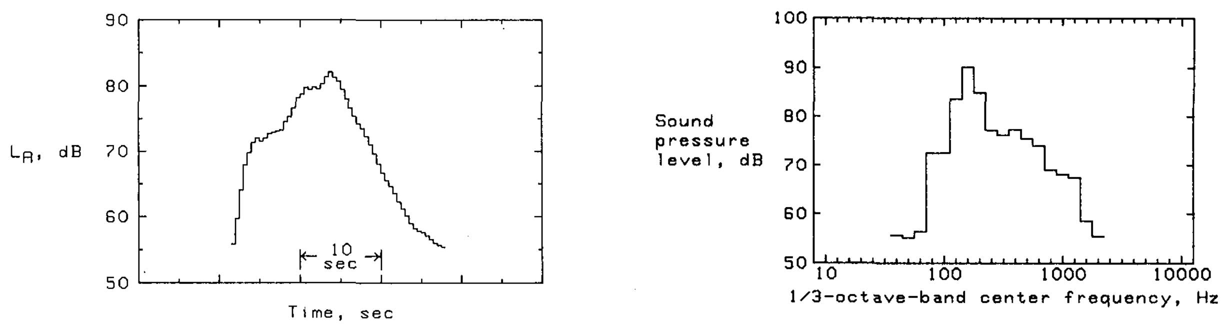


(j) McDonnell Douglas DC-10 landing.

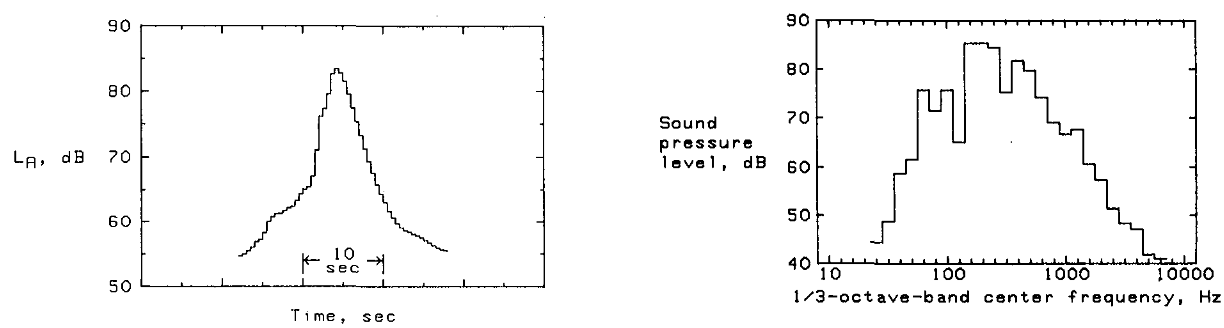
Figure A2.- Concluded.



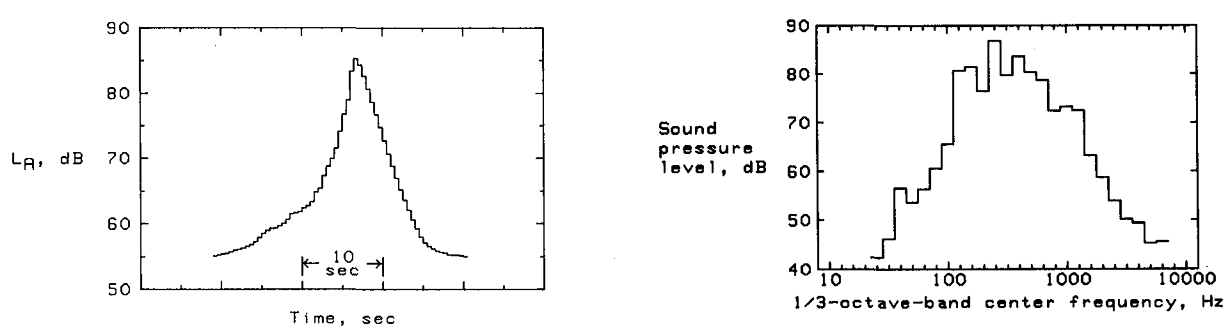
(a) Beechcraft Bonanza V takeoff.



(b) Cessna 172 takeoff.

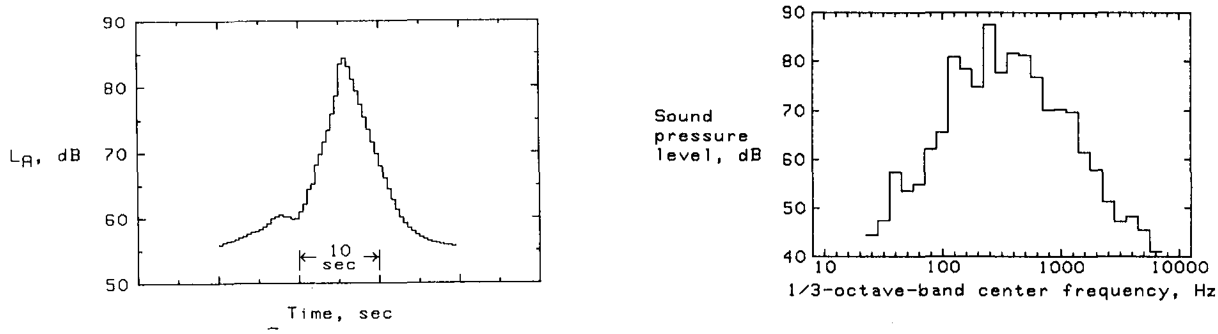


(c) Cessna 177 takeoff.

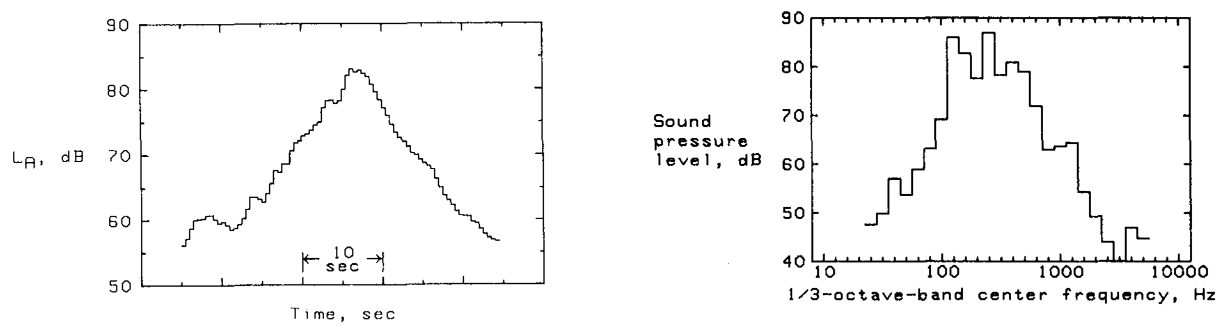


(d) Cessna 210 takeoff.

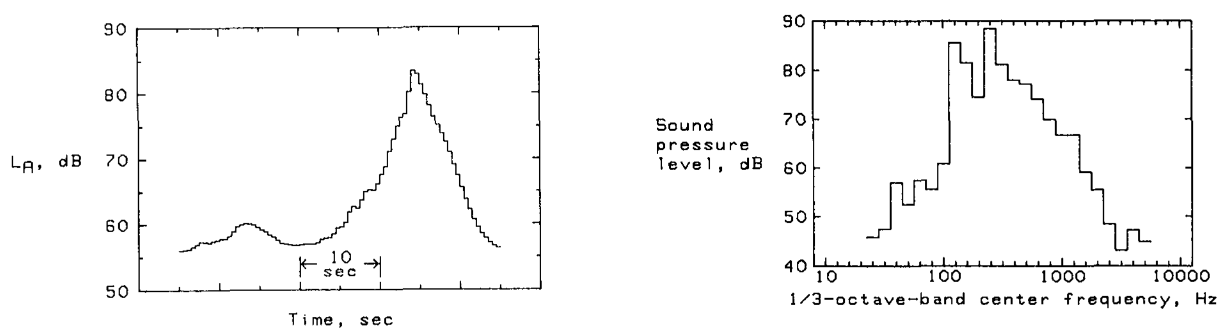
Figure A3.- L_A time histories and 1/3-octave-band spectra at peak L_A of operations of propeller airplanes included in basic data set of second experiment.



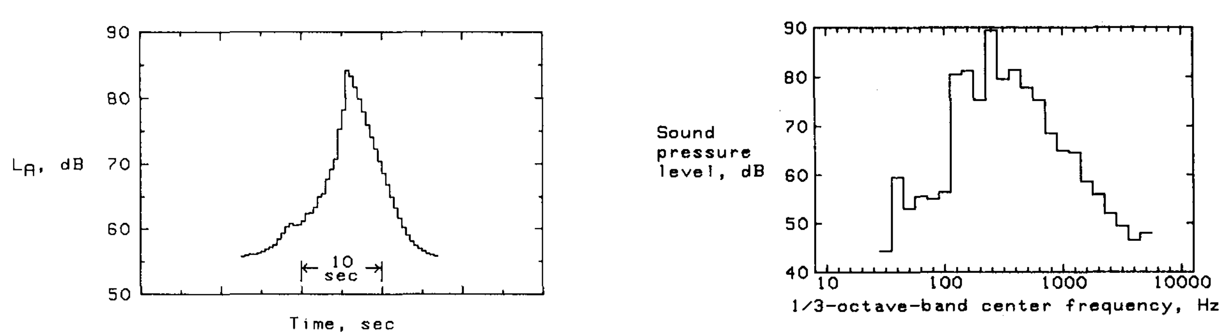
(e) Cessna 210 takeoff with power cutback.



(f) Cessna 210 flyover.

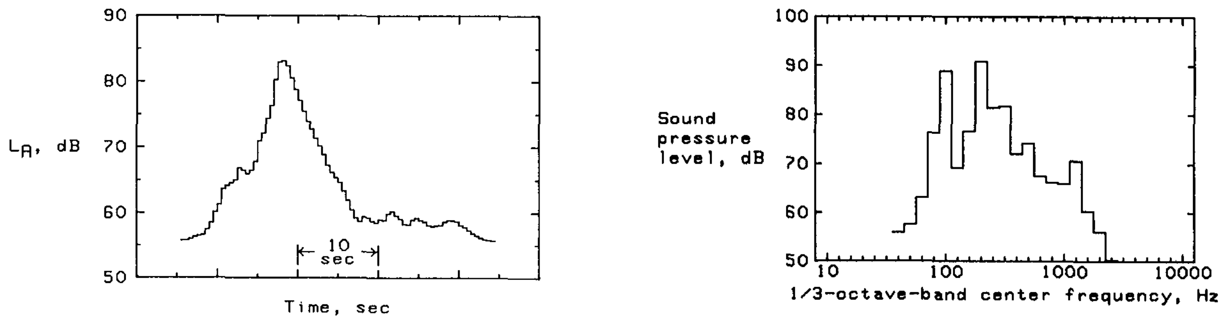


(g) Cessna 335 takeoff.

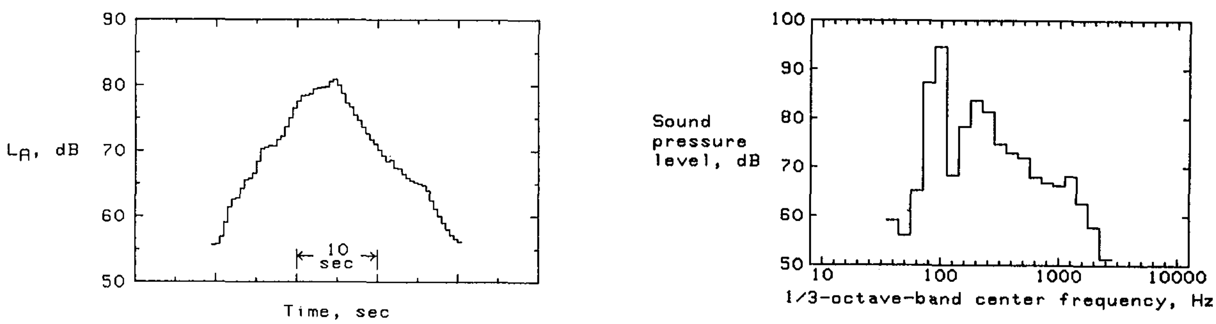


(h) Cessna 335 takeoff with power cutback.

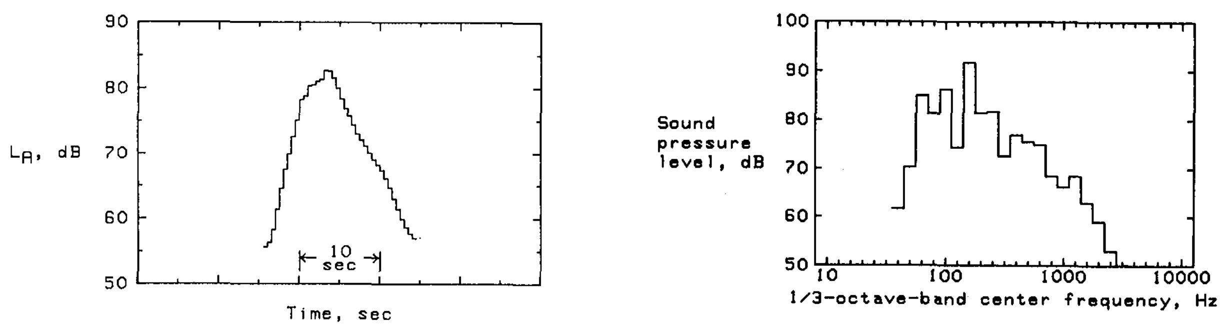
Figure A3.- Continued.



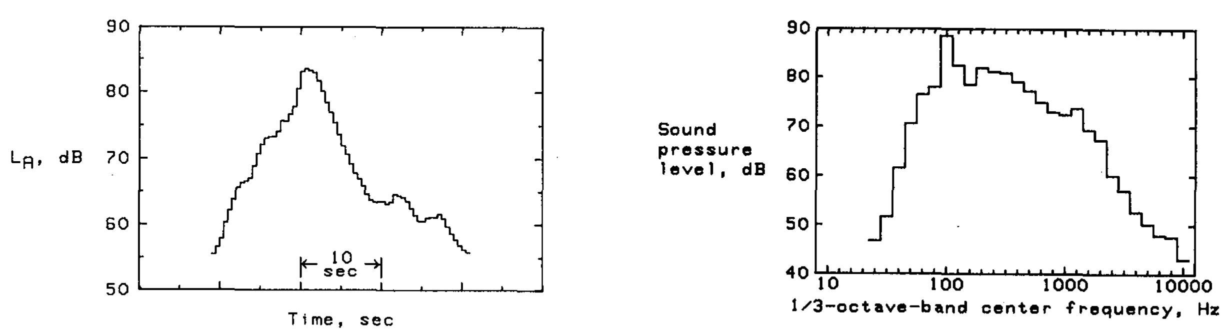
(i) Cessna 425 takeoff.



(j) Cessna 425 takeoff with power cutback.

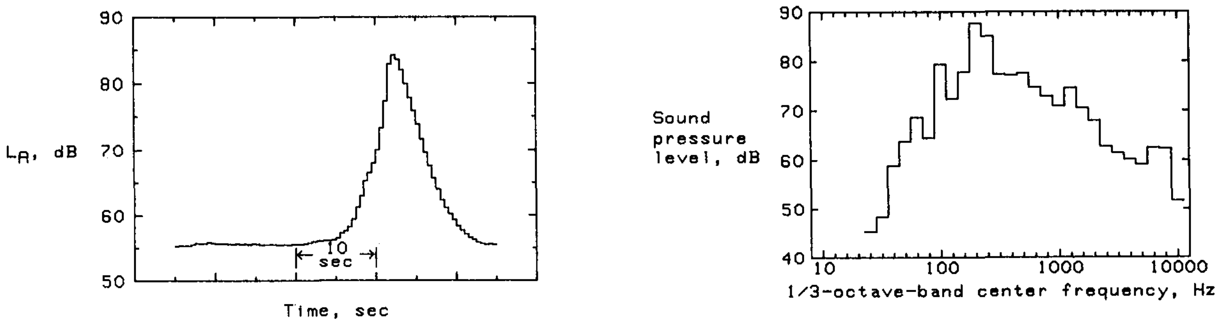


(k) Gulfstream American Tiger takeoff.

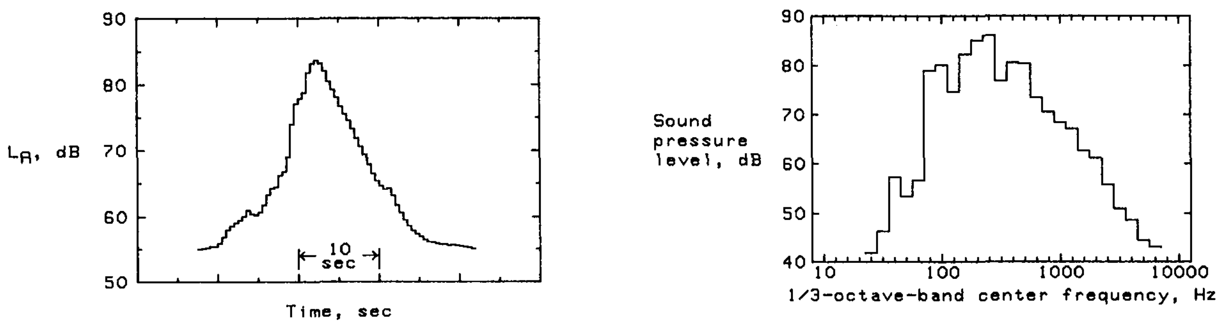


(l) Mitsubishi MU-2 takeoff.

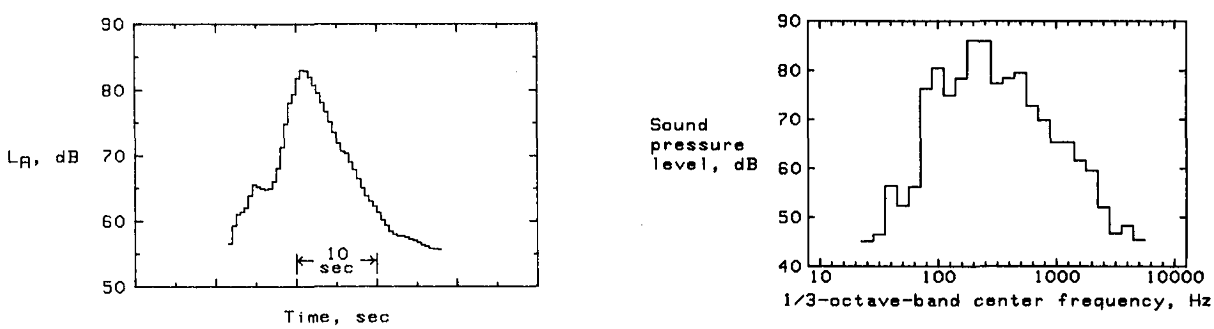
Figure A3.- Continued.



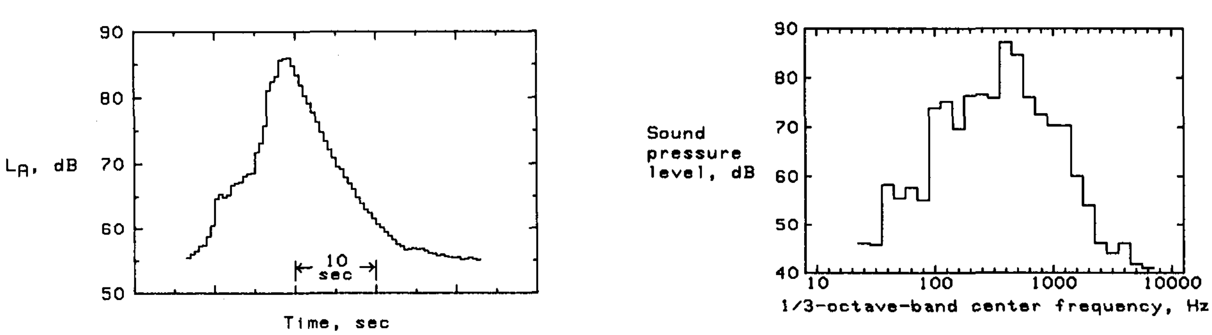
(m) Mitsubishi MU-2 landing.



(n) Mooney 231 takeoff.

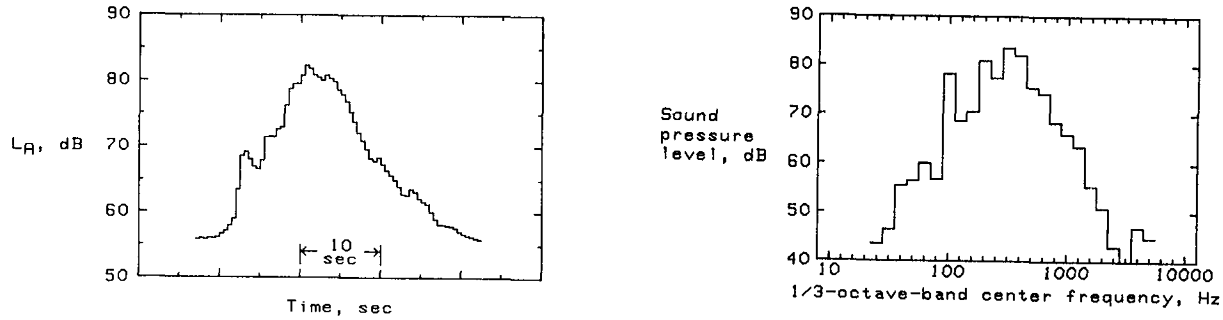


(o) Mooney 231 takeoff with power cutback.

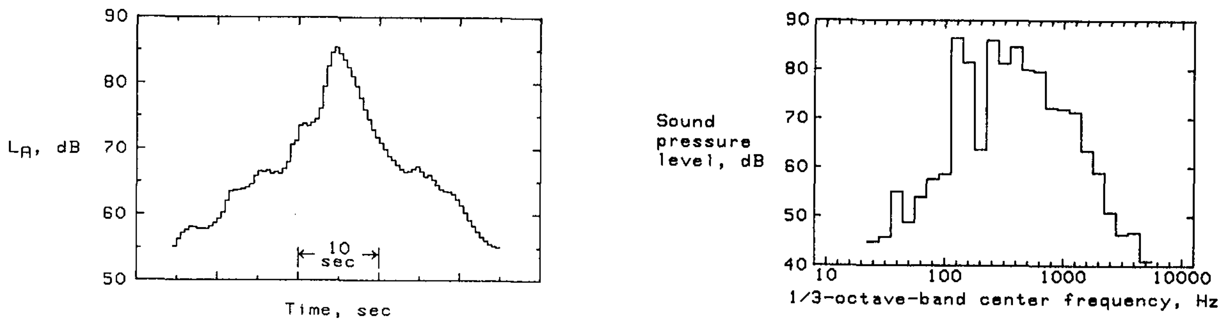


(p) Piper Cheyenne II takeoff.

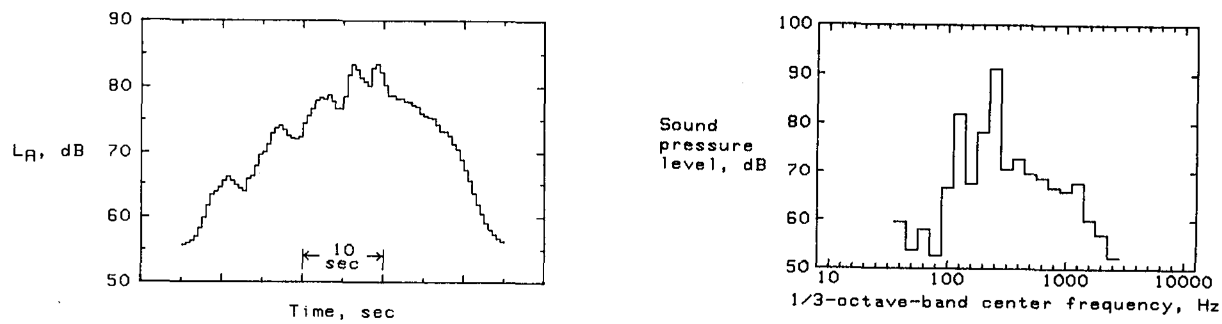
Figure A3.- Continued.



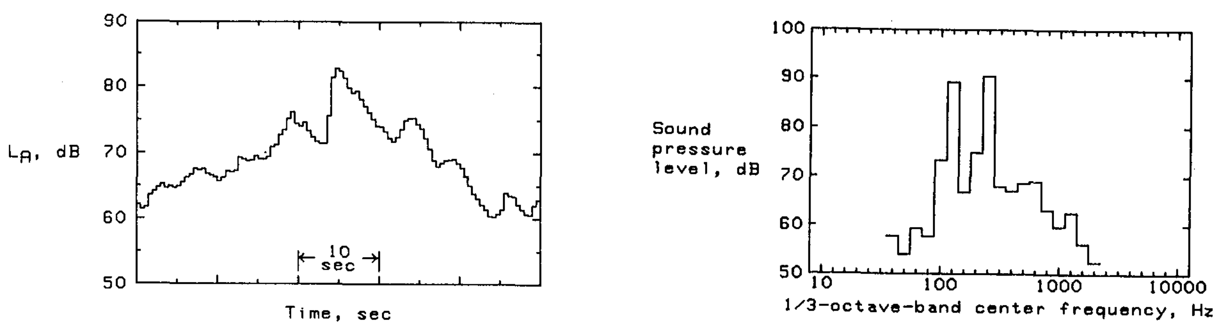
(q) Piper Cheyenne II takeoff with power cutback.



(r) Piper Seneca III takeoff.

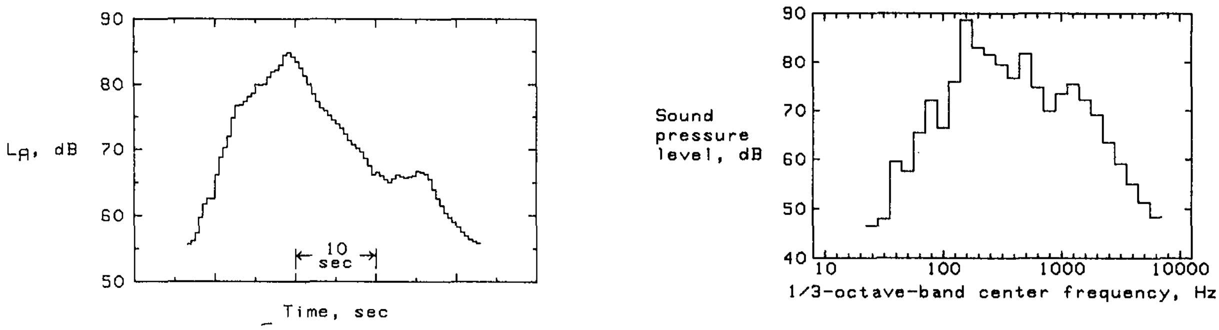


(s) Piper Seneca III takeoff with power cutback.

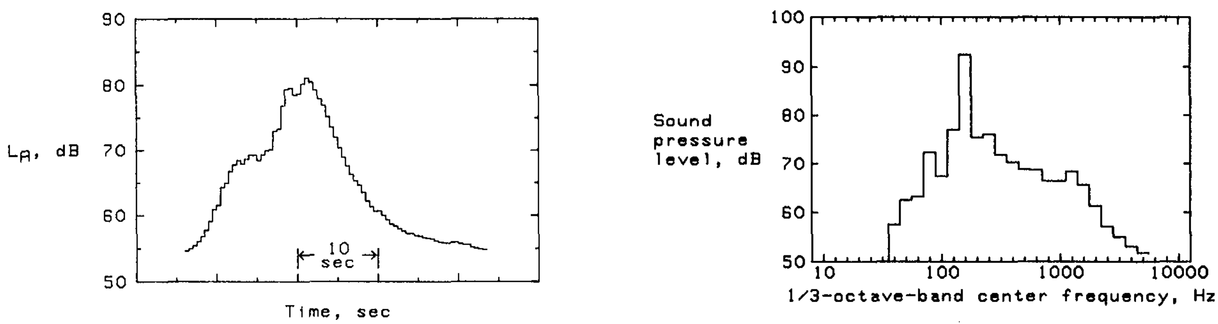


(t) Piper Seneca III flyover.

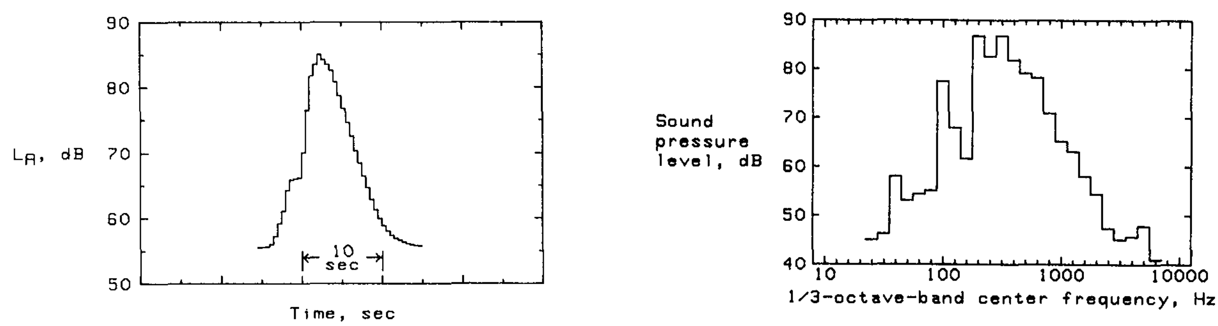
Figure A3.- Continued.



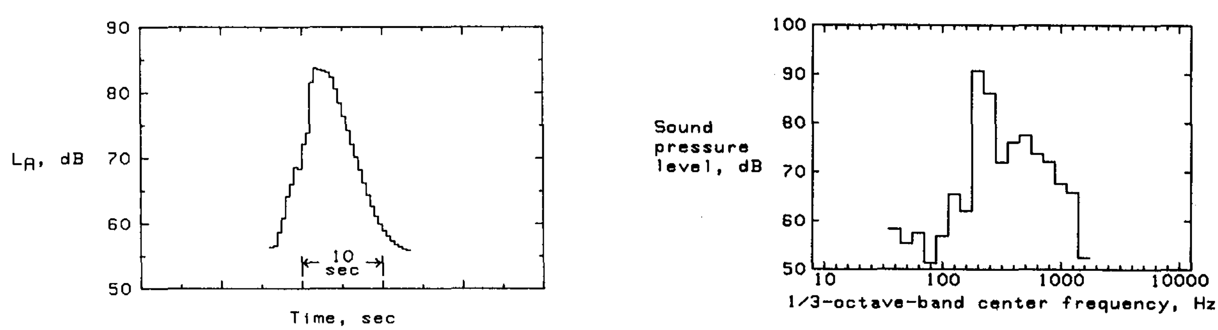
(u) Piper Super Cub takeoff.



(v) Rockwell Turbo Commander 690B takeoff.

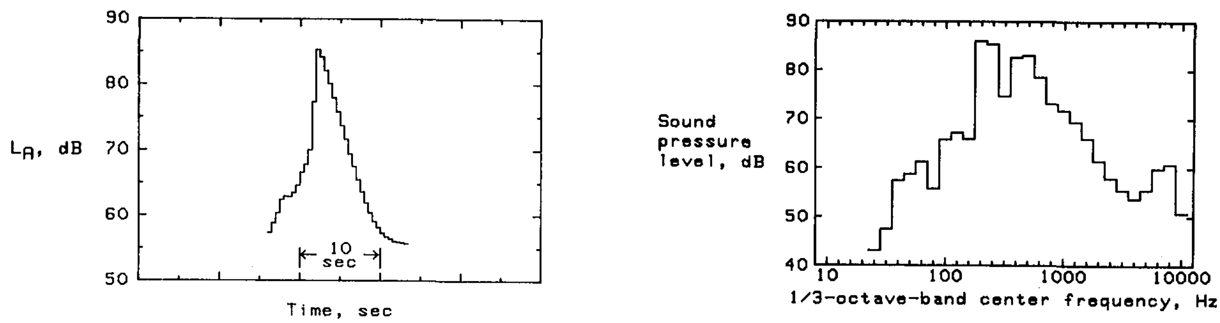


(w) Swearingen Metro II takeoff.

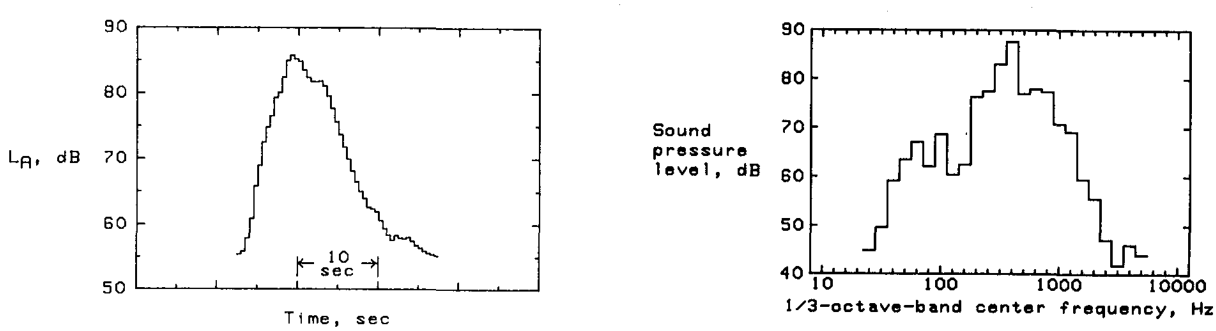


(x) Swearingen Metro II takeoff with power cutback.

Figure A3.- Continued.



(y) Swearingen Metro II landing.



(z) Swearingen Metro II flyover.

Figure A3.- Concluded.

APPENDIX B

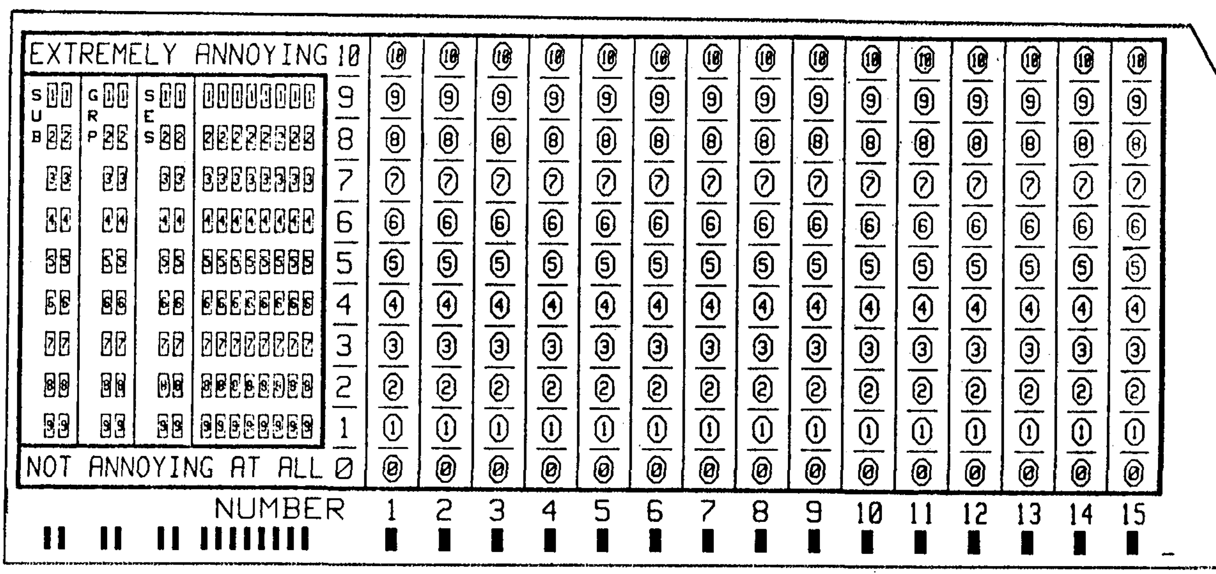
INSTRUCTIONS AND CONSENT FORM

APPENDIX B

INSTRUCTIONS

The experiment in which you are participating will help us understand the characteristics of aircraft sounds which can cause annoyance in airport communities. We would like you to judge how ANNOYING some of these aircraft sounds are. By ANNOYING we mean - UNWANTED, OBJECTIONABLE, DISTURBING, OR UNPLEASANT.

The experiment consists of four 20-minute sessions. During each session 27 aircraft sounds will be presented for you to judge. You will record your judgments of the sounds on computer cards like the one below:



After each sound there will be a few seconds of silence. During this interval, please indicate how annoying you judge the sound to be by marking the appropriate numbered circle on the computer card. The number of each sound is indicated across the bottom of the card. If you judge a sound to be only slightly annoying, mark one of the numbered circles close to the NOT ANNOYING AT ALL end of the scale, that is a low numbered circle near the bottom of the card. Similarly, if you judge a sound to be very annoying, then mark one of the numbered circles close to the EXTREMELY ANNOYING end of the scale, that is a high numbered circle near the top of the card. A moderately annoying judgment should be marked in the middle portion of the scale. In any case, make your mark so that the circle that most closely indicates your annoyance to the sound is completely filled in. There are no right or wrong answers; we are only interested in your judgment of each sound.

Before the first session begins you will be given a practice computer card and three sounds will be presented to familiarize you with making and recording judgments. I will remain in the testing room with you during the practice time to answer any questions you may have.

Thank you for your help in conducting the experiment.

APPENDIX B

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 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 instructions 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.

____
Signature of Subject

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TABLE I.- DATA ON TEST SUBJECTS

Experiment	Sex	Number of participants	Mean age	Median age	Age range
1	Male	18	28	26.5	20-53
	Female	46	36	36	21-67
	All subjects	64	34	33	20-67
2	Male	16	32	27.5	20-65
	Female	48	40	41.5	18-74
	All subjects	64	38	35.5	18-74

TABLE II.- AIRPLANES IN BASIC DATA SET OF FIRST EXPERIMENT

Airplane	Number of engines	Engine type	Maximum takeoff weight, kg	Operations*
Beechcraft Super King Air 200	2	Turboprop	5 700	T, L
de Havilland Canada DHC-7 Dash 7	4	Turboprop	20 000	T, L
Embraer EMB-110 Bandeirante	2	Turboprop	5 700	T, L
Gulfstream American Gulfstream I	2	Turboprop	15 900	T, L
Lockheed C-130	4	Turboprop	70 300	T, L
Lockheed P-3	4	Turboprop	61 200	T, L
NAMC YS-11	2	Turboprop	24 500	T, L
Nord 262	2	Turboprop	10 600	T, L
Shorts 330	2	Turboprop	10 300	T, L
Swearingen Metro II	2	Turboprop	5 700	T, L
Vickers Viscount	4	Turboprop	32 900	T, L
Airbus Industrie A-300	2	Turbofan	≥142 000	T, L
Boeing 707	4	Turbofan	≥117 000	T, L
Boeing 727-200	3	Turbofan	86 900	T, L
McDonnell Douglas DC-9	2	Turbofan	≥41 100	T, L
McDonnell Douglas DC-10	3	Turbofan	≥206 400	T, L

*T = Takeoff; L = Landing.

TABLE III.- AIRPLANES IN BASIC DATA SET OF SECOND EXPERIMENT

Airplane	Number of engines	Engine type	Maximum takeoff weight, kg	Operations*
Beechcraft Bonanza V	1	Piston	1 500	T
Cessna 172	1	Piston	1 100	T
Cessna 177	1	Piston	1 100	T
Cessna 210	1	Piston	1 700	T, C, F
Cessna 335	2	Piston	2 700	T, C
Cessna 425	2	Turboprop	3 700	T, C
Gulfstream American Tiger	1	Piston	1 100	T
Mitsubishi MU-2	2	Turboprop	5 200	T, L
Mooney 231	1	Piston	1 300	T, C
Piper Cheyenne II	2	Turboprop	4 100	T, C
Piper Seneca III	2	Piston	2 100	T, C, F
Piper Super Cub	1	Piston	800	T
Rockwell Turbo Commander 690B	2	Turboprop	4 700	T
Swearingen Metro II	2	Turboprop	5 700	T, C, L, F
Airbus Industrie A-300	2	Turbofan	$\geq$142 000	T, L
Boeing 707	4	Turbofan	$\geq$117 000	T, L
Boeing 727-200	3	Turbofan	86 900	T, L
McDonnell Douglas DC-9	2	Turbofan	$\geq$41 100	T, L
McDonnell Douglas DC-10	3	Turbofan	$\geq$206 400	T, L

*T = Takeoff; L = Landing; C = Takeoff with power cutback at 152-m altitude; F = Constant altitude flyover at 305 m.

TABLE IV.- PRESENTATION ORDER OF STIMULI ON TAPES FOR FIRST EXPERIMENT

Practice tape	Tape 1 ↓	Tape 2 ↓	Tape 3 ↓	Tape 4 ↓
D10 T 80	DC9 L 80	DC9 T 70	D7 T 80	SWM T 70
110 L 70	GUL L 90	GUL T 70	130 T 70	P3 L 80
YS1 T 90	262 L 70	VIC L 90	727 T 75 R	727 L 90
	707 T 80	707 L 80	VIC L 80	110 L 70
	130 T 90	P3 L 70	DC9 T 90	DC9 L 70
	300 L 90	727 T 80	110 T 70	300 T 80
	727 T 90	D7 L 90	SWM T 80	330 T 90
	330 T 70	SKA T 70	T28 F 70	727 T 70
	D10 L 80	130 L 70	P3 L 90	262 L 80
	110 T 90	330 T 80	D7 L 70	DC9 T 80
	330 L 80	DC9 L 90	300 T 70	727 T 95 R
	T28 F 90	SKA L 80	110 L 80	GUL L 70
	D10 T 70	D7 T 90	SKA T 90	300 L 80
	130 L 90	300 L 70	YS1 L 70	130 T 80
	D7 L 80	YS1 T 80	707 L 90	YS1 T 90
	YS1 T 70	T28 F 80	727 L 80	727 T 80 R
	727 T 85 R	SWM T 90	P3 T 90	330 L 70
	SWM L 70	GUL L 80	D10 L 70	YS1 L 80
	YS1 L 90	727 L 70	262 L 90	D10 T 90
	727 T 70 R	707 T 90	130 L 80	P3 T 70
	VIC L 70	110 L 90	GUL T 90	SWM L 90
	P3 T 80	VIC T 70	727 T 90 R	VIC T 90
	707 L 70	727 T 65 R	SKA L 70	SKA T 80
	300 T 90	110 T 80	D10 T 80	D10 L 90
	GUL T 80	SWM L 80	262 T 80	262 T 70
	D7 T 70	262 T 90	707 T 70	SKA L 90
	VIC T 80	SWM T 80 E	330 L 90	SWM L 80 E
	Tape 5 ↑	Tape 6 ↑	Tape 7 ↑	Tape 8 ↑

Stimuli key			
Airplane	Operation	Nominal L_D	Special purpose
110 = EMB-110 130 = C-130 262 = Nord 262 300 = Airbus A-300 330 = Shorts 330 707 = Boeing 707 727 = Boeing 727 D7 = Dash 7 DC10 = DC-10 DC9 = DC-9 GUL = Gulfstream I P3 = P-3 SKA = Super King Air SWM = Swearingen Metro II T28 = North American T-28A VIC = Viscount YS1 = YS-11	T = Takeoff L = Landing F = Constant altitude fly-over at 305 m (152-m altitude for T28)	90 = 90 dB 80 = 80 dB 70 = 70 dB	R = L_S reference stimulus E = Repeated stimulus

TABLE V.- PRESENTATION ORDER OF STIMULI ON TAPES FOR SECOND EXPERIMENT

Practice tape	Tape 1 ↓	Tape 2 ↓	Tape 3 ↓	Tape 4 ↓
425 C 80	727 T 70	DC9 T 70	262 L 70	BBV T 80
210 F 70	TIG T 70	MU2 L 90	210 C 70	262 L 70 G
YS1 T 90	PS3 C 80	210 C 80	SWM C 80	210 C 90
	D10 T 90	727 L 70	BBV T 90	PS3 C 70
	727 T 90 R	177 T 70	425 T 80	DC9 T 80
	425 C 80	YS1 T 70	300 T 70	SWM L 70
	BBV T 70	CUB T 90	PS3 T 70	YS1 T 80
	210 F 90	SWM T 80 E	PC2 C 90	MU2 T 90
	SWM F 80	PS3 C 90	727 T 80	231 C 90
	177 T 90	172 T 80	YS1 T 90	PS3 F 80
	231 T 80	707 T 70	425 C 70	D10 T 70
	D10 L 70	300 T 80	PS3 F 90	727 T 80 R
	300 T 90	SWM C 90	RTC T 70	SWM T 80
	SWM C 70	727 T 90	TIG T 80	TIG T 90
	727 L 80	T28 F 90	727 T 70 R	172 T 70
	PS3 F 70	335 C 70	300 L 90	300 L 70
	335 T 70	DC9 L 80	262 L 80 G	D10 L 80
	DC9 L 90	YS1 T 80 G	172 T 90	T28 F 70
	707 T 80	707 L 90	210 F 80	707 T 90
	SWM T 90	MU2 T 70	DC9 L 70	PC2 C 70
	MU2 T 80	425 T 70	727 T 85 R	727 T 95 R
	727 T 65 R	SWM L 80	PC2 T 70	210 T 80
	300 L 80	727 T 75 R	SWM L 90	SWM F 90
	RTC T 90	262 L 90	MU2 L 80	177 T 80
	231 C 70	231 T 90	D10 T 80	231 T 70
	PC2 T 90	210 F 70	T28 F 80	PC2 T 80
	262 L 80	335 T 80	CUB T 70	727 L 90
	335 C 90	425 C 90	210 T 90	PS3 T 90
	CUB T 80	RTC T 80	707 L 80	707 L 70
	YS1 T 70 G	SWM F 70	DC9 T 90	425 T 90
	SWM L 80 E	PC2 C 80	335 T 90	335 C 80
	210 T 70	PS3 T 80	SWM T 70	YS1 T 90 G
	262 L 90 G	D10 L 90	231 C 80	MU2 L 70
	Tape 5 ↑	Tape 6 ↑	Tape 7 ↑	Tape 8 ↑

Stimuli key			
Airplane	Operation	Nominal L_D	Special purpose
172 = Cessna 172 177 = Cessna 177 210 = Cessna 210 231 = Mooney 231 262 = Nord 262 300 = Airbus A-300 335 = Cessna 335 425 = Cessna 425 707 = Boeing 707 727 = Boeing 727 BBV = Beechcraft Bonanza V CUB = Piper Super Cub D10 = DC-10 DC9 = DC-9 MU2 = Mitsubishi MU-2 PC2 = Piper Cheyenne II PS3 = Piper Seneca III RTC = Rockwell Turbo Commander SWM = Swearingen Metro II T28 = North American T-28A TIG = Gulfstream American Tiger YS1 = YS-11	T = Takeoff C = Takeoff with power cutback at 152-m altitude L = Landing F = Constant altitude fly-over at 305 m (152 m for T28)	90 = 90 dB 80 = 80 dB 70 = 70 dB	R = L_S reference stimulus E = Repeated stimulus G = Stimulus recorded with micro-phone at ground level

TABLE VI.- ORDER OF TAPES PRESENTED TO TEST SUBJECTS

Test subject group	Tapes presented during session -			
	1	2	3	4
1	1	2	3	4
2	2	1	4	3
3	3	4	1	2
4	4	3	2	1
5	5	6	7	8
6	6	5	8	7
7	7	8	5	6
8	8	7	6	5
9	1	3	4	2
10	2	4	3	1
11	3	1	2	4
12	4	2	1	3
13	5	7	8	6
14	6	8	7	5
15	7	5	6	8
16	8	6	5	7

TABLE VII.- REGRESSION ANALYSES FOR L_S ON PEAK L_A AND EPNL FOR FIRST EXPERIMENT

Airplane type	Intercept	Slope	Correlation coefficient	Standard error of estimate, dB
Peak L_A				
Jet	10.17	1.047	0.967	2.33
Propeller	4.83	1.087	.942	3.24
EPNL				
Jet	1.50	1.007	0.939	3.16
Propeller	-9.36	1.142	.958	2.79

TABLE VIII.- REGRESSION ANALYSES FOR L_S ON PEAK L_A AND EPNL FOR SECOND EXPERIMENT

Airplane type	Intercept	Slope	Correlation coefficient	Standard error of estimate, dB
Peak L_A				
Jet	8.33	1.074	0.966	2.34
Propeller	10.55	.960	.947	2.74
EPNL				
Jet	1.94	1.004	0.940	3.11
Propeller	.51	.969	.951	2.65

TABLE IX.- STANDARD DEVIATIONS OF PREDICTION ERROR FOR PROPELLER AIRPLANES IN FIRST EXPERIMENT

Metric	Standard deviation, dB, for -						
	No duration correction			Duration corrected			Average across tone and duration
	No tone correction	T_1	T_2	No tone correction	T_1	T_2	
L_A	3.30	3.31	3.09	3.11	3.08	2.82	3.12
L_D	3.12	3.35	3.06	2.97	3.15	2.78	3.07
L_E	3.41	3.51	3.26	3.11	3.22	2.87	3.23
LL	3.05	3.20	3.03	3.11	3.20	3.04	3.11
PL	3.03	3.13	2.99	3.03	3.06	2.90	3.02
PNL	2.81	3.11	2.74	2.76	3.00	2.59	2.84
Average across metric	3.12	3.27	3.03	3.02	3.12	2.83	
Average across metric and tone	3.14			2.99			
PNL_K	2.77	2.98	2.78	2.63	2.79	2.55	2.75
PNL_M	2.76	2.98	2.79	2.63	2.81	2.56	2.76
PNL_W	2.72	2.93	2.77	2.58	3.00	2.53	2.76
Average across metric	2.75	2.96	2.78	2.61	2.87	2.55	
Average across metric and tone	2.83			2.68			
L_1	2.33	2.66	2.55	2.29	2.57	2.39	2.47
L_2	2.74	3.18	3.09	2.61	2.96	2.79	2.90
Average across metric	2.54	2.92	2.82	2.45	2.77	2.59	
Average across metric and tone	2.76			2.60			

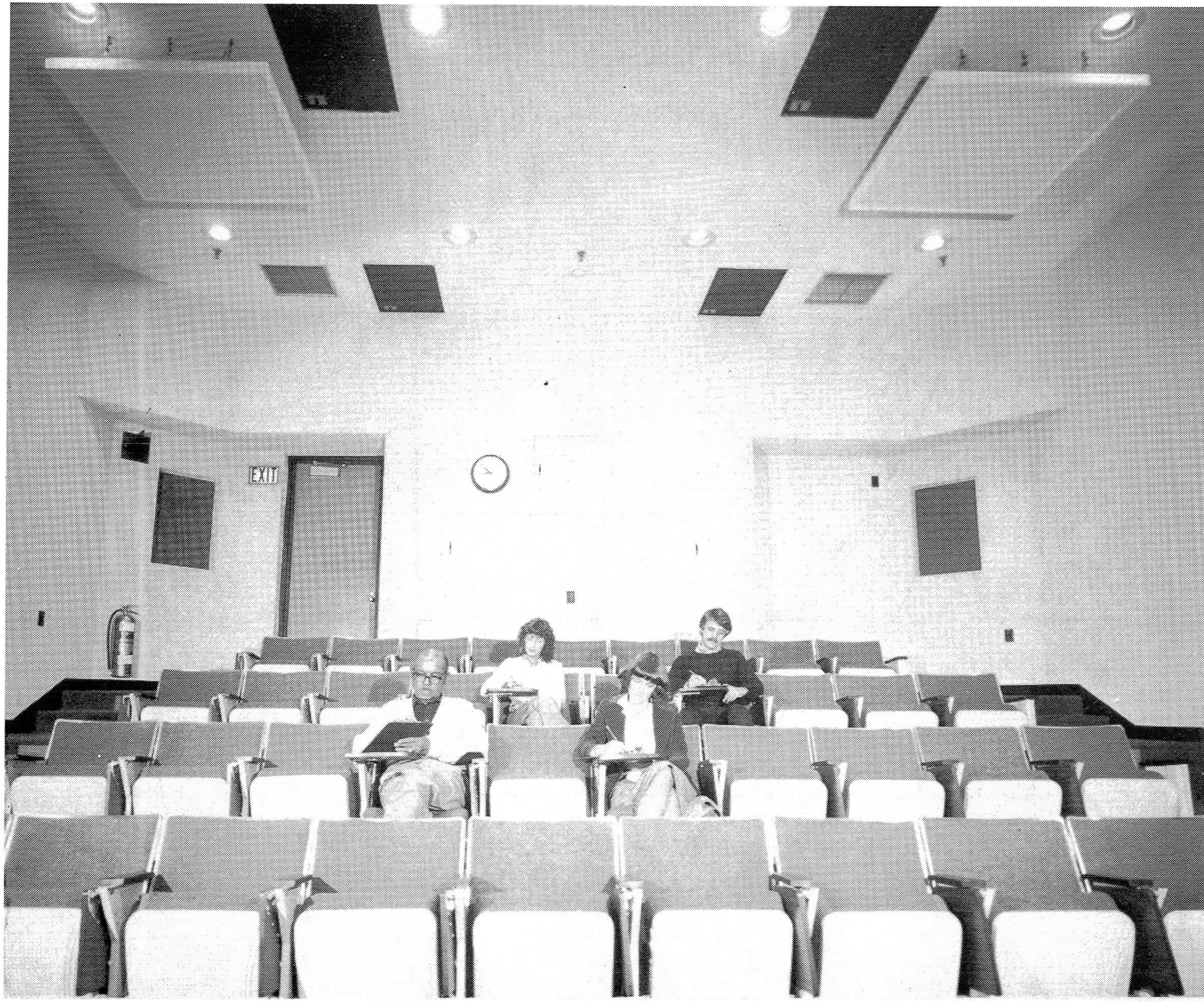
TABLE X.- STANDARD DEVIATIONS OF PREDICTION ERROR FOR PROPELLER AIRPLANES IN SECOND EXPERIMENT

Metric	Standard deviation, dB, for -						
	No duration correction			Duration corrected			Average across tone and duration
	No tone correction	T_1	T_2	No tone correction	T_1	T_2	
L_A	2.74	2.82	2.79	2.63	2.82	2.70	2.75
L_D	2.61	2.86	2.70	2.79	3.04	2.88	2.81
L_E	2.69	2.86	2.76	2.77	3.03	2.86	2.83
LL	2.47	2.51	2.36	2.53	2.74	2.61	2.54
PL	2.24	2.33	2.24	2.29	2.51	2.37	2.33
PNL	2.24	2.44	2.28	2.39	2.65	2.49	2.42
Average across metric	2.50	2.64	2.52	2.57	2.80	2.65	
Average across metric and tone	2.55			2.67			
PNL_K	2.29	2.48	2.35	2.41	2.63	2.45	2.44
PNL_M	2.29	2.49	2.34	2.36	2.64	2.46	2.43
PNL_W	2.27	2.49	2.34	2.39	2.61	2.44	2.42
Average across metric	2.28	2.49	2.34	2.39	2.63	2.45	
Average across metric and tone	2.37			2.49			
L_1	2.41	2.56	2.48	2.50	2.75	2.63	2.56
L_2	2.67	2.91	2.78	2.82	3.13	2.94	2.88
Average across metric	2.54	2.74	2.63	2.66	2.94	2.79	
Average across metric and tone	2.64			2.80			

TABLE XI.- REGRESSION ANALYSES WITH AND WITHOUT SIGNIFICANT OPERATION-TYPE TERMS FOR PROPELLER AIRPLANES IN FIRST EXPERIMENT

Regression type	Correlation coefficient	Standard error of estimate, dB	Constant	Metric coefficient	Operation* coefficient
Peak L_A					
Without operation	0.942	3.24	4.826	1.087	
With operation	.950	3.06	5.859	1.088	-2.240*
Duration-corrected L_A					
Without operation	0.950	3.04	10.688	1.087	
With operation	.959	2.79	11.702	1.090	-2.498*
Peak PNL					
Without operation	0.967	2.47	-15.803	1.173	
With operation	.974	2.20	-14.800	1.175	-2.295*
EPNL					
Without operation	0.958	2.79	-9.363	1.142	
With operation	.968	2.46	-8.468	1.147	-2.666*

*Operation is an indicator (dummy) variable which is equal to 1 for takeoff operations and to 0 for all other operations.



L-82-1512

Figure 1.- Subjects in exterior effects room in Langley Aircraft Noise Reduction Laboratory.

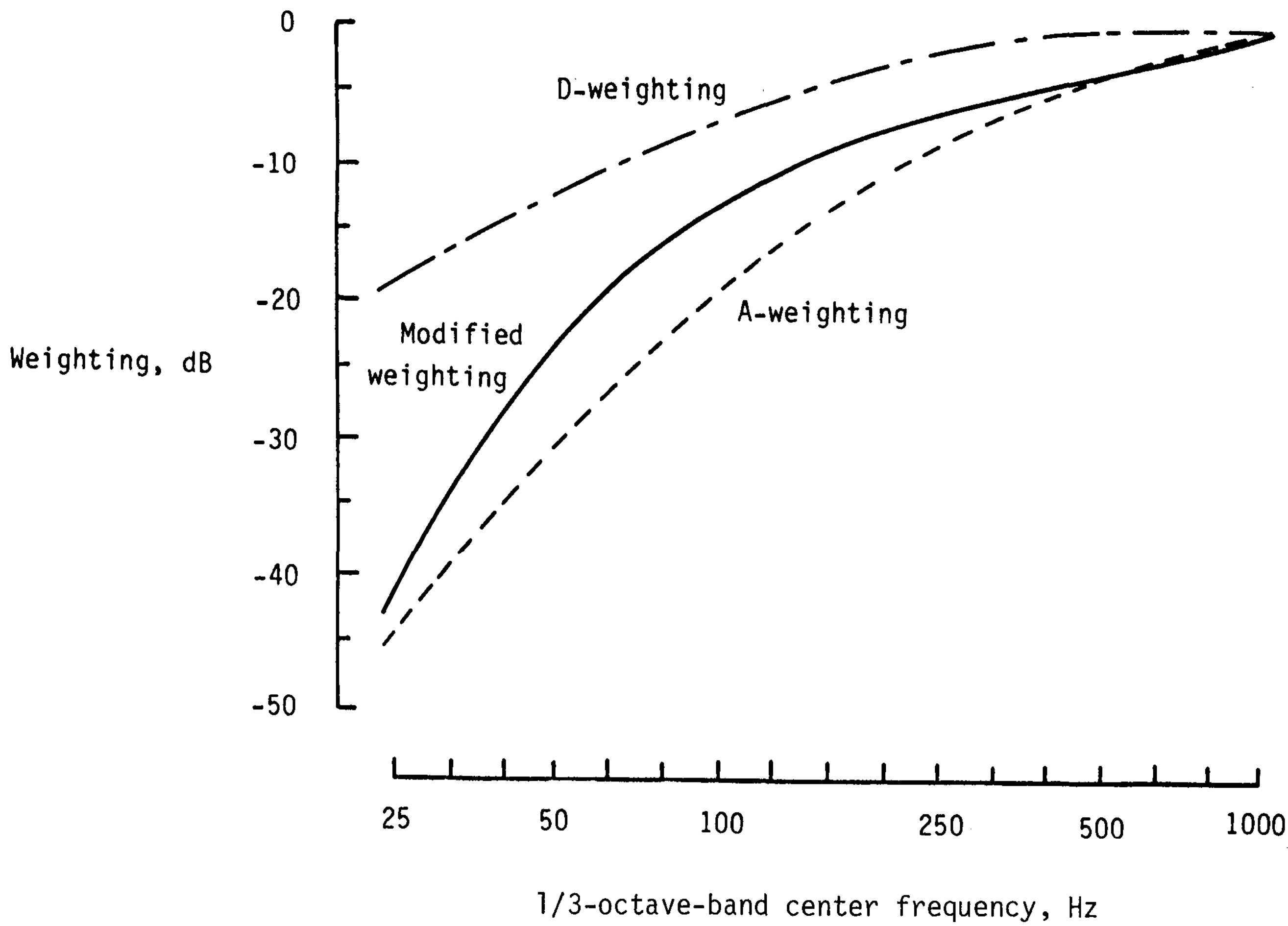


Figure 2.- Modified frequency weighting compared with A- and D-weightings.

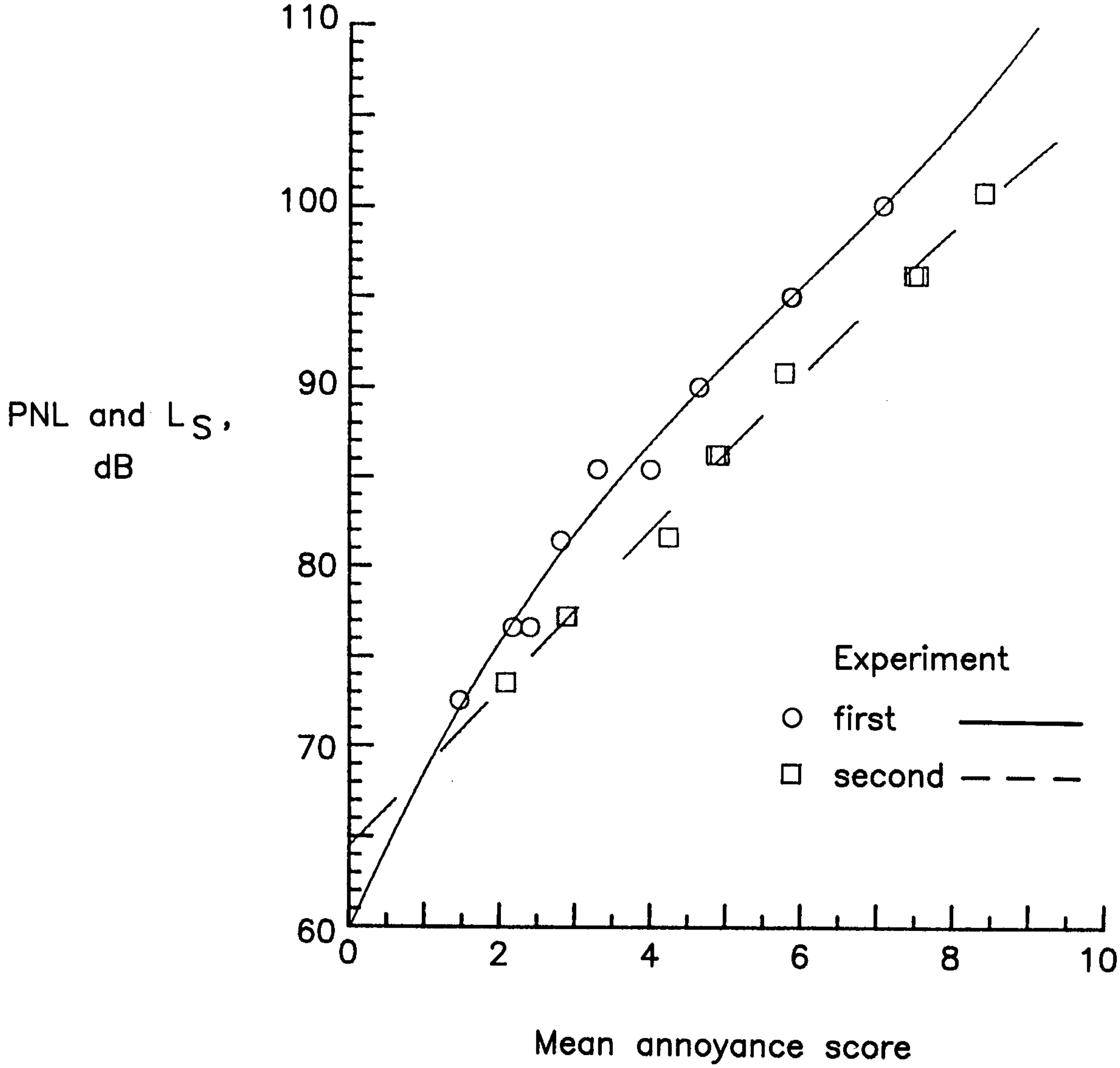
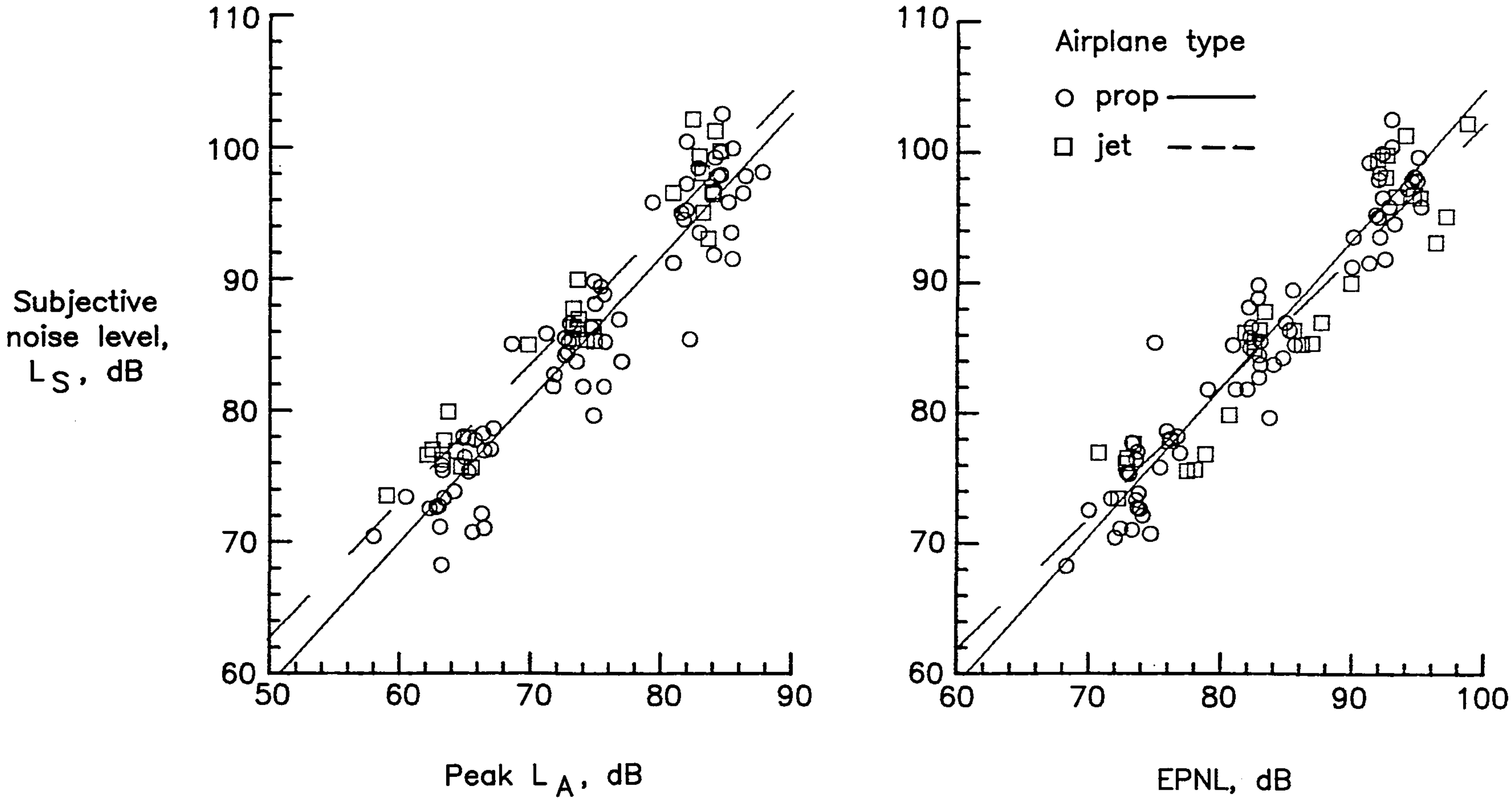


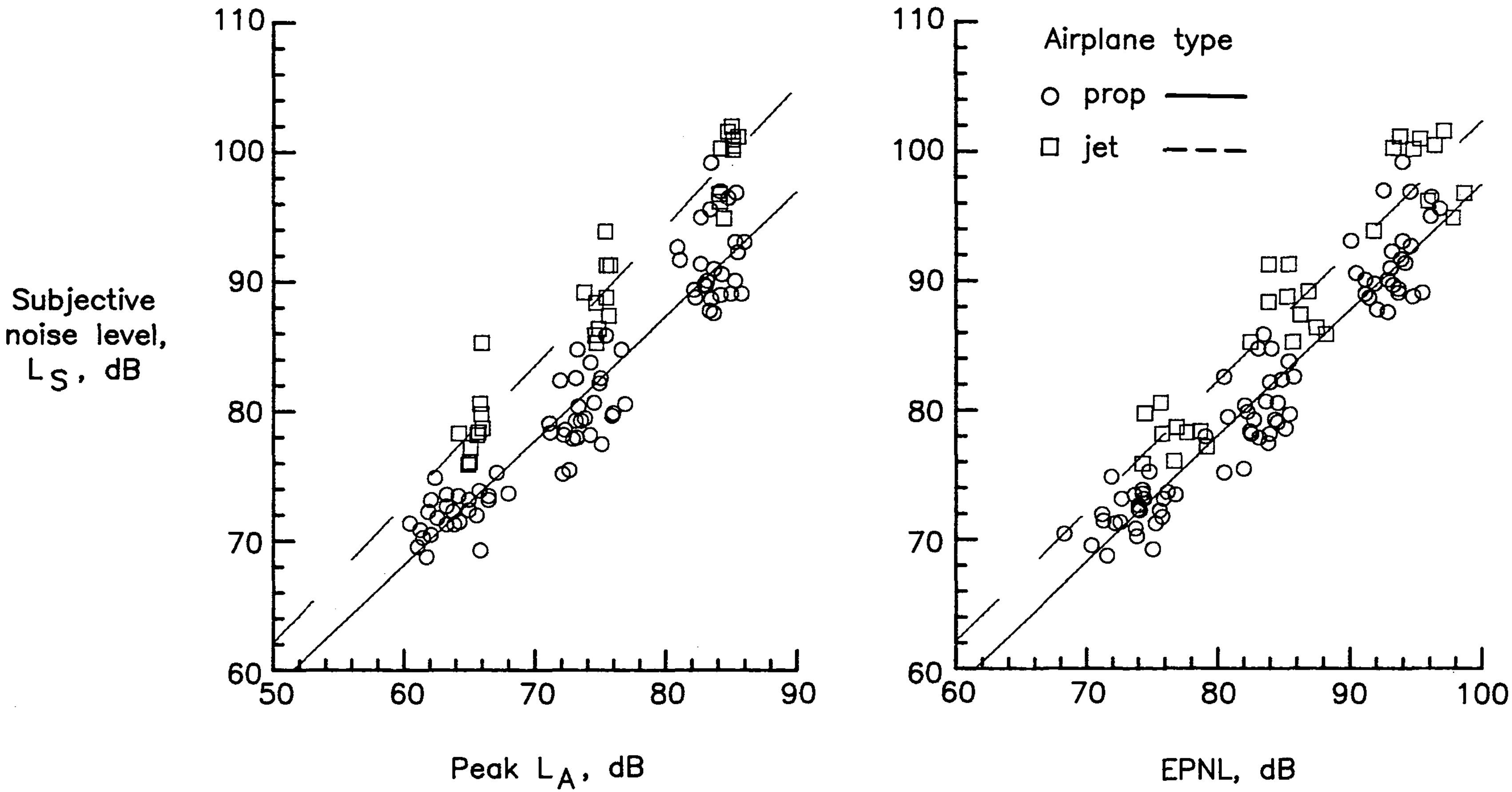
Figure 3.- Regression analyses of PNL on mean annoyance scores for Boeing 727 takeoff stimuli used to convert annoyance judgments to subjective noise levels L_S.



(a) Comparison using L_A.

(b) Comparison using EPNL.

Figure 4.- Comparison between annoyance results for propeller airplanes and jet airplanes in first experiment.



(a) Comparison using L_A.

(b) Comparison using EPNL.

Figure 5.- Comparison between annoyance results for propeller airplanes and jet airplanes in second experiment.

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15. Supplementary Notes

16. Abstract

Two laboratory experiments were conducted to provide information on quantifying the annoyance response of people to propeller airplane noise. The items of interest were current noise metrics, tone corrections, duration corrections, critical band corrections, and the effects of engine type, operation type, maximum takeoff weight, blade passage frequency, and blade tip speed. In each experiment, 64 subjects judged the annoyance of recordings of propeller and jet airplane operations presented at D-weighted sound pressure levels of 70, 80, and 90 dB in a testing room which simulates the outdoor acoustic environment. The first experiment examined 11 propeller airplanes with maximum takeoff weights greater than or equal to 5700 kg. The second experiment examined 14 propeller airplanes weighing 5700 kg or less. Five jet airplanes were included in each experiment. For both the heavy and light propeller airplanes, perceived noise level and perceived level (Stevens Mark VII procedure) predicted annoyance better than other current noise metrics. Duration corrections and corrections for tones greater than or equal to 500 Hz generally improved prediction ability for the heavy propeller airplanes. Duration corrections and tone corrections generally degraded prediction ability for the light propeller airplanes. The effect on prediction ability of critical band corrections to perceived noise level varied. Takeoffs of the heavy propeller airplanes were less annoying than landings. No consistent effects of the other parameters were found.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Propeller airplane noise Noise annoyance Aircraft noise Subjective acoustics Psychoacoustics	Unclassified - Unlimited Subject Category 71

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