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A SUBJECTIVE EVALUATION OF SYNTHESIZED STOL AIRPLANE NOISES

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16. Abstract

A magnitude-estimation experiment was conducted to evaluate the subjective annoyance of the noise generated by possible future turbofan STOL aircraft as compared to that of several current CTOL aircraft. In addition, some of the units used to scale the magnitude of aircraft noise were evaluated with respect to their applicability to STOL noise. Twenty test subjects rated their annoyance to a total of 119 noises over a range of 75 PNdB to 105 PNdB. Their subjective ratings were compared with acoustical analysis of the noises in terms of 28 rating scale units. The synthesized STOL noises of this experiment were found to be slightly more annoying than the conventional CTOL noises at equal levels of PNL and EPNL. Over the range of levels investigated the scaling units, with a few exceptions, were capable of predicting the points of equal annoyance for all of the noises within ±3 dB. The inclusion of duration corrections, in general, improved the predictive capabilities of the various scaling units; however, tone corrections reduced their predictive capabilities.

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A SUBJECTIVE EVALUATION OF SYNTHESIZED STOL AIRPLANE NOISES*

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SUMMARY

A magnitude-estimation experiment was conducted at Langley Research Center to examine the annoyance of the recorded synthesized noises of a future powered-lift turbofan short take-off and landing (STOL) aircraft as compared with recorded noises of several conventional take-off and landing (CTOL) aircraft commonly used in short-haul commercial operations. Twenty test subjects rated their annoyance to a total of 119 noises over a range of 75 PNdB to 105 PNdB. Their subjective ratings were compared with acoustical analysis of the noises in terms of 28 physical measuring units. The noises were evaluated for three measurement locations which were approximately the tentative STOL noise certification points: (1) centerline under take-off, (2) centerline under landing, and (3) sideline of take-off. The synthesized STOL noises were designed to include the following predicted differences from present day turbofan CTOL aircraft: (1) an increase in relative intensity for frequencies below 300 Hz and (2) longer duration for near-terminal operation. The first of these differences arises from the planned use of externally or internally blown flaps to provide additional lift during take-off and landing at much lower speeds than conventional commercial aircraft. The inherent reduction in speed results in longer durations of the near-terminal noise.

From linear least-squares fitting of the subjective ratings to the scaling units, it was found that the STOL sounds, in order to be equally annoying subjectively, were required to be less intense in terms of the scaling units than were the CTOL sounds. This difference was, on the average, 3.0 PNdB and 1.6 EPNdB. No major differences were determined for the STOL noises at the different measuring locations used in the experiment. An effort was made to evaluate the capabilities of a number of other scaling units to predict the annoyance of all the sounds used in the tests and it was found that the units, with a few exceptions, were capable of predicting the points of equal annoyance within ±3 dB over the range of levels investigated. The inclusion of tone corrections did

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not improve the predictive abilities. However, the inclusion of duration corrections, in general, did improve the predictive abilities of the units.

INTRODUCTION

The short take-off and landing (STOL) aircraft are a possible solution to the ever-increasing congestion and ground transportation problems at present day airports. Such future aircraft are of particular interest for short-haul intercity transportation where close-in or even downtown STOL ports could save much of the time spent traveling to and from remotely located airports. Another application for STOL aircraft is to serve small communities which could neither support nor afford the runway facilities presently required by conventional take-off and landing (CTOL) commercial aircraft. The short runway lengths required for STOL aircraft could help solve these problems.

Community noise awareness is a rapidly growing field of interest and consequently, the concern over effects of noise from these future STOL aircraft is an important issue, secondary only to operational safety in the development of STOL transportation. The Federal Aviation Administration is in the process of making noise certification rulings for STOL aircraft as they have done for CTOL aircraft with the Conventional Subsonic Transport Rule described in reference 1. The tentative noise certification rulings for STOL and some of the design characteristics anticipated for the aircraft are given in references 2 and 3, respectively.

Most human-related noise research connected with STOL aircraft has been conducted using noises of propeller-driven aircraft. In references 4 and 5 pair-comparison types of experiments were conducted to evaluate the commonly used scaling methods for aircraft noises. Propeller- or rotor-driven STOL aircraft were compared with CTOL aircraft. Results of these tests showed that EPNL was as good a predictor of the STOL noises as any of the commonly used units. However, all units were less consistent for the STOL noises than for CTOL noises.

The recent design trend for future commercial STOL aircraft has been toward turbofan-driven aircraft. Reference 3 gives a review of several of the most promising types of STOL aircraft and engine configurations. Very little subjective noise information is available for such STOL aircraft. However, in reference 6 synthesized flight noises of a turbofan STOL and several V/STOL aircraft were compared with a CTOL jet aircraft. This STOL noise, however, did not consider what is now believed to be a major noise source for the future STOL aircraft – the internally or externally blown flap. Reference 7 gives a review of current blown-flap noise research. The introduction of externally blown flaps into the exhaust stream has been shown to increase the downwardly directed jet exhaust noise by 10 to 20 dB, particularly at low frequencies. The combined use of such flap systems with large high-bypass-ratio engines in the new generation STOL aircraft, it is believed, will cause the predominant noise energy to be concentrated below 300 Hz.

The main purpose of the research effort reported herein was to investigate the subjective annoyance of humans to synthesized flyover noises for this type of STOL aircraft and secondarily to evaluate some of the rating scale units and their applicability to STOL noises. In this experiment 20 test subjects rated the subjective magnitude of 119 noise stimuli which were presented in a series of five magnitude-estimation tests. The noise stimuli were presented via loudspeakers in an acoustically isolated chamber. The primary noise stimuli included recordings of take-off and landing noises under the flight centerline and sideline take-off noises of three types of currently used CTOL aircraft and the synthesized noise of a blown-flap STOL aircraft. An electronically generated noise having frequency and duration characteristics approximating the STOL noises was used as the standard stimulus for the experiment.

The author wishes to acknowledge the assistance given by C. G. Rice of the Institute of Sound and Vibration Research, The University, Southampton, England in the development of the experimental design and analysis procedures used in this research program. During the course of this research Mr. Rice was an Associate Professor of Engineering at the NASA/George Washington University Graduate Program.

SYMBOLS

a — intercept of the subjective scale values on the rating scale units from the linear least-squares analysis

a' — intercept of the rating scale units on the subjective scale values from the linear least-squares analysis

$\bar{a}$ — best mean intercept from the linear least-squares analysis

b — slope of the subjective scale values on the rating scale units from the linear least-squares analysis, dB

b' — slope of the rating scale units on the subjective scale values from the linear least-squares analysis, dB

$\bar{b}$ — best mean slope from the linear least-squares analysis, dB

D — duration correction using the method of reference 1, dB

EAP_1 equally annoying point solution determined from least-squares analysis, dB

EAP_2 equally annoying point solution determined from treatment of data as pair-comparison, dB

N total number of stimuli and levels used in a least-squares fitting

r correlation coefficient from linear least-squares analysis

RA_1 relative annoyance determined from least-squares analysis, dB

RA_2 relative annoyance determined from treatment of data as pair-comparison, dB

RSU rating scale unit or physical acoustic unit used in the linear least-squares analysis, dB

S_e standard error of estimate of RSU, dB

SSV subjective scale value or subjective annoyance rating used in the linear least-squares analysis

T tone correction using the method of reference 1, dB

α measurement location, centerline under take-off

β measurement location, centerline under landing

γ measurement location, sideline of take-off

Rating Scale Units

EPL effective perceived level with tone and duration correction, EPLdB (EPL = PL + T + D)

EPNL effective perceived noise level, EPNdB (EPNL = PNL + T + D)

IPL integrated perceived level, PLdB (IPL = PL + D)

IPNL integrated perceived noise level, PNdB (IPNL = PNL + D)

L weighted sound pressure level, dB; subscripts A, B, C, D_1, D_2, and D_3 indicate the one-third-octave band weights given in reference 8

PL perceived level according to Stevens Mark VII procedure of reference 10, PLdB

PLT perceived level with tone corrections, PLdB (PLT = PL + T)

PNL perceived noise level, PNdB

PNLT perceived noise level with tone corrections, PNdB (PNLT = PNL + T)

Note: A prime (') will denote rating scale units with critical band corrections. The terms (c) or (m) will denote rating scale units calculated on a composite or maximum basis. The term composite is used to indicate that the highest level recorded in each one-third-octave band is used in the subsequent calculations regardless in which 0.5-second time interval this highest value occurred. The term maximum is used to indicate the highest value for the unit of interest which resulted from combining the one-third-octave band levels for each successive 0.5-second time interval.

APPARATUS AND PROCEDURE

Noise Stimuli

The stimuli used in this experiment were loudspeaker-presented recordings of conventional-jet and turboprop-aircraft noise, synthesized noise of STOL aircraft, and a shaped noise which was used as the standard sound. The recordings of the actual CTOL aircraft flyover noises were made at locations conforming as close as practicable to the proposed STOL certification points (ref. 2) of 600 m (2000 ft) from threshold for landing on the centerline and 300 m (1000 ft) from the runway centerline for sideline during take-off. The take-off noise recordings were made at a point approximately 670 m (2200 ft) from the lift-off point on the centerline.

The sources of sound used and the identifying designations for later use in this report are shown in table I along with the measurement locations and median noise levels. In further sections of this report the numerals 1 to 5 will indicate the intensity levels in the order of decreasing level.

STOL noise synthesis.- The STOL noise synthesis was obtained by rerecording the two-engine conventional jet aircraft noise recordings at twice the original tape speed and shaping the low-frequency spectra with one-third-octave filters to obtain the desired spectral shape. On playback at normal speed, the synthesized STOL noises incorporate the most significant differences from present day CTOL aircraft predicted for future blown-flap STOL aircraft. These differences result primarily from the reduced speed of take-off and landing (approximately one-half that of present CTOL jet aircraft) and a much greater low-frequency noise component produced by the blown flaps. One-third-octave spectra at the time of maximum overall sound pressure level (OASPL) for the four types of aircraft are shown in figures 1 to 3 and the time histories of OASPL for each noise is shown in figures 4 to 6. The shaped noise which was used as the standard noise was made by filtering and attenuating the output of a pink noise generator with one-third-octave filters so that each one-third-octave band was approximately the average of the band levels of the take-off, landing, and sideline noises for the simulated STOL aircraft. The frequency spectrum for this noise is shown in figure 7. The rise and fall rates for the shaped noise were approximately the average rise and fall rates for the synthesized STOL noises. The time history of OASPL for the shaped noise is shown in figure 8.

Test noises.- The original recordings were rerecorded on a master tape so that the instantaneous peak level of each of the stimuli was approximately equal based on D_1 frequency weighting (converse of the 40-noy contour). This tape was used to make the presentation tapes for the magnitude-estimation tests by using five steps of attenuation, each step of which was 6 dB. Table I also gives the nominal peak value of PNdB for each of the types of stimuli at the middle playback level.

Test Subjects

Of the 20 test subjects used in this experiment, eight were females. The age span was from 22 to 54 years with median age of 30. The occupations of the subjects were clerk-typists, engineering technicians, engineers, mathematicians, and students at the Langley Research Center. Participation in the experiment was voluntary. The subjects were not paid but were relieved from their normal duties during regular working hours to take part in the tests. Each subject was given an audiogram prior to the tests and no subject had hearing losses greater than 15 dB (refer to the 1964 standard of the International Standards Organization) at more than one frequency.

Test Design

A magnitude-estimation experiment was chosen for this annoyance study so that as much information as possible could be obtained from each test subject in a minimum length of time. The five tests were constructed to form a balanced design so that as many experimental error factors as possible, such as fatigue and order effects, could be taken into account or averaged out.

The total duration of the experiment for each subject was approximately $2\frac{1}{2}$ hours. To prevent fatigue and other temporal effects from influencing results, the test subjects were each assigned to one of four groups which were given the various tests in different orders. The tests were as follows:

Test 1 was composed of all take-off noises at all levels for each of the four aircraft plus the shaped noise at all levels.

Test 2 included just landing noises and the shaped noise.

Test 3 consisted of the sideline noises plus the shaped noise.

Test 4 was composed of synthesized take-off, landing, and sideline noises for the STOL aircraft plus the shaped noise.

Test 5 consisted of take-off, landing, and sideline noises for all four aircraft but only at the next to the highest (level 2) and the next to the lowest levels (level 4).

Each group was assigned to a particular test sequence order by means of the array shown in table II. The order for the first four tests was based on a balanced Latin square design and test 5 was presented to all groups as the final test. By breaking the tests into these segments it was possible to compare all noises against the standard, compare all STOL noises with each other and to the standard, and to get essentially a retest comparison of all aircraft noises to each other. The standard sound for all tests was the shaped noise at the middle intensity level. This sound was presented and announced three times during each test; at the beginning, after the eighth stimulus, and after the sixteenth stimulus. The presentation orders for each of the tests are given in table III and are based on balanced Greco-Latin square designs and random number sequences.

Test Facility

Each of the test subjects was presented the stimuli in a double wall chamber of a type designed for audiometric testing. The chamber was 3.7 m (12 ft) long, 2.7 m (9 ft) wide, and 2.0 m (6.5 ft) high. The subjects were tested one at a time and sat in the center of the chamber facing a bass-reflex speaker enclosure (see fig. 9). The response of the room and speaker was equalized to ±1 dB for pink noise and ±6 dB for pure tones over the frequency range of 25 Hz to 10 kHz.

The voltage levels to the speaker were monitored and recorded after filtering with a D_1 weighting network during the testing of each subject. These records provided a check on the reproduction system performance and assured that all subjects received the same stimuli intensity levels. In no case were there intersubject variations of more than ±0.3 dB for each stimulus.

Test Procedure

The test subjects were given an air-conduction audiogram just prior to their participation in the experiment. They also were given a sheet of written instructions on how to rate the stimuli with respect to the standard sound. A copy of these instructions is shown in appendix A.

At the beginning of the first of the tests the subjects heard a recorded copy of the instructions, then a few of the stimuli from the tests to familiarize them with the sounds and levels they would be rating. The subjects were presented the standard sound and proceeded to rate the individual stimuli on the scoring sheets shown in appendix B. The time interval between stimuli was approximately 6 seconds.

At the end of each test, which took approximately 25 minutes, the subjects were allowed to take a rest break of 5 to 10 minutes. The subjects continued with each test in the order determined by the group to which they were assigned until the entire series was completed. The total time required for the tests, breaks, and audiogram was approximately 2 hours and 45 minutes.

Acoustic Analysis of the Stimuli

In order to calculate the various physical scaling units which were to be used in the analysis of the subjective data, it was necessary to obtain the one-third-octave levels of the stimuli for each one-half second time interval over the duration of the stimulus. This was accomplished by recording each stimulus at the position of the test subject's head in the test chamber using a microphone-recorder system with a frequency response of ±0.5 dB from 20 Hz to 12.5 kHz. These recordings were subsequently played back into a real-time analysis system which provided the one-third-octave time histories in the range of 25 Hz to 10 kHz.

The stimuli were analyzed into the following composite and maximum frequency weighted units using the one-third-octave time histories and the weights given in reference 8: dB(A), dB(B), dB(C), dB(D_1), dB(D_2), and dB(D_3). The stimuli were also analyzed to determine the composite and maximum perceived noise levels with and without tone corrections and with and without critical bandwidth corrections as described in reference 9. In addition, the effective and time-integrated perceived noise levels (EPNdB and IPNdB) were calculated for each stimulus both with and without critical bandwidth corrections. The stimuli were also analyzed to determine the perceived level designated and originated by Stevens as Mark VII in reference 10. The Mark VII analysis was also performed with the tone corrections, the duration corrections, and the combined tone and duration corrections of reference 1.

Subjective Data Analysis

The annoyance ratings given by the subjects to each stimulus were analyzed using two different techniques. The first technique, a linear least-squares regression analysis of the mean (over subjects) of the logarithm of the subjective scale values (SSV) on the rating scale units (RSU), provided information on the relative annoyance of the stimuli and provided an evaluation of the units. The second technique, a pair-comparison type of treatment provided information only on the relative annoyance of the stimuli.

Least-squares analysis.- The following brief discussion of the least-squares analysis describes how the subjective data were fitted to the scaling units.

Taking the mean of the logarithm of the subjective scale values as the dependent variable and performing a linear least-squares regression on the rating scale units as the independent variable, the following relationship is established:

$$\overline{\log(SSV)} = a + b \times RSU \tag{1}$$

where a is the intercept and b is the slope determined from the least-squares analysis.

If the independent and dependent variables are interchanged the following relationship is established:

$$RSU = a' + b' \times \overline{\log(SSV)} \tag{2}$$

where a' and b' are again the intercept and slope determined in the analysis. The correlation coefficient r can be shown to be the geometric mean of b and b'. Therefore,

$$r = \sqrt{bb'} \tag{3}$$

If there is a perfect correlation of the data to the fitted line (i.e., $r = 1$), the slope would be the reciprocal of b'. It has been suggested in reference 4 that the geometric mean of b and $1/b'$ would be a better fit to the data because there is no strong mathematical reason to determine in which direction the regression should be performed. For further discussion in this report the term slope shall be represented by the following geometric mean:

$$\bar{b} = \sqrt{\frac{b}{b'}} = \frac{b}{r} \tag{4}$$

The intercept $\bar{a}$ is the result of using slope $\bar{b}$ in the equations established by the least-squares criteria.

Using the subjective data from all subjects for a single type of noise stimulus and the physical measurements of the stimulus in terms of one of the rating scale units, the best fitting line can be found for each stimulus/rating-scale-unit pair. The equally annoying point EAP_1 in this analysis was defined as that point on the least-squares fit line for the rating scale unit of interest which gave a subjective annoyance score equal to the annoyance score obtained by the middle level of the shaped noise stimulus.

In figure 10 two examples are shown illustrating the fit for the subjective data to the scaling units. Figure 10(a) shows the result of fitting the subjective data for the STOL landing in test 2 to EPNL. The correlation coefficient for this case was 1.000 and represents one of the best fits in the experiment. Figure 10(b) shows the fit for the shaped noise in test 3 fitted to Stevens PL (ref. 10). The correlation for this case was 0.971, the worst case found in any of the tests for fitting a single stimulus type to any scaling unit.

By considering the subjective data from a group of different stimuli and performing the least-squares analysis for each rating scale unit, the ability of the unit to predict the annoyance of different stimuli is determined by the correlation coefficient r and the standard error of estimate S_e, which is given by the following relationship:

$$S_e = \sqrt{\frac{\sum_{i=1}^{N} \left\{ RSU_i - \left[\frac{\overline{\log(SSV)_i - \bar{a}}}{\bar{b}} \right] \right\}^2}{N - 2}} \tag{5}$$

where N is total number of stimuli and levels of the grouping.

Pair-comparison analysis.- The second technique of analysis allowed the treatment of the subjective data as would be done in a pair-comparison type of test. The rating given to a stimulus by a subject was compared to the rating he gave to the shaped noise stimulus given at the middle level during each of the first four segments of the series. If the stimulus was rated less than, equal to, or more annoying than the standard, a score of 0, 1/2, or 1 was, respectively, assigned to that stimulus for the test subject. These scores were averaged over all subjects at each level for each type of stimulus. These averages resulted in five points on a psychometric function for each stimulus which was fit by a straight line using least squares and Muller-Urban weighting as given in reference 11. The 50-percent crossover point was computed for each psychometric function to give the equally annoying point solution EAP_2 for the stimulus as compared to the standard noise. An example of fitting a psychometric function and the resulting equally annoying point solution is shown in figure 11. The fitting of these data resulted in correlation coefficients of no less than 0.93 for any stimulus/rating-scale-unit pair.

RESULTS AND DISCUSSION

Relative Annoyance of STOL Noise to Other Aircraft Noises

In order to compare the STOL noises with the other noises used in the tests, the equally annoying points were found for each type of noise used in tests 1 to 3 and for each rating scale unit. The result of this analysis is shown in table IV for the two units most commonly used to rate aircraft noise annoyance, PNL and EPNL. The values of EAP_2 are obtained by treating the subjective data as pair-comparisons where the same shaped noise stimulus was used as the standard sound. The relative annoyances shown in the table are the differences between the STOL noise and the noise to which it was compared. The positive numbers indicate that for equal annoyance the STOL noise resulted in lower values of the rating scale units than did the CTOL noises. The values for RA_1 should have greater validity than those for RA_2 because it was possible to fit the subjective scale values to the rating scale units with much better correlation than it was to fit the psychometric functions of the pair-comparison treatment to the units. Averaged over just the aircraft sounds, the STOL noises resulted in equally annoying points 3.0 PNdB and 1.6 EPNdB lower than the CTOL noises.

The repeatability of these data can be seen by examining the data from test 5 as compared with tests 1 to 3. In test 5 the subjects heard the same sounds as in the first three tests, however, without the shaped noise and at only two levels. The results of this comparison are shown in table V where the relative annoyance of the STOL noises to the other aircraft noises is given. The mean differences between the results of tests 1, 2, and 3 and the results of test 5 for all of the sounds were -0.5 PNdB and -0.7 EPNdB with standard deviations of 1.1 PNdB and 1.1 EPNdB.

The STOL noises for the three different measuring locations are compared with each other in table VI. The data from tests 1 to 3 and from test 4 are shown as a comparison of annoyance of the STOL sounds to the standard shaped noise. The values for RA_2 are for the data treated as pair-comparisons. There is some discrepancy between the results of test 4 and the combined results of tests 1 to 3 regarding the ordering of landing or take-off sideline as being more annoying. There is no conclusive evidence as to why this occurred; however, the correlation coefficient of the annoyance ratings of the subjects to the scaling units for the individual sounds was better in tests 2 and 3 than in test 4. Because of this inconsistency and the fact that the annoyance difference between the types of STOL noises are small, no major emphasis will be placed on this difference.

Evaluation of Units for Scaling Aircraft-Noise Annoyance

The evaluation of some of the units used to scale the noisiness or annoyance of aircraft sounds was performed by fitting the subjective data, grouped into several categories, to the values of the various units. The result of this analysis is shown in table VII. The primary groupings used were: all sounds, all sounds except the standard sounds, CTOL sounds, and STOL sounds. In addition three other groupings were used as a check on reliability and repeatability. These included: all sounds from tests 1, 2, and 3; all sounds from test 5; and all standard sounds. The statistical characteristics $\bar{b}$ and $\bar{a}$ are, respectively, the best mean slope and the intercept obtained using this slope in the least-squares fitting of the logarithm of the geometric mean (over all subjects for a particular sound) of the subjective data to the rating scale unit of interest. The characteristics r and S_e are, respectively, the correlation coefficient and standard error of estimate of the deviations in the value of the scaling unit for each data point from the straight line determined by $\bar{a}$ and $\bar{b}$.

Evaluation of scaling units.- In the group of all sounds except standards, it can be seen that many of the units predicted the subjective annoyance with standard errors of estimate less than 3 dB. The worst predictors, as expected, were $L_C(m)$ and $L_C(c)$ which have less frequency weighting or are more similar to OASPL. It is also seen that the units which incorporate tone corrections do not in general improve upon their parent unit without tone corrections. In reference 4 very similar findings were reported. The removal of the STOL sounds from the analysis reduced the standard error of estimate slightly for all units except $L_A(m)$ as shown in the group of all CTOL sounds. If the STOL sounds are considered as a group, the standard error of estimate is in general less than for the CTOL sounds. The exceptions to this are the units with duration corrections and $L_B(c)$, $L_C(m)$, and $L_C(c)$. For the STOL sounds the composite calculations result in greater standard errors of estimate than for the maximum level calculations.

From the first four groups of table VII, it is also shown that the use of duration corrections offered some improvement to the units except for the group of only STOL sounds. Critical band corrections did not necessarily improve on the standard error for the perceived-noise-level units. However, the inclusion of critical band corrections did improve the effective and duration corrected perceived-noise-level units.

For the groups of all sounds and all sounds except standards, the A-weighted sound pressure levels performed better than did the other simple weighted units. The A-weighted units also performed very well for the group of all STOL sounds. This good performance should serve as a stimulus for further investigation for the possible incorporation of some type of simple weighted unit for the noise certification of future STOL aircraft. The use of such a weighted type of sound pressure level has some obvious advantages in the simplicity and repeatability of the measurements required. Although the tests reported herein are somewhat limited in both the types and intensity levels of the stimuli, sufficient justification exists for further study on the use of a simple weighted unit, at least for monitoring if not for certifying STOL aircraft noise. Further study should be conducted, particularly when better estimates of future STOL aircraft noise are available.

Reliability and repeatability.- The remaining three groups of table VII offer some insight into test reliability and repeatability. In comparing all sounds in tests 1, 2, and 3 with all sounds in test 5, it is immediately apparent that the growth of annoyance with increasing levels was greater in test 5 for all units. This comparison between the two groupings is shown in figure 12 for the unit IPNL'. For test 5 the growth is 7.3 dB per doubling of annoyance and for tests 1, 2, and 3 the growth is 8.4 dB per doubling. Test 5 was given to all subjects as a final test and this increase in growth of annoyance could be the result of fatigue and increased irritability and sensitivity to the noises. The growth of annoyance, expressed as the number of decibels required to induce a doubling of annoyance for any grouping examined, ranged from 6.7 dB to 9.8 dB. Although these values are lower than the usually assumed value of 10 dB (9 dB for Stevens Mark VII methods), they are in general agreement with those found in reference 4. A linear regression of the subjective scale values obtained for the noises of test 5 on those obtained for the same noises and levels included in tests 1, 2, and 3 was performed with the following results. The correlation coefficient was 0.79 with a slope of 0.84. This value of the slope was found not to differ from the expected value of 1.00 at the 0.1 level of significance.

The last group considered only the standard or shaped noise. As would be expected, there is practically no difference in the correlation coefficients or standard error of estimates between units. The values of the slope are also indistinguishable except for the Stevens Mark VII units which are based on 9 dB per doubling of perception rather than the 10 dB per doubling of the other units. The low standard error of estimate values give an indication of how well a group of subjects, each under the same testing conditions, can rate their annoyance to a series of sounds with level as the only variable.

The average value of the correlation coefficient over all scaling units for all standard sounds was 0.9881. The value of $(1 - r^2)$ can be described as the undetermined deviation from the least-squares fitting of the data, or that deviation not explained by the linear relationship of equation (1). For the standard sounds this unexplained deviation was approximately 0.024 and is probably a result of intersubject variability and variability in the physical measurements of the sounds used in the tests.

CONCLUSIONS

An experiment was performed to determine relative annoyance of the recorded noise of a simulated blown-flap turbofan STOL aircraft to recorded noise of three present day commercial CTOL aircraft which are commonly used in short-haul operations. Twenty test subjects gave annoyance ratings to a total of 119 recorded noises in a magnitude-estimation type of experiment. In addition the data were analyzed to determine which of 28 commonly used scaling units best predicted the annoyance of the test subjects to the sounds which they heard. The following conclusions are noted:

1. The STOL noises were in general more annoying than were the CTOL noises for the same level of PNL and EPNL. For the same level of subjective annoyance, it was necessary to reduce the PNL for STOL aircraft by 3.0 PNdB and 1.6 EPNdB averaged over the conditions of take-off and landing.

2. No major differences were determined for the annoyance of the different types of STOL noises investigated (take-off under centerline, landing under centerline, and sideline of take-off).

3. Most of the commonly used scaling units were able to predict annoyance with standard errors of estimate of approximately 3 dB.

4. For the sounds considered in this report, the A-weighted units proved to be the most reliable and consistent predictor of subjective annoyance among the simple weighted scaling units.

5. The use of tone corrections did not improve the accuracy of the scaling units considering all of the aircraft sounds as a whole.

6. The use of duration corrections, however, did offer some improvement in the units with the exception of the STOL sounds.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., December 11, 1972.

APPENDIX A

INSTRUCTIONS

We are asking you to help us solve a problem concerned with noise: How annoying are various kinds of sounds?

The sounds you are to rate will be presented to you one at a time. Listen to all of the sound before making your judgment. In a moment, we will have you listen to a sound with an annoyance score of 10. Use that sound as a standard, and judge each succeeding sound in relation to that standard. For example, if a sound seems twice as annoying as the standard, you will write 20 in the space for that sound on the answer sheet. If it seems only one-quarter as annoying, write $2\frac{1}{2}$. If it seems three times as annoying, write 30. If one-half as annoying, write 5, and so on.

Your ratings should reflect only your own opinion of the noises; that is what we want.

APPENDIX B

ANSWER SHEET

Name: ______________________________ Date: ______________

Age: ______________ Occupation: ______________________________

Sex: M______ F______ Part: ______________

If the noise you are rating is two times as annoying as the Standard, write "20" in the space for that noise. If it is one-half as annoying, write "5" and so on.

Noise number	Rating
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	

Noise number	Rating
21	
22	
23	
24	
25	
26	
27	
28	
29	
30	
31	
32	
33	
34	
35	
36	
37	
38	
39	
40	

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TABLE I.- SOUND SOURCES, DESIGNATIONS, MEASUREMENT LOCATIONS, AND MEDIAN NOISE LEVELS

Sound source	Measurement location	Median noise level, PNdB
A 3 aft-mounted turbofan engines (USA airframe and engines)	α Centerline take-off	91.0
	β Centerline landing	90.1
	γ Sideline take-off	90.9
B Synthesized STOL noise with turbofan engines and blown flaps	α Centerline take-off	90.4
	β Centerline landing	89.1
	γ Sideline take-off	89.7
C 2 turboprop engines (Japanese airframe and British engines)	α Centerline take-off	94.0
	β Centerline landing	87.6
	γ Sideline take-off	93.6
D 2 wing-mounted turbofan engines (USA airframe and engines)	α Centerline take-off	89.7
	β Centerline landing	92.4
	γ Sideline take-off	91.4
E Shaped noise		93.1

TABLE II.- TEST PRESENTATION ORDER FOR THE SUBJECT GROUPS

Group	Test presentation order				
1	1	2	4	3	5
2	2	3	1	4	5
3	3	4	2	1	5
4	4	1	3	2	5

TABLE III.- STIMULI PRESENTATION ORDER

Stimuli \ Test	1 (Take-off)	2 (Landing)	3 (Sideline)	4 (STOL)	5 (Mixed)
Standard	E, 3	E, 3	E, 3	E, 3	E, 3
1	[a]A, α, 1	D, β, 3	A, γ, 3	B, γ, 1	A, γ, 4
2	B, α, 2	C, β, 2	E, 4	B, α, 2	B, β, 2
3	E, 5	E, 4	B, γ, 2	E, 3	D, α, 2
4	C, α, 3	B, β, 1	D, γ, 5	B, β, 4	C, β, 4
5	D, α, 4	A, β, 5	C, γ, 1	B, γ, 3	B, γ, 2
6	B, α, 5	C, β, 4	B, γ, 4	B, β, 1	C, α, 4
7	C, α, 1	B, β, 3	A, γ, 5	B, α, 4	A, α, 2
8	A, α, 4	D, β, 5	C, γ, 3	E, 5	D, β, 4
Standard	E, 3	E, 3	E, 3	E, 3	E, 3
9	D, α, 2	A, β, 2	E, 1	B, β, 3	C, γ, 2
10	E, 3	E, 1	D, γ, 2	E, 2	D, γ, 4
11	C, α, 4	B, β, 5	C, γ, 5	B, γ, 5	B, α, 2
12	D, α, 5	A, β, 4	B, γ, 1	B, α, 1	A, β, 4
13	B, α, 3	C, β, 1	D, γ, 4	E, 4	D, α, 4
14	E, 1	E, 3	A, γ, 2	B, β, 5	A, α, 2
15	A, α, 2	D, β, 2	E, 3	B, α, 3	C, β, 2
16	D, α, 3	A, β, 1	D, γ, 1	B, γ, 2	B, γ, 4
Standard	E, 3	E, 3	E, 3	E, 3	E, 3
17	E, 4	E, 5	C, γ, 2	B, α, 5	B, β, 4
18	C, α, 2	B, β, 2	E, 5	E, 1	A, α, 4
19	A, α, 5	D, β, 4	B, γ, 3	B, γ, 4	C, α, 2
20	B, α, 1	C, β, 3	A, γ, 4	B, β, 2	D, γ, 2
21	E, 2	E, 2	E, 2		A, β, 2
22	A, α, 3	D, β, 1	D, γ, 3		D, β, 2
23	D, α, 1	A, β, 3	A, γ, 1		B, α, 4
24	B, α, 4	C, β, 5	C, γ, 4		C, γ, 4
25	C, α, 5	B, β, 4	B, γ, 5		

[a]Numerals 1 to 5 indicate the intensity levels in the order of decreasing level.

TABLE IV.- EQUALLY ANNOYING POINTS AND RELATIVE ANNOYANCE OF THE SYNTHESIZED STOL AIRCRAFT NOISE TO THE OTHER STIMULI. VALUES OF EAP_2 AND RA_2 ARE DATA TREATED AS PAIR-COMPARISONS

Rating scale unit	Sound source									
	A (3-eng. jet)		B (STOL)		C (2-eng. t'prop)		D (2-eng. jet)		E (Std. noise)	
Test 1.- Take-off noise under centerline										
	EAP_1	EAP_2	EAP_1	EAP_2	EAP_1	EAP_2	EAP_1	EAP_2	EAP_1	EAP_2
PNL(m), PNdB	93.2	92.8	90.3	89.2	94.8	93.5	91.9	91.2	93.4	93.3
EPNL(m), EPNdB	88.1	87.7	85.9	84.6	89.8	88.7	86.1	85.4	90.4	90.2
	RA_1	RA_2	RA_1	RA_2	RA_1	RA_2	RA_1	RA_2	RA_1	RA_2
PNL(m), PNdB	2.9	3.6	---	---	4.5	4.3	1.6	2.0	3.1	4.1
EPNL(m), EPNdB	2.2	3.1	---	---	3.9	4.1	.2	.8	4.5	5.6
Test 2.- Landing noise under centerline										
	EAP_1	EAP_2	EAP_1	EAP_2	EAP_1	EAP_2	EAP_1	EAP_2	EAP_1	EAP_2
PNL(m), PNdB	95.7	94.7	89.7	89.5	90.1	89.3	92.4	91.5	92.3	91.5
EPNL(m), EPNdB	86.1	85.0	84.7	84.5	88.4	87.4	85.7	84.6	89.3	88.3
	RA_1	RA_2	RA_1	RA_2	RA_1	RA_2	RA_1	RA_2	RA_1	RA_2
PNL(m), PNdB	6.0	4.8	---	---	0.4	-0.2	2.7	2.0	2.6	2.0
EPNL(m), EPNdB	1.4	.5	---	---	3.7	2.9	1.0	.1	4.6	3.8
Test 3.- Sideline noise of take-off										
	EAP_1	EAP_2	EAP_1	EAP_2	EAP_1	EAP_2	EAP_1	EAP_2	EAP_1	EAP_2
PNL(m), PNdB	88.9	87.7	86.7	87.1	89.9	89.7	90.1	89.7	92.5	92.8
EPNL(m), EPNdB	86.9	85.6	87.2	87.1	89.0	88.5	87.5	87.0	89.5	89.7
	RA_1	RA_2	RA_1	RA_2	RA_1	RA_2	RA_1	RA_2	RA_1	RA_2
PNL(m), PNdB	2.2	0.6	---	---	3.2	2.6	3.4	2.6	5.8	5.7
EPNL(m), EPNdB	-.3	-2.1	---	---	1.8	.8	.3	-.7	2.3	2.0

TABLE V.- REPEATABILITY OF SUBJECTIVE JUDGMENTS SHOWING THE RELATIVE ANNOYANCE OF THE SYNTHESIZED STOL NOISE TO THE OTHER AIRCRAFT NOISES

Measurement location	Rating scale unit	Sound source					
		A (3-eng. jet)		C (2-eng. t'prop)		D (2-eng. jet)	
		Tests 1 to 3	Test 5	Tests 1 to 3	Test 5	Tests 1 to 3	Test 5
Take-off under centerline	PNL(m), PNdB	2.9	3.3	4.5	3.4	1.6	3.3
	EPNL(m), EPNdB	2.2	2.8	3.9	3.3	.2	1.4
Landing under centerline	PNL(m), PNdB	6.0	5.4	0.4	-0.2	2.7	3.4
	EPNL(m), EPNdB	1.4	.7	3.7	3.8	1.0	1.5
Sideline of take-off	PNL(m), PNdB	2.2	3.6	3.2	3.4	3.4	5.6
	EPNL(m), EPNdB	-.3	1.1	1.8	2.2	.3	3.0

TABLE VI.- COMPARISON OF THE NOISES FROM THE VARIOUS MEASUREMENT LOCATIONS SHOWING THE RELATIVE ANNOYANCE OF THE SYNTHESIZED STOL NOISE TO THE STANDARD SHAPED NOISE

Rating scale unit \ STOL noise	Take-off under centerline		Landing under centerline		Sideline of take-off	
(a)	RA_1	RA_2	RA_1	RA_2	RA_1	RA_2
PNL(m), PNdB	3.1	4.1	2.6	2.0	5.8	5.7
EPNL(m), EPNdB	4.5	5.6	4.6	3.8	2.3	2.0
(b)						
PNL, PNdB	3.5	2.8	4.6	4.1	2.7	2.0
EPNL, EPNdB	5.0	3.8	6.7	6.0	.3	1.3

[a] From tests 1 to 3.

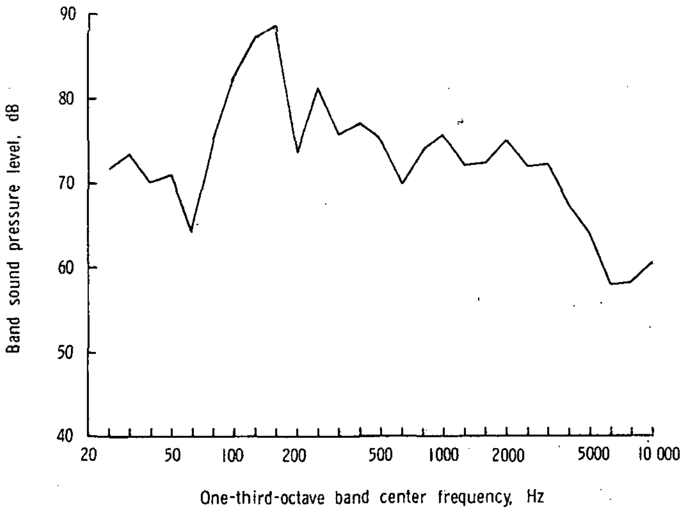
[b] From test 4.

TABLE VII.- LEAST-SQUARES FIT TO VARIOUS GROUPINGS OF THE NOISE STIMULI

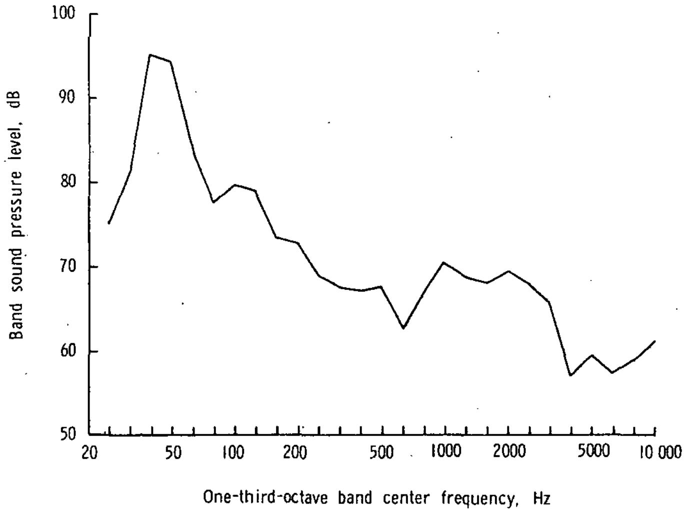
RSU	All sounds				All sounds except standards				All CTOL sounds				All STOL sounds			
	$\bar{a}$	$\bar{b}$	r	S_e	$\bar{a}$	$\bar{b}$	r	S_e	$\bar{a}$	$\bar{b}$	r	S_e	$\bar{a}$	$\bar{b}$	r	S_e
PNL(m)	-2.411	0.0375	0.9465	2.69	-2.445	0.0380	0.9422	2.77	-2.552	0.0387	0.9529	2.50	-2.161	0.0357	0.9806	1.64
PNLT(m)	-2.472	.0374	.9459	2.71	-2.502	.0378	.9393	2.85	-2.623	.0386	.9550	2.45	-2.204	.0355	.9809	1.64
PNL(c)	-2.472	.0376	.9555	2.44	-2.502	.0379	.9490	2.60	-2.585	.0384	.9623	2.25	-2.252	.0360	.9775	1.75
PNLT(c)	-2.505	.0373	.9542	2.50	-2.523	.0375	.9471	2.68	-2.635	.0382	.9664	2.13	-2.232	.0353	.9736	1.94
IPNL	-2.084	.0359	.9614	2.38	-2.102	.0364	.9668	2.19	-2.163	.0369	.9769	1.83	-1.912	.0345	.9576	2.51
EPNL	-2.131	.0358	.9577	2.50	-2.143	.0362	.9600	2.41	-2.208	.0366	.9735	1.98	-1.929	.0343	.9564	2.56
L_A(m)	-1.945	.0377	.9617	2.26	-1.970	.0382	.9589	2.32	-2.042	.0388	.9551	2.43	-1.754	.0360	.9826	1.54
L_A(c)	-1.999	.0380	.9689	2.02	-2.026	.0384	.9656	2.11	-2.083	.0388	.9680	2.05	-1.830	.0365	.9807	1.60
L_B(m)	-1.778	.0350	.9369	3.12	-1.258	.0349	.9291	3.34	-1.730	.0342	.9336	3.36	-1.738	.0352	.9377	2.98
L_B(c)	-1.820	.0349	.9345	3.19	-1.797	.0346	.9245	3.47	-1.797	.0344	.9356	3.28	-1.727	.0342	.9087	3.72
L_C(m)	-1.607	.0315	.8804	4.78	-1.541	.0307	.8645	5.24	-1.514	.0304	.8735	5.22	-1.601	.0314	.8365	5.42
L_C(c)	-1.652	.0316	.8806	4.76	-1.590	.0308	.8650	5.21	-1.569	.0305	.8784	5.09	-1.622	.0313	.8295	5.56
L_{D1}(m)	-2.255	.0382	.9343	2.92	-2.285	.0386	.9234	3.14	-2.409	.0395	.9345	2.89	-1.985	.0360	.9677	2.10
L_{D1}(c)	-2.329	.0386	.9506	2.51	-2.375	.0391	.9434	2.66	-2.461	.0396	.9516	2.47	-2.125	.0371	.9821	1.52
L_{D2}(m)	-2.242	.0382	.9238	3.15	-2.272	.0386	.9109	3.38	-2.410	.0396	.9163	3.25	-1.949	.0357	.9610	2.33
L_{D2}(c)	-2.310	.0386	.9395	2.77	-2.352	.0391	.9296	2.97	-2.466	.0398	.9382	2.78	-2.065	.0367	.9756	1.52
L_{D3}(m)	-2.059	.0381	.9401	2.79	-2.089	.0386	.9315	2.96	-2.215	.0397	.9416	2.71	-1.783	.0357	.9610	2.33
L_{D3}(c)	-2.110	.0384	.9505	2.52	-2.143	.0389	.9430	2.68	-2.244	.0396	.9543	2.40	-1.874	.0365	.9719	1.93
PL	-2.273	.0403	.9510	2.39	-2.297	.0408	.9480	2.45	-2.369	.0411	.9590	2.19	-2.069	.0389	.9794	1.55
PLT	-2.336	.0402	.9518	2.38	-2.353	.0405	.9468	2.49	-2.444	.0411	.9655	2.01	-2.100	.0385	.9754	1.72
IPL	-2.005	.0393	.9446	2.61	-2.008	.0396	.9487	2.50	-2.035	.0398	.9655	2.08	-1.897	.0384	.9189	3.12
EPL	-2.068	.0394	.9437	2.63	-2.068	.0396	.9453	2.58	-2.098	.0397	.9654	2.09	-1.920	.0382	.9222	3.07
PNL'(m)	-2.423	.0380	.9377	2.86	-2.456	.0385	.9299	3.01	-2.573	.0392	.9455	2.65	-2.172	.0363	.9752	1.82
PNLT'(m)	-2.490	.0377	.9237	3.19	-2.516	.0380	.9124	3.40	-2.685	.0392	.9417	2.74	-2.191	.0357	.9662	2.17
PNL'(c)	-2.501	.0378	.9577	2.37	-2.530	.0382	.9518	2.51	-2.603	.0385	.9637	2.20	-2.292	.0364	.9747	1.84
PNLT'(c)	-2.543	.0374	.9524	2.54	-2.564	.0376	.9458	2.71	-2.686	.0384	.9669	2.11	-2.261	.0353	.9737	1.93
IPNL'	-2.106	.0366	.9656	2.20	-2.125	.0370	.9701	2.04	-2.182	.0374	.9798	1.69	-1.931	.0352	.9676	2.15
EPNL'	-2.188	.0366	.9615	2.33	-2.207	.0370	.9641	2.24	-2.271	.0373	.9768	1.82	-1.991	.0352	.9737	1.94

TABLE VII.- LEAST-SQUARES FIT TO VARIOUS GROUPINGS OF THE NOISE STIMULI

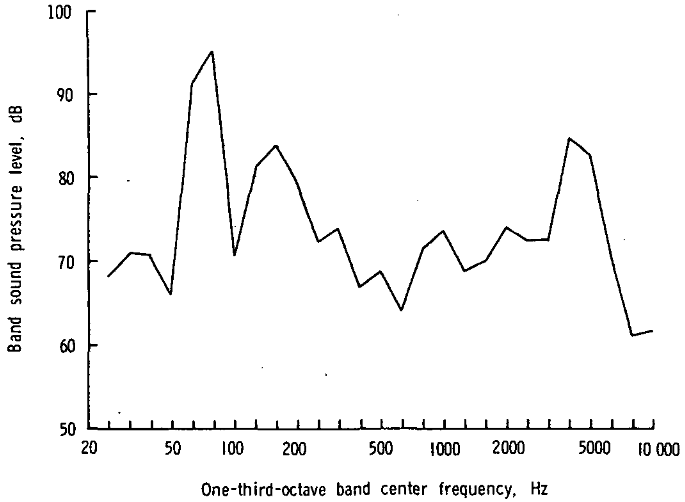
RSU	All sounds				All sounds except standards				All CTOL sounds				All STOL sounds			
	$\bar{a}$	$\bar{b}$	r	S_e	$\bar{a}$	$\bar{b}$	r	S_e	$\bar{a}$	$\bar{b}$	r	S_e	$\bar{a}$	$\bar{b}$	r	S_e
PNL(m)	-2.411	0.0375	0.9465	2.69	-2.445	0.0380	0.9422	2.77	-2.552	0.0387	0.9529	2.50	-2.161	0.0357	0.9806	1.64
PNLT(m)	-2.472	.0374	.9459	2.71	-2.502	.0378	.9393	2.85	-2.623	.0386	.9550	2.45	-2.204	.0355	.9809	1.64
PNL(c)	-2.472	.0376	.9555	2.44	-2.502	.0379	.9490	2.60	-2.585	.0384	.9623	2.25	-2.252	.0360	.9775	1.75
PNLT(c)	-2.505	.0373	.9542	2.50	-2.523	.0375	.9471	2.68	-2.635	.0382	.9664	2.13	-2.232	.0353	.9736	1.94
IPNL	-2.084	.0359	.9614	2.38	-2.102	.0364	.9668	2.19	-2.163	.0369	.9769	1.83	-1.912	.0345	.9576	2.51
EPNL	-2.131	.0358	.9577	2.50	-2.143	.0362	.9600	2.41	-2.208	.0366	.9735	1.98	-1.929	.0343	.9564	2.56
L_A(m)	-1.945	.0377	.9617	2.26	-1.970	.0382	.9589	2.32	-2.042	.0388	.9551	2.43	-1.754	.0360	.9826	1.54
L_A(c)	-1.999	.0380	.9689	2.02	-2.026	.0384	.9656	2.11	-2.083	.0388	.9680	2.05	-1.830	.0365	.9807	1.60
L_B(m)	-1.778	.0350	.9369	3.12	-1.258	.0349	.9291	3.34	-1.730	.0342	.9336	3.36	-1.738	.0352	.9377	2.98
L_B(c)	-1.820	.0349	.9345	3.19	-1.797	.0346	.9245	3.47	-1.797	.0344	.9356	3.28	-1.727	.0342	.9087	3.72
L_C(m)	-1.607	.0315	.8804	4.78	-1.541	.0307	.8645	5.24	-1.514	.0304	.8735	5.22	-1.601	.0314	.8365	5.42
L_C(c)	-1.652	.0316	.8806	4.76	-1.590	.0308	.8650	5.21	-1.569	.0305	.8784	5.09	-1.622	.0313	.8295	5.56
L_{D1}(m)	-2.255	.0382	.9343	2.92	-2.285	.0386	.9234	3.14	-2.409	.0395	.9345	2.89	-1.985	.0360	.9677	2.10
L_{D1}(c)	-2.329	.0386	.9506	2.51	-2.375	.0391	.9434	2.66	-2.461	.0396	.9516	2.47	-2.125	.0371	.9821	1.52
L_{D2}(m)	-2.242	.0382	.9238	3.15	-2.272	.0386	.9109	3.38	-2.410	.0396	.9163	3.25	-1.949	.0357	.9610	2.33
L_{D2}(c)	-2.310	.0386	.9395	2.77	-2.352	.0391	.9296	2.97	-2.466	.0398	.9382	2.78	-2.065	.0367	.9756	1.52
L_{D3}(m)	-2.059	.0381	.9401	2.79	-2.089	.0386	.9315	2.96	-2.215	.0397	.9416	2.71	-1.783	.0357	.9610	2.33
L_{D3}(c)	-2.110	.0384	.9505	2.52	-2.143	.0389	.9430	2.68	-2.244	.0396	.9543	2.40	-1.874	.0365	.9719	1.93
PL	-2.273	.0403	.9510	2.39	-2.297	.0408	.9480	2.45	-2.369	.0411	.9590	2.19	-2.069	.0389	.9794	1.55
PLT	-2.336	.0402	.9518	2.38	-2.353	.0405	.9468	2.49	-2.444	.0411	.9655	2.01	-2.100	.0385	.9754	1.72
IPL	-2.005	.0393	.9446	2.61	-2.008	.0396	.9487	2.50	-2.035	.0398	.9655	2.08	-1.897	.0384	.9189	3.12
EPL	-2.068	.0394	.9437	2.63	-2.068	.0396	.9453	2.58	-2.098	.0397	.9654	2.09	-1.920	.0382	.9222	3.07
PNL'(m)	-2.423	.0380	.9377	2.86	-2.456	.0385	.9299	3.01	-2.573	.0392	.9455	2.65	-2.172	.0363	.9752	1.82
PNLT'(m)	-2.490	.0377	.9237	3.19	-2.516	.0380	.9124	3.40	-2.685	.0392	.9417	2.74	-2.191	.0357	.9662	2.17
PNL'(c)	-2.501	.0378	.9577	2.37	-2.530	.0382	.9518	2.51	-2.603	.0385	.9637	2.20	-2.292	.0364	.9747	1.84
PNLT'(c)	-2.543	.0374	.9524	2.54	-2.564	.0376	.9458	2.71	-2.686	.0384	.9669	2.11	-2.261	.0353	.9737	1.93
IPNL'	-2.106	.0366	.9656	2.20	-2.125	.0370	.9701	2.04	-2.182	.0374	.9798	1.69	-1.931	.0352	.9676	2.15
EPNL'	-2.188	.0366	.9615	2.33	-2.207	.0370	.9641	2.24	-2.271	.0373	.9768	1.82	-1.991	.0352	.9737	1.94



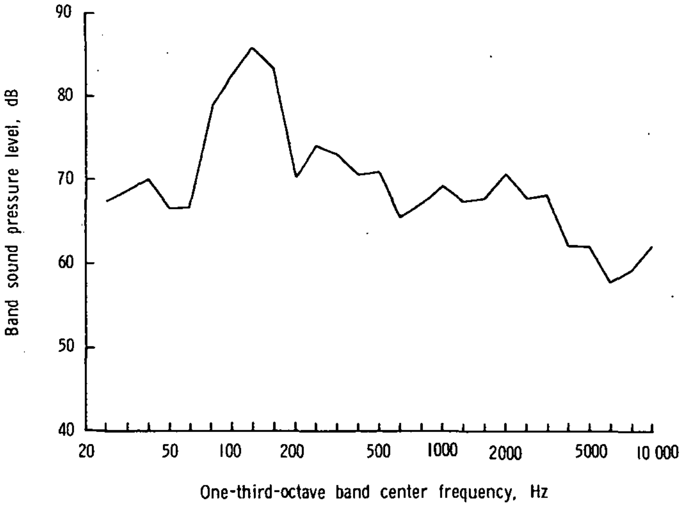
(a) Aircraft A, 3-engine jet.



(b) Aircraft B, simulated STOL.

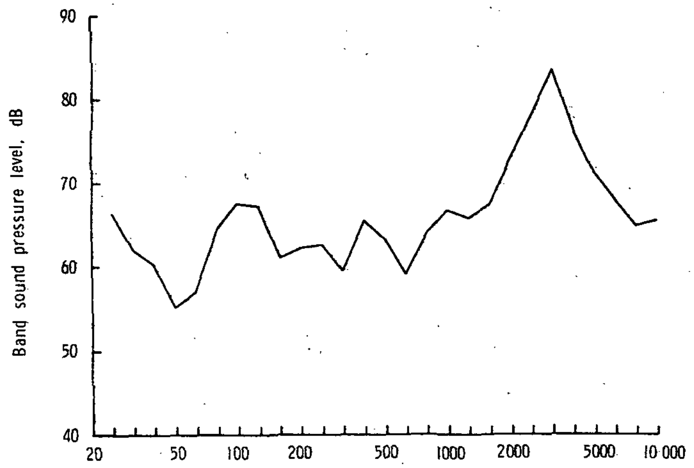


(c) Aircraft C, 2-engine turboprop.



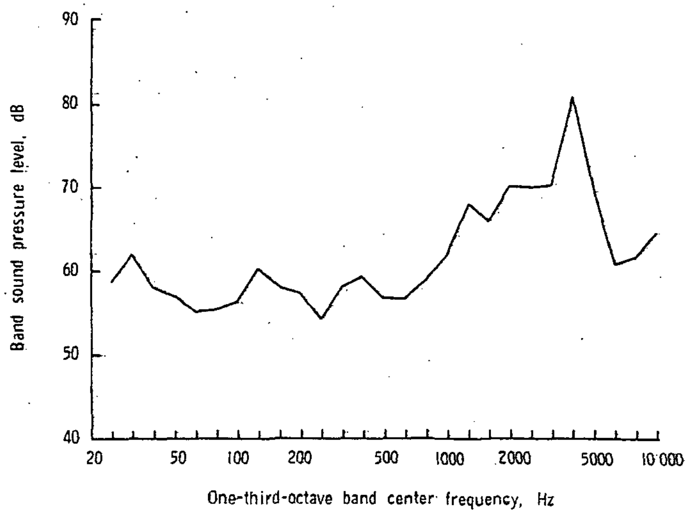
(d) Aircraft D, 2-engine jet.

Figure 1.- Maximum one-third-octave spectra of take-off stimuli presented to the subjects.

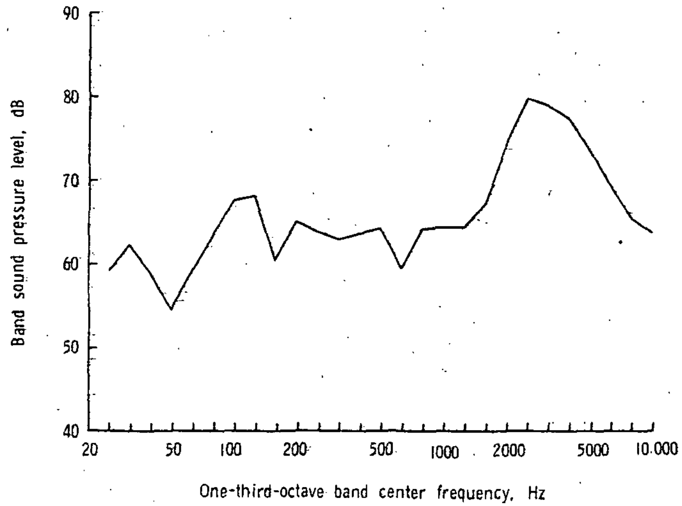


(a) Aircraft A, 3-engine jet.

(b) Aircraft B, simulated STOL.

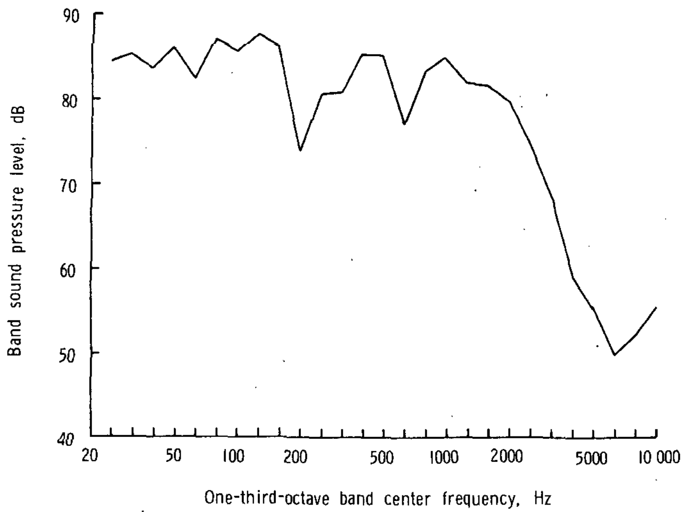


(c) Aircraft C, 2-engine turboprop.

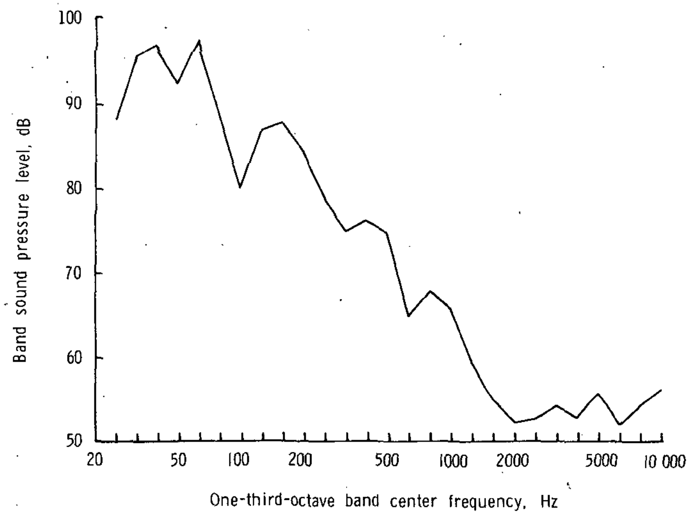


(d) Aircraft D, 2-engine jet.

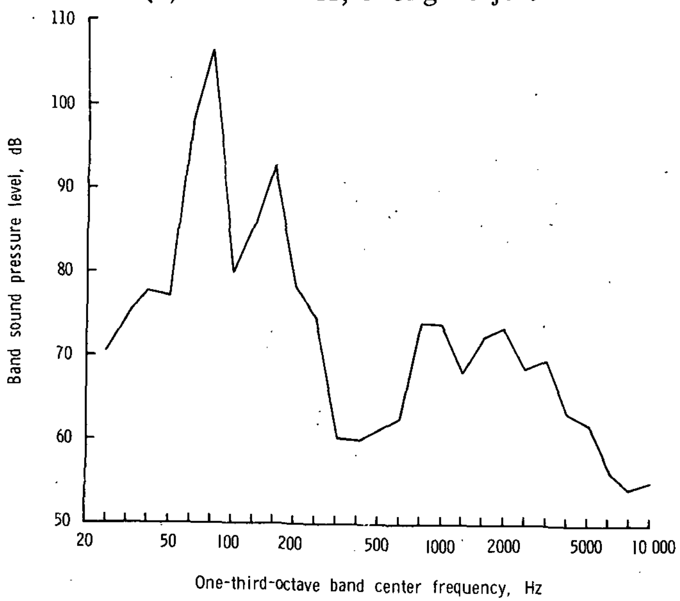
Figure 2.- Maximum one-third-octave spectra of landing stimuli presented to the subjects.



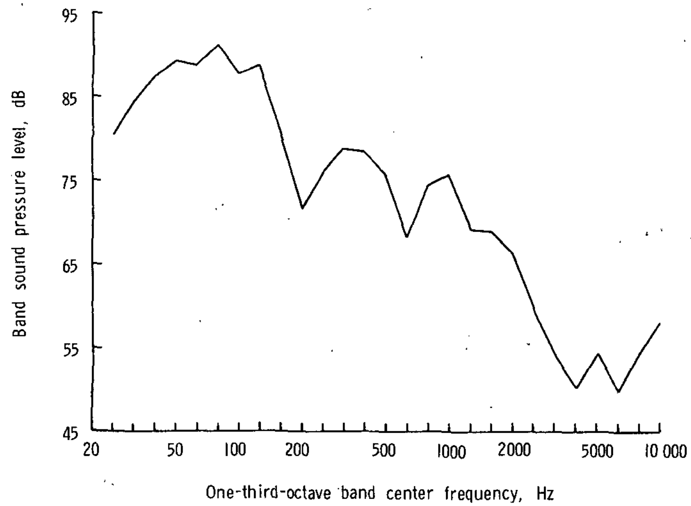
(a) Aircraft A, 3-engine jet.



(b) Aircraft B, simulated STOL.

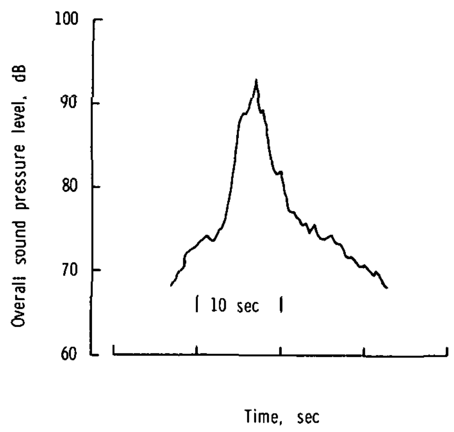


(c) Aircraft C, 2-engine turboprop.

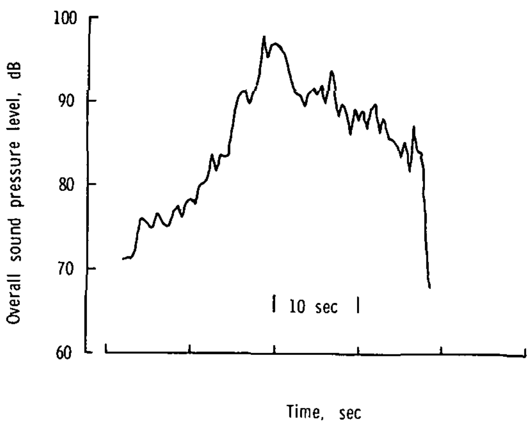


(d) Aircraft D, 2-engine jet.

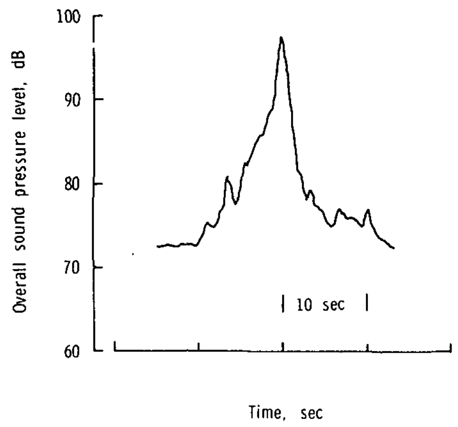
Figure 3.- Maximum one-third-octave spectra of sideline stimuli presented to the subjects.



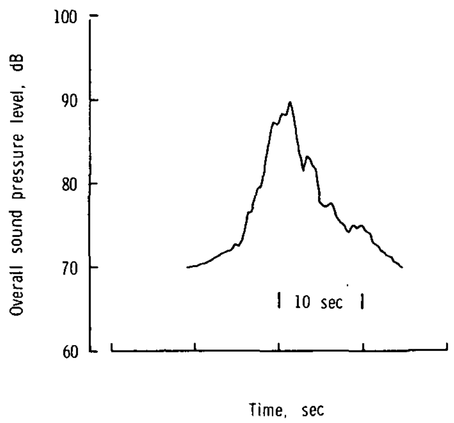
(a) Aircraft A, 3-engine jet.



(b) Aircraft B, simulated STOL.

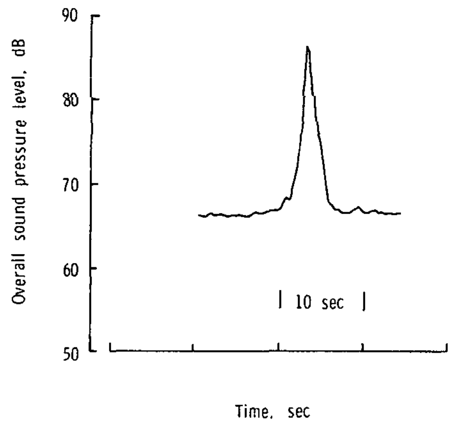


(c) Aircraft C, 2-engine turboprop.

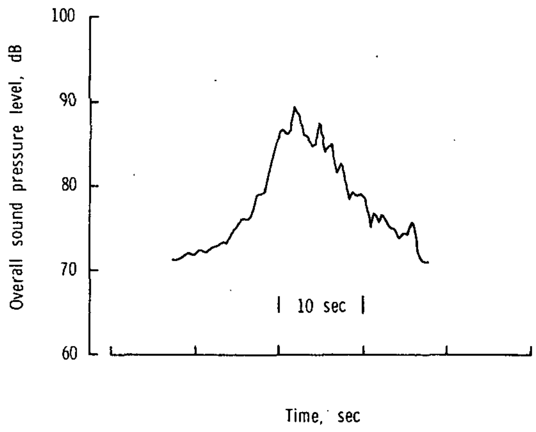


(d) Aircraft D, 2-engine jet.

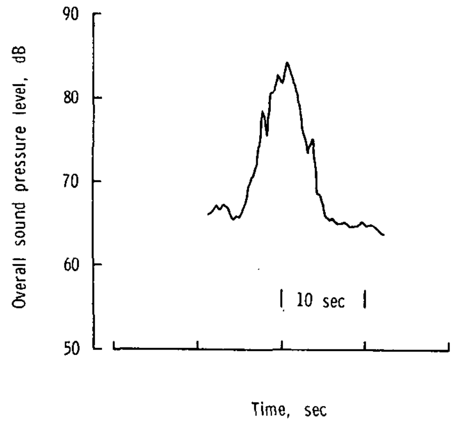
Figure 4.- Time histories of overall sound pressure levels for take-off stimuli.



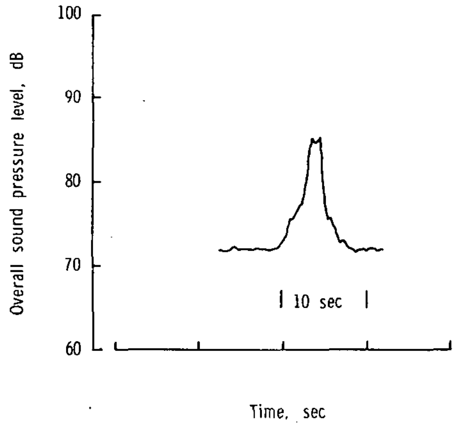
(a) Aircraft A, 3-engine jet.



(b) Aircraft B, simulated STOL.

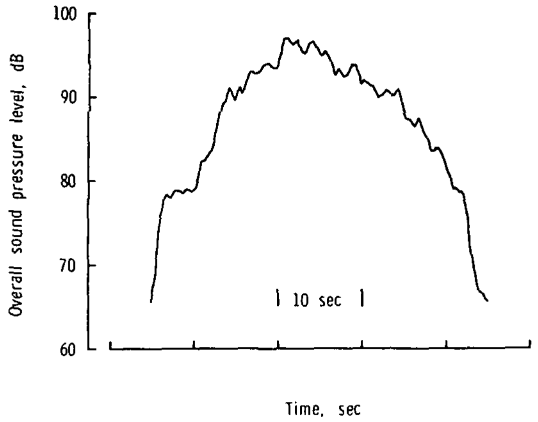


(c) Aircraft C, 2-engine turboprop.

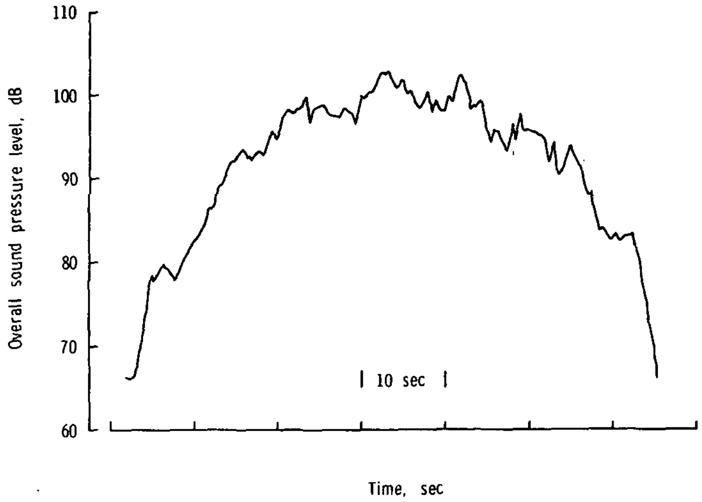


(d) Aircraft D, 2-engine jet.

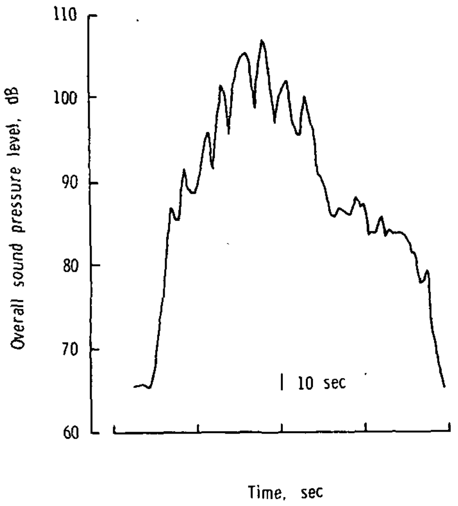
Figure 5.- Time histories of overall sound pressure levels for landing stimuli.



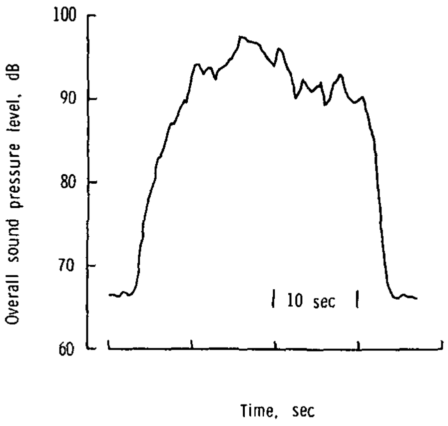
(a) Aircraft A, 3-engine jet.



(b) Aircraft B, simulated STOL.



(c) Aircraft C, 2-engine turboprop.



(d) Aircraft D, 2-engine jet.

Figure 6.- Time histories of overall sound pressure levels for sideline stimuli.

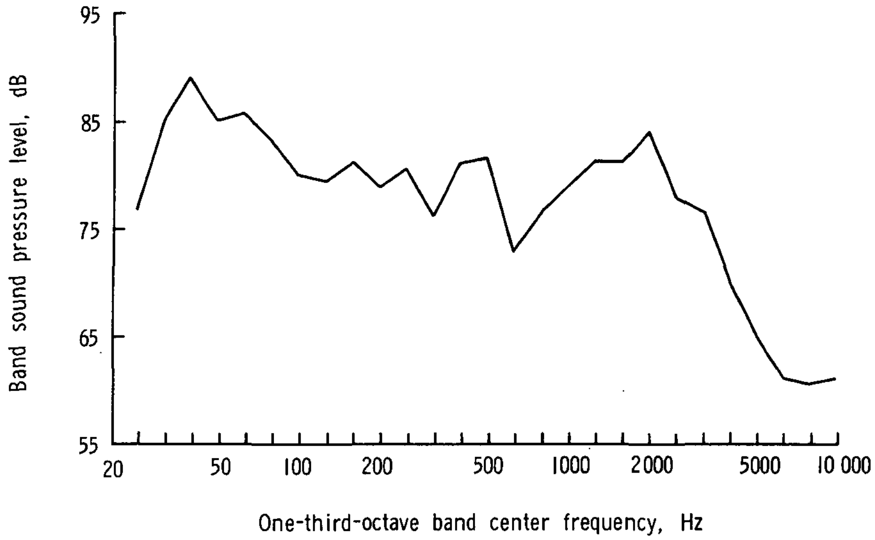


Figure 7.- Maximum one-third-octave spectrum of the shaped noise used as the standard stimulus.

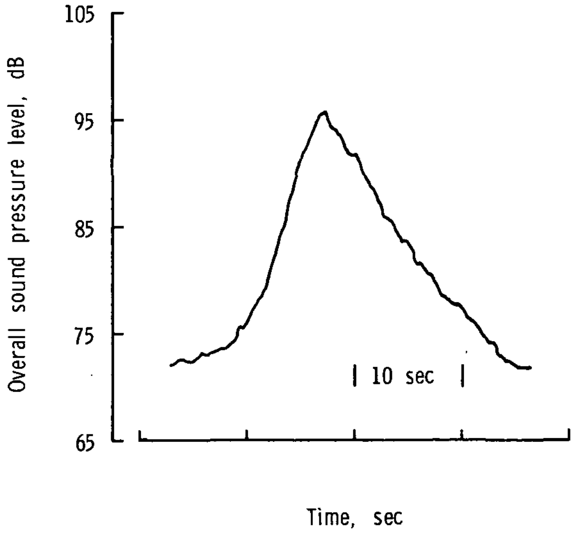


Figure 8.- Time history of overall sound pressure level for the shaped noise used as the standard stimuli.

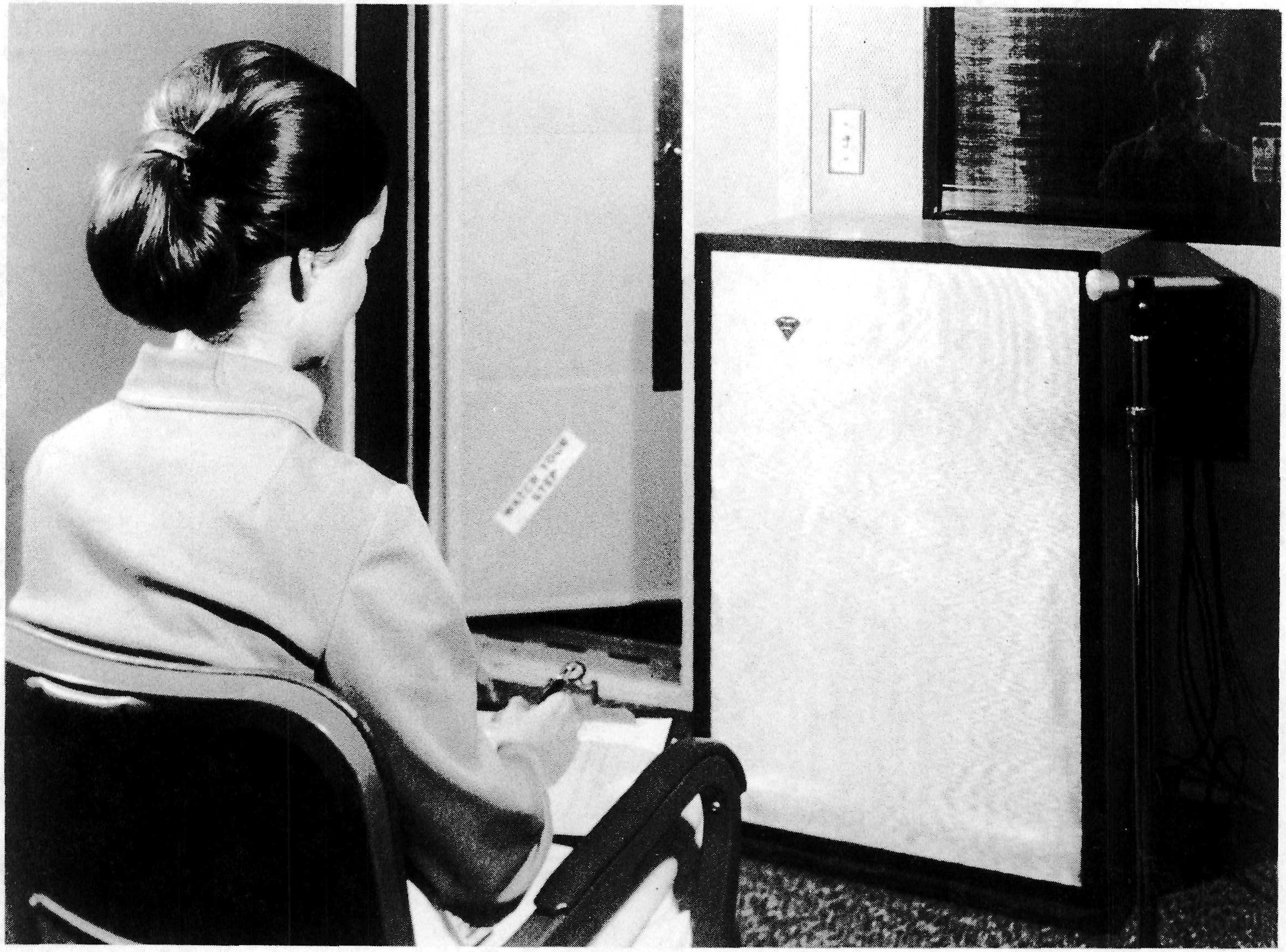


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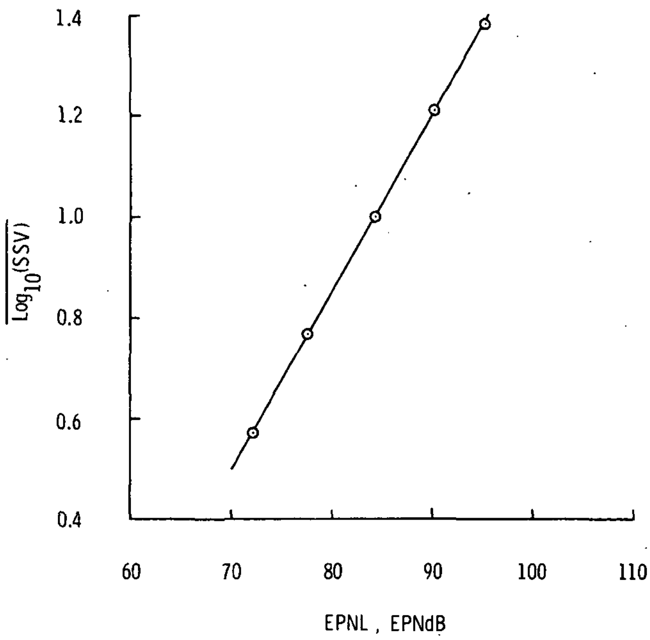
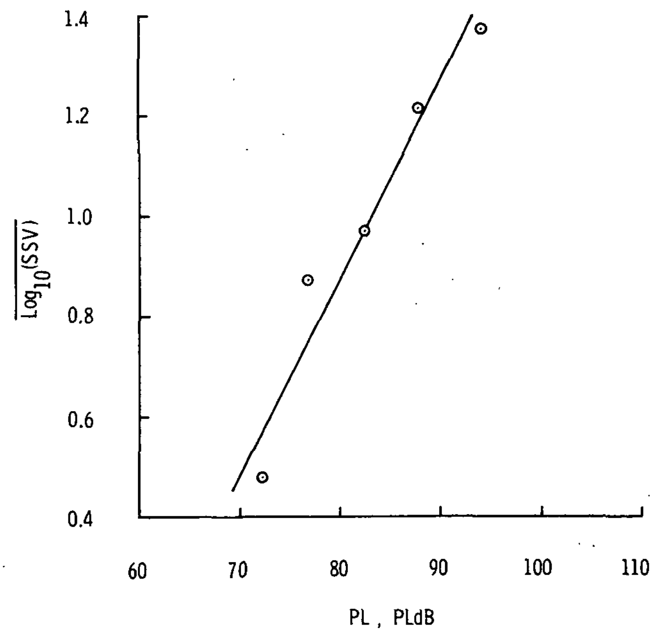
Figure 9.- Subjective test facility.



(a) Best case (r = 1.000).



(b) Worst case (r = 0.971).

Figure 10.- Examples of fitting the subjective data to the scaling units.

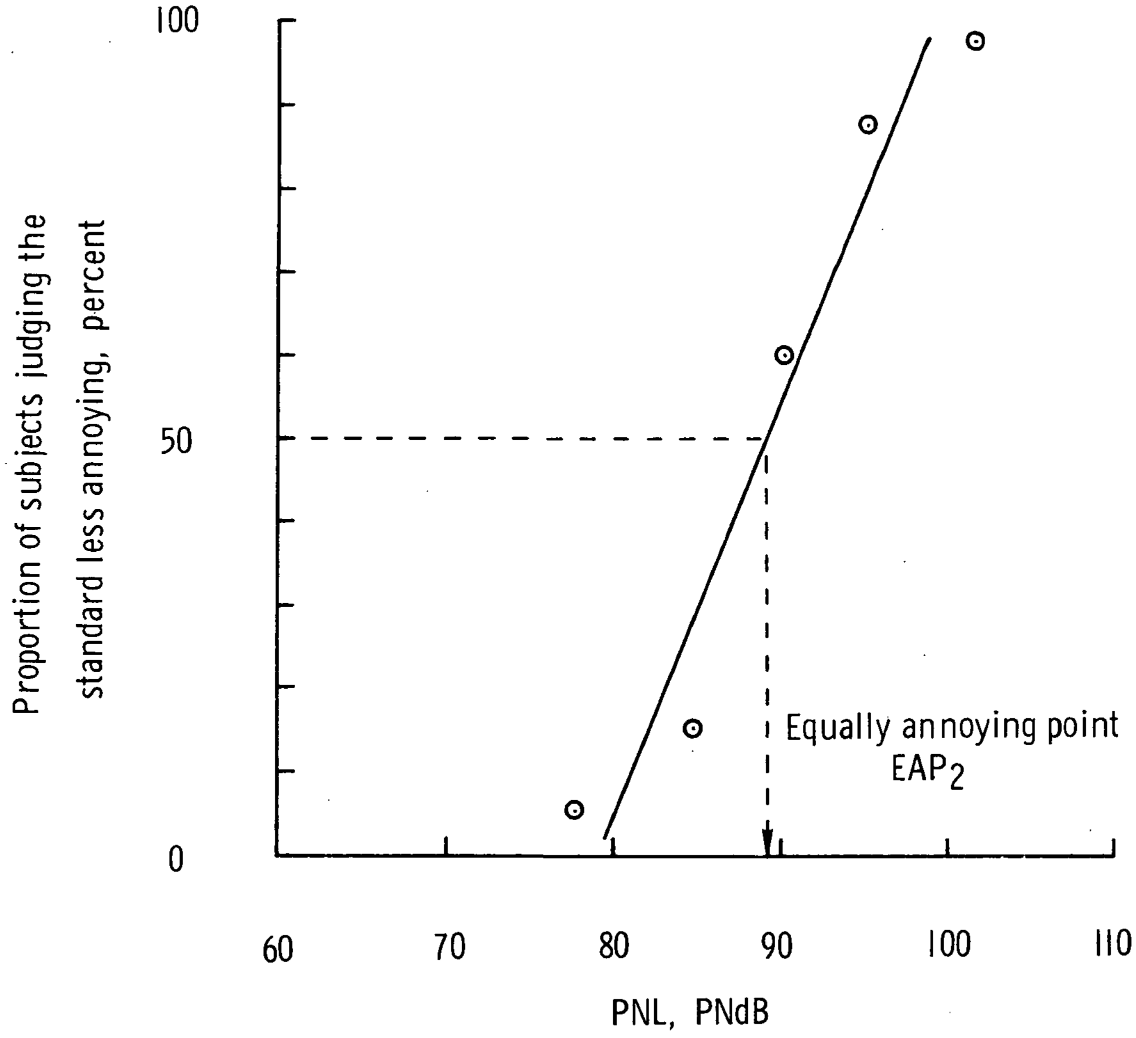


Figure 11.- Example of fitting a psychometric function to determine the equally annoying point EAP_2.

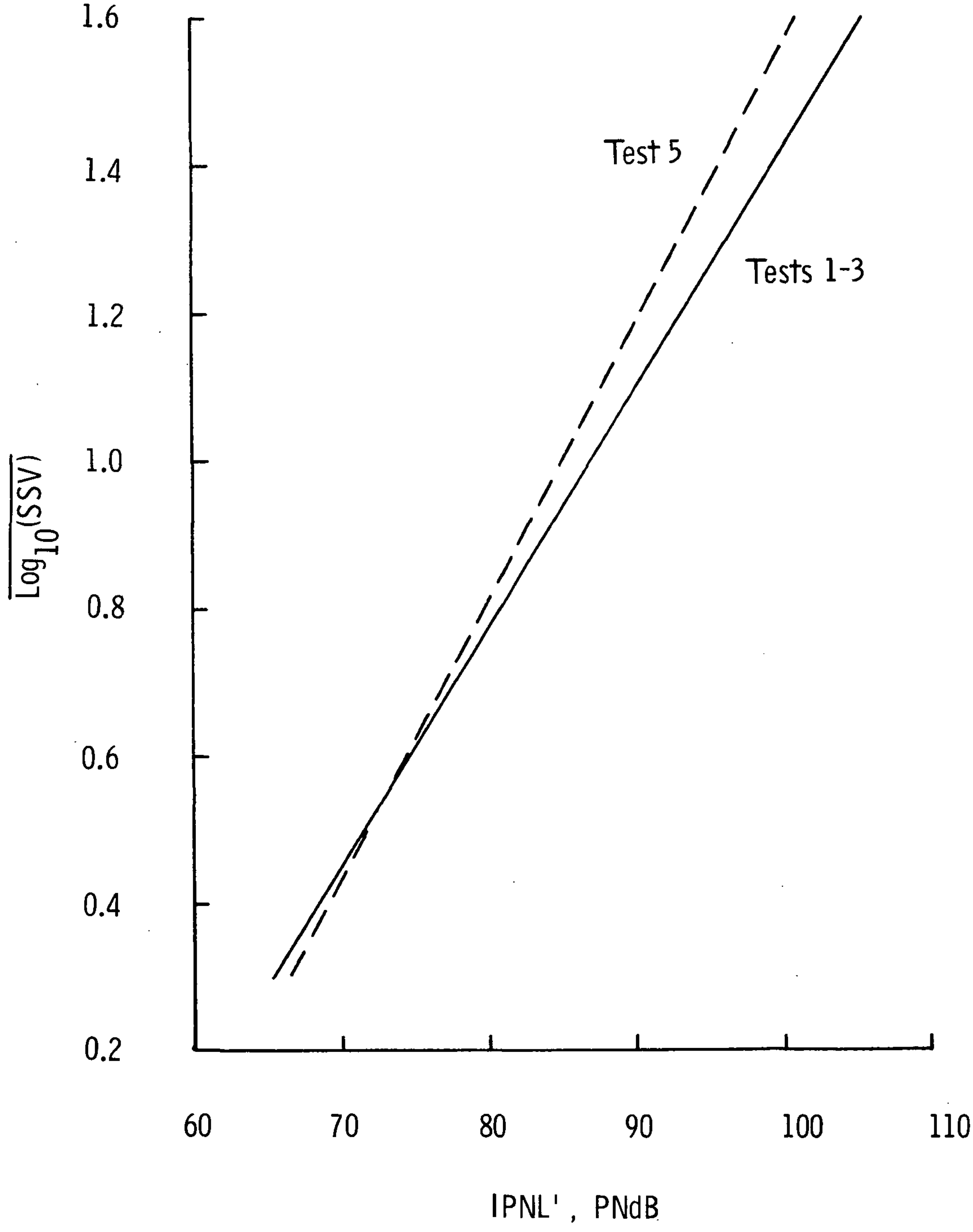


Figure 12.- Best mean fit of tests 1 to 3 as compared to test 5.

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—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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