NASA Technical Memorandum 87637

COMPARISON OF ADVANCED TURBOPROP AND CONVENTIONAL JET AND PROPELLER AIRCRAFT FLYOVER NOISE ANNOYANCE: PRELIMINARY RESULTS

(NASA-TM-87637) COMPARISON OF ALVANCED TURBOPROP AND CONVENTIONAL JET AND PROPELLER AIRCRAFT FLYOVER NOISE ANNOYANCE: PRELIMINARY RESULTS (NASA) 30 p HC A03/MF A01
CSCL 20A G3/71
N86-17077
Unclas
05256

DAVID A. McCURDY

NOVEMBER 1985

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665

COMPARISON OF ADVANCED TURBOPROP AND CONVENTIONAL JET AND PROPELLER AIRCRAFT FLYOVER NOISE ANNOYANCE: PRELIMINARY RESULTS

David A. McCurdy

ABSTRACT

A laboratory experiment was conducted to compare the flyover noise annoyance of proposed advanced turboprop aircraft with that of conventional turboprop and jet aircraft. The effects of fundamental frequency and tone-to-broadband noise ratio on advanced turboprop annoyance were also examined. A computer synthesis system was used to generate 18 realistic, time varying simulations of propeller aircraft takeoff noise in which the harmonic content was systematically varied to represent the factorial combinations of six fundamental frequencies ranging from 67.5 Hz to 292.5 Hz and three tone-to-broadband noise ratios of 0, 15, and 30 dB. These advanced turboprop simulations along with recordings of five conventional turboprop takeoffs and five conventional jet takeoffs were presented at D-weighted sound pressure levels of 70, 80, and 90 dB to 32 subjects in an anechoic chamber. Analyses of the subjects' annoyance judgments compare the three categories of aircraft and examine the effects of the differences in harmonic content among the advanced turboprop noises. The annoyance prediction ability of various noise measurement procedures and corrections is also examined.

SYMBOLS AND ABBREVIATIONS

ATP	advanced turboprop
EPNL	effective perceived noise level, dB (ref. 1, 5)
F_o	fundamental frequency, Hz
FAR	Federal Aviation Regulation
L_A	A-weighted sound pressure level, dB (ref. 5)
L_D	D-weighted sound pressure level, dB (ref. 5)
L_E	E-weighted sound pressure level, dB (ref. 5)
L_S	subjective level, dB
LL	loudness level (Stevens Mark VI procedures), dB (ref. 5)
LL_Z	Zwicker's loudness level, dB (ref. 5)
PL	perceived level (Stevens Mark VII procedure), dB (ref. 5)
PNL	perceived noise level, dB (ref. 1, 5)
T_1	EPNL tone correction method (ref. 1)
T_2	tone correction method identical to T_1 except that no corrections are applied for tones below the 500 Hz one-third-octave band

ATP

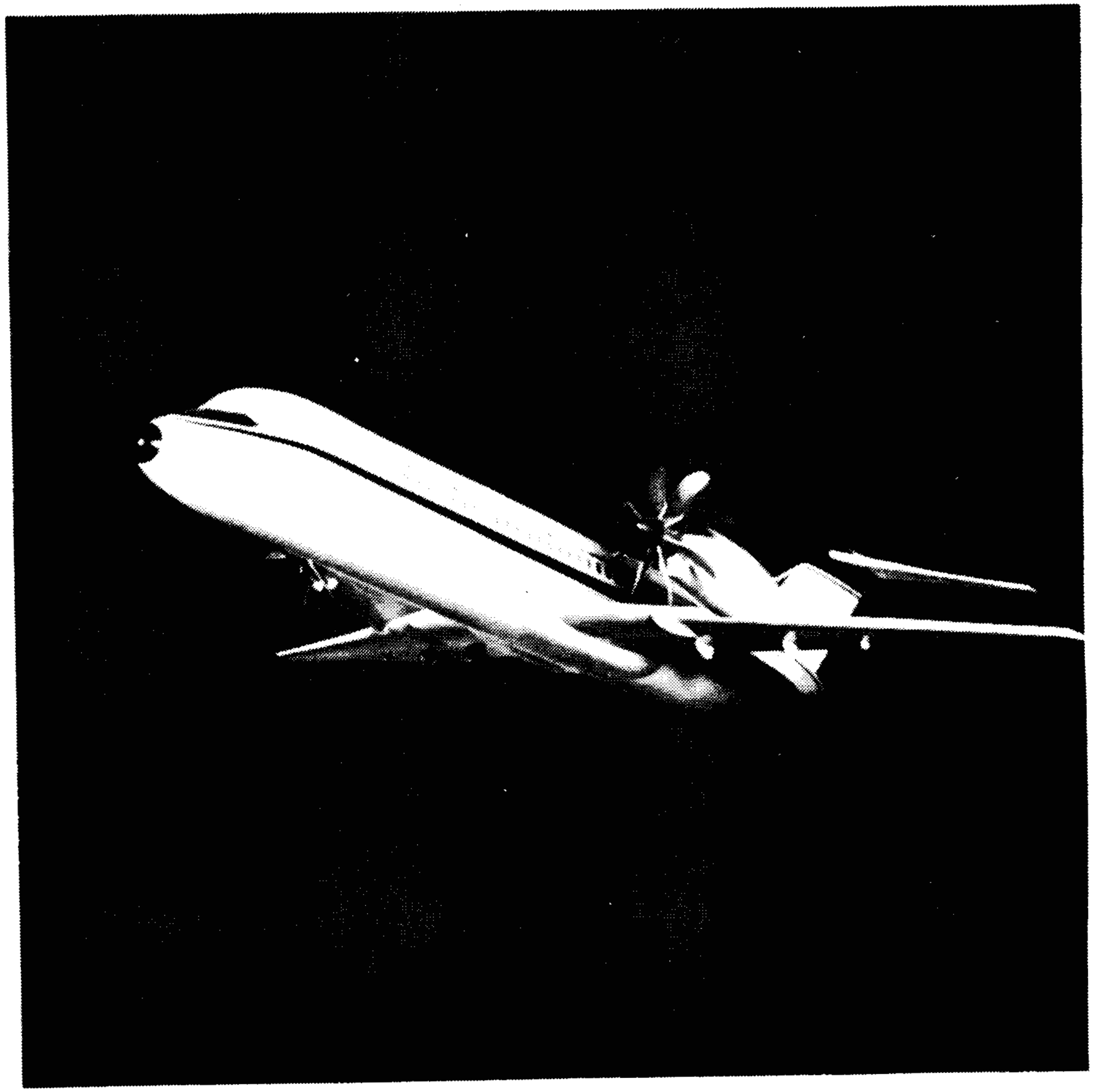


Figure 1.- A wing-mounted, tractor, single rotating propeller configuration of an advanced turboprop aircraft.

INTRODUCTION

The return of propeller aircraft to long haul commercial service may be rapidly approaching in the form of the advanced turboprop (ATP) or "propfan" aircraft. The advanced turboprop aircraft, whose propeller is vastly different from conventional propellers in shape and number of blades (figure 1), offers substantial savings in operating costs through improved energy efficiency. However, such an aircraft will come into general usage only if its noise, which has unique spectral characteristics, meets standards of community acceptability currently applied to existing aircraft. Much research has been directed towards understanding and quantifying the annoyance caused by jet aircraft flyover noise, but relatively little research has been conducted for conventional propeller noise and almost none has been done for advanced turboprop noise. To address this need, a laboratory experiment was conducted to quantify the annoyance of people to advanced turboprop and conventional turboprop and jet aircraft flyover noise.

The laboratory experiment had three specific objectives. The first was to compare annoyance responses to the three categories of aircraft. The second objective was to determine the effects on annoyance of fundamental frequency and tone-to-broadband noise ratio. Determining the ability of aircraft noise measurement procedures and corrections to predict annoyance was the last objective.

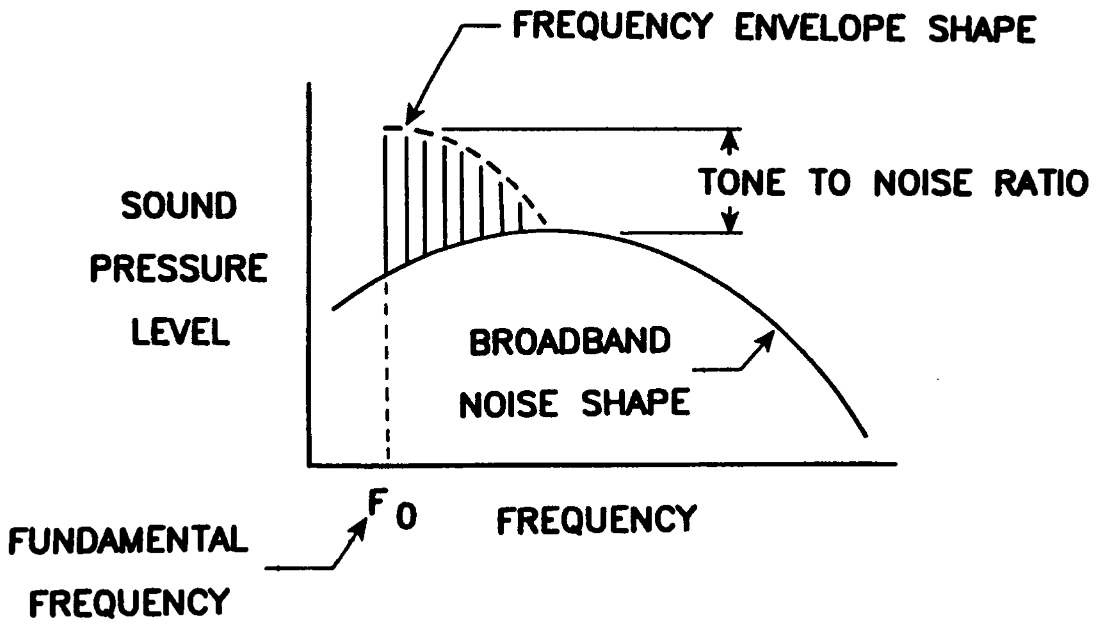


Figure 2.- Propeller aircraft noise characteristics.

ADVANCED TURBOPROP NOISE CHARACTERISTICS

The primary concern in quantifying advanced turboprop noise annoyance is the unique spectral characteristics of the noise. In general, propeller noise typically consists of a number of harmonically related pure tone components which are superimposed on broadband noise (figure 2). The fundamental frequency of these tones, which can dominate the total noise produced by the aircraft, occurs at the propeller blade passage frequency and ranges from 50 Hz to about 150 Hz for conventional propeller aircraft. For advanced turboprop aircraft, the fundamental frequency is predicted to range from 150 Hz to as high as 300 Hz, hence the uniqueness of the noise. The annoyance caused by noise sources with strong tonal components has historically been more difficult to quantify than broadband noise. The uncertainty in accounting for tonal content is increased in this case because less basic psychoacoustic research has been conducted in the lower frequency ranges of tones from conventional and advanced turboprop propellers than in the higher frequency range of tones from jet aircraft.

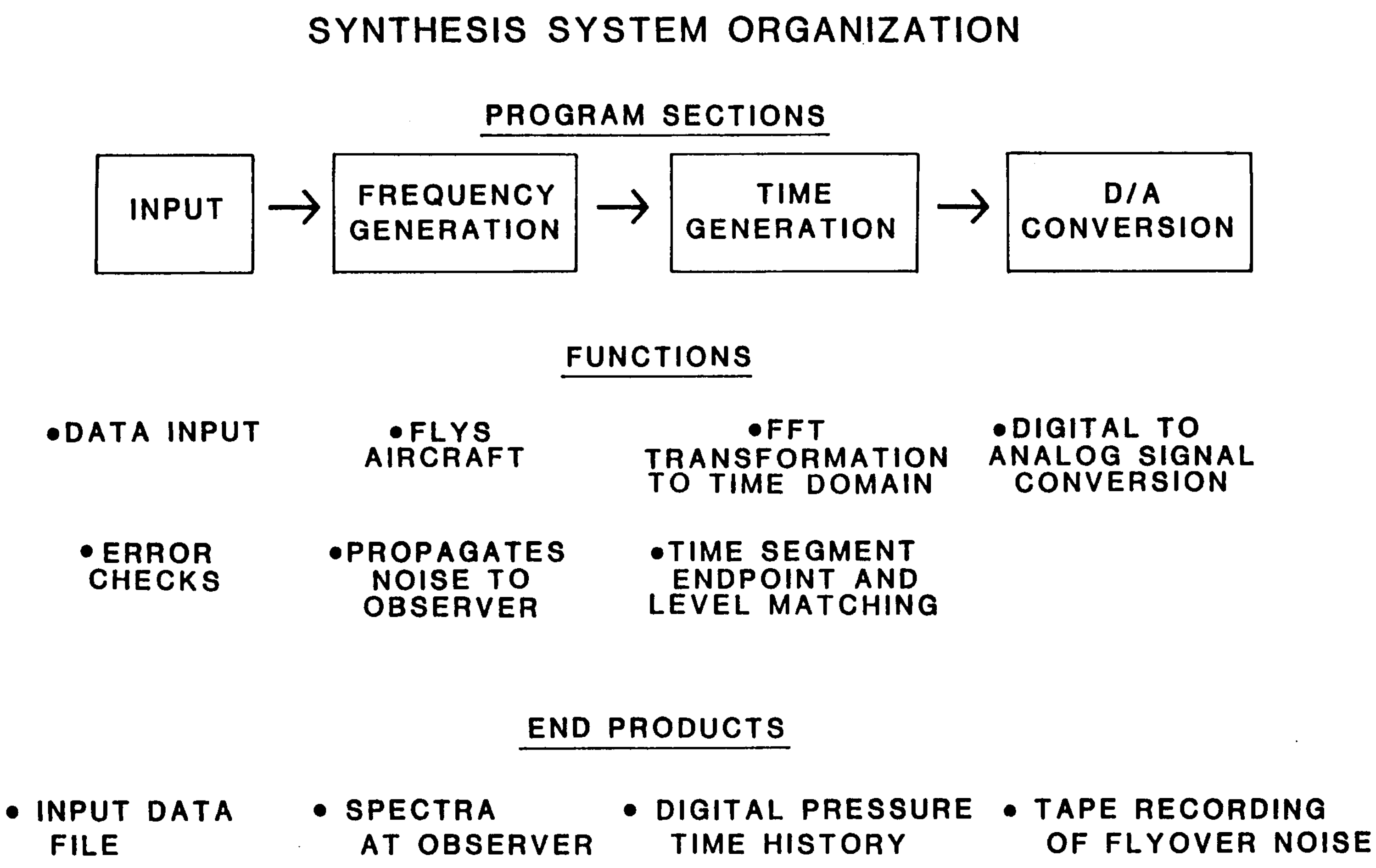
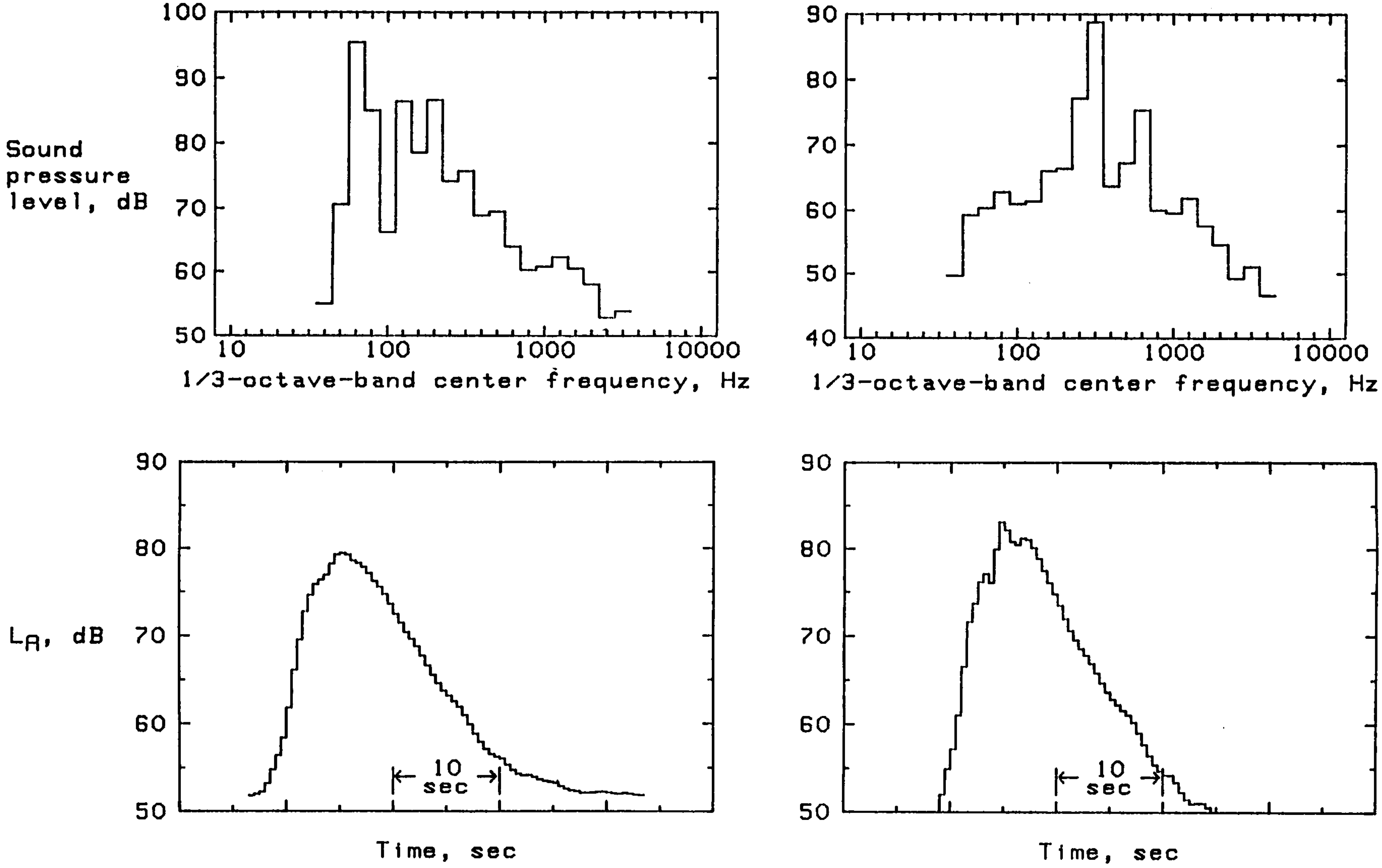


Figure 3.- Aircraft Noise Synthesis System.

AIRCRAFT NOISE SYNTHESIS SYSTEM

A recently developed Aircraft Noise Synthesis System (figure 3) was used to generate the advanced turboprop noise stimuli used in this experiment. The computer-based system generates realistic, time-varying, audio simulations of aircraft flyover noise at a specified observer location on the ground. The synthesis takes into account the time-varying aircraft position relative to the observer; specified reference spectra consisting of broadband, narrowband and pure tone components; directivity patterns; Doppler shift; atmospheric effects; and ground effects. These parameters can be specified and controlled in such a way as to generate stimuli in which certain noise characteristics such as fundamental frequency or duration are independently varied while the remaining characteristics such as broadband content are held constant.



(a) Fundamental frequency = 67.5 Hz

(b) Fundamental frequency = 292.5 Hz

Figure 4.- L_A time histories and one-third-octave band spectra at peak L_A of the highest level presentations of the advanced turboprop flyover noises with 30 dB tone-to-broadband noise ratios and fundamental frequencies of 67.5 and 292.5 Hz.

ADVANCED TURBOPROP NOISE STIMULI

The synthesis system was used to generate 18 simulations of advanced turboprop aircraft flyover noise in which the tonal content was systematically varied to represent the factorial combinations of six fundamental frequencies (67.5, 135, 180, 225, 260, and 292.5 Hz) and three tone-to-broadband noise ratios (0, 15, and 30 dB). (Tone-to-broadband noise ratio was defined to be the difference between the level of the fundamental tone and the level of the highest one-third-octave band of broadband noise). Although the range of fundamental frequencies covers both the conventional propeller aircraft (50 to 150 Hz) and the advanced turboprop aircraft (150 to 300 Hz), all the synthesized simulations are considered as advanced turboprops in comparisons in this preliminary report. Typical time histories and one-third-octave band spectra are shown in figure 4.

The simulations were limited to one takeoff flight profile, one observer location, one broadband noise spectrum, one broadband noise directivity pattern, and one helical tip Mach number. Each of these parameters was the same for each simulation. The takeoff flight profile used resulted in an altitude at closest approach to the observer of 380 m, about the altitude expected at the FAR 36 takeoff noise measurement location (ref. 1). The observer was located on the centerline of the ground track. Since predictions of advanced turboprop broadband noise were not available, the broadband spectral content was based on measurements of an existing, large, turboprop aircraft. Aircraft speed was 70 m/sec. A wing-mounted, tractor, single rotating propeller configuration using the SR-3 blade was assumed for all the simulations.

A computer program which calculates the discrete frequency noise of propellers (ref. 2) was used to determine the tonal components, frequency envelope shape (i.e. the sound pressure levels of the harmonics relative to the fundamental), and directivity patterns for the simulations. This information was then used as input to the synthesis system. The helical tip Mach number of 0.73 resulted in a frequency envelope shape with an approximately linear roll-off rate of 6.2 dB per 100 Hz. Each of the 18 simulations was presented to the test subjects at D-weighted sound pressure levels of 70, 80, and 90 dB. The factorial combinations of six fundamental frequencies, three tone-to-broadband noise ratios, and three levels resulted in 54 advanced turboprop aircraft flyover noise stimuli.

- 18 ADVANCED TURBOPROP TAKEOFFS
  - 6 FUNDAMENTAL FREQUENCIES – 67.5 to 292.5 Hz
  - 3 TONE TO BROADBAND NOISE RATIOS – 0, 15, 30 dB
  - GENERATED USING AIRCRAFT NOISE SYNTHESIZER
- 5 CONVENTIONAL TURBOPROP TAKEOFFS
  - P–3, YS–11, DASH–7, NORD 262, SHORTS 330
- 5 CONVENTIONAL JET TAKEOFFS
  - A–300, 707, 727, DC–9, DC–10
- 3 LEVELS
  - $L_D = 70, 80, 90$ dB

Figure 5.- Test stimuli.

CONVENTIONAL TURBOPROP AND JET NOISE STIMULI

A summary of the test stimuli is presented in figure 5. Takeoff recordings of five conventional turboprop aircraft (P-3, YS-11, Dash-7, Nord 262, Shorts 330) and five conventional jet aircraft (A-300, B-707, B-727, DC-9, DC-10) were included in the experiment. Each takeoff was presented at D-weighted sound pressure levels of 70, 80, and 90 dB for a total of 15 conventional turboprop noise stimuli and 15 conventional jet noise stimuli. The recordings of the jet aircraft were made on the runway centerline approximately 5000 m from the brake release point. The conventional turboprop aircraft all had maximum takeoff weights greater than 5700 kg. The turboprop aircraft recordings were made at several different airports and the distances from brake release varied. At each location, the turboprop aircraft recordings were made on or near the runway centerline. Because of the higher flight profiles and lower source noise levels of the turboprop aircraft, the recording sites for the turboprop aircraft were located closer to the brake release point than those for the jet aircraft.

Figure 6.- Subjects in anechoic test facility.

EXPERIMENTAL METHOD AND DESIGN

A small anechoic room in the Langley Aircraft Noise Reduction Laboratory was used as the test facility in the experiment (figure 6). Thirty-two test subjects judged the annoyance of each noise stimulus using a numerical category scale. The scale 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."

The means (across subjects) of the judgments were calculated for each stimulus. In order to obtain a subjective scale with meaningful units of measure, these mean annoyance scores were converted to "subjective levels," L_S, having decibel-like properties through the following process. Included in the experiment for the purpose of converting the mean annoyance scores to L_S values were seven additional presentations of the B-727 takeoff recording ranging in values of L_D from 65 to 95 dB in 5 dB increments. A second order polynomial regression analysis was performed using data obtained for these seven stimuli. The dependent variable was the calculated PNL and the independent variable was the mean annoyance score for each of the seven stimuli. The regression equation thusly determined was subsequently used to predict the level of the B-727 takeoff noise which would produce the same mean annoyance score as each of the other noise stimuli in the experiment. These levels were then considered as the "subjective level" for each stimulus.

Each stimulus was analyzed to provide one-third-octave band sound pressure levels from 20 Hz to 20 kHz for use in computing a selected group of noise metrics. These included the simple weighting procedures L_A, L_D, and L_E and the more complex calculation procedures LL, LL_Z, PL, and PNL. Six different variations of each of the noise metrics were calculated. The first was the peak or maximum level occurring during the flyover 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 (EPNL) defined in the Federal Aviation Administration FAR 36 regulation (ref. 1). 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.

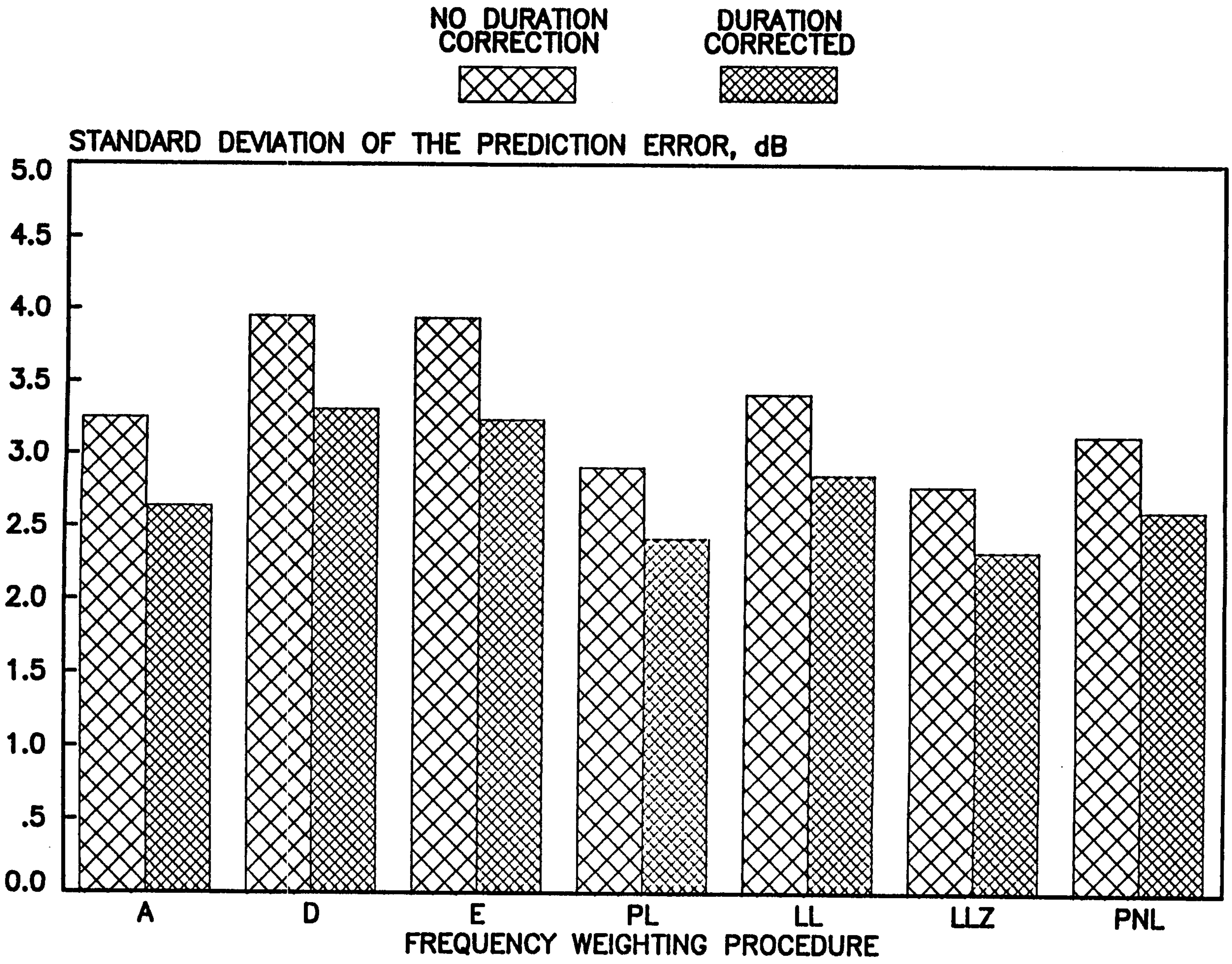


Figure 7.- Comparison of frequency weighting procedures for all aircraft.

COMPARISON OF FREQUENCY WEIGHTING PROCEDURES

In order to investigate the prediction ability of the noise measurement procedures and corrections, the differences between the subjective level and the calculated noise level for each of the six variations of the measurement procedures and corrections were determined for each stimulus. 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, the greater the prediction accuracy. The results for all three types of aircraft combined are given in figure 7. The figure illustrates the standard deviations of prediction error, averaged across the different tone correction variations, for the seven noise metrics both with and without duration corrections. Comparisons of the procedures in figure 7 clearly indicate that annoyance prediction was improved by the addition of duration corrections. LL_Z, followed by PL, PNL, and L_A, had the smallest standard deviation of prediction error for both the duration corrected and uncorrected cases. It should be noted that, because of interrelationship between the data cases, statistical tests for significance of differences in the standard deviations of prediction error are not straightforward. Approximate statistical tests indicate that differences in standard deviations as small as 0.10 dB could be significant.

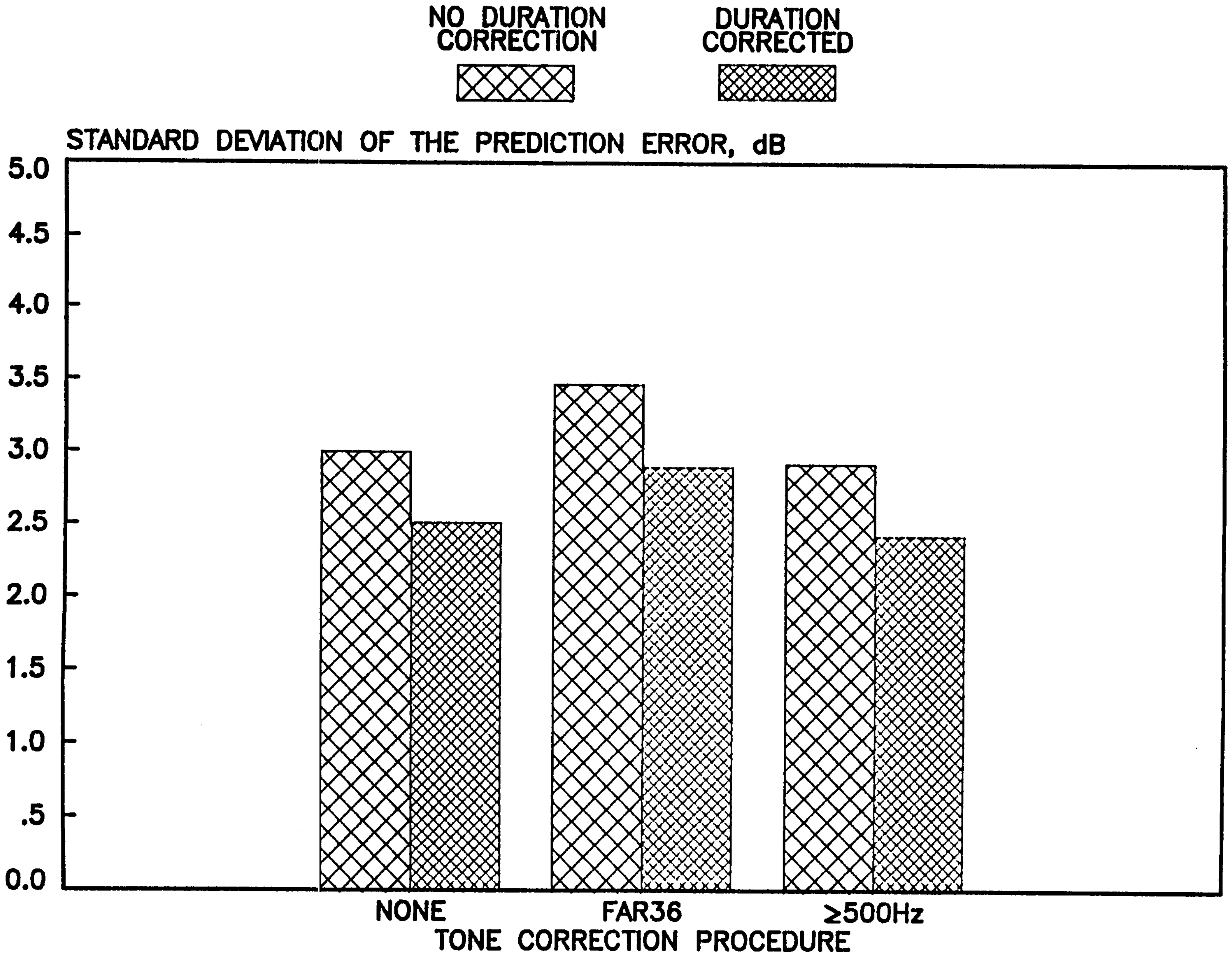


Figure 8.- Comparison of tone correction procedures when applied to PNL for all aircraft.

COMPARISON OF TONE CORRECTION PROCEDURES

Figure 8 compares the standard deviations of prediction error for the three variations of tone corrections when all three types of aircraft are considered together. The figure plots the standard deviation of prediction error for each of the six variations of the PNL noise metric. For both the duration corrected and uncorrected cases, the modified tone correction, T_2, which does not apply corrections for tones below 500 Hz, improved prediction ability while the standard tone correction, T_1, degraded prediction ability. This result was consistent for each of the noise metrics considered and agrees with results from previous studies of propeller noise (ref. 3, 4).

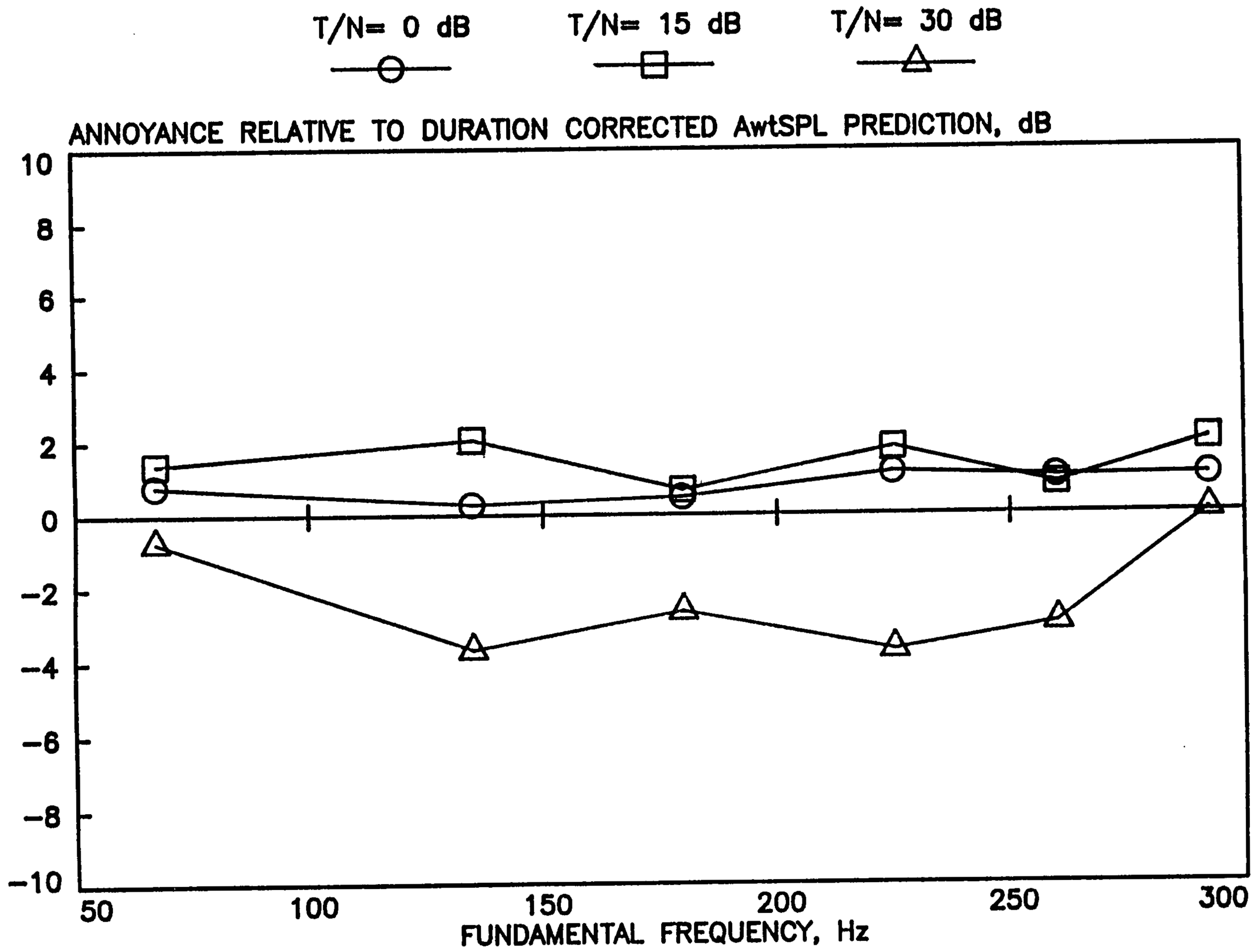


Figure 9.- Interaction of fundamental frequency and tone-to-broadband noise ratio for ATP stimuli in terms of duration corrected L_A.

INTERACTION OF FUNDAMENTAL FREQUENCY AND TONE-TO-BROADBAND NOISE RATIO -- DURATION CORRECTED L_A

Figure 9 illustrates the effects of fundamental frequency and tone-to-broadband noise ratio on annoyance to the advanced turboprop flyover noises. The figure shows that the interaction of fundamental frequency and tone-to-broadband noise ratio did have a large effect on annoyance. In the figure, annoyance relative to duration corrected L_A is plotted versus fundamental frequency for each of the three tone-to-broadband noise ratios. "Annoyance relative to a metric" is the prediction error (subjective level minus the calculated level of the metric) normalized by substracting the average prediction error for the metric. Thus a positive number represents annoyance greater than that predicted by the metric and results for different metrics can be directly compared. Annoyance to the high tone-to-noise ratio, 30 dB, flyovers was less than the annoyance to the other flyovers and varied considerably depending on the fundamental frequency of the tonal content. A previous study (ref. 4) also found an interaction, but indicated a somewhat more severe impact on annoyance.

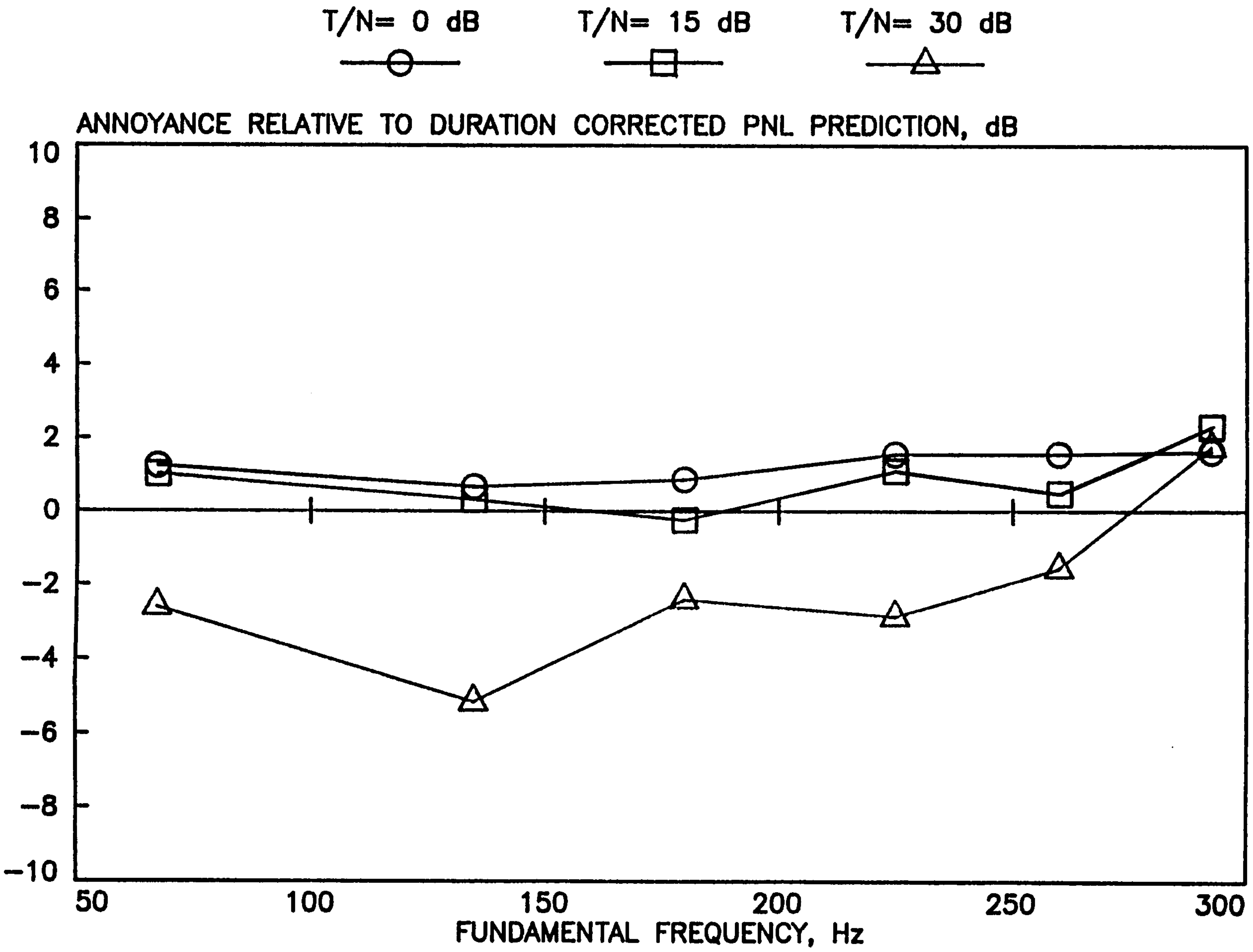


Figure 10.- Interaction of fundamental frequency and tone-to-broadband noise ratio for ATP stimuli in terms of duration corrected PNL.

INTERACTION OF FUNDAMENTAL FREQUENCY AND TONE-TO-BROADBAND NOISE RATIO — OTHER METRICS

Figure 10 illustrates the interaction of fundamental frequency and tone-to-broadband noise ratio for duration corrected PNL. As in figure 9 for duration corrected L_A, a significant interaction is indicated. However, for duration corrected PNL the difference between the 30 dB tone-to-noise ratio and the lower ratios was slightly less in the higher frequencies. In general, the better the annoyance prediction ability of the metrics (as shown in figure 7), the smaller the difference in annoyance between the tone-to-noise ratios at the higher fundamental frequencies.

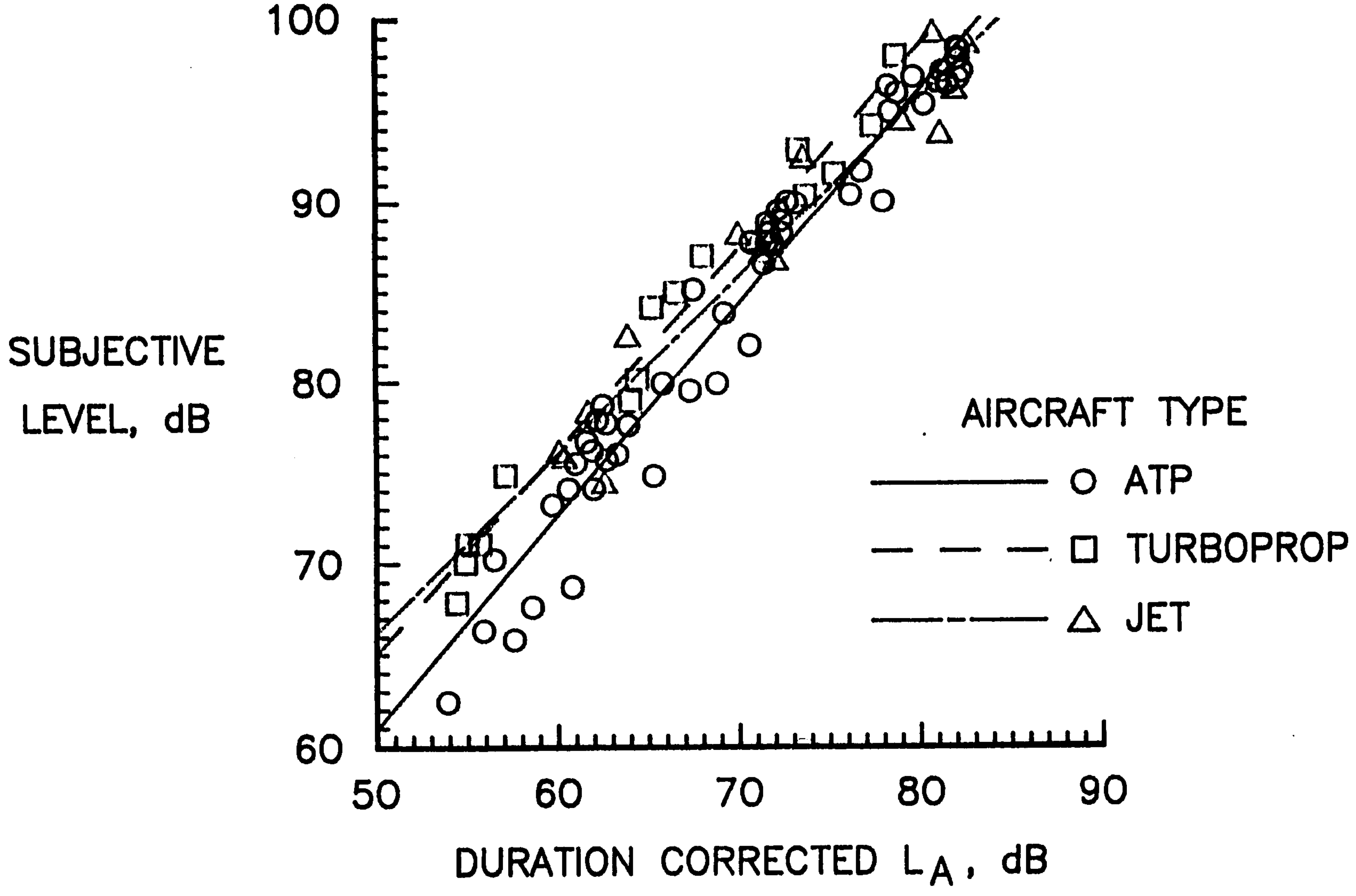


Figure 11.- Comparison of annoyance responses using duration corrected L_A.

COMPARISONS OF ANNOYANCE RESPONSES BETWEEN AIRCRAFT TYPES -- DURATION CORRECTED L_A

Figure 11 compares the annoyance responses to advanced turboprop, conventional turboprop and conventional jet aircraft flyover noises. The figure plots subjective level versus duration corrected L_A for each of the three categories of aircraft. Simple linear regression lines for each of the aircraft types are also shown. Although the differences in annoyance between aircraft types are small, indicator (dummy) variable analyses for the duration corrected L_A metric show a significant difference in slope and intercept between the appropriate regressions for the advanced turboprop noises and the combined set of conventional turboprop and jet noises.

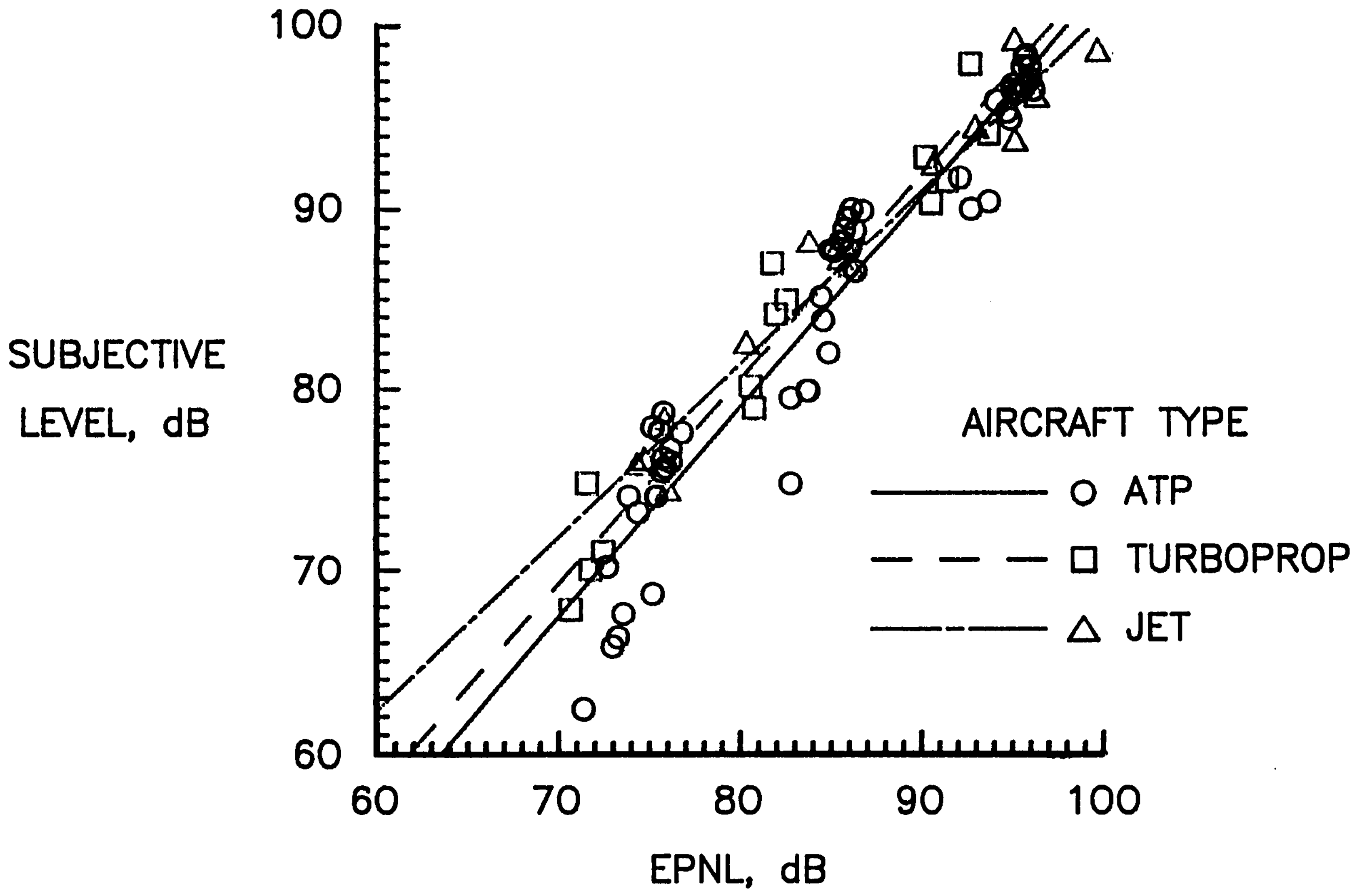


Figure 12.- Comparison of annoyance responses using EPNL.

COMPARISON OF ANNOYANCE RESPONSES BETWEEN AIRCRAFT TYPES — OTHER METRICS

Figure 12 compares the annoyance responses to advanced turboprop, conventional turboprop, and conventional jet aircraft flyover noises using EPNL. The results for EPNL are similar to those for duration corrected L_A, except that the difference between the advanced turboprop and conventional turboprop noises is less. For EPNL, indicator variable analyses show a significant difference in intercept between the appropriate regressions for the advanced turboprop noises and the combined set of conventional turboprop and jet noises. For all the metrics considered, indicator variable analyses demonstrated a significant difference in appropriate regression slope and/or intercept between the advanced turboprop noises and the separate or combined conventional turboprop and jet noises.

SUMMARY

A laboratory experiment was conducted to compare the annoyance to advanced turboprop aircraft flyover noise with the annoyance to conventional turboprop and jet aircraft flyover noise. Thirty-two test subjects judged the annoyance of 54 advanced turboprop, 15 conventional turboprop, and 15 conventional jet aircraft flyover noise stimuli in an anechoic listening facility. The following preliminary results were noted:

- Duration corrections improved annoyance prediction
- Limiting tone corrections to tones at or above 500 Hz improved annoyance prediction
- Zwicker's loudness level had the smallest standard deviation of prediction error
- The interaction of fundamental frequency and tone-to-broadband noise ratio did have a significant effect on annoyance response
- Small, but significant, differences in annoyance response between the advanced turboprops and the conventional turboprops and jets were found. The advanced turboprops were slightly less annoying.

REFERENCES

1. Noise Standards: Aircraft Type Certification, Federal Aviation Regulations, Vol. III, pt. 36, FAA, 1978.
2. Martin, R. M. and Farassat, F.: Users' Manual for a Computer Program to Calculate Discrete Frequency Noise of Conventional and Advanced Propellers. NASA TM 83135, August 1981.
3. McCurdy, David A.: Annoyance Caused by Propeller Airplane Flyover Noise. NASA TP 2356, August 1984.
4. McCurdy, David A.: Quantification of Advanced Turboprop Aircraft Flyover Noise Annoyance. AIAA-84-2293, October 1984.
5. Pearsons, Karl S. and Bennett, Ricarda L.: Handbook of Noise Ratings. NASA CR 2376, 1974.

1. Report No.
NASA TM-87637

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
COMPARISON OF ADVANCED TURBOPROP AND CONVENTIONAL JET AND PROPELLER AIRCRAFT FLYOVER NOISE ANNOYANCE: PRELIMINARY RESULTS

5. Report Date
November 1985

6. Performing Organization Code
535-03-12-01

7. Author(s)
David A. McCurdy

8. Performing Organization Report No.

9. Performing Organization Name and Address
NASA Langley Research Center
Hampton, VA 23665-5225

10. Work Unit No.

11. Contract or Grant No.

12. Sponsoring Agency Name and Address
National Aeronautics and Space Administration
Washington, DC 20546

13. Type of Report and Period Covered
Technical Memorandum

14. Sponsoring Agency Code

15. Supplementary Notes

To be presented at 110th Acoustical Society America Conference, November 4-8, 1985, Nashville, TN.

16. Abstract

A laboratory experiment was conducted to compare the flyover noise annoyance of proposed advanced turboprop aircraft with that of conventional turboprop and jet aircraft. The effects of fundamental frequency and tone-to-broadband noise ratio on advanced turboprop annoyance were also examined. A computer synthesis system was used to generate 18 realistic, time varying simulations of propeller aircraft takeoff noise in which the harmonic content was systematically varied to represent the factorial combinations of six fundamental frequencies ranging from 67.5 Hz to 292.5 Hz and three tone-to-broadband noise ratios of 0, 15, and 30 dB. These advanced turboprop simulations along with recordings of five conventional turboprop takeoffs and five conventional jet takeoffs were presented at D-weighted sound pressure levels of 70, 80, and 90 dB to 32 subjects in an anechoic chamber. Analyses of the subjects' annoyance judgments compare the three categories of aircraft and examine the effects of the differences in harmonic content among the advanced turboprop noises. The annoyance prediction ability of various noise measurement procedures and corrections is also examined.

17. Key Words (Suggested by Author(s))
Advanced Turboprop Noise
Propfan Noise
Propeller Noise
Subjective Acoustics
Psychoacoustics

18. Distribution Statement

Unclassified - Unlimited

Subject Category - 71

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	30	A03

N-305

For sale by the National Technical Information Service, Springfield, Virginia 22161