NASA-TM-87129

NASA Technical Memorandum 87129

NASA-TM-87129 19860009654

Laboratory Experiments on Active Suppression of Advanced Turboprop Noise

James H. Dittmar
Lewis Research Center
Cleveland, Ohio

December 1985

LIBRARY COPY

MAR 7 1986

LANGLEY RESEARCH CENTER
LIBRARY, NASA
HAMPTON, VIRGINIA

NF01471

NASA

LABORATORY EXPERIMENTS ON ACTIVE SUPPRESSION OF ADVANCED TURBOPROP NOISE

James H. Dittmar
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

E-2740

SUMMARY

The noise generated by supersonic tip speed propellers may be a cabin environment problem for future propeller-driven airplanes. Active suppression from speakers inside the airplane cabin has been proposed for canceling out this noise. The potential of active suppression of advanced turboprop noise was tested by using speakers in a rectangular duct. Experiments were first performed with sine wave signals. The results compared well with the ideal cancellation curve of noise as a function of phase angle. Recorded noise signals from subsonic and supersonic tip speed propellers were then used in the duct to determine the potential for canceling their noise. The subsonic propeller data showed significant cancellations but less than those obtained with the sine wave. The blade-passing-tone cancellation curve for the supersonic propeller was very similar to the subsonic curve, indicating that it is potentially just as easy to cancel supersonic as subsonic propeller blade-passing-tone noise. Propeller duct data from a recorded propeller source and spatial data taken on a propeller-driven airplane showed generally good agreement when compared versus phase angle. This agreement, combined with the similarity of the subsonic and supersonic duct propeller data, indicates that the area of cancellation for advanced supersonic propellers will be similar to that measured on the airplane. Since the area of cancellation on the airplane was small, a method for improving the active noise suppression by using outside speakers is discussed.

INTRODUCTION

Advanced design turboprop-powered aircraft show significant fuel saving advantages over equivalent technology turbofan-powered aircraft. However, the cabin noise from the high-speed propellers may pose a passenger acceptance problem for turboprop-powered aircraft. Active suppression has been proposed as a method for reducing the cabin noise. In this method the propeller noise is suppressed by adding sound that is out of phase with it. It has been suggested that a speaker to broadcast the out-of-phase sound be placed inside the passenger cabin (e.g., ref. 1). An excellent review of the state of the art of active noise suppression (ref. 2) indicates that this technology is sufficiently mature that the noise reduction could be significant.

The airborne noise from an advanced propeller is envisioned as entering the passenger cabin somewhat as shown in figure 1(a). The noise impacts the outer fuselage of the airplane over a somewhat limited area, as indicated by the model tests of reference 3 and shown here in figure 1(b). The noise is then transmitted into the airplane frame and stringer structure, into the air between the trim panels and outer skins, and then into the interior floor and trim, which reradiate the noise to the passenger compartment. In the airplane

N86-19195#

cabin the source may not be as compact as that striking the outer skin since the noise could now be coming from different sections of the airplane trim. Even if the noise comes from a localized area inside the airplane, it is probably composed of different components with various phase relationships since it arrives via different transmission paths. In either case the active noise suppression achieved by an out-of-phase speaker may be limited in extent. In some canceling region the speaker radiates sound that is out of phase with the propeller noise, but as one moves away from that region the phase relationship of primary and canceling signals changes. In these regions the sound from the speaker is not 180° out of phase with the propeller noise and less suppression occurs.

To evaluate the potential for active noise suppression in an airplane, some laboratory experiments were performed with first sine wave and then recorded propeller noise signals in a duct to determine the dependence of the cancellation on the phase angle between the sound and the canceling signal. The noise from an advanced propeller operating at a subsonic helical tip Mach number was the first propeller signal used, and then noise from the propeller operating at supersonic conditions was evaluated. This was done to determine if the different acoustic pressure pulse shape of the noise at supersonic helical tip speed had any effect on the potential for active noise suppression. The results of these experiments, some comparisons with previously published airplane data and their implications, and some suggestions for improving the active suppression of advanced propeller noise are described in this report.

APPARATUS AND PROCEDURE

The experiments were performed in a rectangular duct with a 3.81- by 10.16-cm (1.5- by 4-in.) cross section (fig. 2(a)). The test section (fig. 2(a)) was the 1.42-m (4.75-ft) long section adjacent to the exponential horn. This section consisted of hard side walls with removable hard plates on the top and bottom. This duct and its acoustic characteristics are described in reference 4. Two of the hard plates on the top of the duct were replaced with sections containing horns and speakers. A third plate was replaced with a flush-mounted microphone holder. One end of the duct terminated in a horn open to the room, and the other end terminated in an acoustically lined section before it also opened to the room. Figure 2(b) shows the duct apparatus and the speaker and microphone installation.

The source signal was input to speaker A (fig. 2(a)), and a canceling signal of the same strength was input to speaker B located 50.8 cm (20 in.) away. The phase of the canceling signal was varied with respect to the source signal, and the resultant noise was measured with a microphone placed approximately in the center of the duct cross section and 50.8 cm (20 in.) from speaker B. These experiments used frequencies low enough so that only plane waves were present in the duct. (Again see ref. 4 for the duct characteristics.)

For the sine wave experiments a sine wave generator was used that enabled the signals coming from the generator to be varied in relative phase (fig. 3(a)). For the recorded propeller noise experiments an analog phase shifting network was used, and the phase was measured by a phase meter installed as shown in figure 3(b). The noise measured by the microphone was

analyzed on a narrowband analyzer with approximately a 25-Hz bandwidth. The spectra were used to accurately determine the noise attenuation at the fundamental frequency.

RESULTS AND DISCUSSION

Ideal Cancellation

The summation of two sinusoidal pressure waves of amplitude P_0 with relative phase angle Φ can be expressed simply as

$$P(t) = P_0 \sin(wt) + P_0 \sin(wt + \Phi)$$

where w is frequency and t is time. When the two sine waves are in phase ($\Phi = 0$), the pressure amplitude is $2P_0$; when they are out of phase ($\Phi = 180°$), the pressure amplitude is zero. If these two sine waves represent the sound being generated by the duct-mounted speakers, an ideal cancellation curve of sound versus phase angle can be calculated. Expressed in decibels relative to the amplitude of a single wave (dB = 20 $\log_{10} P/P_0$), the preceding equation yields the ideal cancellation curve presented in figure 4. When the two signals are in phase, there is an additional 6 dB of noise; when they are out of phase, the cancellation results in $-\infty$. As shown in figure 4 the resultant level is below the pressure of the single source for some 120° of phase angle, between 120° and 240°.

Sine Wave Duct Experiments

Some 0.61-m (2-ft) diameter models of advanced propellers have been tested in the NASA Lewis 8- by 6-Foot Wind Tunnel (refs. 5 and 6) and on the NASA Jetstar airplane (refs. 7 and 8). At the cruise condition (axial Mach number, M, 0.8; helical tip Mach number, M_{ht}, 1.14), these propeller models generate a blade passing tone at approximately 1000 Hz. (Full-scale propellers would be significantly larger and have a correspondingly lower blade passing frequency.) Experiments were performed in the duct starting at 125 Hz, corresponding to a nominally 4.9-m (16-ft) diameter propeller, and were repeated in 125-Hz steps to 1000 Hz. A sine wave generator was set at the test frequency and connected through an amplifier to speaker A (fig. 2(a)) while a signal of equal strength but with varying relative phase angle was applied to speaker B. The phase angle was varied in 10° steps except near the 180° position, where the phase was varied in 0.1° steps to find the minimum pressure. The resultant data, noise level as a function of phase angle, were almost identical for all eight frequencies tested. Rather than plot them all, four representative frequencies (250, 500, 750, and 1000 Hz) were chosen (fig. 5). The sine wave data indicated 30 to 35 dB of cancellation at the out-of-phase (180°) condition and 6 dB of reinforcement at the in-phase (0°) condition. The data fall on the ideal curve except near 180°, where the amount of duct cancellation is probably limited by background noise. This good comparison with the ideal gives confidence to proceed with the more complicated propeller noise signals.

SR-2 Propeller Noise in Duct

The recorded noise from the SR-2 propeller model on the Jetstar airplane (ref. 8) was used in the duct apparatus to measure its cancellation potential. Airplane data were used for the propeller operating at a subsonic helical tip speed ($M = 0.606$, $M_{ht} = 0.85$) and at a supersonic helical tip speed ($M = 0.792$, $M_{ht} = 1.11$). Here the recorded signal was played through speaker A; the signal was also put through a phase-shifting network and adjusted to equal strength and played through speaker B. The SR-2 model data had blade passing tones of approximately 750 Hz at subsonic conditions and 975 Hz at supersonic conditions. For these experiments the tape recorder was slowed to one-quarter of its normal speed so that the tones came at approximately 187 and 244 Hz to simulate full scale. Typical wave shapes for these conditions (fig. 6) were taken by triggering an oscilloscope with a once-per-revolution signal that was recorded with the propeller noise data. The wave shapes are different at subsonic and supersonic conditions. Pulse shape differences exist between each successive blade passing. The nonrepeatability of the signal is important because the distance between the speakers means that, when the wave arrives from speaker A, the wave being canceled is not the same one as being emitted by speaker B. This nonrepeatability of the signal would also be important for canceling propeller noise in an airplane because an active noise synthesizer would probably not be able to account for these apparent blade-to-blade differences either.

Spectra of the propeller noise as played into the duct (fig. 7) show blade passing tones at 187 Hz (subsonic) and 244 Hz (supersonic). Although both spectra are dominated by the blade passing tone and the first harmonic, the supersonic spectrum also has several higher harmonics.

For the blade-passing-tone data obtained with the subsonic propeller noise signal (fig. 8(a)), the amount of noise cancellation was significant but somewhat less than observed with the sine wave. The differences can be more easily seen in figure 8(b) where the SR-2 data and the 250-Hz sine wave curve are shown on the same plot. Here the subsonic SR-2 data show less maximum cancellation and also a smaller cancellation range (45°) than the sine wave (120°). These results are possibly related to the nonrepeatability of the SR-2 wave shape.

For the blade-passing-tone data obtained with the supersonic propeller noise signal (fig. 9(a)), the amount of noise cancellation was again significant but less than observed with the sine wave. It was very similar to the subsonic noise cancellation (fig. 9(b)). Thus it is potentially as easy to cancel the blade passing tone of supersonic propellers as that of subsonic propellers.

Comparison with Airplane Experiments

Experiments were performed (ref. 9) wherein a single speaker was used in an airplane to actively suppress propeller noise. This airplane had a conventional subsonic helical tip speed propeller operated such that its blade passing tone was at approximately 100 Hz. In the airplane experiments the system was optimized to give maximum cancellation at a given location. The amount of cancellation at other positions was measured by a microphone array. The airplane data at the different microphone locations can be converted to phase

plots for comparison with the duct data. The amount of cancellation at each grid point is shown in figure 19 of reference 9. This figure is redrawn and presented here as figure 10. By assuming that the position where the maximum cancellation occurred (-25 dB) was where the canceling speaker signal was 180° out of phase with the propeller signal, the phase at the other positions could be calculated. It was first assumed (as indicated in fig. 1) that part of the noise at the other positions was coming either from another component (some other part of the trim) or from the same area but with different phase. The positions of the microphones were known; so the distances from the out-of-phase (180°) position were used to calculate a phase angle change based on the wavelength of the signal and the distance to the canceling speaker (fig. 10). Because the available data only showed one-half of the range the curve was assumed to be symmetric. The resultant plot (fig. 11(a)) has the same general shape as the propeller noise curves from the duct experiments, exhibiting roughly a 25-dB maximum cancellation and showing a noise increase when the signals were in phase.

The airplane data taken at 100 Hz compared well with the propeller duct data taken at 187 and 244 Hz (fig. 11(b)). In the plane-wave duct test, where the phase was adjusted to achieve maximum cancellation, the cancellation was observed everywhere in the duct downstream of speaker B. The duct data were obtained by the intentional variation of phase angle. On the airplane the active noise suppressor was adjusted to give maximum cancellation at a particular location. The amount of cancellation decreased with distance from this location probably because of multiple, separated components or components of different phase in the same area and the interior geometry of the airplane. When the spatial variation of the airplane cancellation was converted to a phase plot, the airplane data fell surprisingly close to the subsonic propeller data taken in the duct. This, combined with the similarity of the subsonic and supersonic propeller duct data, indicates that the area of cancellation for advanced supersonic propellers would be similar to that measured with a conventional propeller on the airplane.

Enlarging Airplane Noise Cancellation Area

In the duct experiments, where cancellation occurred, it occurred everywhere downstream of speaker B. The reason was that the duct had a single coherent source, speaker A, producing a plane wave in the duct that was canceled by the downstream speaker B. The phase variation was input to obtain the data curves of cancellation as a function of phase angle. In the airplane experiments either multiple, separated sources or out-of-phase sources in the same area and the airplane interior geometry significantly limited the area over which the cancellation occurred. A number of methods for enlarging the area of cancellation have been suggested, such as more speakers inside the airplane and the use of optimum speaker locations. There is, however, some indication that a better active noise suppression scheme might be to provide the cancellation outside the airplane.

In a study of noise reduction by synchrophasing (ref. 10) it was concluded that the propeller noise enters the airplane exterior wall in a limited area about one propeller diameter in size and then propagates through the airplane interior. This is also suggested by model supersonic propeller data from figure 18 of reference 3. Thus on the outside of the fuselage a much smaller area would need to be controlled by active noise cancellation. This concept

is supported by reference 11, where it is indicated that active noise suppression can be effectively used at a boundary to block the passage of noise from one subfield to another (i.e., across the boundary). In this case the outside noise would be blocked from entering the airplane. Although reference 1 indicates the difficulty of canceling noise outside the fuselage because of an assumed large area, the study of reference 10 and the data of reference 3 suggest the area would be limited. Reference 12 shows that exterior speakers mounted behind the nacelle of a model propeller can provide significant cancellation but also indicates some of the possible problems with external speakers, such as high power requirements.

Another support for the outside scheme as possibly the most promising is the airplane experiment itself (ref. 9). A microphone placed on the outside of the airplane was found to be the most effective method for providing input to the active noise suppression network; an interior microphone was found to be the least effective. Because of the relatively limited area over which outside cancellation would have to be applied, as contrasted to the interior cancellation area, externally mounted speakers may be a more effective active noise suppression configuration than speakers mounted inside the airplane.

CONCLUDING REMARKS

The potential of active suppression of advanced turboprop noise was initially evaluated by using speakers in a rectangular duct. Experiments were first performed by using sine waves and varying the phase angle between the source speaker and a canceling speaker. This resulted in variations of sound pressure level with phase angle that were very close to the predicted ideal. The maximum cancellation observed in the duct test was probably limited by the background noise level. Recordings of subsonic and supersonic advanced propeller noise data were used in the duct to measure the ability to cancel the blade passing tone resulting from their realistic pressure-time wave shapes and to examine the relative noise canceling potential at subsonic and supersonic conditions. The amount of cancellation observed for the subsonic propeller was significant but less than that of the sine wave. The subsonic propeller data showed less maximum cancellation and a smaller range of phase angles over which cancellation occurred than did the sine wave data. The supersonic propeller blade-passing-tone cancellation curve was very similar to the subsonic curve, indicating that it is potentially just as easy to cancel the blade passing tone of a supersonic propeller as of a subsonic one.

The cancellations were performed at the blade passing tone of the recorded propeller signals. It has been implied (fig. 19 of ref. 9) that it is harder to cancel the harmonics of the blade passing tone than the tone itself. If so, it may be harder to completely cancel the supersonic propeller noise signal since it has more harmonics than the subsonic propeller signal (fig. 8). This would also apply to counterrotating propellers with their even higher harmonic content.

Some existing data from active noise suppression experiments on an airplane were compared with the duct data. This experiment had used a speaker inside an airplane at cruise. The variation with distance that was observed on the airplane was converted, by using the sound wavelength, into a phase variation. The resulting variation in sound pressure level with phase angle was similar to that obtained for the propeller source in the duct experiments.

The good comparison of the airplane subsonic propeller data and the duct data, combined with the similarity of the subsonic and supersonic duct propeller data, indicates that the area of cancellation for advanced propellers will be similar to that measured on an airplane with conventional propellers.

Some discussion of the method of active noise control was undertaken. It was inferred that the mounting of speakers on the outside of the airplane might provide better active noise suppression that using speakers inside the cabin. This was based on the concepts that the noise enters only through a limited portion of the fuselage and that active noise control works well in stopping noise from propagating across a boundary.

REFERENCES

1. Chaplin, Barrie: Anti-Noise - The Essex Breakthrough. Chart. Mech. Eng., vol. 30, no. 1, Jan. 1983, pp. 41-47.

2. Warnaka, G.E.: Active Attenuation of Noise - The State of The Art. Noise Control Engineering, vol. 18, May-June 1982, pp. 100-110.

3. Magliozzi, B.; and Brooks, B.M.: Advanced Turbo-Prop Airplane Interior Noise Reduction - Source Definition. NASA CR-159668, 1979.

4. Succi, G.P.; Baumeister, K.J.; and Ingard, K.U.: Interaction of a Turbulent Jet Noise Source with Transverse Modes in a Rectangular Duct. NASA TP-1248, 1978.

5. Dittmar, J.H.; Jeracki, R.J; and Blaha, B.J.: Tone Noise of Three Supersonic Helical Tip Speed Propellers in a Wind Tunnel. NASA TM-79167, 1979.

6. Dittmar, J.H.; Burns, R.J.; and Lecijewski, D.J.: An Experimental Investigation of the Effect of Boundary Layer Refraction on the Noise from a High-Speed Propeller. NASA TM-83764, 1984.

7. Dittmar, J.H.; and Lasagna, P.L.: A Preliminary Comparison Between the SR-3 Propeller Noise in Flight and in a Wind Tunnel. NASA TM-82805, 1982.

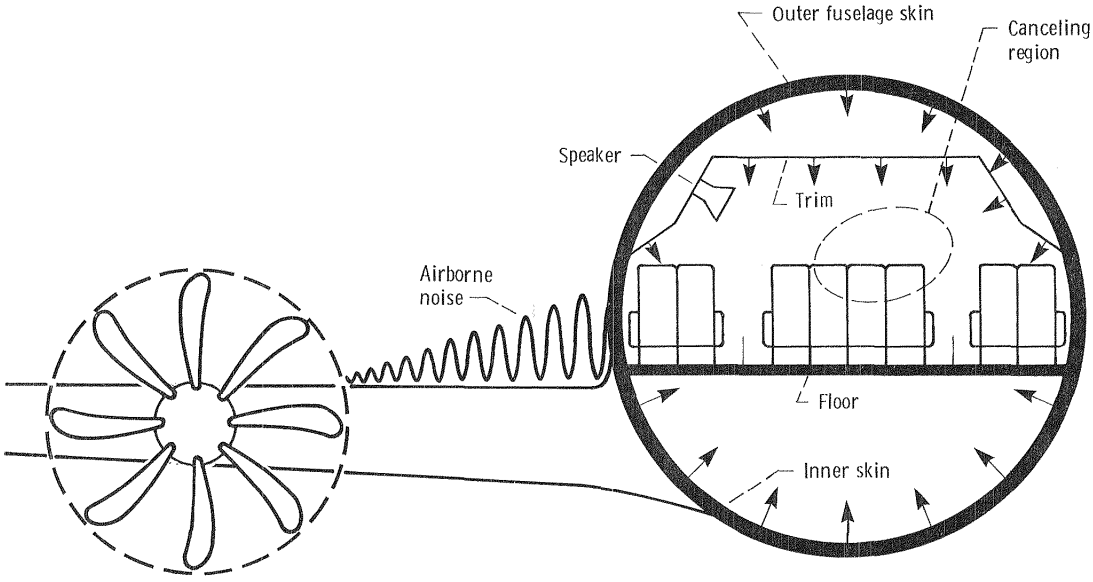
8. Lasagna, P.L.; Mackall, K.G.; and Cohn, R.B.: In-Flight Acoustic Test Results for the SR-2 and SR-3 Advanced Propellers. AIAA Paper 83-1214, June 1983.

9. Zalas, J.M.; and Tichy, J.: Active Attenuation of Propeller Blade Passage Noise. NASA CR-172386, 1984.

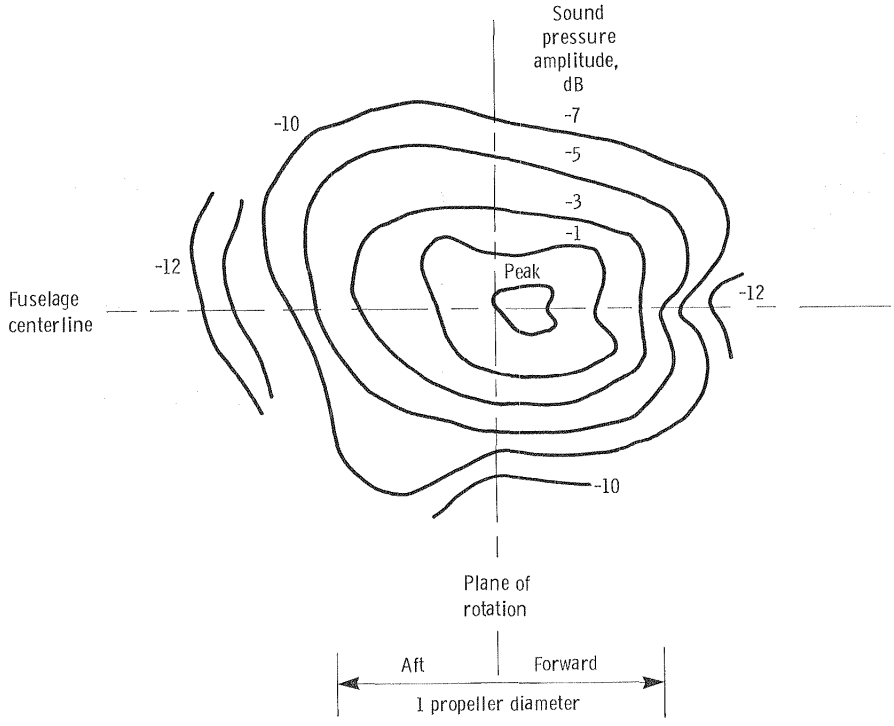
10. Fuller, C.R.: Analytical Investigation of Synchrophasing as a Means of Reducing Aircraft Interior Noise. NASA CR-3823, 1984.

11. Lindqvist, E.: Active Sound Reduction: A Study of Recent Developments and Some Future Possibilities. F83-06, Chalmers University of Technology, Goteborg, Sweden, 1984.

12. Salikuddin, M., et al.: Application of Active Noise Control to Model Propeller Noise. AIAA Paper 84-2344, Oct. 1984.

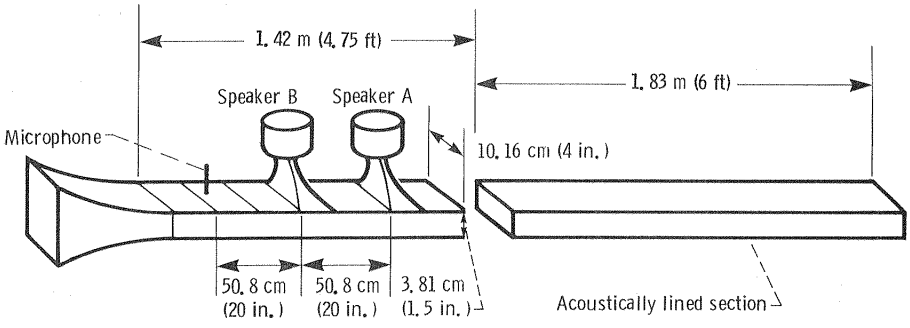


(a) Cancellation with interior speaker.



(b) Sound pressure amplitude contours on simulated fuselage measured 0.4-diameter from tip of model advanced propeller. (From ref. 3.).

Figure 1. - Propeller noise.



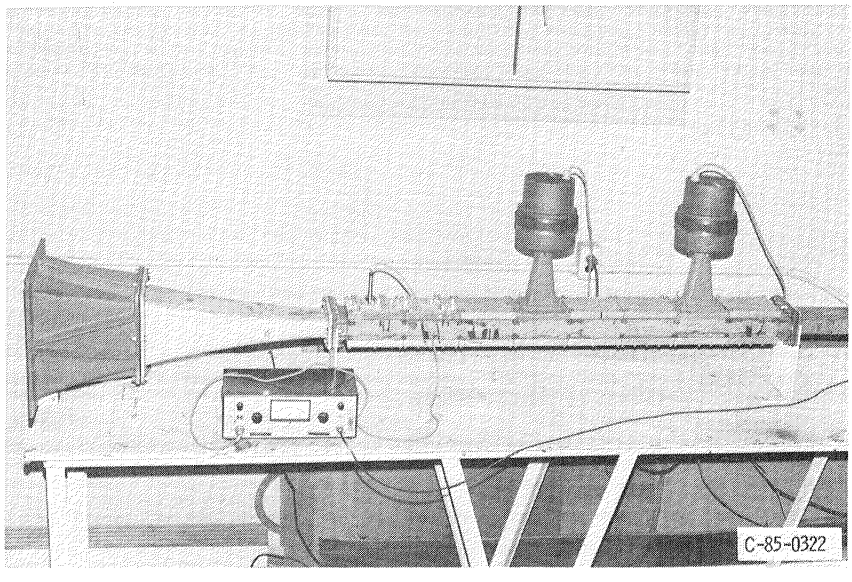
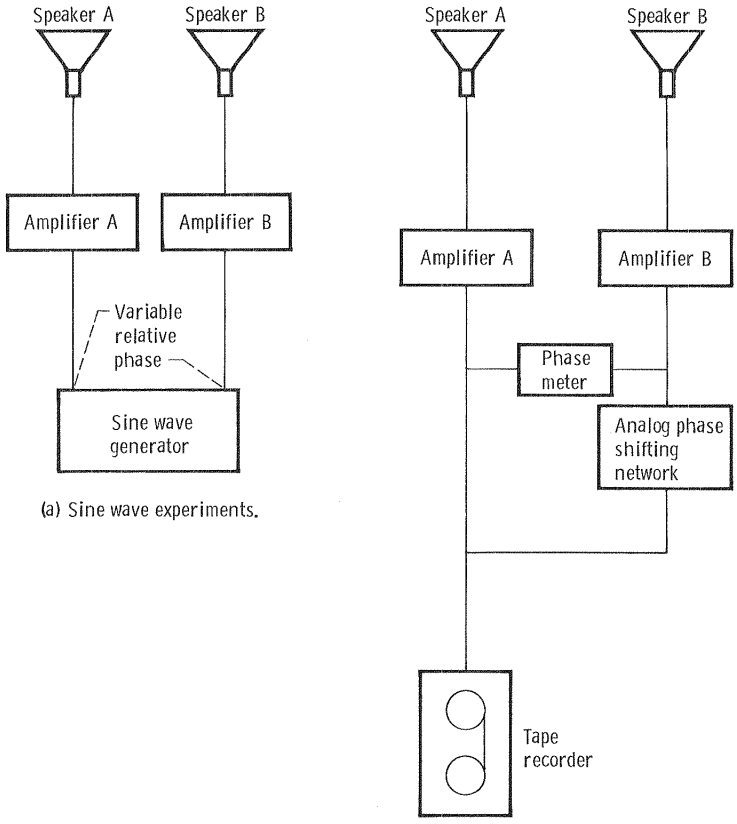


Figure 2. - Apparatus for rectanglular duct experiment.



(a) Sine wave experiments.

(b) Propeller noise experiments.

Figure 3. - Block diagram of cancellation equipment.

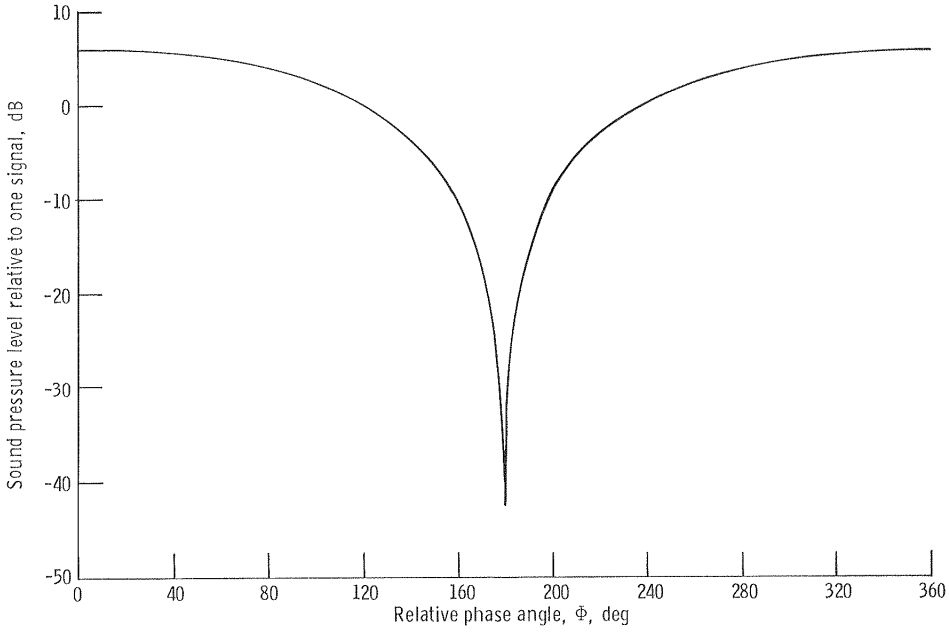


Figure 4. - Ideal cancellation of noise as function of phase angle.

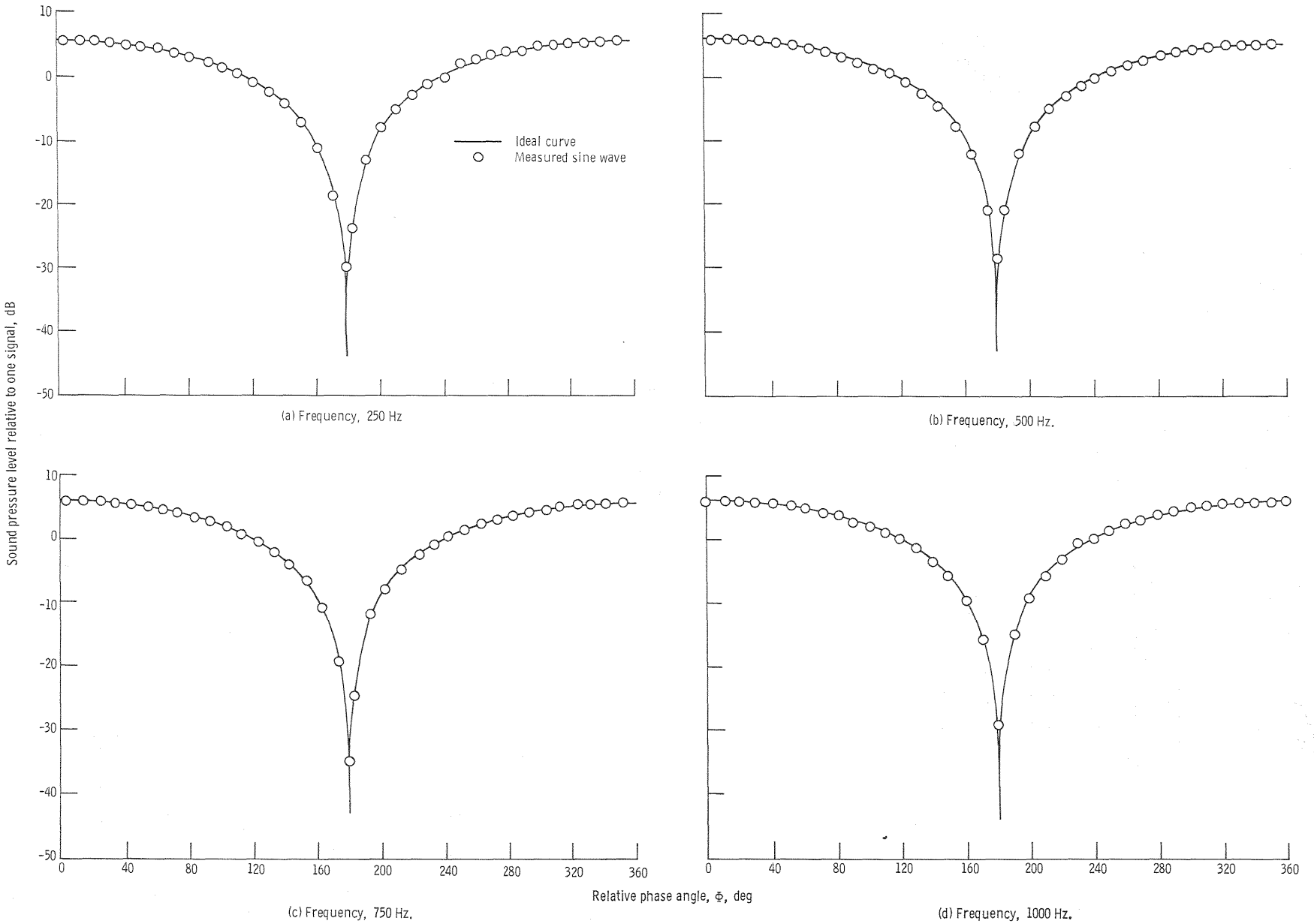
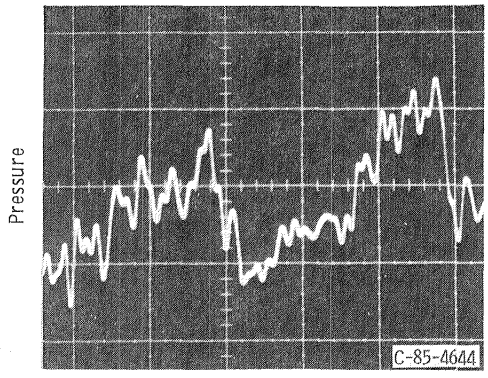
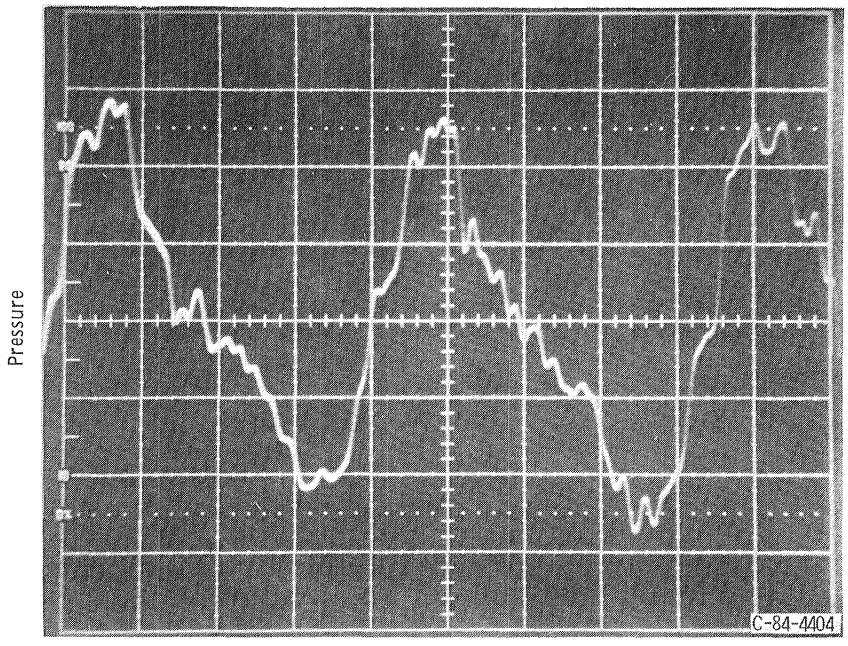


Figure 5. - Comparison of sine wave cancellations measured in duct with ideal curve.

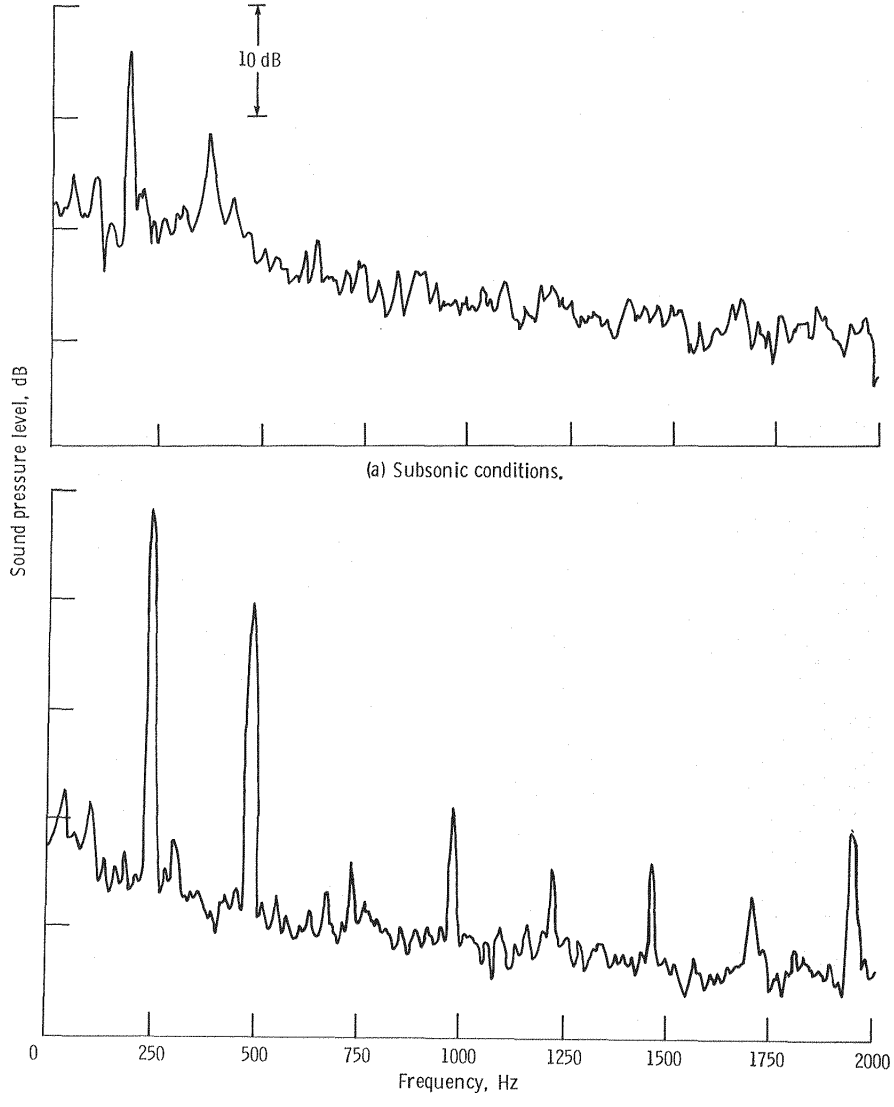


(a) Subsonic conditions.



(b) Supersonic conditions.

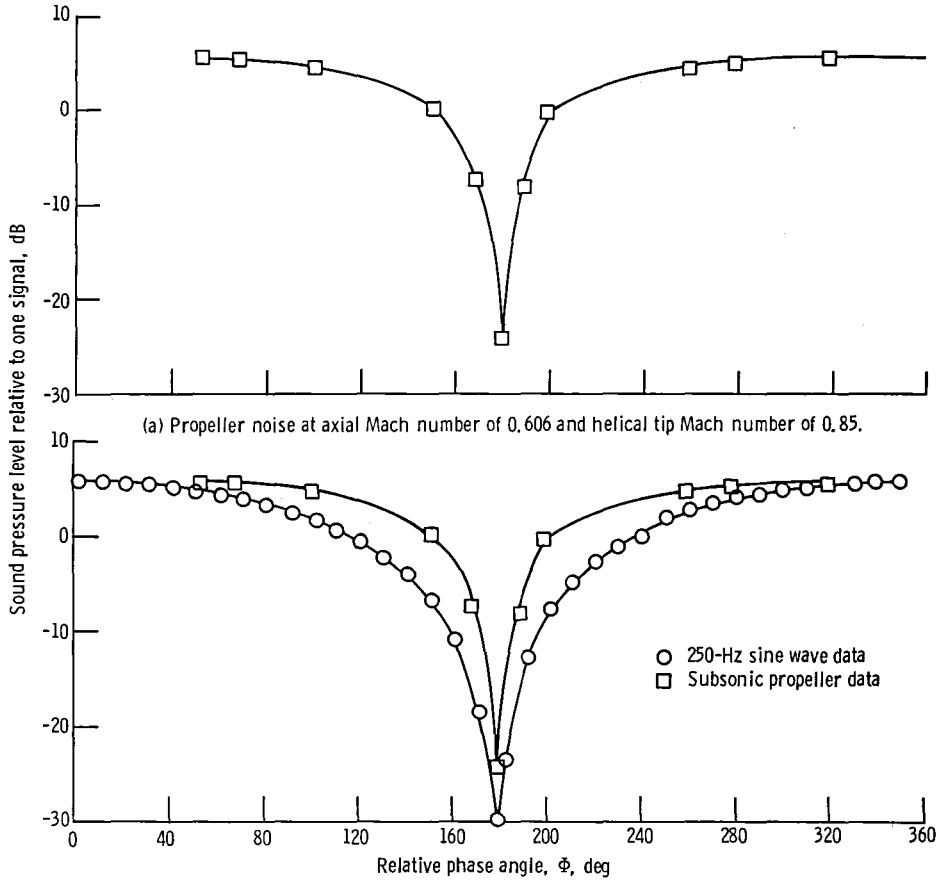
Figure 6. - Pressure-time signals.



(a) Subsonic conditions.

(b) Supersonic conditions.

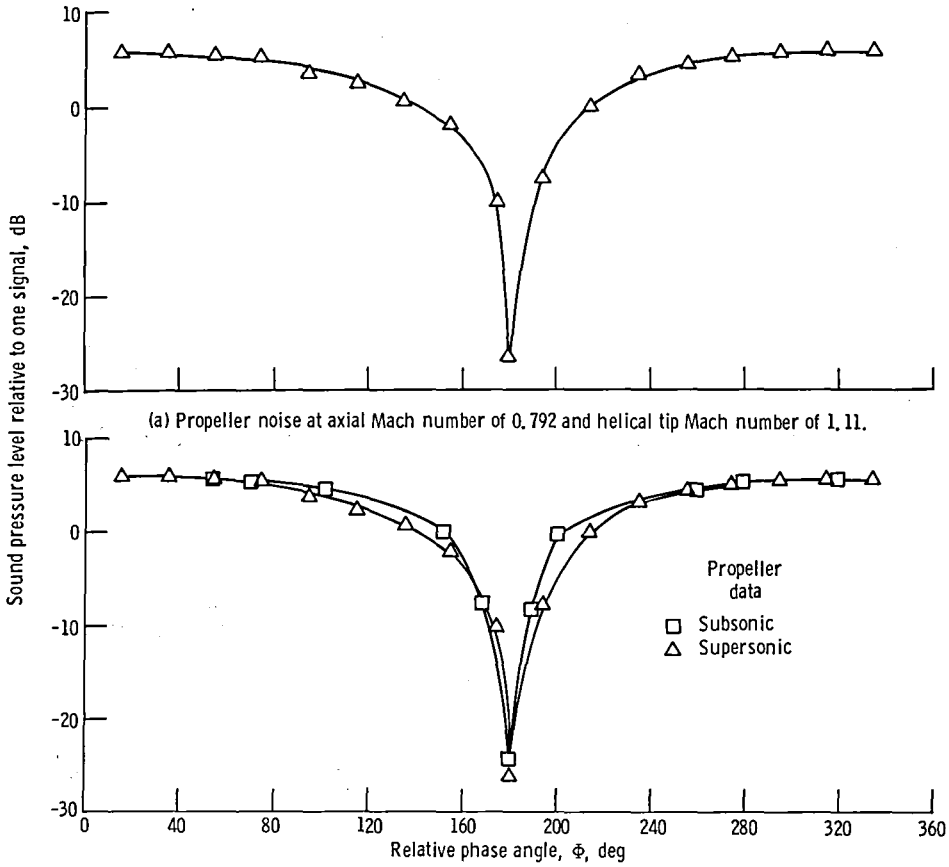
Figure 7. - Propeller noise spectra.



(a) Propeller noise at axial Mach number of 0.606 and helical tip Mach number of 0.85.

(b) Comparison with 250-Hz sine wave data.

Figure 8. Duct data taken with subsonic propeller noise.



(a) Propeller noise at axial Mach number of 0.792 and helical tip Mach number of 1.11.

(b) Comparison with subsonic propeller data.

Figure 9. - Duct data taken with supersonic propeller noise.

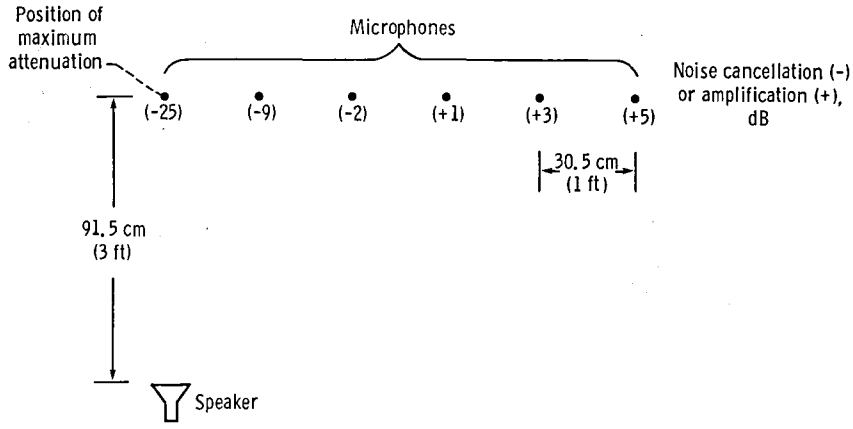
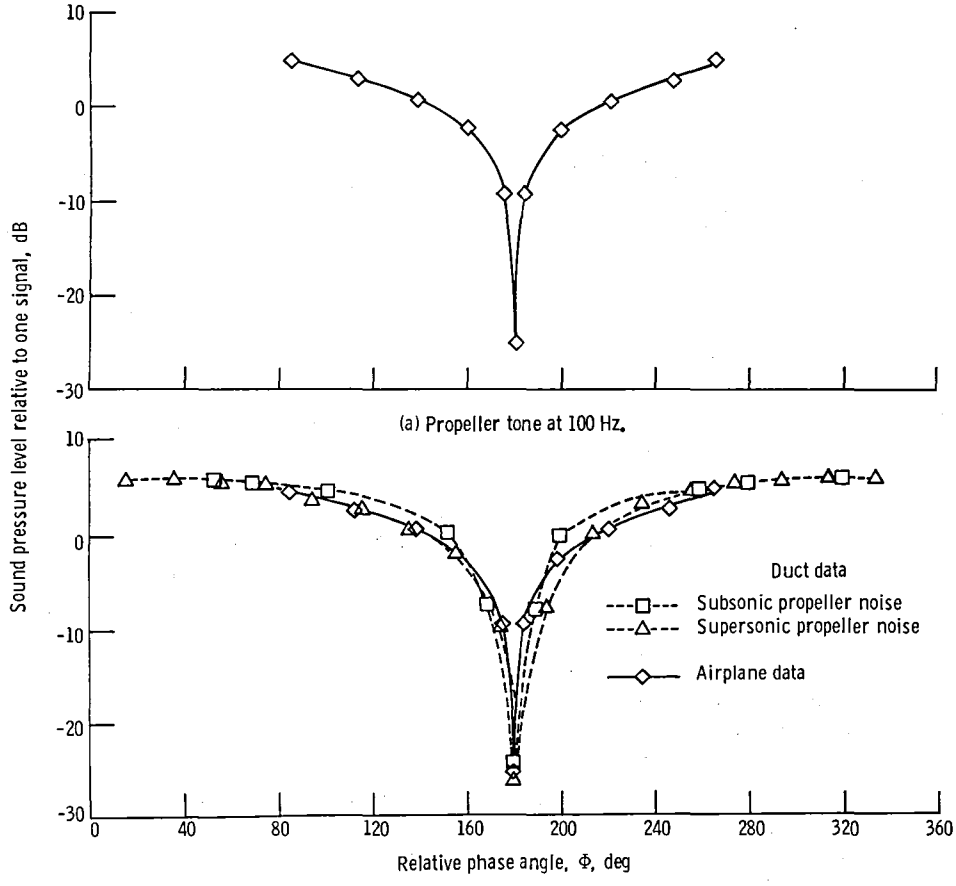


Figure 10. - Microphone positions for airplane tests. (From ref. 9.)



(b) Comparison of airplane data with propeller duct data.

Figure 11. - Airplane data translated from spatial to phase information.

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM-87129		

4. Title and Subtitle	5. Report Date
Laboratory Experiments on Active Suppression of Advanced Turboprop Noise	December 1985
	6. Performing Organization Code: 505-45-58
7. Author(s): James H. Dittmar	8. Performing Organization Report No.: E-2740
	10. Work Unit No.
9. Performing Organization Name and Address: National Aeronautics and Space Administration, Lewis Research Center, Cleveland, Ohio 44135	11. Contract or Grant No.
	13. Type of Report and Period Covered: Technical Memorandum
12. Sponsoring Agency Name and Address: National Aeronautics and Space Administration, Washington, D.C. 20546	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

The noise generated by supersonic tip speed propellers may be a cabin environment problem for future propeller-driven airplanes. Active suppression from speakers inside the airplane cabin has been proposed for canceling out this noise. The potential of active suppression of advanced turboprop noise was tested by using speakers in a rectangular duct. Experiments were first performed with sine wave signals. The results compared well with the ideal cancellation curve of noise as a function of phase angle. Recorded noise signals from subsonic and supersonic tip speed propellers were then used in the duct to determine the potential for canceling their noise. The subsonic propeller data showed significant cancellations but less than those obtained with the sine wave. The blade-passing-tone cancellation curve for the supersonic propeller was very similar to the subsonic curve, indicating that it is potentially just as easy to cancel supersonic as subsonic propeller blade-passing-tone noise. Propeller duct data from a recorded propeller source and spatial data taken on a propeller-driven airplane showed generally good agreement when compared versus phase angle. This agreement, combined with the similarity of the subsonic and supersonic duct propeller data, indicates that the area of cancellation for advanced supersonic propellers will be similar to that measured on the airplane. Since the area of cancellation on the airplane was small, a method for improving the active noise suppression by using outside speakers is discussed.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Propeller noise; Noise; Supersonic tip speed; Active noise control	Unclassified - unlimited STAR Category 71

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of pages	22. Price*
Unclassified	Unclassified		

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

End of Document