NASA TM-83327

NASA Technical Memorandum 83327
AIAA-83-0745

NASA-TM-83327
19830013624

Farfield Inflight Measurements of High-Speed Turboprop Noise

Joseph R. Balombin and Irvin J. Loeffler
Lewis Research Center
Cleveland, Ohio

Prepared for the
Eighth Aeroacoustics Conference
sponsored by the American Institute of Aeronautics and Astronautics
Atlanta, Georgia, April 11-13, 1983

NASA

FARFIELD INFLIGHT MEASUREMENTS OF HIGH-SPEED TURBOPROP NOISE

Joseph R. Balombin and Irvin J. Loeffler
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

Abstract

A flight program was carried out to determine the variation of noise level with distance from a model high-speed propeller. Noise measurements were obtained at different distances from a SR-3 propeller mounted on a JetStar aircraft, with the test instrumentation mounted on a Learjet flown in formation. The propeller was operated at 0.8 m flight Mach number, 1.12 helical tip Mach number and at 0.7 flight Mach number, 1.0 helical tip Mach number. The instantaneous pressure from individual blades was observed to rise faster at the 0.8 flight speed, than at the 0.7 M flight speed. The measured levels appeared to decrease in good agreement with a 6 dB/doubling of distance decay, over the measurement range of approximately 16 m to 100 m distance. Further extrapolation, to the distances represented by a community, would suggest that the propagated levels during cruise would not cause a serious community annoyance.

Introduction

One of the requirements for the next generation of commercial aircraft is for a powerplant with low noise levels as well as high efficiency. High-tip-speed propellers, or turboprops, offer the promise of significant fuel savings, so the noise characteristics are being seriously studied. During the past few years, NASA has had several 0.62 m (24 in.) diameter model propellers built and tested for noise levels. As part of this program, nearfield and fuselage acoustic pressure measurements have been made because of a cabin noise concern. These acoustic measurements have been made both in wind tunnels with flow and in flight[1-4]. Measurements had been made[4] only to 3 m (10 ft.) distance.

Since these high-speed propellers are designed for operation at supersonic tip speeds, there was some concern[3,5] that the noise levels generated and propagated at these design conditions might be higher than those to which one is accustomed during subsonic operation. During supersonic-tip-speed operation, it was speculated that shock waves might propagate from the blade tips. Because these pressures may propagate without spherical spreading they would then be attenuated at less than the 6 dB/doubling rate[5,6]. It became desirable to determine if this was a consideration of importance in extrapolating noise levels from a propeller in flight.

To explore the possibility of this reduced propatation rate and the potential community annoyance problem during propeller supersonic-tip-speed operation, a flight test program was completed that used the SR-3 propeller[3] mounted on a JetStar as a test source, and a Learjet flown in formation to serve a measuring station (fig. 1a). For this flight, the JetStar windshield wipers were removed to give a cleaner configuration. Prior tests had shown that the wipers, by their influence on the fuselage boundary layer, affected the sound pressure measured on the fuselage. Based on directivity data from reported flight tests[3], the area of maximum sound pressure was identified as being slightly behind the propeller plane of rotation. During the flight test, the Learjet was flown in the vicinity of this maximum at flight Mach numbers of 0.6, 0.7 and 0.8, and generally at 9100 m altitude. At these conditions, the Learjet maintained at selected microphone distances ranging from about 16 to 100 m from the turboprop (fig. 1b).

The reported test program required the extra efforts of a number of individuals from both NASA Centers. Among them were Paul Lasagna and Robert Cohn of Dryden Field Center and Earl Boyer and William Rieke of Lewis Research Center.

Equipment Description

Propeller Characteristics

The propeller used in this test program is shown in figure 2. This is an eight-bladed, advanced design propeller, designated as SR-3. The SR-3 propeller,[1-3] which was 62 cm (24 in.) in diameter, was extensively tested. For the purpose of propeller flight testing, the JetStar aircraft was modified by the addition of the support pylon and an air turbine drive using low pressure bleed air from the JetStar engines. The propeller was driven at approximately 149 kW (200 hp) at its 9100 m (30,000 ft.) altitude, 0.8 flight Mach number cruise condition.

Measurement Equipment

To prepare for the test program inflight measurements, it was first necessary to instrument the Learjet aircraft. Four miniature pressure transducers of the type shown in figure 3 were flush mounted in two locations on the aircraft surface. The transducer is a 2 psig piezoelectric unit, vented through a small tube in the back. Its sensitivity is nominally 190 dB/V. One pair of transducers was located on the plate (fig. 4) mounted on the right tip tank (fig. 5), as a replacement for the standard strobe and navigation light assembly. The second pair was mounted on the aircraft nose, beneath the right side angle-of-attack indicator (fig. 6).

Additional support equipment such as a tape recorder, spectrum analyzer, signal conditioners and amplifiers were mounted in racks inside the Learjet. During the test, the tape recorder was

N83-21895 #

run continuously at 15 ips, and in addition to the four pressure signals, a time code and propeller once revolution synchronization pulse were recorded. The propeller once/revolution signal was transmitted from the JetStar by a UHF telemetry link. At the beginning of each data point, the pressure signal levels were checked on a scope to confirm that the amplifier levels were appropriate, and the time was then noted.

The position of the transducers (nose and wingtip pairs) relative to the propeller was determined from calculations involving the locations of the transducers relative to a camera station and information from pictures taken from the Learjet of the SR-3 propeller. The camera station is shown (fig. 7) as operated. On the ground, reference pictures were taken of the propeller from the anticipated flight orientation, at known distances, with the same camera and lens. During the flight test, pictures were taken of the propeller as acoustic data were being recorded; in addition, elevation and azimuth angles were noted from the protractors mounted on the left and bottom of the camera swivel. By comparing the image dimensions of flight and reference pictures the distance between aircraft was determined.

In identifying the transducers, the two pressure transducers at the front of the Learjet are called either transducers 1 and 2, or nose transducers; the two in the wing are designated either transducers 3 and 4 or wing tip transducers.

The JetStar instrumentation that will be referred to in this report consists of a line of microphones mounted on the fuselage beneath the propeller (fig. 2).

Flight Procedure

The acoustic data that are presented is derived from a flight test on August 30, 1982. For this flight, the JetStar was operated by NASA-Dryden personnel, the Learjet by NASA-Lewis personnel. The JetStar was flown at 0.6 Mach number at 6100 m (20,000 ft.) altitude and at 0.7 and 0.8 flight Mach numbers at 9100 m (30,000 ft.) altitude. The instrumented Learjet was flown in formation with the JetStar, in the same horizontal plane and slightly behind the propeller plane of rotation. This position was chosen in accordance with figure 8, reproduced from reference 3 that shows nearfield blade passage frequency tone level contours generated from previous flight test data. As the directivity pattern indicates, levels are greater on the propeller's left side. Consequently the Learjet was flown (fig. 1) on that side, approximately 10° behind the plane of rotation.

Table I lists the test points in sequence, with some of the propeller operational parameters as monitored. Table II lists the calculated distances from the propeller to the wing tip and nose microphones on the Learjet, and also lists the azimuthal angle (in the horizontal plane) between the propeller axis and the microphone stations. Table III contains values of fundamental and second harmonic sound levels; these were obtained by subtracting measured broadband from tone levels.

Results and Discussion

First, some background comments on the data will be made. At distances beyond 100 m, the propeller tone could not be detected. Also, even at 16 m (53 ft.) the propeller tone could not be detected at 0.6 Mach number flight speed. There were other limits to the measurements. There was a broadband noise floor of about 105 dB in the 7 Hz bandwidth analyses that could have had several sources. Some extraneous features in the noise spectra were the Learjet's engine tone sensed by the nose transducers and occasional low frequency contamination from the Learjet's electric power system.

Pressure Waveform

A feature of some interest was the appearance of the pressure waveform. Since the propeller blades are turning at relative tip speeds of 1.0 and 1.12 Mach numbers at the 0.7 and 0.8 Mach number (cruise) air speeds, it was thought that some evidence of impulsive noise associated with shock waves on the blade trailing edge[4] might be observed. To aid in observing the pressure, the SR-3 propeller tachometer signal was used in the data reduction to define the start of a single revolution. By adding together several revolutions of pressure data, an enhanced average pressure waveform was obtained. However, because the relative separation between the two aircraft varied, the time for the propeller sound to propagate to the microphones varied; this variation was about 5 percent at the most. During those times that the aircraft separation was relatively constant, a constructive average pressure was obtained; at other times the average pressure would approach zero as the sound pressure waves would cancel. Only constructive averages were analyzed.

The pressure waveform displayed in figure 9 was averaged over 32 revolutions of the propeller. This data comes from one of the wing tip transducers at 16 m (25 propeller diameters) with the SR-3 at a tip helical Mach number of 1.01. It shows a distinctive increase and decrease in pressure that is similar for the eight blades. A similar example of averaged pressure appears in figure 10a for the relative Mach number of 1.13. At this condition, the pattern of individual blade pressure is somewhat more distinctive and similar from blade to blade. The higher frequency variation superimposed on the averaged pressure does not appear to occur at the propeller rate. With four times the number of averages, the peak-to-peak variation (fig. 10b) is reduced as would then be expected. Figure 11 indicates the less distinctive waveform present at greater distances (34 m).

Propeller Tone Steadiness

As part of the analysis, the pressure data were examined to confirm that the measurement of variations in SR-3 noise level with distance was not compromised by an uncontrolled variation of propeller characteristics with time. To assess this possibility, the variation in tone level at a given test point was examined.

For this analysis, a one-second running average of the SR-3 fundamental tone (1,000 Hz) was plotted as a function of time. The behavior of each of the four pressure transducers at 0.8 flight Mach number air speed and 16 m aircraft separation is illustrated (fig. 12) for a one-minute run. Individual curves for each pair are slightly offset so as to more clearly show the variation. The nose transducers, during this period of time, sense about a 2 dB variation. Some of this variation is due to the variation in aircraft separation. Based on a series of camera pictures taken at each test point, this might contribute as much as 0.5 dB to the variation. The wing tip transducers are near a peak in the directional pattern of the SR-3 noise field, and they therefore would be more sensitive to relative aircraft movement. An additional time history is shown in figure 13 which compares the variation at the two closest locations (16 and 34 m). In computing the noise spectra levels shown later, a 37 second averaging time was used, which should be sufficient to reduce the variability at a given aircraft separation to a small fraction of the difference between locations.

Noise Level Variation with Distance

The main purpose of this flight test program was to determine over what range of distance, if any, the variation of propeller tone level was compatible with a 6 dB/doubling extrapolation. In calculating or predicting community noise as a result of aircraft operation at cruise conditions, the attenuation rate is important. Reference 5 discusses the possibility of shock noise being generated in addition to subsonic propeller noise and being attenuated so slowly as to reduce the net attenuation of propeller noise with distance. References 5 and 6 suggest a 15 dB/decade rather than a 20 dB/decade rate for use in predicting farfield levels; these rates correspond to a reduction in sound pressure level of 4.5 dB and 6 dB respectively, for each doubling of distance.

A typical noise spectrum is presented in figure 14. These data, from a wing tip transducer, are for 0.8 Mach number flight speed, 9100 altitude, 1.12 tip helical Mach number and 17 m distance. The fundamental blade passage frequency tone appears at about 1000 Hz, and three harmonics are also observable above the baseline. At this frequency resolution (7 Hz), no other harmonics were observed; with finer resolution, the small differences in frequency due to propeller speed variation had the effect of spreading the tones among several adjacent spectrum bands. Consequently the data were analyzed with no finer resolution.

Figure 15 shows the fundamental tone sound pressure level at the 0.8 Mach number flight speed over the range of distances of 16 to 91 m. The lines faired through the data are for an attenuation rate of 6 dB/doubling. Both wing tip and nose transducer data are in fairly good agreement with this rate. Part of the apparent scatter is due to variation in the azimuthal angle as will be discussed in the next section.

The 0.7 Mach number flight speed data is presented (fig. 16) in a similar way. No tone was observed in the data at aircraft separations greater than about 30 m. The 6 dB/doubling attenuation reference lines are again shown.

At twice blade passage frequency, the variation with distance of the SR-3 propeller noise, at 0.8 Mach number flight speed, also agrees with the acoustic attenuation rate of 6 dB/doubling of distance over the range of distances studied (fig. 17). A similar evaluation (fig. 18) for 0.7 Mach number flight speed yields results which indicate a higher sound level at the nose transducers than at the wing transducers. This result indicates that a different tone directivity may exist for the second harmonics at this low helical tip Mach number.

Farfield Directivity

Since the Learjet's position varied not only in separation distance, but also to some degree in azimuthal angle (horizontal plane) it was possible to obtain some limited information about the SR-3 sound directivity pattern, and also about sound attenuation as a function of radiation angle.

Figure 19 presents the projected azimuthal angle as a function of distance between transducer and propeller for the test points in this study. The target angle held by the Learjet pilots was about 100°, or 10° behind the SR-3 plane of rotation. At greater separations, this angle is approached at all transducers. Obviously at closer distances, a greater difference in angle exists between the nose and wing tip transducer positions.

Directivity information was obtained for the propeller fundamental tone sound field for those microphones on the JetStar fuselage. This near field data was reduced from JetStar data tapes recorded simultaneously with the Learjet data tapes. The data of figure 15 were extrapolated to the 0.8 m (2.6 ft.) sideline at which the JetStar microphones were located, providing farfield directivity over the range from about 85 to 115 degrees. (There will be some uncertainty in the farfield data because of a variation in elevation above and below the propeller centerline of about ± 7 degrees total; the JetStar fuselage microphones are in a single horizontal plane). The farfield data at angles less than about 100° were extrapolated to the fuselage location by a 6 dB/doubling rate. The agreement (fig. 20) is good for these data, indicating that spherical spreading exists at these angles.

The farfield data beyond 100° were extrapolated in three different ways. The data were first extrapolated at 6 dB/doubling. This rate overestimates the near field levels. Because the N-wave pressures of figures 9 and 10 resemble shocks, and pressure shocks are thought[5,6] to decay at a 4.5 dB/doubling rate, the farfield data were next extrapolated at this rate. This rate underestimates the nearfield level. Finally the farfield data are extrapolated using the 6 dB/doubling rate from the actual transducer locations to an arbitrary distance of 15 m (50 ft.) and then extrapolated using 4.5 dB/doubling from there to the fuselage. It appears that this is the best fit for the fundamental tone levels behind the propeller plane of rotation.

Concluding Remarks

A test program was conducted to measure the farfield noise characteristics of a high-speed turboprop in flight. Because of the high speed operation of the propeller, that is its 1.12 Mach number helical tip speed at 0.8 flight Mach number, shock waves are generated near the blade tips. While the attenuation of subsonic noise in a free field is the spherical spreading rate of 6 dB/doubling, it was not previously clear at what distance this rate would occur for this high speed propeller.

The observed inverse square law attenuation appears to apply over much of the range of separation distances for which the two aircraft were operated. Behind the propeller plane of rotation, where sharper N-wave type pressures were observed, the 6 dB/doubling or 20 dB/decade attenuation rate seemed to hold, at least beyond about 15 m (50 ft.). For a full scale propeller such as might be used for a commercial transport, this study indicates that the spherical spreading attenuation rate should be applied over most of the propagation path distance to over-flown communities.

References

1. 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.
2. Dittmar, J. H., "A Comparison Between an Existing Propeller Noise Theory and Wind Tunnel Data," NASA-TM-81519, May 1980.
3. Mackall, K. G., Lasagna, P. L., Walsh, K., and Dittmar, J. H., "In-Flight Acoustic Results from an Advanced-Design Propeller at Mach Numbers to 0.8," AIAA Paper 82-1120, June 1982.
4. Brooks, B. M., and Metzger, F. B., "Acoustic Test and Analysis of Three Advanced Turboprop Models," Hamilton Standard, Windsor Locks, Conn., NASA CR-159667, 1980.
5. "Energy Consumption Characteristics of Transports Using the Prop-Fan Concept," D6-75780, Boeing Commercial Airplane Co., Seattle, WA, 1976. (NASA CR-137937).
6. Carlson, H. W., "An Investigation of the Influence of Lift on Sonic-Boom Intensity by Means of Wind-Tunnel Measurements of the Pressure Fields of Several Wing-Body Combinations at a Mach Number of 2.01," NASA TN-D-881, 1961.

Table I - Test Sequence

Test point number	Nominal aircraft separation (m)	Air speed (Mach number)	Helical tip speed (Mach number)	Corrected Rpm	Advance ratio
1	30	.63	.83	4180	3.62
2	120	.63	.83	4170	3.60
3	90	.63	.83	4180	3.61
4	15	.63	.84	4190	3.61
5	30	.80	1.12	5640	3.17
6	240	.80	1.12	5640	3.17
7	120	.80	1.12	5640	3.17
8	90	.80	1.13	5660	3.17
9	15	.80	1.13	5670	3.17
10	60	.79	1.11	5600	3.15
11	30	.79	1.12	5640	3.16
12	240	.80	1.12	5660	3.16
13	120	.80	1.13	5670	3.17
14	90	.80	1.12	5670	3.16
15	15	.80	1.13	5660	3.16
16	30	.72	1.02	5290	3.14
17	120	.71	1.00	5230	3.16
18	15	.72	1.01	5240	3.16

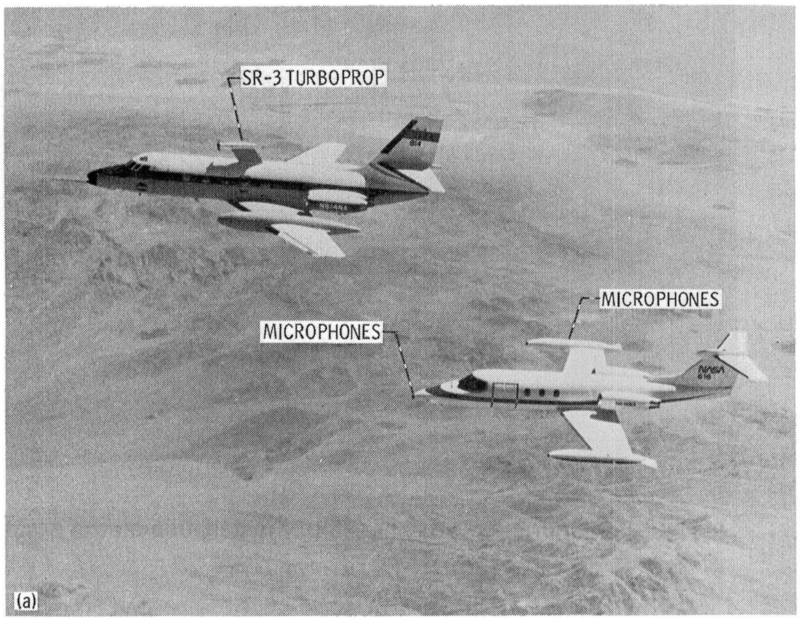
Note: For point 10, the Learjet was throttled back and the JetStar flown past. The nominal separation was that determined at the closest point.

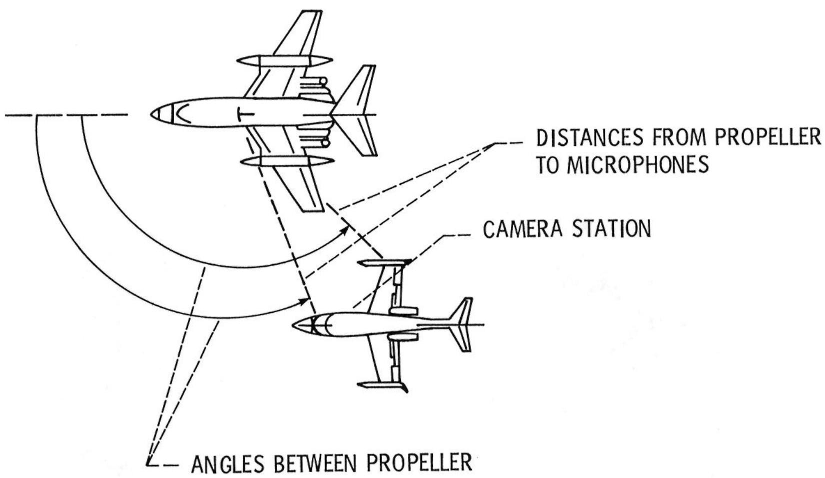
Table II - Propeller Distances

Test point number	Wing tip transducers		Nose transducers	
	Distance to propeller (ft.) m	Azimuthal angle from propeller (deg.)	Distance to propeller (ft.) m	Azimuthal angle from propeller (deg.)
1	(109) 33	107°	(121) 37	93°
2	(547) 167	101°	(560) 171	99°
3	(338) 103	101°	(351) 107	97°
4	(59) 18	113°	(71) 22	89°
5	(111) 34	105°	(124) 38	91°
6	------ ---	----	------ ---	---
7	(357) 109	102°	(369) 112	98°
8	(299) 91	102°	(312) 95	98°
9	(54) 16	117°	(65) 20	89°
10	------ ---	----	------ ---	---
11	(148) 45	105°	(160) 49	95°
12	(1279) 390	99°	(1292) 394	97°
13	(496) 151	99°	(510) 155	95°
14	(323) 98	100°	(337) 103	96°
15	(57) 17	111°	(70) 21	86°
16	(125) 38	104°	(139) 42	92°
17	(544) 166	99°	(558) 170	96°
18	(53) 16	114°	(62) 19	87°

Table III - Transducer Data

Test point number	BPF level				Second harmonic BPF level			
	No. 1	No. 2	No. 3	No. 4	No. 1	No. 2	No. 3	No. 4
1	-----	-----	-----	-----	-----	-----	-----	-----
2	-----	-----	-----	-----	-----	-----	-----	-----
3	-----	-----	-----	-----	-----	-----	-----	-----
4	-----	-----	-----	-----	-----	-----	-----	-----
5	104.5	104.	114.5	115.	95.	95.	102.	102.
6	-----	-----	-----	-----	-----	-----	-----	-----
7	-----	-----	-----	-----	-----	-----	-----	-----
8	98.	98.	103.	102.5	-----	-----	-----	-----
9	112.5	111.5	122.	122.	103.	103.	108.	107.
10	-----	-----	-----	-----	-----	-----	-----	-----
11	106.5	105.5	113.	113.5	93.	94.	98.5	99.
12	-----	-----	-----	-----	-----	-----	-----	-----
13	-----	-----	-----	-----	-----	-----	-----	-----
14	-----	-----	-----	-----	-----	-----	-----	-----
15	109.	109.	120.5	121.	100.	100.	105.	104.5
16	105.	105.5	108.5	106.5	97.5	98.	99.	98.5
17	-----	-----	-----	-----	-----	-----	-----	-----
18	108.5	108.5	116.	115.	106.5	106.	102.5	101.5





(a) View of Jetstar and Learjet (right) in flight.
(b) Flight formation description.

Figure 1.

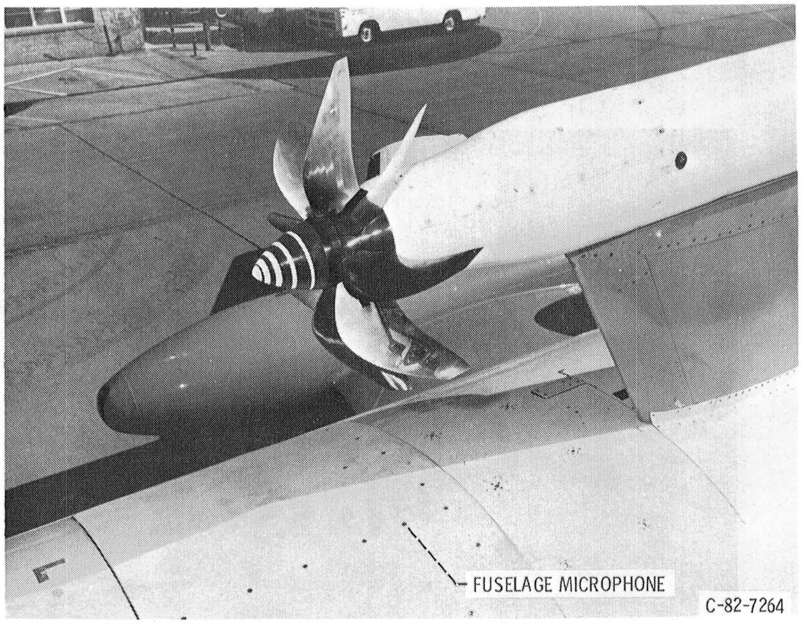


Figure 2. - Advanced-propeller (SR-3) installation on the jetstor.

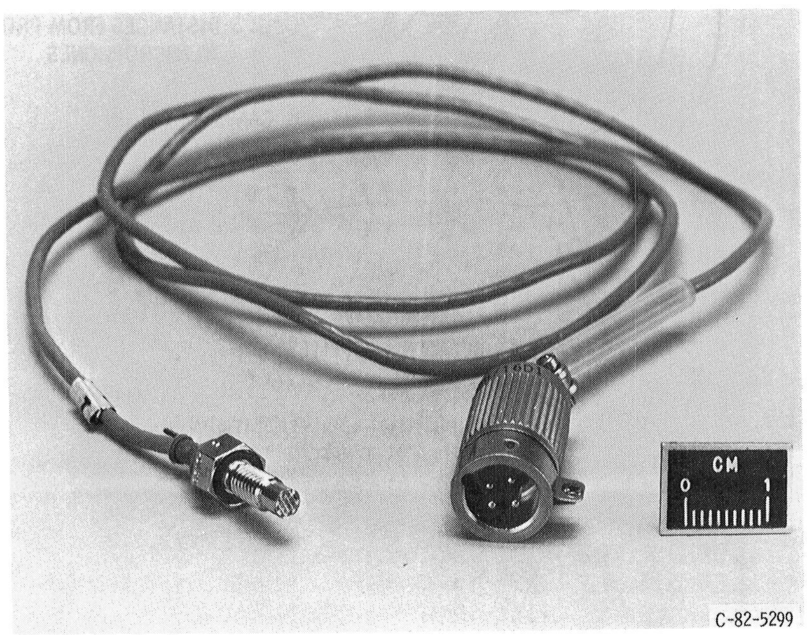


Figure 3. - Pressure transducer.

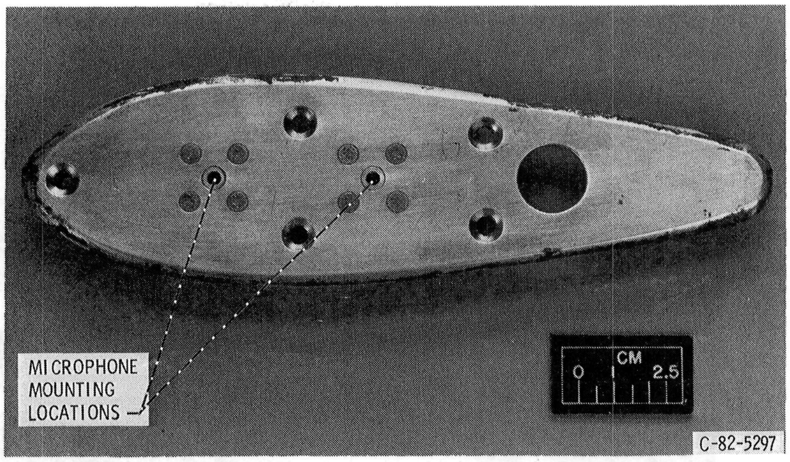


Figure 4. - Wingtip transducer mounting plate.

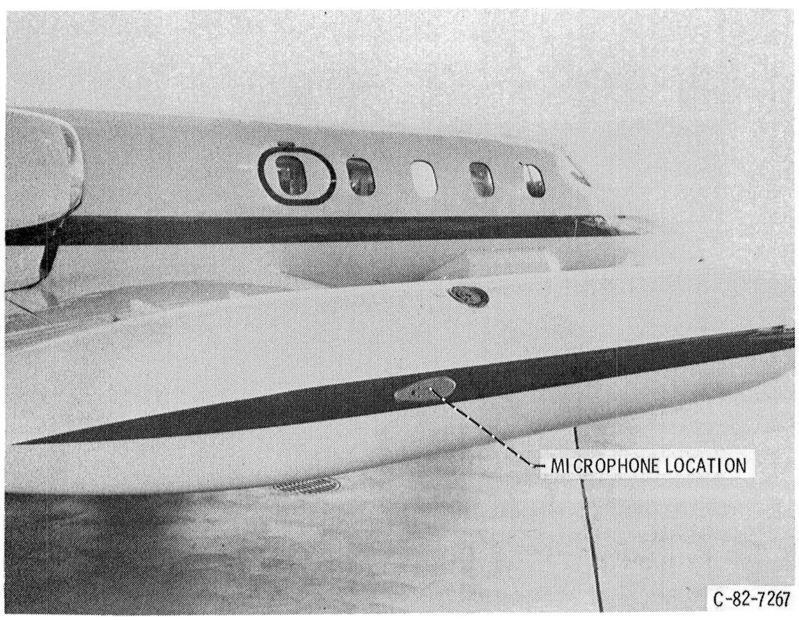


Figure 5. - Learjet wingtip transducer installation.

Figure 6. - Learjet nose transducer installation.

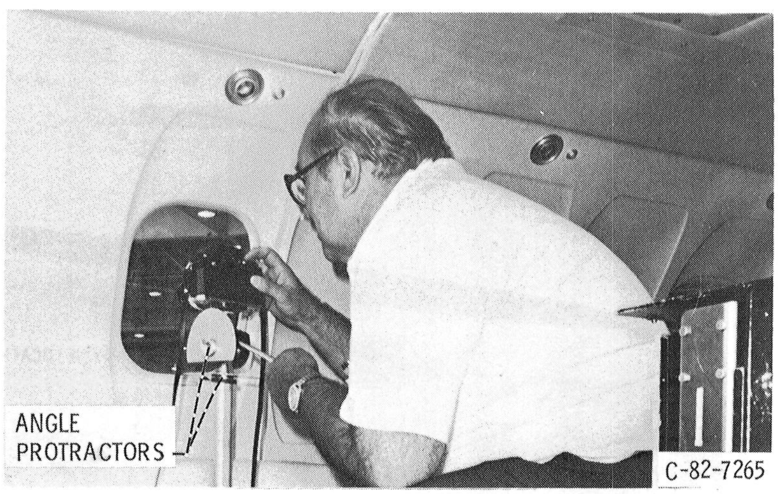


Figure 7. - Camera station.

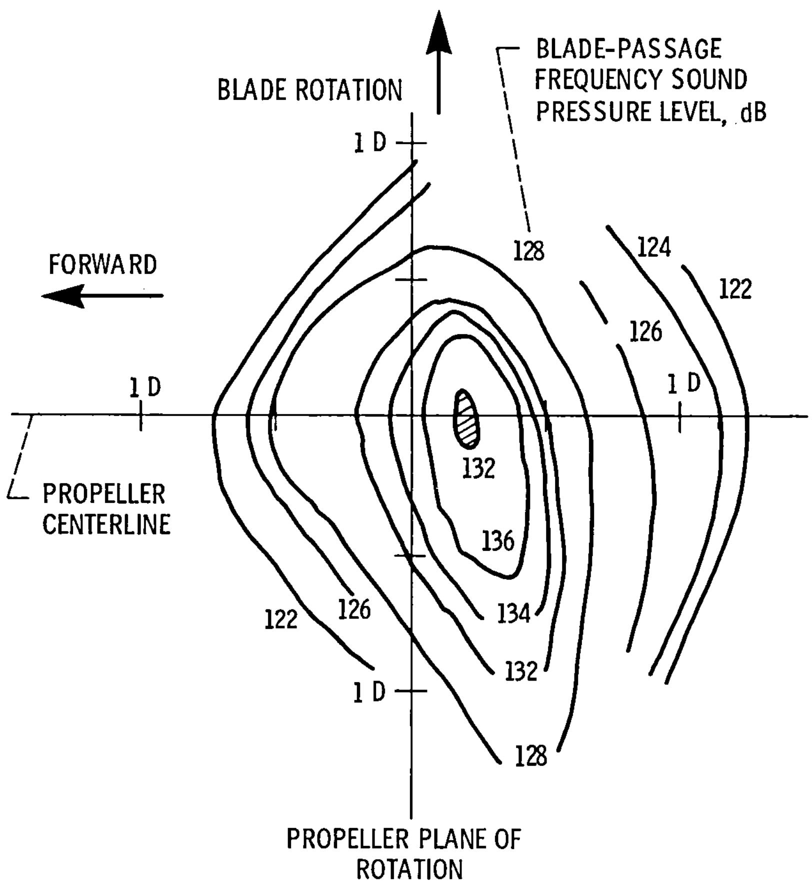


Figure 8. - Blade-passage frequency sound pressure level contour: H = 30 000 ft, M_∞ = 0.76.

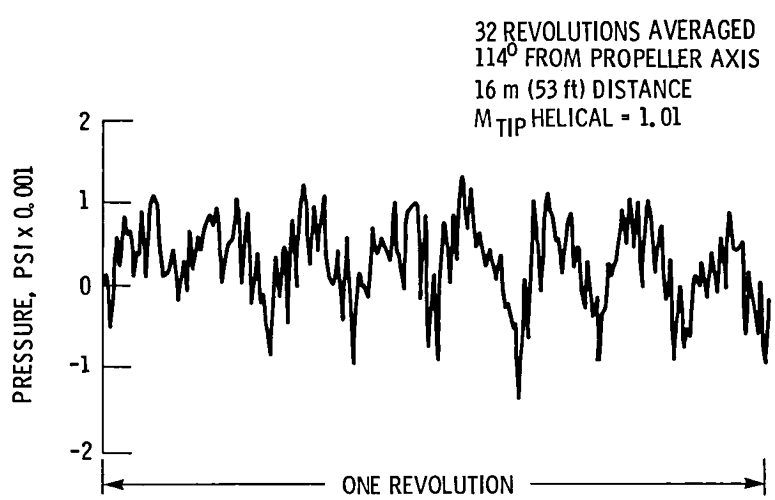
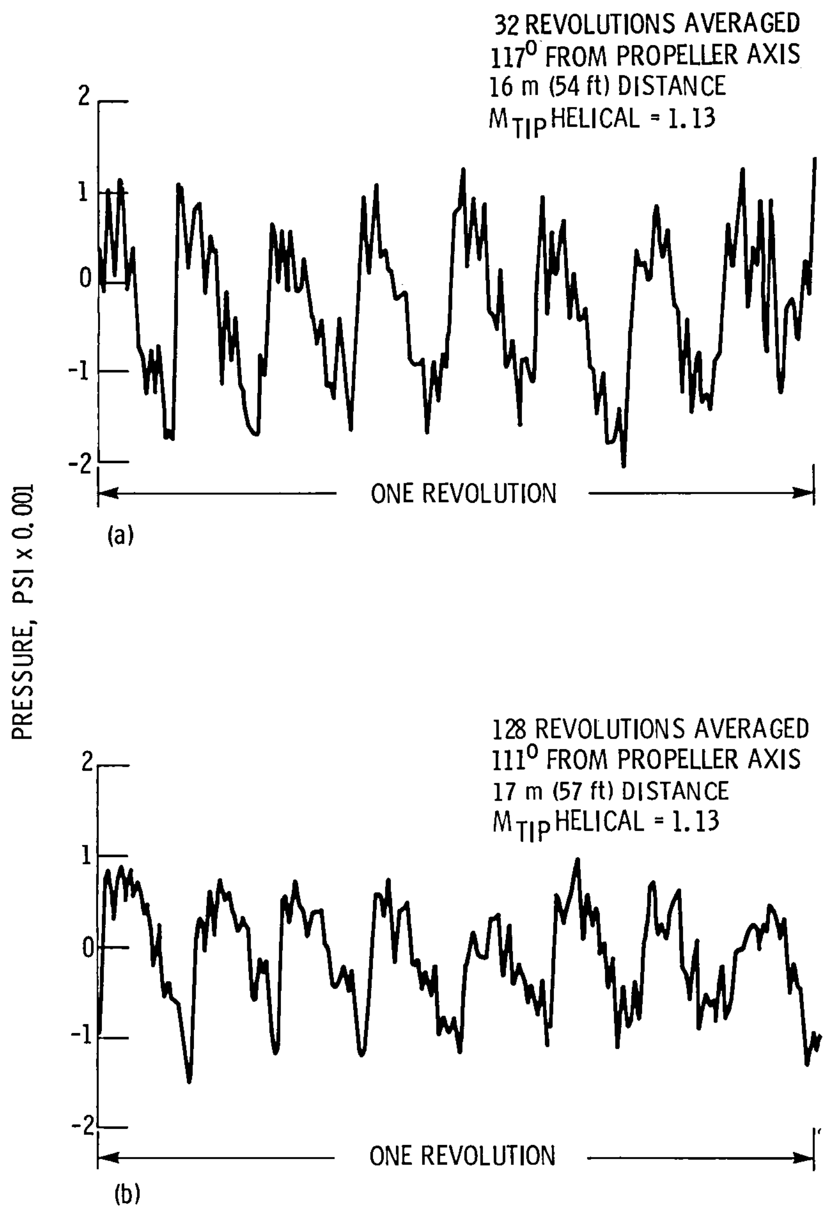


Figure 9. - Average acoustic pressure at 0.7 Mach flight speed.



(a) Average acoustic pressure at 0.8 Mach flight speed.

(b) Average acoustic pressure at 0.8 Mach flight speed with increased averaging.

Figure 10.

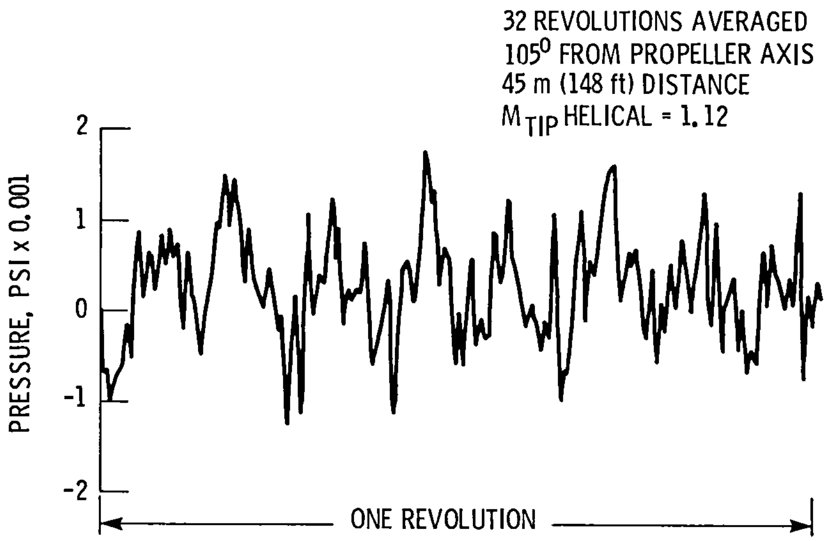


Figure 11. - Average acoustic pressure at 0.8 Mach flight speed at farther distance.

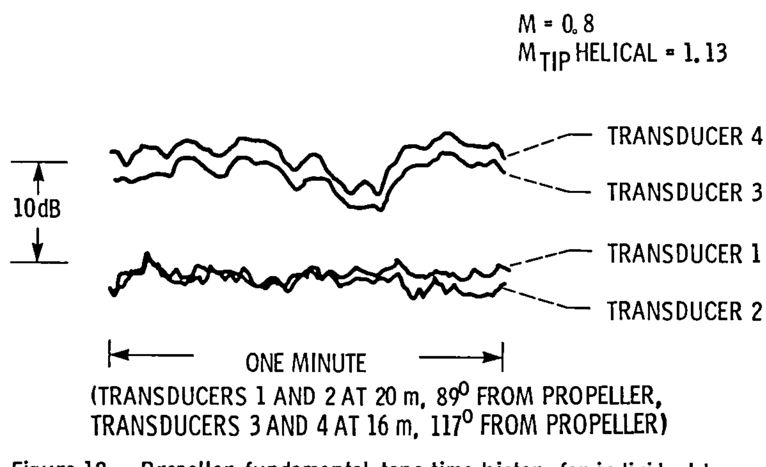
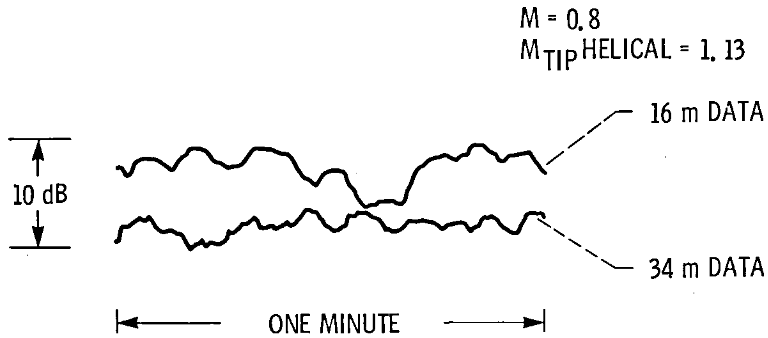


Figure 12. - Propeller-fundamental-tone time history for individual transducers.



(TRANSDUCER AT 16 m, 117° FROM PROPELLER)

Figure 13. - Propeller-fundamental-tone time history at two distances.

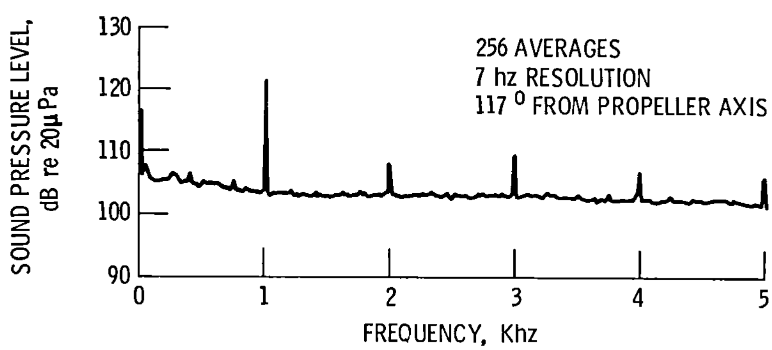


Figure 14. - SR-3 noise spectrum at 16 m for 0.8 Mach number flight speed.

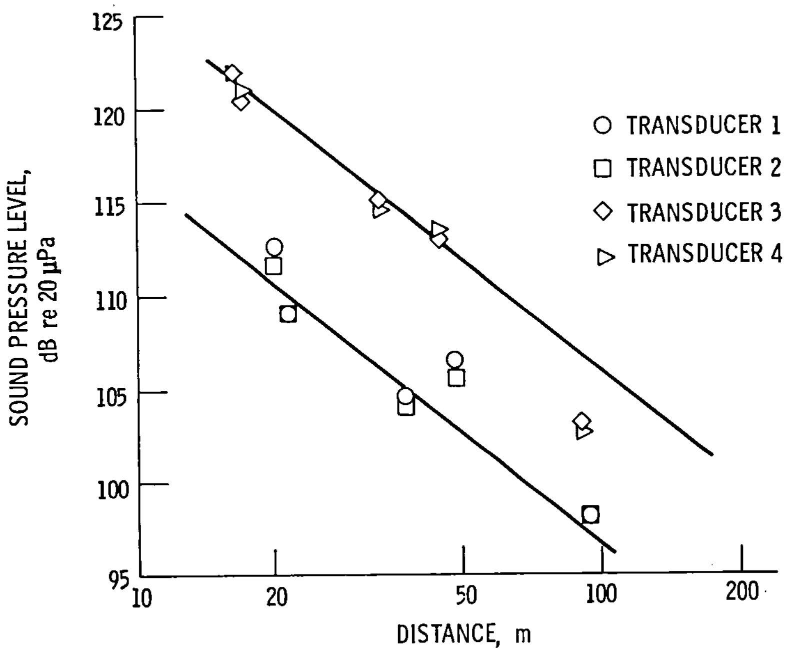


Figure 15. - Variation of fundamental tone with distance at 0.8 m flight speed.

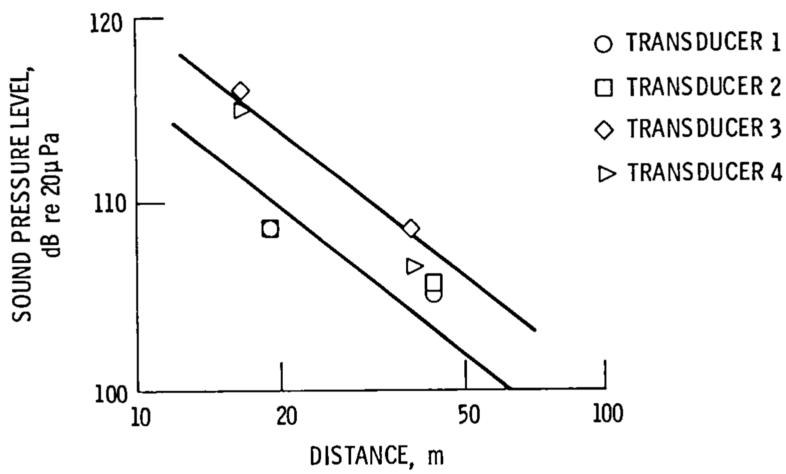


Figure 16. - Variation of fundamental tone with distance at 0.7 m flight speed.

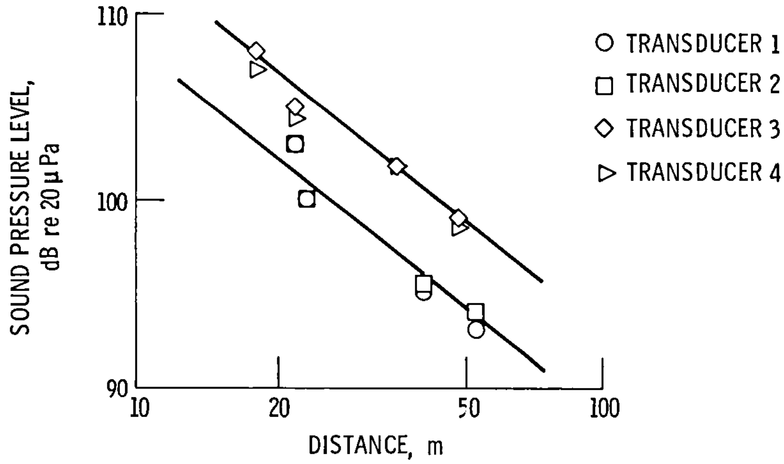


Figure 17. - Variation of second harmonic tone with distance at 0.8 m flight.

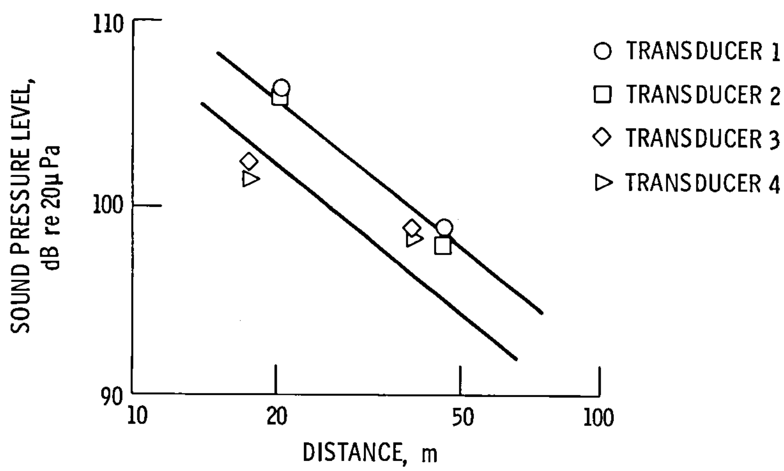


Figure 18. - Variation of second harmonic tone with distance at 0.7 m flight speed.

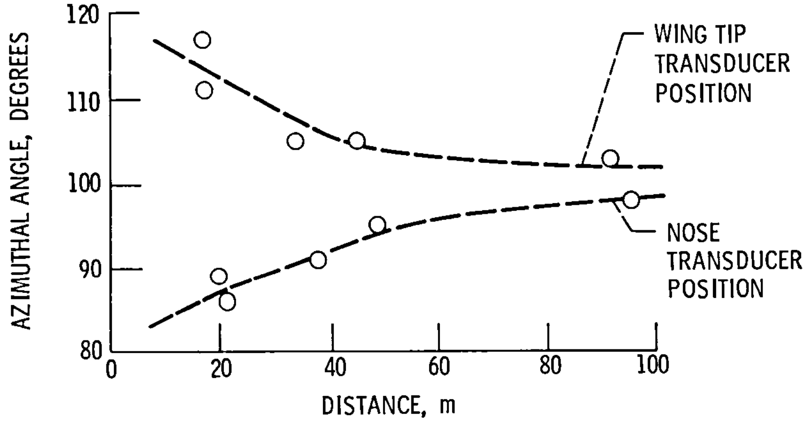


Figure 19. - Variation of angle between transducer and propeller as a function of separation distance.

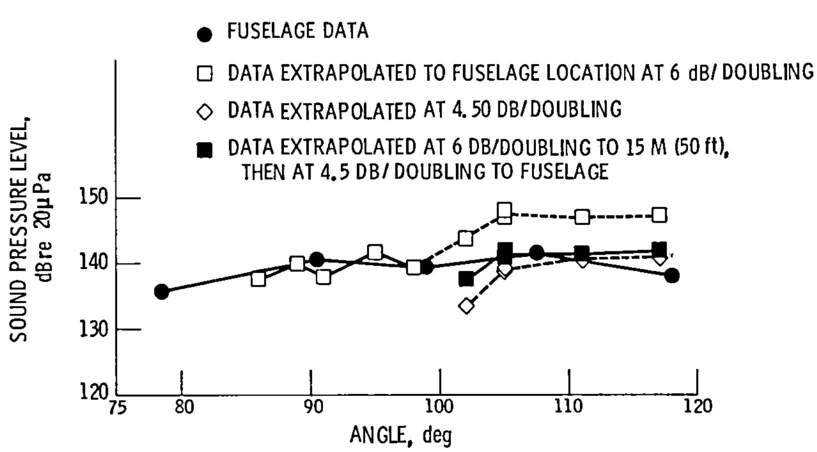


Figure 20. - Comparison of fundamental tone measured on the fuselage with that extrapolated to the fuselage from the farfield.

1. Report No. NASA TM-83327
AIAA-83-0745

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
FARFIELD INFLIGHT MEASUREMENT OF HIGH-SPEED TURBOPROP NOISE

5. Report Date

6. Performing Organization Code
535-03-12

7. Author(s)
Joseph R. Balombin and Irvin J. Loeffler

8. Performing Organization Report No.
E-1574

9. Performing Organization Name and Address
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

10. Work Unit No.

11. Contract or Grant No.

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

13. Type of Report and Period Covered
Technical Memorandum

14. Sponsoring Agency Code

15. Supplementary Notes
Prepared for the Eighth Aeroacoustics Conference sponsored by the American Institute of Aeronautics and Astronautics, Atlanta, Georgia, April 11-13, 1983.

16. Abstract

A flight program was carried out to determine the variation of noise level with distance from a model high-speed propeller. Noise measurements were obtained at different distances from a SR-3 propeller mounted on a JetStar aircraft, with the test instrumentation mounted on a Learjet flown in formation. The propeller was operated at 0.8 flight Mach number, 1.12 helical tip Mach number and at 0.7 flight Mach number, 1.0 helical tip Mach number. The instantaneous pressure from individual blades was observed to rise faster at the 0.8 M flight speed, than at the 0.7 M flight speed. The measured levels appeared to decrease in good agreement with a 6 dB/doubling of distance decay, over the measurement range of approximately 16 m to 100 m distance. Further extrapolation, to the distances represented by a community, would suggest that the propagated levels during cruise would not cause a serious community annoyance.

17. Key Words (Suggested by Author(s))
Flight measurements
Turboprop noise
Propeller noise
Sound attenuation

18. Distribution Statement
Unclassified - unlimited
STAR Category 71

19. Security Classif. (of this report)
Unclassified

20. Security Classif. (of this page)
Unclassified

21. No. of Pages

22. Price*

National Aeronautics and
Space Administration

Washington, D.C.
20546

Official Business
Penalty for Private Use, $300

SPECIAL FOURTH CLASS MAIL
BOOK

U.S. MAIL

Postage and Fees Paid
National Aeronautics and
Space Administration
NASA-451

NASA

POSTMASTER: If Undeliverable (Section 158 Postal Manual) Do Not Return