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SUMMARY

The noise generated by supersonic-tip-speed propellers may create a cabin noise problem for future airplanes powered by these propellers. Noise of a number of propeller models had been measured in the NASA Lewis 8- by 6-Foot Wind Tunnel with flow parallel to the propeller axis. In flight, as a result of the induced upwash from the airplane wing, the propeller may be at an angle of attack with respect to the incoming flow. Therefore, the 10-blade SR-6 propeller was operated at angle of attack to determine its noise behavior. Higher blade passage tones were observed for the propeller operating at angle of attack in a 0.6 axial Mach number flow. The noise increase was not symmetrical, with one wall of the wind tunnel showing a larger noise increase than the other wall. No noise increase was observed at angle of attack in a 0.8 axial Mach number flow. For this propeller the dominance of thickness noise, which does not increase with angle of attack, may explain the lack of noise increase at the higher 0.8 Mach number.

INTRODUCTION

The noise generated by supersonic helical-tip-speed propellers may create a cabin noise problem for turboprop airplanes under cruise conditions. Noise of a number of these propeller models had been measured in the NASA Lewis 8- by 6-Foot Wind Tunnel and on the Jetstar airplane (refs. 1 to 6). These tests were performed with the propeller axis parallel to the flow. In flight, as a result of the induced upwash from the airplane wing, the propellers may be at an angle of attack with respect to the incoming flow. Increases in noise at angle of attack were observed on a subsonic propeller by Tanna et al. (ref. 7), and on the SR-3 supersonic-tip-speed propeller in the 8- by 6-Foot Wind Tunnel (ref. 8). Subsequent to these tests an approximate theoretical model was developed (ref. 9). To further evaluate the noise effect of operating supersonic helical-tip-speed propellers at angle of attack, the SR-6 propeller model (shown in fig. 1) was tested in the Lewis 8- by 6-Foot Wind Tunnel at 2° and 4° angles of attack at tunnel axial Mach numbers of 0.6 and 0.8.

This report presents the data taken under these conditions and evaluates the effect of angle of attack on the noise of this propeller.

APPARATUS AND PROCEDURE

The 10-blade SR-6 propeller was used in the angle-of-attack experiments. The propeller is nominally 0.696 m (27.4 in.) in diameter. Table I shows some of the SR-6 propeller characteristics and more information can be obtained from reference 10. The propeller model mounted on the Lewis 1000-hp propeller test rig at 0° angle of attack is shown in figure 1.

To measure the propeller noise, pressure transducers were installed in the tunnel bleed holes visible in figure 1. Transducers were installed in both side walls of the wind tunnel as shown in figure 2. Transducers 6 to 13 were installed along the propeller axis when the propeller was at 0° angle of attack. To achieve an angle of attack, the propeller rig was pivoted about the pylon support. When this was done, in addition to putting the propeller at angle of attack, the propeller plane was moved forward and elevated in the wind tunnel. In an attempt to keep the transducers on the propeller axis and at the same positions relative to the propeller plane, new transducer positions were chosen. At 2° angle of attack these transducer positions were numbered 14 to 21, and at 4° they were 22 to 29 (fig. 3(a)). The positions are not exactly on the propeller centerlines or exactly the same distances up- or downstream of the propeller plane as they were for the 0° test. The reason is that the transducers could only be installed through the existing tunnel wall bleed holes. Positions of the transducers are shown in figures 3(b) to (d).

These transducers were installed in the same positions on the tunnel wall as for the previous SR-3 testing (ref. 8). The locations (x and x/D) shown in figure 3 are slightly different from those reported for the SR-3 propeller (ref. 8) since SR-6 has its propeller plane 0.74 cm (0.29 in.) behind the SR-3 location, and SR-6 has a 0.696-m (27.4-in.) diameter as compared with the 0.622-m (24.5-in.) diameter of the SR-3 propeller. At the aftmost position at 4° angle of attack (fig. 3(d)) transducer positions 17 and 21 were fairly close to the 4° centerline; data were also taken at these positions.

Data were taken at a nominal propeller advance ratio of 3.5, the design advance ratio, with the tunnel operating at Mach numbers of 0.6 and 0.8. The data were taken with the propeller at 0°, 2°, and 4° angles of attack by using the transducers appropriate for the particular angle of attack (fig. 3). These acoustic tests were performed as an addendum to aerodynamic testing, and not all of the transducers were operating at each test condition. The data were analyzed on a 0- to 10 000-Hz narrowband basis using a 26-Hz bandwidth.

RESULTS AND DISCUSSION

Noise of the SR-6 propeller at 0°, 2°, and 4° angles of attack was measured on the side walls of the Lewis 8- by 6-Foot Wind Tunnel. Sound pressure levels for the first eight harmonics of the blade passage tone have been tabulated and are included in tables II and III. Table II gives the data with the tunnel operating at 0.6 axial Mach number, and table III gives that with the tunnel operating at 0.8. The propeller operated at a nominal advance ratio of 3.5.

Data at 0.6 Axial Mach Number

At 0.6 axial Mach number the trends with angle of attack can be seen in figures 4(a) and (b). In figure 4(a) the noise directivity on the north wall of the wind tunnel is plotted at the three angles tested. The north wall can be seen in figure 2 to represent an inboard-down rotation, while the south wall is inboard-up when the walls are considered as an airplane fuselage. A clear increase in noise is shown as the angle of attack is increased. Data from the south wall of the wind tunnel are given in figure 4(b). On this plot the noise increase is not consistent. In fact, at the 2° angle of attack the noise diminishes at all but the rearmost transducer. At 4° angle of attack the noise then rises above the 0° values. This different behavior on the two walls of the wind tunnel has also been observed (ref. 8) on the SR-3 propeller. This nonsymmetry can be seen in figure 5, where the maximum noise is shown as a function of angle of attack. Noise on the north wall rises steadily with angle of attack, increasing by 4.5 dB from 0° to 4° angle of attack. On the south wall the noise increase is not as regular and is only 3 dB. The asymmetry of the noise increase with angle of attack is not as strong as indicated for the SR-3 propeller (ref. 8); however, the lack of symmetry at angle of attack adds evidence to a conclusion of reference 8 that the use of oppositely rotating propellers on opposite sides of an airplane fuselage may be a way of minimizing the noise due to operation at angle of attack.

Data at 0.8 Axial Mach Number

The noise at 0.8 axial Mach number does not follow the clear pattern shown by either the 0.6 Mach number data or that in reference 8. Figures 6(a) and (b) show the noise directivity at angle of attack for the two wind tunnel walls. No clear trend with angle of attack is apparent in these data. (Some of the curves show a maximum at the rearmost position, and it is possible that the peak noise occurs beyond this position.) The plot of maximum noise as a function of angle of attack (fig. 7) does not show an increase on either wall as the angle of attack is increased; in fact, there is a slight decrease. This is in contrast to the angle-of-attack testing done on the SR-3 propeller (ref. 8), which showed a sizable increase with angle of attack at 0.8 axial Mach number.

A possible reason for the different behavior of SR-6 at 0.8 axial Mach number relative to that of SR-3 involves the acoustic designs of the two propellers. The noise of these propellers is thought to be controlled by the loading noise at the lower helical tip Mach numbers; as the Mach number increases, the thickness noise becomes more important (ref. 11). The increase in angle of attack results in an increase in the loading noise which, in turn, causes the total noise to go up for both SR-6 and SR-3 at the loading-controlled 0.6 axial Mach number. The SR-3 propeller was designed by varying the blade sweep to have the noise outputs from the various hub-to-tip sections cancel each other at the high helical tip Mach numbers. The SR-6 propeller was not designed for this cancellation. As a result the SR-3 blade was quieter than the SR-6 blade when operated at the same condition (ref. 4). At the 0.8 axial Mach number the SR-3 blade noise, because of the noise-cancelling design, may still have been controlled by the loading noise component. In this case when the SR-3 angle of attack was increased, the loading noise was increased; and since the loading noise was dominant, the total noise was increased. This explains the noise increases at 0.8 axial Mach number for the SR-3 propeller. The SR-6 propeller, however, was not designed for cancellation and may have been controlled by thickness noise at the 0.8 axial Mach number. Therefore an increase in the loading noise, as a result of the higher angle of attack, may not have increased the total noise because the thickness noise was dominant.

In addition, the actual blade thickness at the tip is greater for the SR-6 propeller since, with roughly the same thickness-to-chord ratio, it has a longer chord at the tip than the SR-3 propeller. These differences in the designs may have resulted in different controlling noise mechanisms and may explain the different behavior of SR-6 and SR-3 at the 0.8 axial Mach number condition.

CONCLUDING REMARKS

Noise of the SR-6 propeller at 2° and 4° angles of attack was measured in the NASA Lewis 8- by 6-Foot Wind Tunnel at axial Mach numbers of 0.6 and 0.8. At 0.6 axial Mach number the SR-6 propeller showed a noise increase with angle of attack. This increase was not symmetric and the north wall (inboard down) of the wind tunnel showed more of a noise increase than the south wall (inboard up). This lack of symmetry of the noise at angle of attack, which had been observed on the SR-3 propeller, points to the use of oppositely rotating propellers on opposite sides of an airplane fuselage as a way of minimizing the noise effect of angle-of-attack operation.

At 0.8 axial Mach number the SR-6 propeller, in contrast to the SR-3 propeller, did not show an increase in the noise with angle of attack. A possible explanation is that the SR-3 propeller noise is controlled at this condition by the loading noise component, which increases with angle of attack, while the SR-6 propeller is controlled by the thickness noise component, which does not increase with angle of attack.

APPENDIX - SYMBOLS

C_p power coefficient, $C_p = P/\rho N^3 D^5$

D propeller diameter

J advance ratio, V/ND

M tunnel axial Mach number

N propeller rotational speed, rpm

P shaft input power

V tunnel axial velocity

X distance from propeller centerline, positive downstream

ρ density

θ angle from tunnel centerline, deg

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TABLE I. - SR-6 PROPELLER CHARACTERISTICS

Design cruise tip speed, m/sec (ft/sec)	213 (700)
Design cruise power (loading, kW/m^2 (shp/ft^2)	241 (30)
Number of blades	10
Geometric tip sweep, deg	40
Predicted design efficiency, percent	81.9
Nominal diameter, D, cm (in.)	69.6 (27.4)

TABLE II. - SR-6 AT 0.6 TUNNEL MACH NUMBER

[Advance ratio, J, 3.5; blade setting angle, 62°; power coefficient, C_p, 1.87; propeller rotational speed, N, 5087 rpm.]

(a) Angle of attack, 0°.

Harmonic	Sound pressure level, dB (re 2×10^{-5} N/m^2)							
	Transducer position							
	6	7	8	9	10	11	12	13
[a]1	115.0	118.5	117.5	114.0	115.5	119.0	118.5	115.0
2	+[b]	+	+	+	+	+	+	+
3	↓	↓	↓	↓	↓	↓	↓	↓
4	↓	↓	↓	↓	↓	↓	↓	↓
5	↓	↓	↓	↓	↓	↓	↓	↓
6	↓	↓	↓	↓	↓	↓	↓	↓
7	↓	↓	↓	↓	↓	↓	↓	↓
8	↓	↓	↓	↓	↓	↓	↓	↓

(b) Angle of attack, 2°.

Harmonic	Sound pressure level, dB (re 2×10^{-5} N/m^2)							
	Transducer position							
	14	15	16	17	18	19	20	21
[a]1	114.5	120.0	120.5	116.5	116.0	115.5	116.0	119.5
2	+[b]	+	+	+	+	+	+	+
3	↓	↓	↓	↓	↓	↓	↓	↓
4	↓	↓	↓	↓	↓	↓	↓	↓
5	↓	↓	↓	↓	↓	↓	↓	↓
6	↓	↓	↓	↓	↓	↓	↓	↓
7	↓	↓	↓	↓	↓	↓	↓	↓
8	↓	↓	↓	↓	↓	↓	↓	↓

(c) Angle of attack, 4°.

Harmonic	Sound pressure level, dB (re 2×10^{-5} N/m^2)									
	Transducer position									
	22	23	24	25	26	27	28	29	17	21
[a]1	117.5	123.0	122.5	116.0	118.5	121.5	122.0	122.0	117.0	122.0
2	+[b]	+	+	+	+	+	+	+	+	+
3	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
4	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
5	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
6	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
7	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
8	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓

[a]Blade passage frequency.
[b]Tone not visible.

TABLE III. - SR-6 AT 0.8 TUNNEL MACH NUMBER

[Advance ratio, 3.5; blade setting angle, 62°; power coefficient, C_p, 1.68; propeller rotational speed, N, 6627 rpm.]

(a) Angle of attack, 0°.

Harmonic	Sound pressure level, dB (re $2x10^{-5}$ N/m^2)							
	Transducer position							
	6	7	8	9	10	11	12	13
[a]1	127.0	132.5	144.0	148.5	129.5	131.5	143.5	149.0
2	+[b]	+	137.5	131.0	+	+	134.5	134.0
3	↓	↓	131.5	131.0	↓	↓	131.0	131.5
4	↓	↓	128.0	127.5	↓	↓	126.5	128.5
5	↓	↓	124.5	124.5	↓	↓	123.0	127.5
6	↓	↓	121.0	118.0	↓	↓	119.5	121.0
7	↓	↓	117.0	114.5	↓	↓	116.0	118.0
8	↓	↓	+	113.0	↓	↓	+	116.0

(b) Angle of attack, 2°.

Harmonic	Sound pressure level, dB (re $2x10^{-5}$ N/m^2)							
	Transducer position							
	14	15	16	17	18	19	20	21
[a]1	132.0	134.0	145.0	146.5	132.0	138.5	144.0	143.5
2	+[b]	125.0	135.0	131.0	+	127.0	136.5	131.5
3	↓	+	131.0	132.0	↓	+	129.5	130.5
4	↓	↓	127.0	125.0	↓	↓	126.0	130.0
5	↓	↓	121.5	124.0	↓	↓	120.0	126.0
6	↓	↓	117.0	119.0	↓	↓	117.0	121.5
7	↓	↓	+	118.5	↓	↓	+	117.0
8	↓	↓	+	113.5	↓	↓	+	112.5

(c) Angle of attack, 4°.

Harmonic	Sound pressure level, dB (re $2x10^{-5}$ N/m^2)									
	Transducer position									
	22	23	24	25	26	27	28	29	17	21
[a]1	130.5	137.0	147.0	141.0	129.0	140.0	141.5	147.5	142.5	147.0
2	+[b]	126.5	133.0	134.5	+	134.0	135.0	133.5	134.0	133.5
3	↓	+	135.0	129.0	↓	127.0	131.5	126.5	131.5	128.5
4	↓	↓	128.5	124.0	↓	122.0	127.0	124.0	125.0	127.0
5	↓	↓	122.5	121.0	↓	+	126.5	123.5	122.0	127.0
6	↓	↓	121.5	119.5	↓	↓	122.5	121.5	118.5	122.5
7	↓	↓	117.0	116.0	↓	↓	118.5	116.5	116.5	116.5
8	↓	↓	+	114.0	↓	↓	115.5	113.5	113.5	+

[a]Blade passage frequency.
[b]Tone not visible.

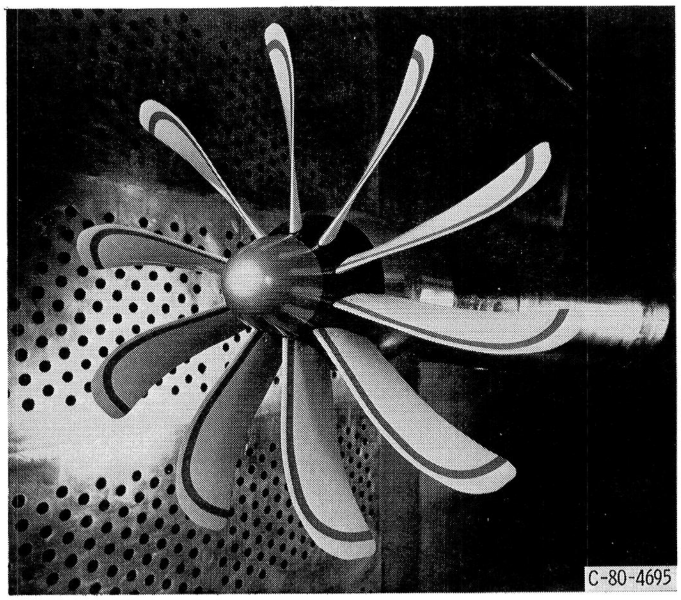


Figure 1. - SR-6 in wind tunnel at 0° angle of attack.

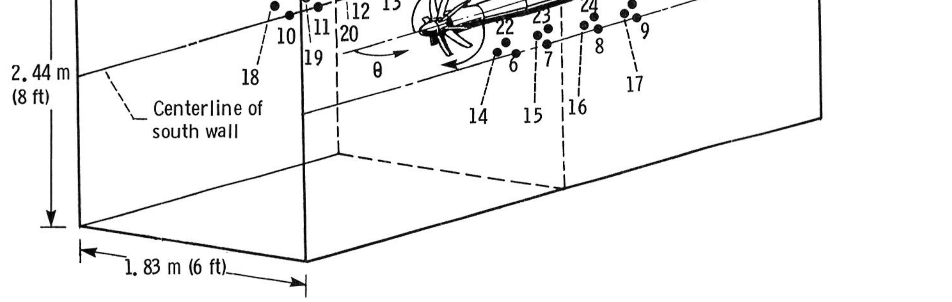
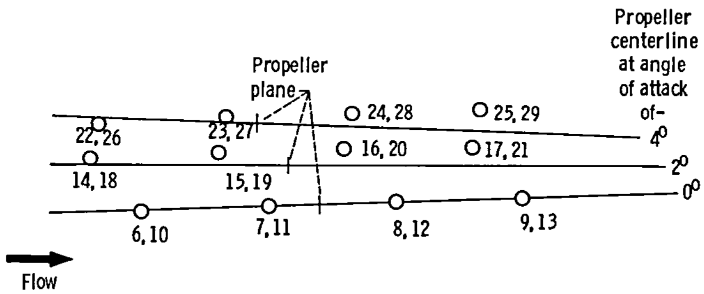
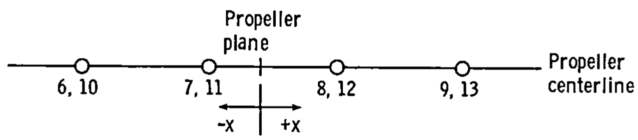


Figure 2. - Transducer positions on tunnel side walls. (The angle θ is measured from tunnel centerline.)



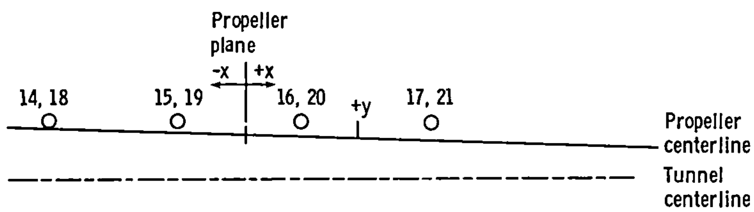
(a) General layout.



	Transducer (north wall, south wall)			
	6, 10	7, 11	8, 12	9, 13
Position, x, cm (in.)	-24.1 (-9.5)	-6.3 (-2.5)	11.5 (4.5)	29.3 (11.5)
Position, x/D, propeller diam	-0.347	-0.091	0.164	0.420
Approximate angle from tunnel centerline (using x only), deg	75.2	86.0	97.1	107.7

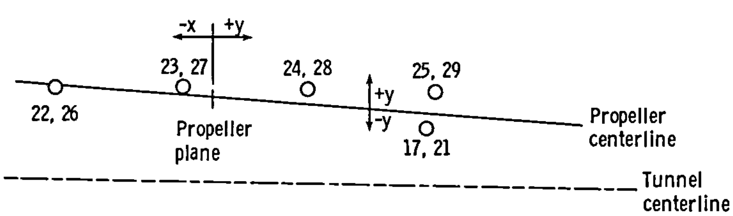
(b) Positions at 0^{0} angle of attack.

Figure 3. - Transducer positions on north and south walls.



	Transducer (north wall, south wall)			
	14, 18	15, 19	16, 20	17, 21
Position, x, cm (in.)	-26.4 (-10.4)	-8.8 (-3.5)	9.0 (3.5)	26.5 (10.4)
Position, y, cm (in.)	1.0 (0.4)	1.5 (0.6)	2.0 (0.8)	3.0 (1.2)
Position, x/D, propeller diam	-0.380	-0.128	0.128	0.380
Approximate angle from tunnel centerline (using x only), θ, deg	73.9	84.4	95.6	106.1

(c) Positions at 2^0 angle of attack.



	Transducer (north wall, south wall)				
	22, 26	23, 27	24, 28	25, 29	17, 21
Position, x, cm (in.)	-20.3 (-8.0)	-2.7 (-1.1)	14.8 (5.8)	32.1 (12.6)	30.8 (12.1)
Position, y, cm (in.)	-0.5 (-0.2)	1.0 (0.4)	2.0 (0.8)	3.3 (1.3)	-1.5 (-0.6)
Position, x/D, propeller diam	-0.292	-0.040	0.212	0.460	0.442
Approximate angle from tunnel centerline (using x only), θ, deg	77.5	88.2	99.2	109.3	108.6

(d) Positions at 4^0 angle of attack.

Figure 3. - Concluded.

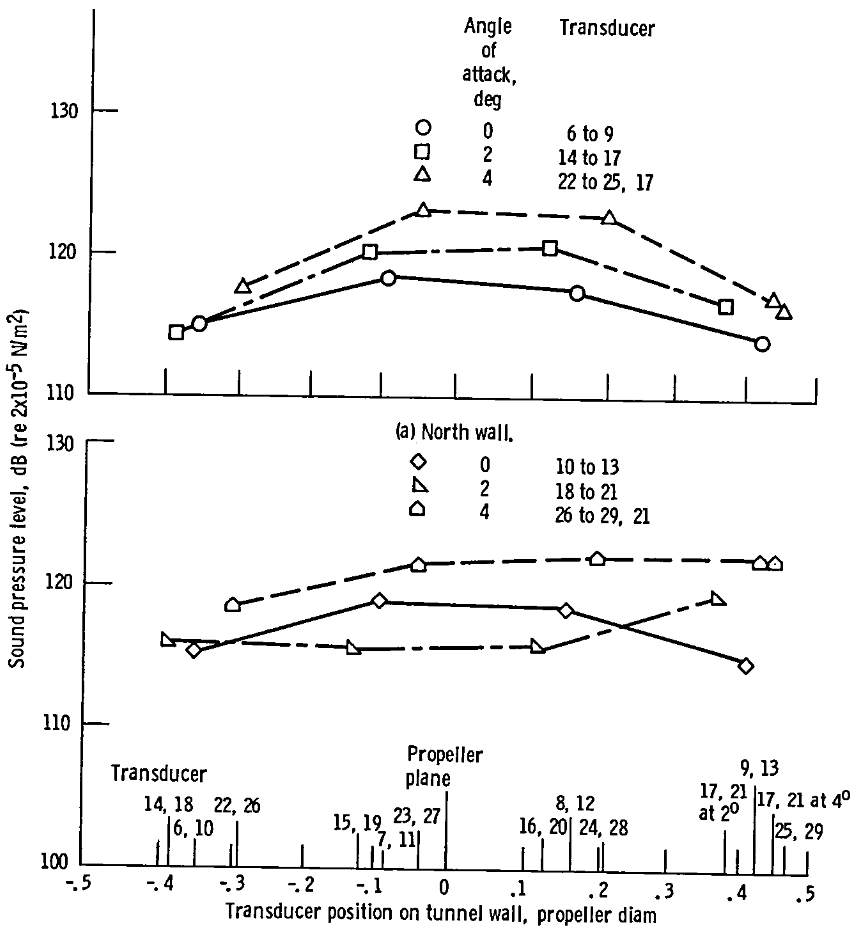


Figure 4. - SR-6 directivity at 0.6 axial Mach number.

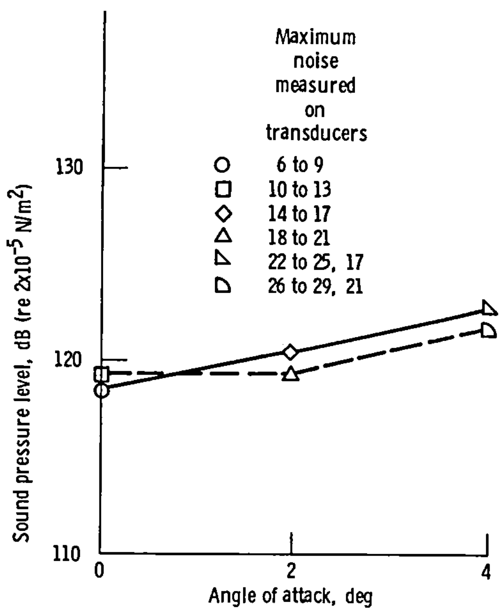


Figure 5. - Maximum blade passage tone variation with angle of attack for SR-6 at 0.6 axial Mach number.

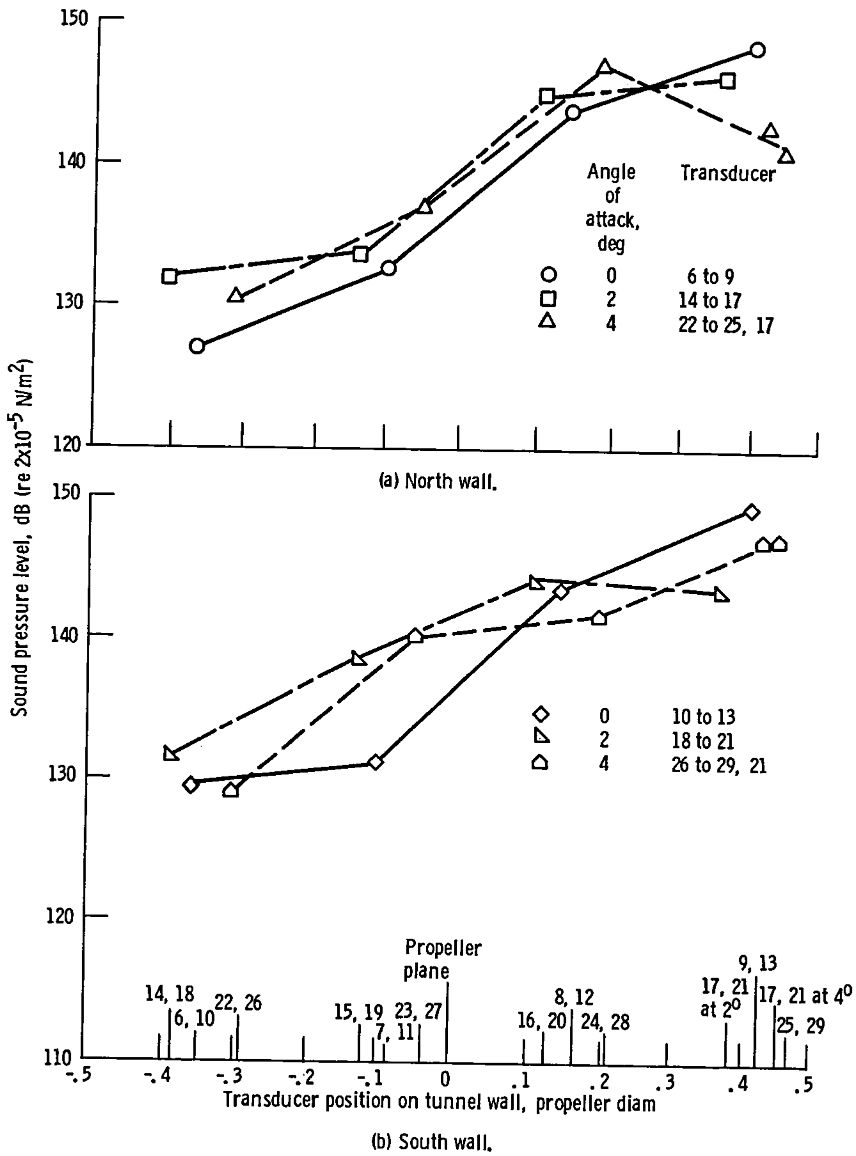


Figure 6. - SR-6 directivity at 0.8 axial Mach number.

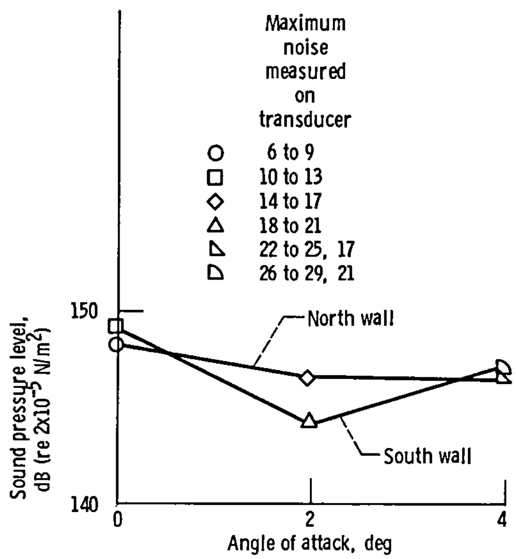


Figure 7. - Maximum blade passage tone variation with angle of attack for SR-6 at 0.8 axial Mach number.

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15. Supplementary Notes

16. Abstract

The noise generated by supersonic-tip-speed propellers may create a cabin noise problem for future airplanes powered by these propellers. Noise of a number of propeller models had been measured in the NASA Lewis 8- by 6-Foot Wind Tunnel with flow parallel to the propeller axis. In flight, as a result of the induced upwash from the airplane wing, the propeller may be at an angle of attack with respect to the incoming flow. Therefore, the 10-blade SR-6 propeller was operated at angle of attack to determine its noise behavior. Higher blade passage tones were observed for the propeller operating at angle of attack in a 0.6 axial Mach number flow. The noise increase was not symmetrical, with one wall of the wind tunnel showing a larger noise increase than the other wall. No noise increase was observed at angle of attack in a 0.8 axial Mach number flow. For this propeller the dominance of thickness noise, which does not increase with angle of attack, may explain the lack of noise increase at the higher 0.8 Mach number.

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