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Additional Noise Data on the SR-3 Propeller

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SUMMARY

The noise generated by supersonic-tip-speed propellers is a possible cabin environment problem for future airplanes powered by these propellers. Three models of these propellers were previously tested in the Lewis 8- by 6-Foot Wind Tunnel. Additional noise data taken on the SR-3 propeller at a new position in the wind tunnel are reported herein. Data were taken at the same operating conditions as in the previous tests and at three additional conditions. The pressure transducers were located as close to the previous positions, with respect to the propeller, as was possible. Two of the present positions were the same as before, two of the positions were slightly up- or downstream, and a new position was added.

The present data were the same as previous data taken at the same positions within what is probably the data accuracy. The additional test conditions added data in the subsonic operating region of the propeller and resulted in a slight reshaping of the curve for blade passing tone as a function of helical tip Mach number. Directivity curves with the additional transducer position gave an indication of a lobe pattern for this propeller that was not previously observed. The present data at the aft-most position indicate that some reflections, possibly from the test rig support strut, may have affected the data taken previously.

INTRODUCTION

One of the possible propulsive systems for a future energy-efficient airplane is a high-tip-speed turboprop. When the turboprop airplane is at cruise, the combination of airplane forward speed and the propeller rotational speed would result in supersonic helical velocities over the outer portions of the propeller blades - and this may create a cabin noise environment problem for the airplane at cruise. Three models of these supersonic propellers were previously tested for noise in the Lewis 8- by 6-Foot Wind Tunnel (refs. 1 and 2).

As part of additional aerodynamic testing on these propellers, which is not included in this report, the propeller test rig was moved to a different axial position in the wind tunnel. Although there was no evidence to indicate that the measured propeller noise levels would be different at this new position, a check was needed since new propellers would be tested in this position and the noise levels would be compared with previous results. This series of noise tests on the SR-3 propeller, besides checking data repeatability for a new tunnel entry, allowed the use of an additional microphone for the determination of the radiation directivity and the expansion of the test condition matrix. This paper reports these data and verifies the propeller near-field data repeatability.

APPARATUS AND PROCEDURE

The eight-bladed propeller used in this test was the SR-3 propeller. This propeller, nominally 0.622 meter (24.5 in.) in diameter, was tested in the Lewis 8- by 6-Foot Wind Tunnel. Table I shows some of the SR-3 propeller characteristics; more information on this propeller can be obtained from references 3 and 4. A plan view of the wind tunnel is shown in figure 1(a), and the SR-3 propeller in the test section is shown in figure 1(b). This is a perforated-wall wind tunnel without acoustic damping material on its walls. The possible effects of these untreated wall surfaces on the noise data are discussed in references 1 and 2. To measure the propeller noise, pressure transducers were installed in the tunnel bleed holes visible in figure 1(b). In the previous tests (refs. 1 and 2), four pressure transducers were installed in the ceiling of the test section as shown in figure 2(a). These transducers were labeled 1 to 4. In the new position, approximately 23 centimeters (9 in.) upstream in the tunnel, five transducers were installed in the tunnel ceiling. These five positions, A to E, are shown in figure 2(b). Because of the tunnel bleed hole locations, only two of the positions are exactly the same, with respect to the propeller, as before. Position B corresponds to position 2, and position D corresponds to position 3. The two extreme positions, A and E, were chosen to be as close to the old positions 1 and 4 as possible. However, A ended up further upstream and E further downstream because of available bleed hole positions. To better define the propeller directivity, a transducer was placed between positions B and D, and it is designated as position C.

Tests were conducted at three propeller advance ratios (ratio of free-stream velocity to the product of rotational speed and propeller diameter) J of 3.06, 3.26, and 3.50 and at the windmill condition for each tunnel Mach number tested. The tunnel Mach numbers were 0.85, 0.80, 0.75, 0.70, and 0.60, which correspond with the previous data points. In addition, data were taken at Mach 0.65 to fill in the range and at 0.55 and 0.50 to extend the range of the previous data.

RESULTS AND DISCUSSION

Spectra

The signals from the five pressure transducers were recorded on magnetic tape, and narrowband spectra from 0 to 10 000 hertz, with a bandwidth of approximately 26 hertz were taken for each of the test points. Some sample spectra are shown in figure 3. These spectra are all for an advance ratio J of 3.06 and at the maximum-tone transducer position. Figure 3(a), for the Mach 0.80 tunnel condition, represents the design cruise condition of the propeller. In this figure the tones generated by the propeller are easily visible above the broadband tunnel noise, and the blade passing frequency is large enough so that no interference with the tunnel compressor noise occurs. Figure 3(b) shows the spectrum at a tunnel Mach number of 0.60. Here the levels of the propeller tones are less than the tunnel background noise at all but the blade passing tone itself. At this Mach number the J = 3.06 condition is the only one that has any tone visible at this analysis bandwith. The data at other propeller advance ratios have all their tones below the tunnel background. Figure 3(c) is for a tunnel Mach number of 0.55. Here the blade passing frequency of the propeller tone is in the same frequency analysis region as the tunnel compressor tones. The propeller tone cannot be determined from the 0- to 1000-hertz spectra. To separate the propeller tone from the compressor tones at the 0.55 and 0.50 Mach number points, narrowband data were taken from 0 to 1000 hertz with a bandwidth of approximately 2.6 hertz.

Sample spectra for the tunnel Mach numbers of 0.55 and 0.50 are shown in figure 4. From this figure, more detail about the tunnel compressor tones is available, as well as the resolution of the propeller blade passing tone. The tone levels were read from these narrow bands (0 to 10 000 Hz or 0 to 1000 Hz, depending on the speed); a compilation of the first eight harmonics is given in table II. In this table the propeller tone levels are tabulated for the conditions where the tones are visible above the tunnel background. For those conditions where the tunnel background masks the tones, the levels have been denoted as not visible. As with the previous data (ref. 2) the propeller noise is not visible at the windmill condition, and that condition is therefore not included in the table.

Variation with Helical Tip Mach Number

The maximum measured blade passing tone levels on the top wall are plotted as a function of helical tip Mach number (vector sum of axial and rotational Mach numbers) in figure 5. The data were obtained by operating the propeller at a fixed blade setting angle at different tunnel Mach numbers. The propeller advance ratio J for all these data points was held at a nominal value of 3.06 to approximate the probable manner in which the propeller would operate at these different Mach numbers. The data from the previous report (ref. 2) are plotted as the squares, and the present data are plotted as the circles. The solid curve drawn through the points is the previous curve from reference 2.

As can be seen from figure 5, the present data, which were taken at the same conditions as the previous data, fall very close to the previous data. The differences that exist, of the order of 1 decibel, are probably an indication of the data repeatability.

The data point that was taken to fill in the curve, at the helical tip Mach number of 0.93, seems to be slightly above the curve from reference 2 (solid line) and may indicate that the curve is slightly in error in this region. The two new points that were taken to extend the lower Mach number region of the curve seem to indicate a reduction of the slope of the curve. These two extensions to the previous data have led to a slight reshaping of the curve in the subsonic region (dashed curve in fig. 5). This dashed curve fairs into the solid curve (ref. 2) at the Mach 1.0 point. In general the present data confirm the previous data and provide more information about the variation of the blade passing tone with helical tip Mach number in the subsonic region.

Directivity

The blade passing tone measured on the top wall of the wind tunnel is shown as a function of the position fore and aft of the propeller plane in figure 6. Here again the previous data are plotted as the squares and the present data as the circles. In this figure part (a) is for a tunnel Mach number of 0.80, (b) for 0.70, (c) for 0.60, (d) for 0.55, and (e) for 0.50.

The data at positions B and D, where the transducers were in the same relative positions to the propeller as before, showed good agreement with the previous data. However, the new transducer position, C, yielded data that were significantly below the levels of transducers B or D. It is possible that this dip in the data is from some reflection in the tunnel, but most likely it is an indication of a lobed pattern from this propeller. This pattern was not seen in the previous data because this transducer position was not used before. The lobe pattern, which is visible in figures 6(a) to (c), adds significantly to the information available about these types of propellers.

The existence of a lobe pattern in the noise field of this propeller may have a significant effect on the design of an airplane using this propeller. A minimum-noise area in the directivity pattern might affect the passenger placement inside the airplane and the type and placement of cabin wall acoustic treatment. Because of its possible importance, the existence and extent of this noise minimum should be the subject of future study.

Transducers A and E were not exactly in the same relative positions as transducers 1 and 4 from the previous tests. Position A was further upstream and position E further downstream than in the previous tests. Position A, in general, showed data that were on an extension of the previous curve. However, data for position E were significantly below an extension of the previous data. It is possible that the noise falls off rapidly in this region, but it may also be that the previous data at position 4 were higher than they should have been because of reflections. This possibility was previously brought out in reference 5. These reflections may be from the test rig support strut (figs. 1 and 2), and consequently the repositioning of this transducer downstream (position e) may have eliminated these reflections.

CONCLUDING REMARKS

Additional noise data on the SR-3 propeller were taken in the NASA Lewis 8- by 6-Foot Wind Tunnel. Data were taken for the propeller in a new position in the wind tunnel at the same propeller operating conditions as in previous tests and at three propeller conditions not previously tested. The pressure transducers were located as close to the previous locations, with respect to the propeller, as was possible. In the present experiments two of the positions were the same as before, two of the positions were slightly up- or downstream of previous positions, and a new position was added.

The present data were the same as previous data taken at the same positions within what is probably the accuracy of the data. The addition of the propeller test conditions added data in the subsonic operating region of the propeller. This new data resulted in a slight reshaping of the curve for blade passing tone as a function of helical tip Mach number in the subsonic region of the curve.

Directivity curves with the additional transducer position gave an indication of a lobe pattern for this propeller that was not previously observed. The present data at the aft-most position are lower than the previous data and may indicate that reflections, possibly from the test rig support strut, affected the data taken previously.

REFERENCES

1. Dittmar, J. H., Blaha, B. J., and Jeracki, R. J.: Tone Noise of Three Supersonic Helical Tip Speed Propellers in a Wind Tunnel at 0.8 Mach Number. NASA TM-79046, 1978.

2. 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.

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4. Dugan, J. F., Miller, B. A., and Sagerser, D. A.: Status of Advanced Turboprop Technology. CTOL Transport Technology, 1978, NASA CP-2036, Pt. 1, 1978, pp. 139-166.

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TABLE I. - SR-3 PROPELLER CHARACTERISTICS

Design cruise tip speed, m/sec (ft/sec)	244 (800)
Design cruise power loading, kW/m^2 (shp/ft^2)	301 (37.5)
Number of blades	8
Tip sweep angle, deg	34
Predicted design efficiency, percent	81
Nominal diameter, D, cm (in.)	62.2 (24.5)

TABLE II. - SR-3 SOUND PRESSURE LEVELS

(a) Tunnel Mach number, 0.85; propeller advance ratio, J, 3.47; power coefficient, C_p, 1.08; propeller speed, 7825 rpm; helical tip Mach number, 1.14.

Harmonic number	Transducer				
	A	B	C	D	E
	Sound pressure level of harmonic, SPL, dB ref. 2×10^{-5} N/m^2				
1 (BPF)	(a)	133.5	138	139	137.5
2	↓	125.5	125	137.5	136.5
3	↓	(b)	126	133.5	131.5
4	↓	↓	122.5	128.5	131.5
5	↓	↓	(b)	127	125
6	↓	↓	↓	118.5	(b)
7	↓	↓	↓	120	(b)
8	↓	↓	↓	(b)	(b)

(b) Tunnel Mach number, 0.85; propeller advance ratio, J, 3.25; power coefficient, C_p, 1.28; propeller speed, 8411 rpm; helical tip Mach number, 1.18

Harmonic number	Transducer				
	A	B	C	D	E
	Sound pressure level of harmonic, SPL, dB ref. 2×10^{-5} N/m^2				
1 (BPF)	(a)	137	136	143	(a)
2	↓	125.5	127	135.5	↓
3	↓	(b)	123.5	135.5	↓
4	↓	↓	121.5	124	↓
5	↓	↓	113	128.5	↓
6	↓	↓	(b)	117.5	↓
7	↓	↓	(b)	119.5	↓
8	↓	↓	(b)	117	↓

(c) Tunnel Mach number, 0.85; propeller advance ratio, J, 3.05; power coefficient, C_p, 1.53; propeller speed, 8933 rpm; helical tip Mach number, 1.21.

1 (BPF)	(a)	139	(a)	145.5	(a)
2	↓	128.5	↓	129	↓
3	↓	119.5	↓	134	↓
4	↓	(b)	↓	127	↓
5	↓	↓	↓	124	↓
6	↓	↓	↓	123.5	↓
7	↓	↓	↓	(b)	↓
8	↓	↓	↓	(b)	↓

(d) Tunnel Mach number, 0.80; propeller advance ratio, J, 3.48; power coefficient, C_p, 1.27; propeller speed, 7437 rpm helical tip Mach number, 1.07.

1 (BPF)	(a)	141	(a)	141.5	130
2	↓	132	↓	133.5	124.5
3	↓	126.5	↓	124	(b)
4	↓	121.5	↓	125.5	119
5	↓	118	↓	122.5	116
6	↓	(b)	↓	116	(b)
7	↓	(b)	↓	115	(b)
8	↓	(b)	↓	111.5	(b)

(e) Tunnel Mach number, 0.80; propeller advance ratio, J, 3.25; power coefficient, C_p, 1.53; propeller speed, 7985 rpm; helical tip Mach number, 1.11.

1 (BPF)	(a)	143	136	143	131
2	↓	132	131.5	130	127
3	↓	127	126	125.5	125
4	↓	121.5	124	127.5	125
5	↓	117	118.5	121	119.5
6	↓	(b)	115.5	122	115
7	↓	(b)	(b)	116	113.5
8	↓	(b)	(b)	113.5	109

(f) Tunnel Mach number, 0.80; propeller advance ratio, J, 3.06; power coefficient, C_p, 1.71; propeller speed, 8495 rpm; helical tip Mach number, 1.14.

1 (BPF)	128	138	136	143	130
2	(b)	128	131	133	128.5
3	↓	125	129.5	128.5	121.5
4	↓	120.5	122	131	126.5
5	↓	(b)	121.5	126.5	117.5
6	↓	↓	115.5	123	116.5
7	↓	↓	112	120	112
8	↓	↓	(b)	117	110

[a]Transducer or recorder malfunction.
[b]Not visible above tunnel background.

TABLE II. - CONTINUED

(g) Tunnel Mach number, 0.75; propeller advance ratio, J, 3.49; power coefficient, C_p, 1.34; propeller speed, 7044 rpm; helical tip Mach number, 1.01.

Harmonic number	Transducer				
	A	B	C	D	E
	Sound pressure level of harmonic, SPL, dB ref. 2×10^{-5} N/m^2				
1 (BPF)	127	139	133.5	128.5	127
2	128	130	127.5	134	124
3	(b)	127	125	124.5	123
4	↓	121	121.5	119	(b)
5	↓	118.5	118	117	↓
6	↓	116.5	116	116	↓
7	↓	113	114	112	↓
8	↓	111	111	110.5	↓

(h) Tunnel Mach number, 0.75; propeller advance ratio, J, 3.26; power coefficient, C_p. 1.58; propeller speed, 7551 rpm; helical tip Mach number, 1.05.

Harmonic number	Transducer				
	A	B	C	D	E
	Sound pressure level of harmonic, SPL, dB, ref. 2×10^{-5} N/m^2				
1 (BPF)	129	137.5	136.5	132.5	131.5
2	125.5	135	132	127	125
3	(b)	130.5	122.5	128	122.5
4	↓	124.5	125	124	118
5	↓	120	120	124	117
6	↓	117	117.5	119.5	(b)
7	↓	113.5	115.5	117	(b)
8	↓	111	110.5	113.5	(b)

(i) Tunnel Mach number, 0.75; propeller advance ratio, J, 3.06; power coefficient, C_p, 1.79; propeller speed, 8039 rpm; helical tip Mach number 1.08.

1 (BPF)	129	140	138.5	146	128.5
2	(b)	136	129.5	137.5	132
3	↓	127	123	130.5	124.5
4	↓	126	122.5	128	119.5
5	↓	120	122	126	118.5
6	↓	116.5	120	123	114
7	↓	113	114	117.5	111.5
8	↓	(b)	110.5	115	108

(j) Tunnel Mach number, 0.70[c]; propeller advance ratio, J, 3.25; power coefficient, C_p, 1.67; propeller speed, 7087 rpm; helical tip Mach number, 0.97.

1 (BPF)	126	135.5	131	137	123.5
2	125.5	133.5	125.5	129	122
3	(b)	130	121.5	(b)	(b)
4	↓	122	120	↓	↓
5	↓	120	(b)	↓	↓
6	↓	115	↓	↓	↓
7	↓	(b)	↓	↓	↓
8	↓	(b)	↓	↓	↓

(k) Tunnel Mach number, 0.70; propeller advance ratio, J, 3.06; power coefficient, C_p, 1.89; propeller speed, 7550 rpm; helical tip Mach number, 1.0.

1 (BPF)	131.5	139	133.5	139	129
2	127	131.5	129	136.5	122.5
3	(b)	133	125	122.5	122.5
4	↓	127	122	119	119
5	↓	130	117.5	117	114.5
6	↓	121	117	113.5	114.5
7	↓	118	116	113	110
8	↓	114.5	110.5	109	108.5

(l) Tunnel Mach number, 0.65[d]; propeller advance ratio, J, 3.25; power coefficient, C_p, 1.68; propeller speed, 6646 rpm; helical tip Mach number, 0.901.

1 (BPF)	(b)	127.5	126	131	129
2	↓	120.5	122	(b)	(b)
3	↓	(b)	(b)	↓	↓
4	↓	↓	↓	↓	↓
5	↓	↓	↓	↓	↓
6	↓	↓	↓	↓	↓
7	↓	↓	↓	↓	↓
8	↓	↓	↓	↓	↓

[b]Not visible above tunnel background.
[c]Data at the advance ratio of 3.50 showed no propeller tones above the tunnel background.
[d]Data at the advance ratio of 3.48 showed no propeller tones above the tunnel background.

TABLE II. - CONCLUDED

(m) Tunnel Mach number, 0.65; propeller advance ratio, J, 3.06; power coefficient, C_p, 1.91; propeller speed, 7072 rpm; helical tip Mach number, 0.93.

Harmonic number	Transducer				
	A	B	C	D	E
	Sound pressure level of harmonic, SPL, dB, ref. 2×10^{-5} N/m^2				
1 (BPF)	130	128	133.5	137	126
2	(b)	130.5	122.5	124.5	(b)
3	↓	122.5	122	122	↓
4	↓	120.5	(b)	(b)	↓
5	↓	114.5	↓	↓	↓
6	↓	(b)	↓	↓	↓
7	↓	(b)	↓	↓	↓
8	↓	(b)	↓	↓	↓

(n) Tunnel Mach number, 0.60[e]; propeller advance ratio, J, 3.06; power coefficient, C_p, 1.91; propeller speed, 6573 rpm; helical tip Mach number, 0.86

Harmonic number	Transducer				
	A	B	C	D	E
	Sound pressure level of harmonic, SPL, dB ref. 2×10^{-5} N/m^2				
1 (BPF)	126	129	126	128	(a)
2	(b)	118.5	(b)	(b)	↓
3	↓	(b)	↓	↓	↓
4	↓	↓	↓	↓	↓
5	↓	↓	↓	↓	↓
6	↓	↓	↓	↓	↓
7	↓	↓	↓	↓	↓
8	↓	↓	↓	↓	↓

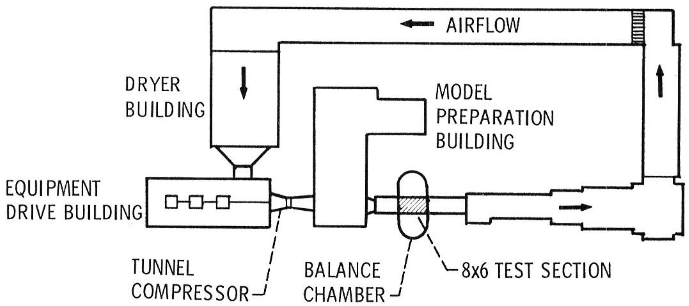
(o) Tunnel Mach number, 0.55[f]; propeller advance ratio, J, 3.05; power coefficient, C_p, 1.94; propeller speed, 6111 rpm; helical tip Mach number, 0.785.

1 (BPF)	120.5	127	120.0	119.0	(a)
2	(b)	(b)	(b)	(b)	↓
3	↓	↓	↓	↓	↓
4	↓	↓	↓	↓	↓
5	↓	↓	↓	↓	↓
6	↓	↓	↓	↓	↓
7	↓	↓	↓	↓	↓
8	↓	↓	↓	↓	↓

(p) Tunnel Mach number, 0.50[g]; propeller advance ratio, J, 3.06; power coefficient, C_p, 1.96; propeller speed, 5443 rpm; helical tip Mach number, ^.714.

1 (BPF)	(b)	119	117	117.5	117
2	↓	(b)	(b)	(b)	(b)
3	↓	↓	↓	↓	↓
4	↓	↓	↓	↓	↓
5	↓	↓	↓	↓	↓
6	↓	↓	↓	↓	↓
7	↓	↓	↓	↓	↓
8	↓	↓	↓	↓	↓

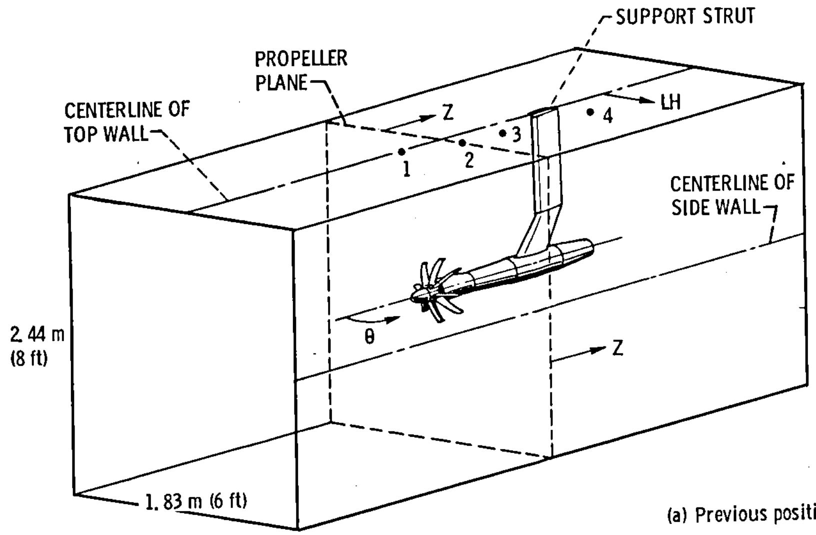
[a]Transducer or recorder malfunction.
[b]Not visible above tunnel background.
[e]Data at advance ratios of 3.50 and 3.25 showed no propeller tones above the tunnel background.
[f]Data at advance ratios of 3.48 and 3.25 showed no propeller tones above the tunnel background.
[g]Data at advance ratios of 3.51 and 3.23 showed no propeller tones above the tunnel background.



(a) Plan view of 8- by 6-Foot Wind Tunnel.

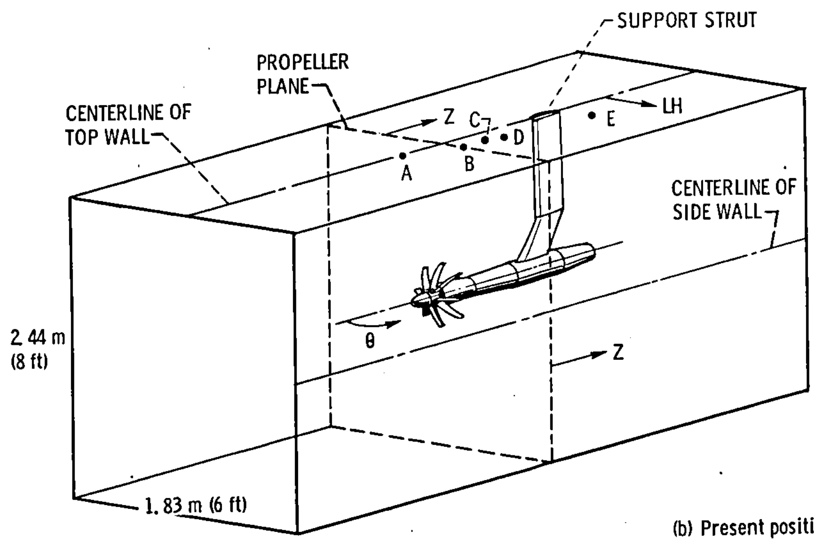
(b) SR-3 propeller in test section.

Figure 1. - Wind tunnel and propeller installation.



POSITION	TRANSDUCER			
	1	2	3	4
	TRANSDUCER POSITION, cm (in.)			
Z LH	-27.7(-10.9) 2.54(1.0)	0.953(0.375) 10.2(4.0)	45.2(17.8) 7.62(3.0)	104.4(41.1) 31.5(12.4)
NOMINAL ANGLE, θ, deg.	77	90	110	130

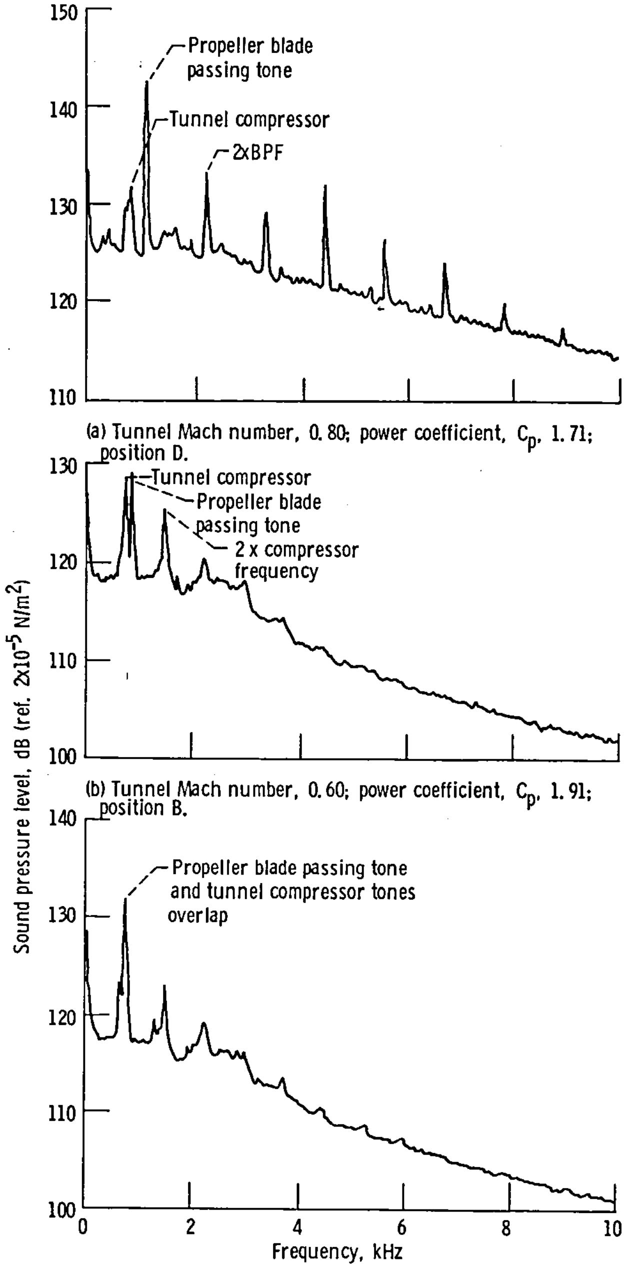
(a) Previous positions.



POSITION	TRANSDUCER				
	A	B	C	D	E
	TRANSDUCER POSITION, cm (in.)				
Z LH	33.0(13.0) 4.83(1.9)	0.953(0.375) 10.2(4.0)	23.9(9.4) 2.54(1.0)	45.2(17.8) 7.62(3.0)	107.4(42.3) 31.5(12.4)
NOMINAL ANGLE, θ, deg.	75	90	101	110	131

(b) Present positions.

Figure 2. - Pressure transducer positions.

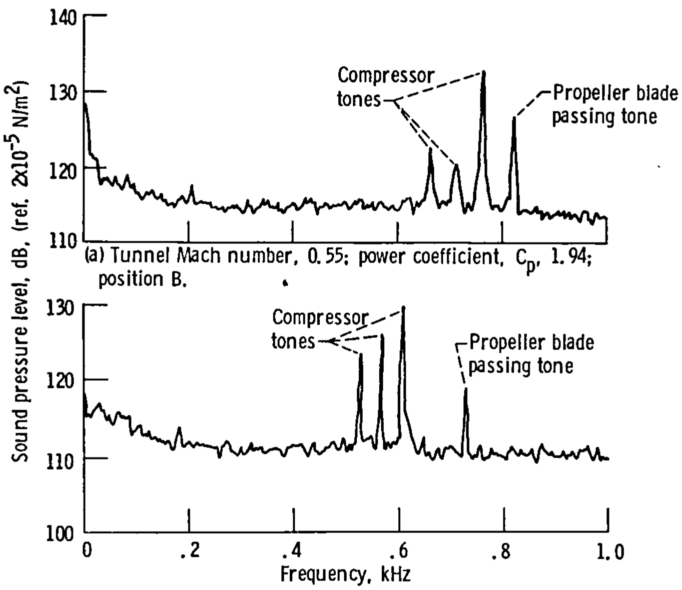


(a) Tunnel Mach number, 0.80; power coefficient, C_p, 1.71; position D.

(b) Tunnel Mach number, 0.60; power coefficient, C_p, 1.91; position B.

(c) Tunnel Mach number, 0.55; power coefficient, C_p, 1.94; position B.

Figure 3. - SR-3 sound pressure level spectra - 26-hertz bandwidth. Propeller advance ratio, J, 3.06.



(b) Tunnel Mach number, 0.50; power coefficient, C_p, 1.96; position B.

Figure 4. - SR-3 sound pressure level spectra - 2.6-hertz bandwidth. Propeller advance ratio; J, 3.06.

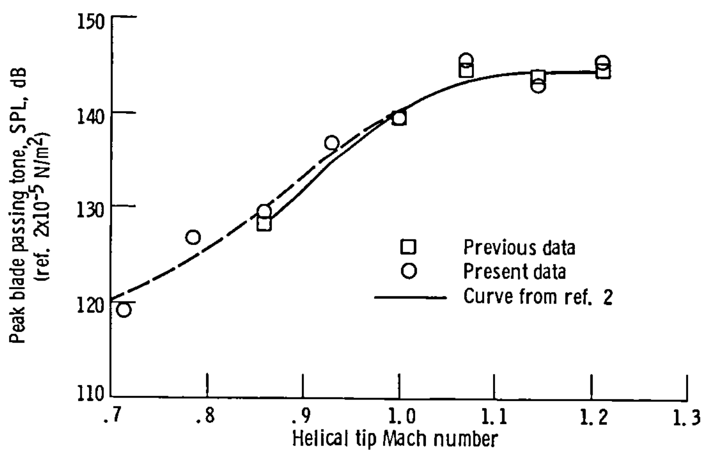
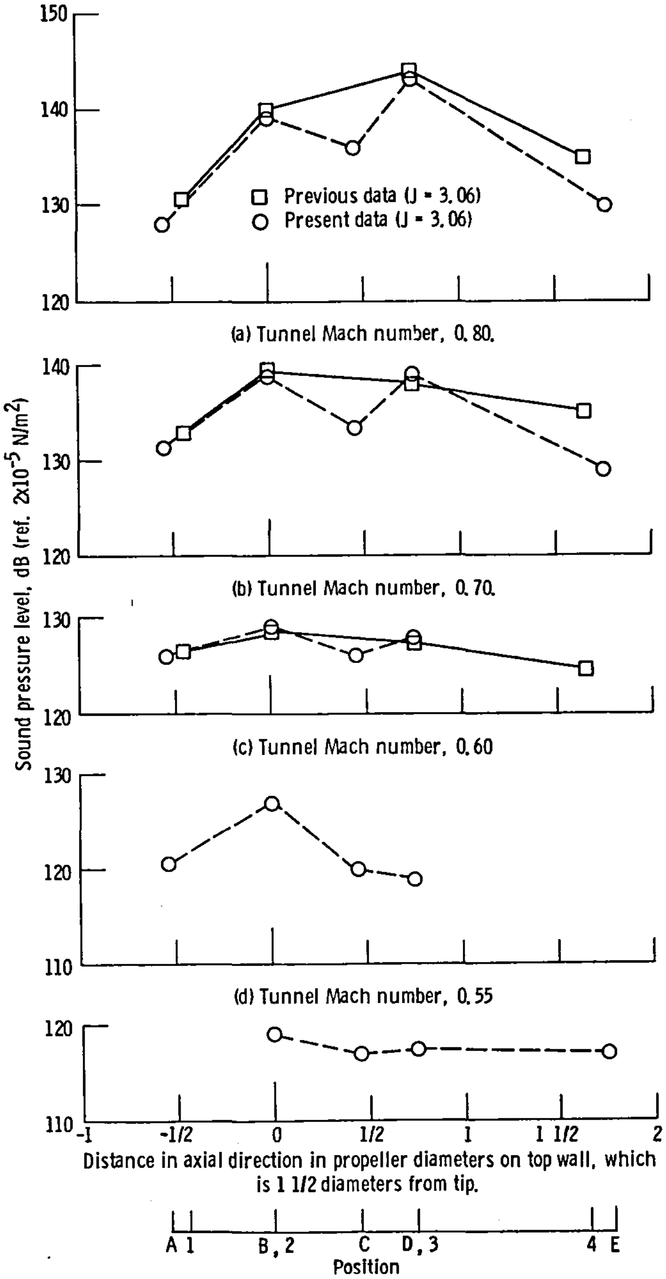


Figure 5. - Maximum blade passing tone variation with helical tip Mach number - at nominal propeller advance ratio of 3.06.



(e) Tunnel Mach number, 0.50

Figure 6. - Sideline directivity of blade passing tone.

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16. Abstract

The noise generated by supersonic-tip-speed propellers is a possible cabin environment problem for future airplanes powered by these propellers. Three models of these propellers were previously tested in the Lewis 8- by 6-Foot Wind Tunnel. Additional noise data on the SR-3 propeller have been taken at a new position in the wind tunnel. Data were taken at the same operating conditions as in the previous tests and at three additional conditions. The pressure transducers were located as close to the previous positions, with respect to the propeller, as was possible. Two of the present positions were the same as before, two of the positions were slightly up- or downstream, and a new position was added. The present data were the same as previous data taken at the same positions within what is probably the data accuracy. The additional test conditions added data in the subsonic operating region of the propeller and resulted in a slight reshaping of the curve for blade passing tone as a function of helical tip Mach number. Directivity curves with the additional transducer position gave an indication of a lobe pattern for this propeller that was not previously observed. The present data at the aft-most position indicate that some reflections, possibly from the test rig support strut, may have affected the data taken previously.

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