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A Preliminary Comparison Between the SR-6 Propeller Noise in Flight and in a Wind Tunnel

Jams H. Dittmar
Lewis Research Center
Cleveland, Ohio

and

Paul L. Lasagna and Karen G. Mackall
Hugh L. Dryden Flight Research Center
Edwards, California

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A PRELIMINARY COMPARISON BETWEEN THE SR-6 PROPELLER NOISE IN FLIGHT AND IN A WIND TUNNEL

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

and

Paul L. Lasagna and Karen G. Mackall
Hugh L. Dryden Flight Research Center
Edwards, California

SUMMARY

High speed turboprops offer an attractive candidate for future aircraft because of their high propulsive efficiency. However, one of the possible problems associated with these propellers is their high noise level at cruise condition that may create a cabin environment problem. Models of these propellers have been tested for acoustics in the Lewis 8-by-6-foot wind tunnel and on the Dryden JetStar airplane. This paper shows comparisons between the airplane and wind tunnel data for the SR-6 propeller.

The comparison of maximum blade passing tone variation with helical tip Mach number between the tunnel and flight data was good when corrected to the same test conditions. Directivity comparisons also showed fairly good agreement. These good comparisons indicate that the wind tunnel is a viable location for measuring the blase passage tone noise of these propellers.

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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 results in supersonic velocities over the outer portions of the propeller blades which may create a cabin noise problem. Models of this type of propeller have been previously tested for noise in the NASA Lewis 8-by-6-foot wind tunnel (refs. 1 to 4). This wind tunnel does not have acoustic damping material on its walls and there has been a concern that this lack of acoustic material may have compromised the noise data.

As part of the program to evaluate the noise of these propellers the NASA Dryden JetStar airplane was modified to test them in flight. A previous comparison between wind tunnel and flight data, for the SR-3 propeller, showed good agreement in the maximum blade passing tone variation with helical tip Mach number (refs. 5 and 6). Another propeller, SR-6, has now been tested both in a wind tunnel, reference 4, and in flight. The intent of this paper is to make a preliminary comparison between the SR-6 propeller noise measured on the JetStar airplane and that previously obtained in the 8- by 6-foot wind tunnel.

APPARATUS AND PROCEDURE

The SR-6 propeller model used in these noise comparisons has ten blades with a 40 degree tip sweep and is nominally 0.696 meter (27.4 in.) in diameter. Table I shows some of its design characteristics and more information is available in reference 7. A picture of the propeller in the 8- by 6-foot wind tunnel can be seen in figure 1(a) and on the JetStar airplane in figure 1(b).

To measure the propeller noise, pressure transducers were installed in the wind tunnel bleed holes visible in figure 1(a). The locations of these transducers are shown in figure 2(a). The positions are identified as A thru E, as in reference 3, and are located on the top wall of the wind tunnel which is approximately one and one-half propeller diameters above the propeller tip. On the JetStar airplane, microphones were installed flush in the airplane fuselage which is approximately eight-tenths of a propeller diameter from the propeller tip. The propeller axis is tipped three degrees downward on the airplane to align it with the flow. The microphones on the airplane were installed along a line directly underneath the propeller centerline. The locations of the microphones reported herein are numbered 1 thru 9 as can be seen in figure 2(b).

The intent of this paper was to compare data taken at the same test points in the wind tunnel and in flight but difficulties in the blade setting angle mechanism for the wind tunnel tests (ref. 4) and drive system limitations on the airplane forced somewhat different test conditions. Experiments in the wind tunnel were performed with blade setting angles (62° and 64°) near the design blade setting angle of the propeller (63°) and at blade setting angles (59° and 61°) near to the blade setting angle (60°) which would give performance close to the design performance of the previously tested SR-3 propeller.

The airplane tests were performed at 62.4 and 58.9 degrees. The intent was to test the propellers at constant advance ratios J (see appendix) at different axial Mach numbers. However, for the airplane tests, an available power limitation prevented the tests from being performed at constant advance ratio and at the higher Mach numbers this resulted in higher advance ratios than desired.

The signals from the pressure transducers in the tunnel and microphones on the airplane were recorded on magnetic tape and narrowband spectra from 0 to 10,000 Hz, with a bandwidth of approximately 26 Hz, were taken for each of the test points. The blade passing tone level was read from each of these spectra and is presented, along with the test conditions, in table II for the tunnel data and in table III for the airplane data.

RESULTS AND DISCUSSIONS

In order to make comparison plots between the wind tunnel and airplane data it is first necessary to bring the two sets of data to the same experimental conditions. There are two primary differences: atmospheric conditions and geometry. The airplane tests were performed at 9.1 km (30,000 ft) where the air is less dense than in the wind tunnel tests. As shown in reference 8, to correct the wind tunnel data to flight conditions, the wind tunnel sound pressure levels are changed by 20 times the log of the ratio of the atmospheric pressure in flight to that in the tunnel. Since at each axial Mach number in the tunnel the pressure is different, this correction results in reductions in the tunnel noise of 9.51 dB at an axial Mach number of 0.6, 9.02 dB at 0.7, 8.56 dB at 0.75, 7.97 dB at 0.8 and 7.45 dB at 0.85. (These corrections are the same as those used previously in ref. 5).

The geometric conditions are also different between the tunnel and flight tests with the propeller being closer to the airplane fuselage than to the wind tunnel wall. Because, in both cases, the measurement locations are so close to the source, the noise does not necessarily meet far-field criteria. Therefore, the proper correction for distance is somewhat uncertain. Reference 9 has suggested that a distance correction of 15 times the log of the distance ratio be used in this near field instead of the normal far-field correction of 20 times the log. The 15 log correction is used here and was used previously in reference 5. It should be noted, however, that, because of the small distance, the standard 20 log correction gives a value less than one decibel different and its use would not materially alter the comparison. Taking the distance from the measurement location to the tangent point on the propeller tip circle gives a distance correction of 3.2 dB. (This is a slightly different correction from that used for SR-3 in reference 5 because of the different diameters of the two propellers.) No correction was made for the slightly different distances to each microphone location that result from the three degree tilt of the propeller. The combination of altitude and distance corrections reduces the wind tunnel data by 6.3 dB at an axial Mach number of 0.6, 5.8 dB at 0.70, 5.4 dB at 0.75, 4.8 dB at 0.80 and 4.3 dB at 0.85. When these corrections are applied to the tunnel data (table II) the data are thereby corrected to flight conditions and presented in table IV.

Variation with Helical Tip Mach Number

The maximum measured blade passing tone levels on the airplane fuselage and on the tunnel wall, corrected to flight, are plotted as a function of helical tip Mach number, M_H, (vector sum of axial and rotational Mach numbers) in figure 3. Figure 3(a) is for the SR-6 propeller operated near its design blade setting angle and figure 3(b) is for the SR-6 propeller operated near its design blade setting angle which would give the same performance (J and C_p) as the SR-3 design. In general the comparisons between the wind tunnel and flight data are very good. The slightly lower sound pressure levels of the airplane data in figure 3(a) are probably the result of the higher advance ratios for the airplane tests necessitated by the power limitations. These good comparisons indicate that the wind tunnel is a viable location for determining the maximum blade passage tone levels of these types of propellers.

Directivity

In the previous comparison between the wind tunnel and flight data, reference 5, the directivities at the lower Mach numbers agreed well, but at the higher Mach numbers the wind tunnel data fell off faster toward the front than did the airplane data. These directivity plots for the SR-3 propeller from reference 5 are repeated here in figure 4. Hanson, reference 10, has suggested that significant reductions in the forward radiated noise measured at the wall may be caused by wall boundary layer refraction. The SR-3 noise at and behind the peak angle was not affected by this boundary layer refraction. The amount of the refraction increases with increasing Mach number, increasing boundary layer thickness and as the measuring position moves forward. Reference 5 indicated that the more rapid forward falloff of the directivity in the wind tunnel may have been caused by a thicker boundary layer in the tunnel than on the airplane. The possibility of boundary layer refraction prompted an investigation by the airplane test personnel of the boundary layer thickness on the airplane. The data, taken with a 5 and an 8 inch rake, are shown in figure 5. The shape of this boundary layer profile is not typical and the bulge around a Y of 5 cm (2 in.) is indicative of an energization of the boundary layer which results in a thinner boundary layer. The airplane windshield wipers and supports were discovered to be the source of the energization and they were removed from the airplane. This resulted in the more typical boundary layer profile shown in figure 6. This thicker boundary layer was present on the airplane during the SR-6 tests since the wipers were removed.

Figure 7 shows the directivities of the blade passing tone obtained with the SR-6 propeller near its design conditions on the airplane and in the wind tunnel. As can be seen the directivities compare fairly well. In particular the large differences in noise fall off toward the front which were observed in the comparison of the SR-3 propeller noise in flight and in the tunnel at M = 0.75 and 0.80 (figs. 4(c) and (d)) do not seem to occur here. At M = 0.75, for the SR-6 propeller (fig. 7(c)), the curves are at different levels because of the different advance ratios and consequently different helical tip Mach numbers of the test (see fig. 3(a)). They are almost the same curve displaced only in level and have similar forward falloff in noise for both flight and wind tunnel tests. The tunnel curves do seem to fall off a little faster. At M = 0.80 the curves are very close to each other and the falloff toward the front is almost the same with the tunnel data falling of just a little bit faster toward the front than the airplane data. The one divergent point on the tunnel curve at position E (solid symbol) appears to be an error in the original SR-6 tunnel data and may be caused by a malfunctioning transducer or an improperly recorded amplifier gain setting. This error appears to exist at the position for all of the data recorded after a certain time in the tunnel test program and represents an uncorrectable error in the data of reference 4.

The similar forward falloff of the data for SR-6 in the wind tunnel and in flight at M = 0.75 and 0.80 is probably the result of the boundary layers in the tunnel and on the airplane now being closer to the same thickness. The directivities are not identical which probably means the boundary layers are also not identical. Another possibility, although less likely, is that the flow around the windshield wipers and supports presented an inlet flow distortion to the SR-3 propeller and caused it to produce more forward radiated noise during the airplane tests. This possibililty is less likely since the distortion from the wipers probably did not extend far enough above the airplane fuselage to impact the propeller. In either case, because of the more nearly equivalent flow conditions during the airplane and wind tunnel tests of SR-6, the noise directivities are also more nearly equivalent. This provides further indication that the wind tunnel is a viabale location for measuring the blade passing tone of these propellers.

CONCLUDING REMARKS

Noise data taken with the SR-6 propeller model flown on the NASA Dryden JetStar airplane were compared with data taken previously in the NASA Lewis 8- by 6-foot wind tunnel. Comparisons of the maximum blade passing tone variation with helical tip Mach number showed good agreement when the tunnel data were corrected to the flight test conditions. Directivity comparisons also showed fairly good agreement. These good comparisons indicate that the wind tunnel is a viable location, having no more complication than the airplane does, for measuring the blade passage tone noise of these propellers. A previous directivity comparison using a different propeller (SR-3) showed that the tunnel directivity data fell off more towards the front than did the airplane data at high axial Mach numbers. This previous difference was attributed to the different boundary layer refractions in the tunnel and on the airplane probably a result of the different boundary layer thicknesses in the two test situations. It was found that the airplane windhsield wipers and their supports were causing an energization of the airplane boundary layer resulting in an apparently thinner airplane boundary layer. The windhsield wipers and supports were subsequently removed for the SR-6 airplane tests, yielding a thicker boundary layer which was probably closer to the tunnel boundary layer, and may have resulted in the improved agreement between the tunnel and airplane noise directivities for the SR-6 propeller model. In both of the data comparisons (SR-6 or SR-3) the noise peak, which lies behind the propeller plane, did not seem to be a function of boundary layer thickness.

APPENDIX

C_p	power coefficient, $C_p = P/\rho N^3 D^5$
D	propeller diameter
J	advance ratio, J = V/ND
M	axial Mach number
M_H	helical tip Mach number (vector sum of tip rotational and axial Mach numbers)
N	propller rotational speed (revolutions/time)
P	shaft input power
V	axial velocity
Y	distance away from airplane fuelage
Z	axial distance from propeller plane (positive downstream)
β	blade setting angle at 0.75 radius with respect to plane of rotation
θ	angle with respect to propeller axis
ρ	density

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TABLE I. - SR-6 PROPELLER CHARACTERISTICS

Design cruise tip speed, m/sec (ft/sec)	213 (700)
Design cruise power loading, $KW/m^2/(shp/ft^2$	30.0 (241)
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. - PROPELLER SR-6 BLADE PASSING TONE MEASURED IN 8- BY 6-FOOT WIND TUNNEL

Test conditions				Transducer position				
Blade setting angle	Approx. tunnel Mach number	Propeller advance ratio	Propeller helical tip Mach number	A	B	C	D	E
				Blade passing tone, SPL, dB, ref. 2×10^{-5} N/m^2				
62°	0.85	3.5	1.149	(a)	138.5	142.0	143.5	141.5
	.80	↓	1.078	131.0	(a)	(a)	(a)	140.5
	.75		1.008	137.0	146.0	142.5	137.5	128.5
	.70		.937	129.5	129.5	130.5	135.0	126.0
	.60		.807	119.0	119.0	118.5	115.0	112.5
64°	.85		1.138	(a)	141.0	143.5	144.5	142.0
	.80		1.074	133.5	147.0	142.0	146.0	143.5
	.75		1.009	137.5	147.5	143.5	139.5	129.0
	.70		.943	134.5	138.0	137.5	136.5	126.5
	.60	↓	.814	121.5	124.5	118.0	124.0	114.0
59°	.85	3.06	1.222	(a)	140.0	147.0	147.5	145.5
	.80	3.04	1.143	131.5	141.5	145.0	147.5	143.5
	.75	3.06	1.074	137.5	145.5	142.5	143.5	142.5
	.70	3.06	1.001	138.5	148.5	139.0	141.0	131.5
	.60	3.06	.86	128.5	127.5	128.0	125.0	126.5
61°	.85	3.04	1.220	(a)	140.0	145.0	149.5	149.0
	.80	3.18	1.131	(a)	145.5	144.5	147.5	147.5
	.75	3.09	1.068	138.0	146.5	145.0	148.5	147.5
	.70	3.06	1.006	138.5	147.0	141.0	141.0	135.0

[a]Data not available.

TABLE III. - PROPELLER SR-6 BLADE PASSING TONE MEASURED ON JETSTAR AIRPLANE

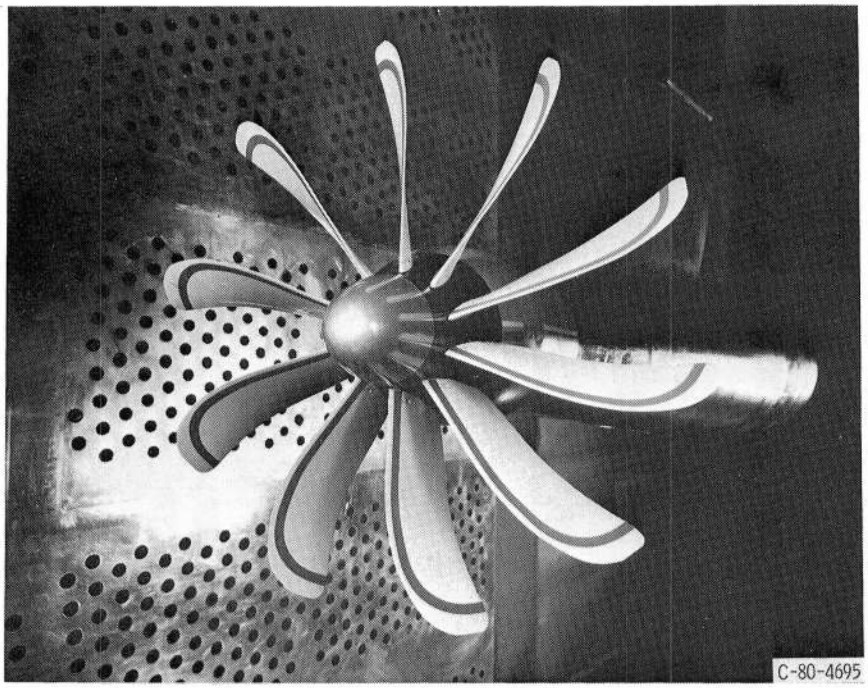
Test conditions				Microphone position								
Blade setting angle	Airplane Mach number	Propeller advance ratio	Propeller helical tip Mach number	1	2	3	4	5	6	7	8	9
				Blade passing tone, SPL, dB, ref. $2x10^{-5}$ N/m^2								
62.4	0.809	3.84	1.05	(b)	125.0	125.0	134.0	139.5	135.5	135.5	119.5	118.0
	.754	3.78	.98	↓	116.0	122.0	130.0	134.0	129.5	127.5	121.0	117.0
	.714	3.61	.95	↓	105.5	120.5	127.0	128.5	126.5	128.5	(a)	118.0
	.614	3.60	.82	↓	(a)	109.0	110.5	116.0	110.5	111.5	112.5	112.0
58.9	.805	3.29	1.11	↓	106.0	120.5	135.0	143.0	141.0	142.5	132.5	(a)
	.753	3.31	1.04	↓	108.0	128.0	136.5	140.0	136.0	135.0	125.0	113.5
	.708	3.29	.98	↓	(a)	126.0	132.0	135.5	131.5	127.0	120.0	113.5
	.623	3.21	.87	↓	(a)	116.0	121.0	123.5	119.5	119.0	114.0	111.0

[a]Data not available.
[b]Not operating.

TABLE IV. - PROPELLER SR-6 BLADE PASSING TONE, MEASURED IN THE WIND TUNNEL, CORRECTED TO FLIGHT

Test conditions				Transducer position				
Blade setting angle	Approx. tunnel Mach number	Propeller advance ratio	Propeller helical tip Mach number	A	B	C	D	E
				Blade passing tone, SPL, dB, ref. $2x10^{-5}$ N/m^2				
62°	0.85	3.5	1.149	(a)	134.2	137.7	139.2	137.2
	.80	↓	1.078	126.2	(a)	(a)	(a)	135.7
	.75		1.008	131.6	140.6	137.1	132.1	123.1
	.70		.937	123.7	123.7	124.7	129.2	120.2
	.60		.807	112.7	112.7	112.2	108.7	106.2
64°	.85		1.138	(a)	136.7	139.2	140.2	137.7
	.80		1.074	128.7	142.2	137.2	141.2	138.7
	.75		1.009	132.1	142.1	138.1	134.1	123.6
	.70		.943	128.7	132.2	131.7	130.7	120.7
	.60	↓	.814	115.2	118.2	111.7	117.7	107.7
59°	.85	3.06	1.222	(a)	135.7	142.7	143.2	141.2
	.80	3.04	1.143	126.7	136.7	140.2	142.7	138.7
	.75	3.06	1.074	132.1	140.1	137.1	138.1	137.1
	.70	3.06	1.001	132.7	142.7	133.2	135.2	125.7
	.60	3.06	.86	122.2	121.2	121.7	118.7	120.2
61°	.85	3.04	1.220	(a)	135.7	140.7	145.2	144.7
	.80	3.18	1.131	(a)	140.7	139.7	142.7	142.7
	.75	3.09	1.068	132.6	141.1	139.6	143.1	142.1
	.70	3.06	1.006	132.7	141.2	135.2	135.2	129.2

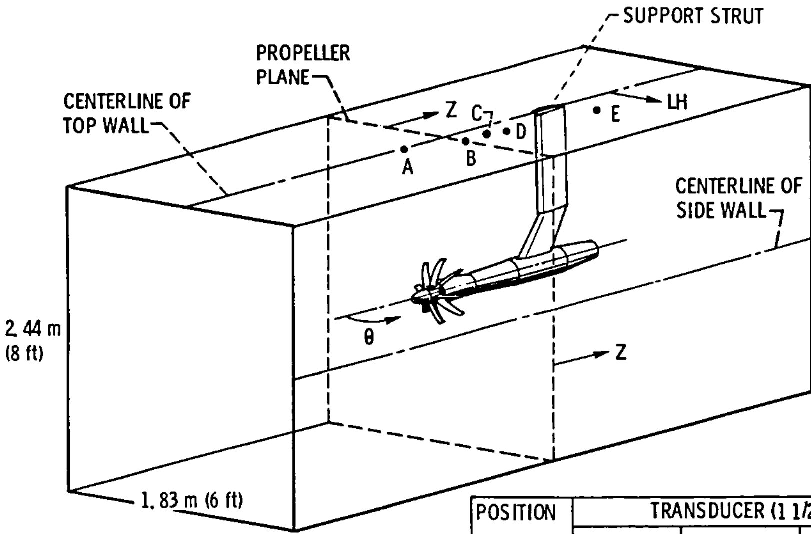
[a]Data not available.



(a) PROPELLER IN 8- BY 6-FOOT WIND TUNNEL.

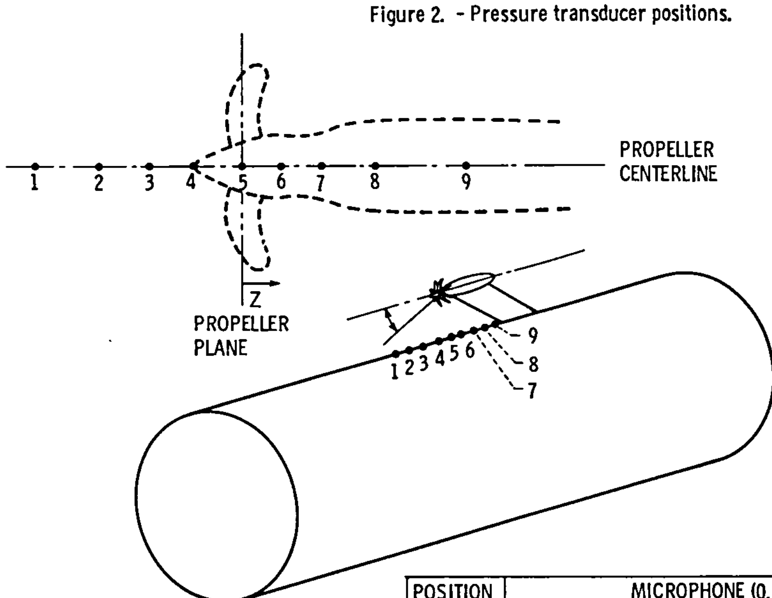
(b) PROPELLER ON JETSTAR AIRPLANE.

Figure 1. - SR-6 propeller installation.



POSITION	TRANSDUCER (1 1/2 DIAMETER FROM TIP)				
	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

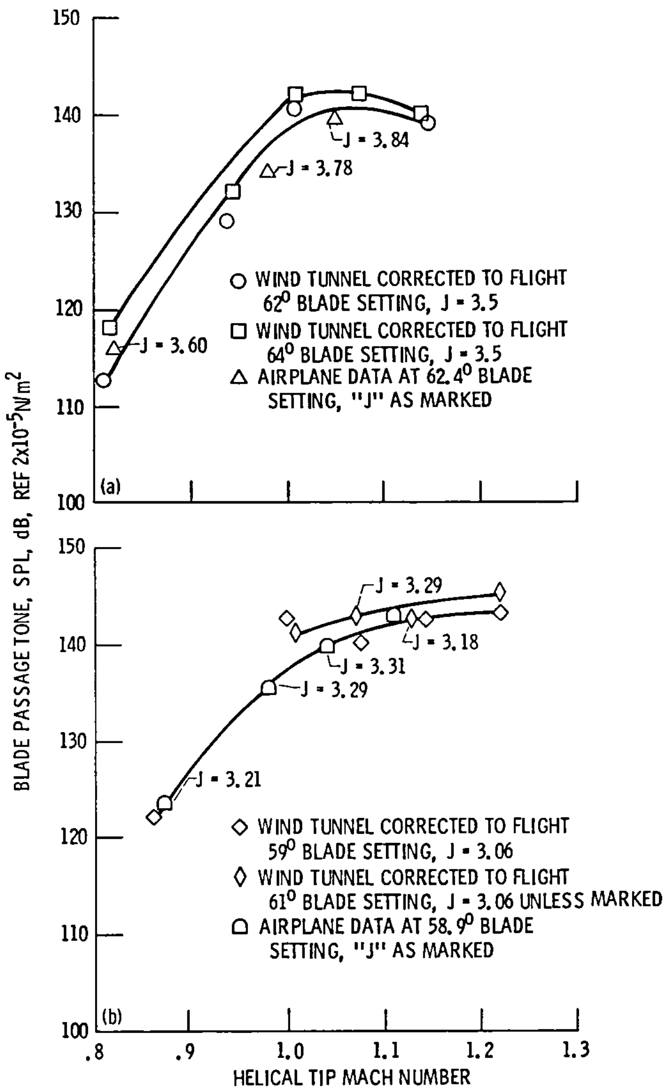
Figure 2. - Pressure transducer positions.



POSITION	MICROPHONE (0.8 DIAMETER FROM TIP)								
	1	2	3	4	5	6	7	8	9
	MICROPHONE POSITION cm (in.)								
Z	-66.0 (-26.0)	-46.7 (-18.4)	-30.5 (-12.0)	-16.0 (-6.3)	.76 (.3)	12.4 (4.9)	25.1 (9.9)	42.4 (16.7)	71.1 (28.0)
NOMINAL ANGLE, θ, deg.	51	59	69	79	91	98	107	117	130

(b) Microphones on airplane.

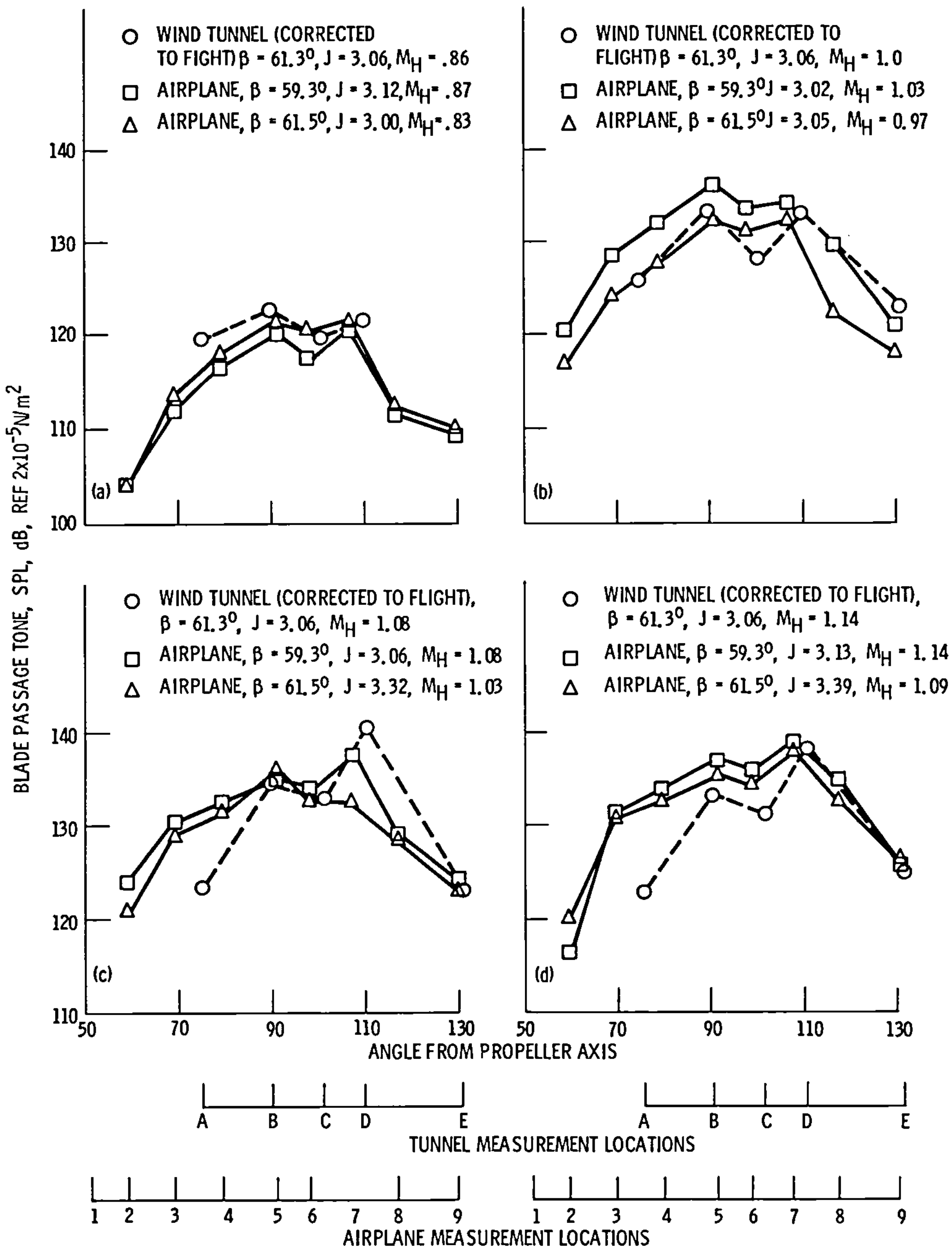
Figure 2. - Measurement locations.



(a) SR-6 operated near its design advance ratio and setting angle.

(b) SR-6 operated near the SR-3 design advance ratio and setting angle.

Figure 3. - Maximum blade passage tone variation with helical tip Mach number.



(a) Nominal axial Mach number = 0.6.

(b) Nominal axial Mach number = 0.7.

(c) Nominal axial Mach number = 0.75.

(d) Nominal axial Mach number = 0.80.

Figure 4. - Blade passing tone directivity for SR-3 propeller (ref. 5).

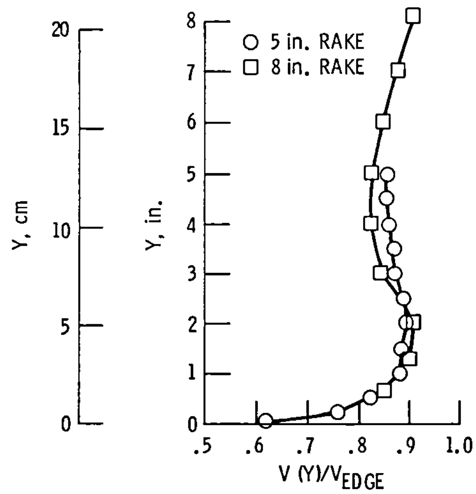


Figure 5. - Airplane boundary layer during SR-3 tests, with wipers; M ≅ 0.8.

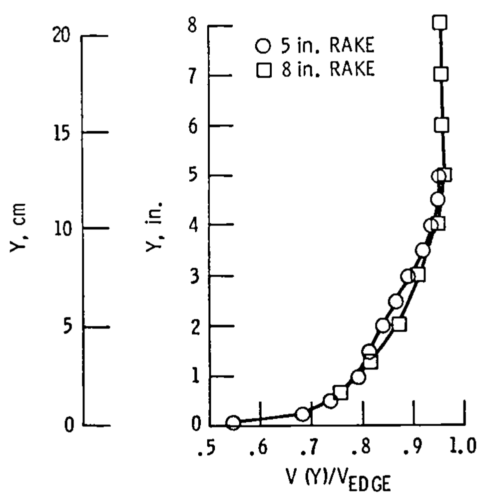
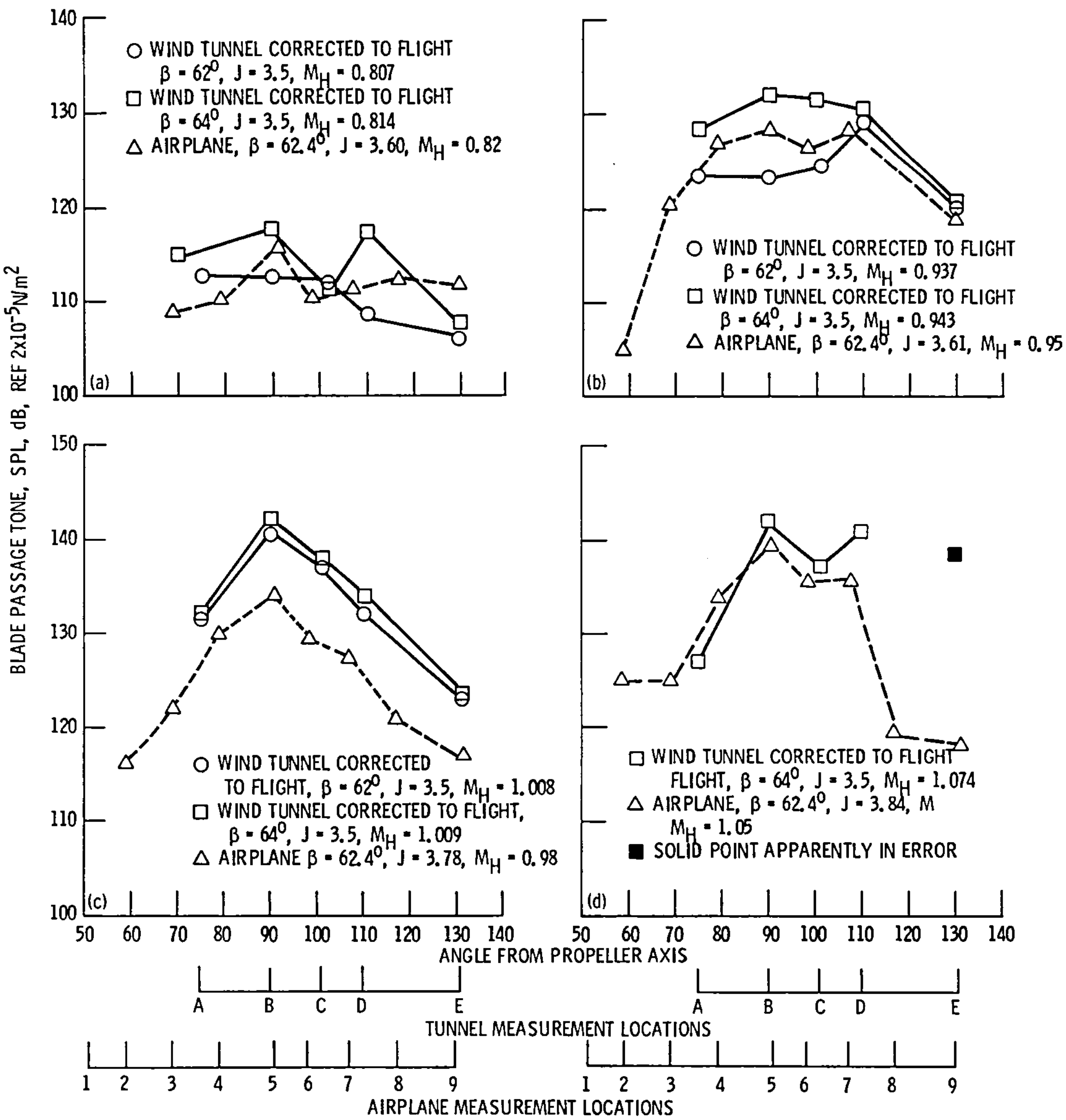


Figure 6. - Airplane boundary layer during SR-6 tests, without wipers; M ≅ 0.8.



(a) Nominal axial Mach number = 0.60.
(b) Nominal axial Mach number = 0.70.
(c) Nominal axial Mach number = 0.75.
(d) Nominal axial Mach number = 0.80.

Figure 7. - Blade passing tone directivity for SR-6 propeller.

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15. Supplementary Notes

James H. Dittmar, NASA Lewis Research Center; Paul L. Lasagna and Karen G. Mackall, Hugh L. Dryden Flight Research Center, Edwards, California. Prepared for the One-hundred-fifth Meeting of the Acoustical Society of America, Cincinnati, Ohio, May 9-13, 1983.

16. Abstract

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