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ABSTRACT

The noise generated by supersonic helical-tip-speed propellers is a likely cabin environment problem for future airplanes powered by these propellers. Three propeller models with different tip sweeps, SR-1M, SR-2, and SR-3, designed for 244 m/sec (800 ft/sec) tip speed at a flight Mach number of 0.8 were previously tested in the NASA Lewis 8- by 6-foot wind tunnel. In order to investigate another design point condition, the SR-6 propeller was designed for 213 m/sec (700 ft/sec) tip speed at a flight Mach number of 0.8. The noise data from this propeller are reported herein.

Curves of blade passing frequency noise versus helical tip Mach number (at constant advance ratio) showed that the SR-6 propeller behaved similarly to the SR-1M propeller. The noise of the SR-6 propeller at its design condition, helical tip Mach number of 1.07, is approximately 3 dB quieter than the SR-2 propeller at its higher design helical tip Mach number of 1.15 but about 2.5 dB noisier than SR-3 at its design condition. The helical tip Mach number shift of the steep noise rise followed the same progression as the blade sweep angle for all of the propellers. When operated at the SR-3 design point the SR-6 propeller was approximately 1.5 dB quieter than SR-2 and 4 dB noisier than SR-3.

SUMMARY

The noise generated by supersonic helical-tip-speed propellers is a likely cabin environment problem for future airplanes powered by these propellers. Three propeller models, with different tip sweeps, SR-1M, SR-2, and SR-3, designed for 244 m/sec (800 ft/sec) tip speed at a flight Mach number of 0.8 were previously tested in the NASA Lewis 8- by 6-foot wind tunnel. In order to investigate another design point condition, the SR-6 propeller was designed for 213 m/sec (700 ft/sec) tip speed at a flight Mach number of 0.8. The noise data from this propeller are reported herein.

Curves of blade passing frequency noise versus helical tip Mach number (at constant advance ratio) showed that the SR-6 propeller behaved similarly to the SR-1M propeller. The noise of the SR-6 propeller at its design condition, helical tip Mach number of 1.07, is approximately 3 dB quieter than the SR-2 propeller at its higher design helical tip Mach number of 1.15 but about 2.5 dB noisier than SR-3 at its design condition. The helical tip Mach number shift of the steep noise rise followed the same progression as the blade sweep angle for all of the propellers. When operated at the SR-3 design point the SR-6 propeller was approximately 1.5 dB quieter than SR-2 and 4 dB noisier than SR-3.

INTRODUCTION

One of the candidate engines for a future energy conservative airplane is a high-tip-speed turboprop. When the turboprop airplane is at cruise, the combination of the airplane forward speed and the propeller rotational speed results in supersonic helical velocities over the outer portions of the propeller blades. During flight these supersonic blade sections and associated shock waves generate significant noise that might present a cabin environment problem.

To investigate the noise of this type of propeller, three propeller models were previously tested in the Lewis 8- by 6-foot wind tunnel (refs. 1 to 3). These three propeller models (SR-1M, SR-2, SR-3) were nominally 0,622 m (24.5 in.) in diameter and were designed for a cruise Mach number of 0.8 and a tip speed of 244 m/sec (800 ft/sec). This resulted in a design advance ratio, J, of 3.06 and a nominal helical tip Mach number M_H of 1.14 at cruise. The three previously tested propellers had eight blades and varying amounts of blade sweep with SR-2 being essentially straight and SR-3 being the most highly swept.

In order to investigate other design-point conditions, additional propellers were designed. One of these, the SR-6 propeller, was also designed for an 0.8 Mach number cruise, but at a lower tip speed, 213 m/sec (700 ft/sec). This resulted in a design advance ratio of 3.5 and a helical tip Mach number of 1.07, which was lower than the three previously tested propellers. This paper reports the data obtained during acoustic experiments with the SR-6 propeller in the Lewis 8- by 6-foot wind tunnel.

SYMBOLS

C_p	power coefficient, $C_p = P/\rho N^3D^5$
D	propeller diameter
J	advance ratio, $J = V/ND$
M_H	helical tip Mach number (vector sum of tip rotational and tunnel axial Mach numbers)
M_T	tunnel axial Mach number
N	propeller rotational speed (revolutions/time)
P	shaft input power
V	tunnel axial velocity
β	blade angle at 0.75 radius with respect to plane of rotation
ρ	density

APPARATUS AND PROCEDURE

Propeller

The 10-bladed propeller used in this test was designated the SR-6 propeller. This propeller, nominally 0.696 m (27.4 in.) in diameter, was tested in the Lewis 8- by 6-foot wind tunnel. The propeller was designed for a cruise Mach number of 0.8 at a tip speed of 213 m/sec (700 ft/sec) and was swept approximately 40° at the tip for aerodynamic purposes. The design advance ratio of this propeller is 3.5 and at design the resultant helical tip Mach number M_H, was 1.07. The design blade setting angle was approximately 63° at 0.75 span. Table I shows some of the design characteristics of this propeller with respect to the other propellers and more information is available in references 4 and 5. A picture of the SR-6 propeller in the Lewis 8- by 6-foot wind tunnel is shown in figure 1.

Installation and Tests

The propeller was installed in the Lewis 8- by 6-foot wind tunnel and five pressure transducers were installed in the tunnel bleed holes visible is figure 1. The five transducer positions, in the tunnel ceiling, are shown in figure 2. The propeller was tested at four blade angle settings. Due to mechanical difficulties in the angle setting mechanism, it was not possible to test at the design blade setting angle of 63°; therefore it was necessary to test on either side of this blade setting angle. Tests were then performed at nominal blade setting angles, β, of 62 and 64°. Figure 3(a), a plot of power coefficient, C_p, with respect to advance ratio, J, at 0.8 Mach number, shows how the test points from the two angles compare with the design data taken during previous aero- dynamic tests. As can be seen the performance at these two angles bracketed the performance of the design angle, as would be expected. Noise data were taken at the 62° nominal blade setting angle at tunnel Mach numbers, M_T, of 0.5, 0.55, 0.60, 0.65, 0.7, 0.75, 0.8, and 0.85 with advance ratios of 3.5, 3.9, and 4.2 at each tunnel Mach number. Windmill noise data were also taken at the listed Mach numbers. At the 64° nominal blade setting angle, noise data were taken at tunnel Mach numbers of 0.60, 0.70, 0.75, 0.80, and 0.85 with J's of 3.5 and 3.9.

In addition to testing the propeller along its design operating curve, it was also possible to overspeed this propeller. Therefore the SR-6 propeller was operated at conditions similar to those of the previously tested propellers. The attempt was made to run the SR-6 blade setting angle of 60° at an advance ratio, J, of 3.06, but the same mechanical problem was encountered and the tests were performed at nominal angles of 59° and 61° instead. This resulted in the Mach 0.8 test points as shown in figure 3(b), one on either side of the SR-3 design point. Acoustic data were taken at the 59° blade setting angle at tunnel Mach numbers of 0.6, 0.7, 0.75, 0.8, and 0.85, all at a nominal advance ratio of 3.06. Acoustic data were taken at the 61° blade setting angle at tunnel Mach numbers of 0.7, 0.75, 0.80, and 0.85. These data were taken at a nominal advance ratio of 3.06 for the 0,85 and 0.70 tunnel Nach numbers, but a strut vibration problem limited the advance ratio to 3.09 at $M_T = 0.75$ and 3.18 at $M_T = 0.80$.

As shown in table I, the SR-6 propeller is slightly larger in diameter than the previously tested propellers and is thus slightly closer to the wall. The resulting distance correction to the measured SR-6 sound pressure levels to make them comparable with data from the prior propeller experiments is negligible, amounting to only a small fraction of a decibel.

RESULTS AND DISCUSSION

The signals from the five pressure transducers were recorded on magnetic tape and narrowband spectra from 0 to 10 000 Hz with a bandwidth of 26 Hz, and were generated for each of the test points. At some of the lower speed conditions, the propeller blade passage tone was very close in frequency to the tones created by the tunnel drive compressor. A discussion of this bandwidth resolution problem can be found in reference 3. At these conditions additional spectra were taken from 0 to 1000 Hz with a bandwidth of 2.6 Hz to assist in obtaining the blade passage tone level. The tone levels were read from these narrowband spectra and a compilation of the first eight harmonics is given in tables II to IV.

Variation with Helical Tip Mach Number at 62 and 64° Setting Angle

The maximum measured blade-passing tone levels for the 62 and 64° blade angles are plotted as a function of helical tip Mach number, M_H, (vector sum of axial and rotational Mach numbers) in figure 4(a). The park levels generally occurred in the plane of rotation (station B) or aft of the plane (station D). As can be seen in this figure, the noise at both blade-setting angles rises rapidly with helical tip mach number and then tends to level out or roll over at the higher values. This general behavior is similar to the noise of the three previously tested propellers (refs. 1 to 3).

The noise of these propellers, using linear noise theory, is generally indicated as coming from two separate mechanisms. These are referred to as thickness noise (monopole), arising from the displacement of the air as the blade passes through it, and loading noise (dipole), the result of forces applied to the air by the propeller blades (ref. 6). The thickness noise at the two blade-setting angles would most likely be the same while the loading noise would be greater at the 64° angle since it is more highly loaded (see fig. 3(a)). As can be seen in figure 4(a), a substantial difference (approximately 5 dB) exists between the data points at the helical tip Mach number of 0.8. Here the noise would be expected to be dominated by the loading noise and the curves indicate that the more highly loaded condition, 64°, is the noisier. This also tends to be the case at a helical tip Mach number of 0.95. At the higher helical tip Mach numbers the noise at the two blade-setting angles comes together and differs by less than 1 dB at the high end. This is the region where the thickness noise should approach and perhaps exceed the loading noise based on linear noise theory. Since the thickness noise should be the same for the two blade-setting angles it is consistent that the measured noise levels at the two blade angles should also be close to the same. This higher helical tip Mach number range is also where nonlinear shock wave effects could become important in the noise generation process. The noise being the same for similar shock waves at the two blade angles is also consistent.

Figure 4(b) shows the previously published noise curves of propellers SR-1M, SR-2 and SR-3 (ref. 2) plotted in the form of figure 4(a). This is not an exact comparison among all of the propellers since the previous curves were for the blades designed for an advance ratio of 3.06 and a tip speed of 244 m/sec (800 ft/sec) while SR-6 was designed for an advance ratio of 3.5 at a tip speed of 213 m/sec (700 ft/sec). Other differences also exist since SR-6 has 10 blades and a diameter of 69.6 cm (27.4 in.) while the first set of propellers had eight blades and a diameter of 62.2 cm (24.5 in). Under the assumption that the design blade angle noise curve for propeller SR-6 falls between the 62 and 64° noise curves, figure 4(b) indicates that SR-6 operated at its design condition $M_H = 1.07$ would be about 3 dB quieter than SR-2 operated at its higher helical tip Mach number design condition $M_H = 1.15$. The SR-6 propeller is about 2.5 dB noisier at its design condition than the SR-3 propeller operated at its higher helical tip Mach number design point $M_H = 1.15$.

As discussed in reference 2, the aerodynamic sweep (30°) built into SR-1M "delayed" the noise rise portion of the curve to a higher helical tip Mach number when compared with SR-2, but the noise level at the higher helical tip Mach numbers was about the same. The tailored sweep (45°) was built into SR-3 for aerodynamic improvement and to provide noise cancellation between the various hub-to-tip blade sections. The 45° of sweep resulted in a further "delay" in the Mach number of the noise rise and the cancellation feature resulted in a lower asymptotic noise level. The SR-6 sweep was built in primarily for aerodynamic purposes and not for noise cancellation.

Figure 4(b) indicates that the sweep in the SR-6 design "delayed" the noise rise much in the same manner as for SR-1M. The 40° of sweep in SR-6 appear to "delay" the rise to a slightly higher Mach number than for SR-1M, but not quite as much as did the 45° of SR-3. It may also be that the SR-3 "delay" appears larger than it is because of its lower asymptotic noise level.

The noise of the SR-6 propeller at its design advance ratio ($J = 3.5$) exhibits a rollover at the higher helcial tip Mach numbers that has not been observed for the other propellers. Figure 5 is a plot of the SR-6 performance taken from reference 4. Here it can be seen that the performance of SR-6 decreases rapidly in the same helical tip Mach number region as its noise starts to roll off. The sharp reduction in the performance was not expected at this low a Mach number and was attributed to a choking condition near the hub of the SR-6 propeller. This hub choking may also have resulted in different Mach numbers over the outer portions of the blade from those that would normally be indicated by the helical tip Mach number. Such a change in the flow over the blades, if present, might be the cause of the noise rollover exhibited by SR-6.

Directivity at 62 and 64° Setting Angle

The noise directivities at two blade-setting angles on either side of design have been plotted in figure 6. Directivities at tunnel through flow Mach numbers of 0.85, 0.7, and 0.6, corresponding to helical tip Mach numbers of approximately 1.15, 0.94, and 0.81, have been plotted in figures 6(a) thru (c) respectively. (Data were not plotted at a flow Mach number of 0.8 because of improper recording at the 62° setting angle, see table II.)

At the tunnel Mach number of 0.85, $M_H \cong 1.15$, the two blade-setting angle noise curves are very close to each other. This similarity is commensurate with the expected thickness noise domination of the noise at both blade angles at this condition. The slight differences toward the front may be an indication of the difference in loading noise at this condition.

In figure 6(b), $M_T = 0.70$, and $M_H \cong 0.94$, a marked difference in the two directivities is observed. Even though the peak values are close to each other in level, the noise at the 64° blade angle peaks roughly in the plane of rotation while the noise at the 62° blade angle peaks aft the plane. Here the 64° blade-setting angle, with its higher loading, would appear to be loading-dominated while the noise at the lower-loaded 62° angle may be thickness-dominated. Large differences in the levels forward of the plane of rotation may be an indication of the additional loading noise at the 64° blade-setting angle.

At the $M_T = 0.60$, $M_H = 0.81$ condition (fig 6(c)) both of the curves appear to peak around the plane of rotation and are probably loading dominated. The more highly loaded 64° blade-setting angle shows considerably more noise and the dip in the directivity at position C gives some indication of the lobed noise pattern which was previously observed on the SR-3 blade (ref. 3).

Variation with Helical Tip Mach Number at 59 and 61° Setting Angle

In addition to testing the SR-6 propeller along its design operating curve, it was also possible to test it near the SR-3 design conditions. Figure 7(a) shows the noise variation with helical tip Mach number at a constant J of 3.06. Data are shown at blade setting angles of 59 and 61°, one degree on either side of the blade angle which would match the SR-3 design conditions. As can be seen, these curves show the sharp noise rise observed of the curves at J = 3.5, but then they level off. These curves do not show the rollover previously observed at the 62 and 64° blade-setting angles with an advance ratio of 3.5. It may be that the smaller blade setting angle helps relieve the choking problem at the hub and resuts in better tip flows.

Figure 7(b) compares the previously published propeller noise curves (SR-1M, SR-2, SR-3) with the SR-6 data from figure 7(a). Here the helical tip Mach number "delay" of the noise rise can be seen. The SR-6 propeller behaved in a manner similar to the SR-1M propeller with slightly more of a rise "delay" than SR-1M. This would be expected since SR-6 has 40° of sweep as opposed to the 30° of sweep for SR-1M. The SR-6 propeller sweep was not designed to have noise from the sections of the blade cancel each other. The result of this can be seen as the SR-6 noise level approaches the noise level of SR-2 at the higher helical tip Mach numbers rather than the lower asymptote of SR-3 which had acoustically tailored sweep. At the SR-3 design condition, J = 3.06, and M_H = 1.15, the SR-6 propeller is about 1.5 dB quieter than SR-2 and some 4 dB noisier than SR-3.

CONDLUDING REMARKS

The SR-6 propeller was tested for acoustics in the Lewis 8- by 6-foot wind tunnel. A small mechanism problem prevented testing the SR-6 propeller at its design blade-setting angle (63°) and consequently the testing was performed at setting angles on either side of design, 62 and 64°. Plots of the peak blade-passing noise versus helical tip Mach number, M_H, showed curve shapes similar to previously tested propellers (SR-1M, SR-2, SR-3). The curves indicated an area of sharp noise rise with a final levelling off toward the higher helical tip Mach numbers. The SR-6 propeller, approximately at its design condition, was about 3 dB quieter than the SR-2 propeller at its design condition. The SR-6 design condition is an advance ratio of 3.5 and a helical tip Mach number of 1.07 while the SR-2 design condition has a higher helical tip Mach number of 1.15 and an advance ratio of 3.06. The SR-6 propeller was about 2.5 dB noisier than the SR-3 propeller as its 1.15 helical tip Mach number, J = 3.06, design point. When the SR-6 propeller noise was compared with the curves for the previously tested propellers the area of noise rise was "delayed" to a higher helical tip Mach number when compared with the straight bladed SR-2 as a result of the 40° of aerodynamic tip sweep incorporated in this blade. The "delay" was a little larger than that of the 30°-swept SR-1M but not as much as that for the 45° swept SR-3.

Directivities taken at the higher helical tip Mach numbers indicated that the noise was dominated by the thickness noise mechanism with both of the blade angles, 62 and 64°, showing the same noise levels despite their different loadings. At the lower helical tip Mach number $M_H \cong 0.80$, the noise at both of the blade angles appears to be loading-noise dominated with the more highly loaded 64° case showing a peak noise some 5 dB greater than the 62° blade angle.

Noise data were also taken for the SR-6 propeller operating near the design conditions of the SR-3 propeller. Here the noise of the SR-6 at J = 3.06, and M_H = 1.15 is only about 1.5 dB quieter than SR-2 and some 4 dB noisier than SR-3. The SR-6 propeller sweep was primarily for aerodynamics and was not tailored to have the noise from the different blade sections cancel each other. The effect of this was seen in the noise versus helical tip Mach number curves where the noise of the SR-6 propeller behaved similarly to the aerodynamically swept SR-1M by rising to the same asymptotic level as SR-2 rather than to a lower value as did the sweep-tailored SR-3.

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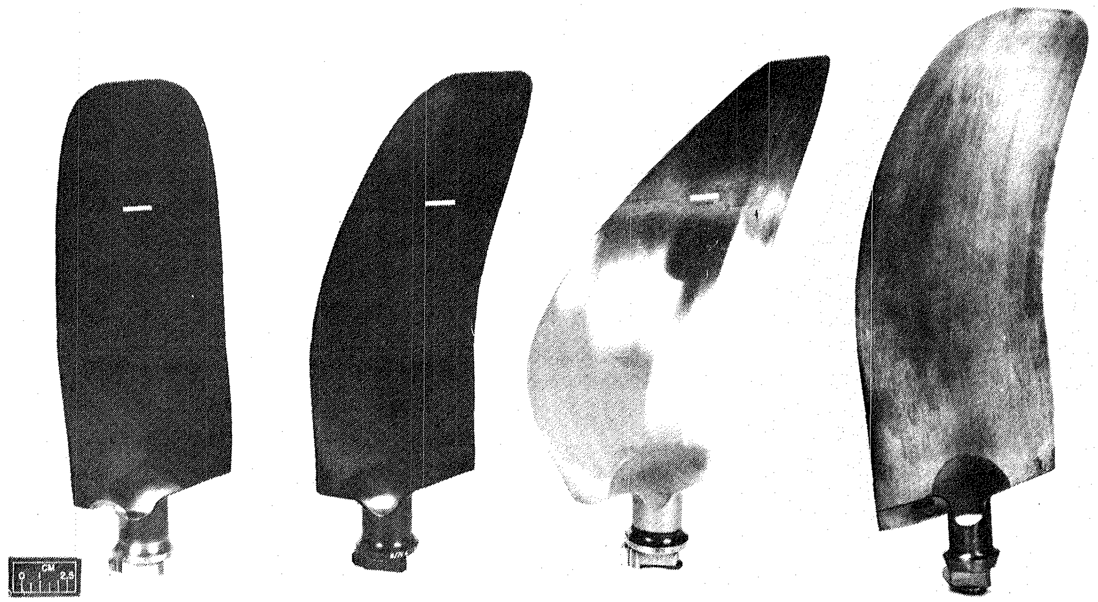


	SR-2	SR-1M	SR-3	SR-6
TIP SWEEP ANGLE, deg	0	30	45	40
PREDICTED DESIGN EFF, %	76.6	79.3	81.1	81.9
DIAMETER IN (cm)	24.5 (62.2)	——————→		27.4 (69.6)
TIP SPEED, ft/sec (m/sec)	800 (244)	——————→		700 (213)
POWER LOADING, P/D^2, hp/ft^2 (kW/m^2)	37.5 (301)	——————→		30.0 (241)
NO. OF BLADES	8	——————→		10

Table I - Design characteristics and planforms of high speed propeller models.

TABLE II. - SR-6 at 62° SETTING ANGLE

(a) Tunnel Mach number, 0.85; propeller advance ratio, 3.5; power coefficient, 1.23; propeller speed, 7010 rpm; helical tip Mach number, 1.149.

Harmonic	Transducer				
	A	B	C	D	E
	Sound pressure level of harmonic, SPL, dB ref 2×10^{-5} N/m^2				
1 (BPF)	(a)	138.5	142.0	143.5	141.5
2	↓	128.0	132.5	136.0	131.0
3	↓	122.0	129.5	133.0	123.5
4	↓	(a)	125.0	130.0	122.0
5	↓	↓	120.0	128.5	119.0
6	↓	↓	116.0	120.0	114.5
7	↓	↓	(a)	121.0	112.0
8	↓	↓	(a)	116.5	108.0

[a] Not visible above tunnel background.

TABLE II. - Continued.

(b) Tunnel Mach number, 0.85; propeller advance ratio, 3.9; power coefficient, 0.40; propeller speed, 6268 rpm; helical tip Mach number, 1.093.

1 (BPF)	(a)	128.0	137.0	138.0	127.5
2	↓	(a)	132.5	137.5	129.0
3		↓	127.0	132.0	(a)
4			(a)	124.0	↓
5			↓	126.0	
6				118.5	
7				117.0	
8				115.0	

[a] Not visible above tunnel background.

TABLE II

(c) Tunnel Mach number, 0.85; propeller advance ratio[b], 4.08; power coefficient, 0; propeller speed, 5976 rpm; helical tip Mach number, 1.071.

1 (BPF)	(a)	132.0	133.0	137.5	126.0
2	↓	(a)	131.0	134.5	(a)
3		↓	127.0	132.5	↓
4			(a)	123.0	
5			↓	124.0	
6				120.5	
7				(a)	
8				(a)	

[a] Not visible above tunnel background.

[b] No data was taken at an advance ratio of 4.2 since windmill occurred at 4.08.

TABLE II

(d) Tunnel Mach number, 0.80; propeller advance ratio, 3.5; power coefficient, 1.68; propeller speed, 6627 rpm; helical tip Mach number, 1.078.

1 (BPF)	131.0	(c)	(c)	(c)	140.5
2	(a)				(a)
3	↓				↓
4					
5					
6					
7					
8					

[+] Not visible above tunnel background.
[c] Data not recorded on tape properly.

TABLE II

(e) Tunnel Mach number, 0.80; propeller advance ratio[d], 3.9; power coefficient, 1.02; propeller speed, 5933 rpm; helical tip Mach number, 1.029.

1 (BPF)	134.0	137.5	139.5	143.0	130.0
2	(a)	131.0	127.0	129.0	(a)
3	↓	127.0	125.5	(a)	↓
4		122.0	121.5	↓	
5		(a)	(a)		
6		↓	↓		
7					
8					

[a] Not visible above tunnel background.
[d] No tones visible at a J of 4.2 or at windmill.

TABLE II

(f) Tunnel Mach number, 0.75; propeller advance ratio, 3.5; power coefficient, 1.86; propeller speed, 6233 rpm; helical tip Mach number, 1.008.

1 (BPF)	137.0	146.0	142.5	137.5	128.5
2	(a)	133.5	131.0	131.0	121.5
3	↓	129.0	126.0	125.0	(a)
4		125.5	125.0	121.0	↓
5		122.0	121.0	(a)	
6		118.5	117.5	↓	
7		115.0	(a)		
8		(a)	(a)		

[a] Not visible above tunnel background.

Table II

(g) Tunnel Mach number, 0.75; propeller advance ratio[d], 3.9; power coefficient, 1.19; propeller speed, 5595 rpm, helical tip Mach number, 0.964.

Harmonic	Transducer				
	A	B	C	D	E
	Sound pressure level of harmonic, SPL, dB ref 2×10^{-5} N/m^2.				
1 (BPF)	130.0	138.5	132.0	127.5	126.5
2	(a)	131.0	(a)	(a)	(a)
3	↓	(a)	↓	↓	↓
4		↓			
5					
6					
7					
8					

[a] Not visible above tunnel background.
[d] No tones vivible at a J of 4.2 or at windmill.

TABLE II

(h) Tunnel Mach number. 0.70; propeller advance ratio, 3.5; power coefficient, 1.88; propeller speed, 5849; helical tip Mach number, 0.937.

1 (BPF)	129.5	129.5	130.5	135.0	126.0
2	(a)	125.0	125.0	(a)	(a)
3	↓	(a)	(a)	↓	↓
4		↓	↓		
5					
6					
7					
8					

[a] Not visible above tunnel background.

TABLE II

(i) Tunnel Mach number, 0.70; propeller advance ratio[d], 3.9; power coefficient, 1.17; propeller speed, 5254 rpm; helical tip Mach number, 0.901.

1 (BPF)	124.0	124.0	118.0	125.5	118.0
2	(a)	(a)	(a)	(a)	(a)
3	↓	↓	↓	↓	↓
4					
5					
6					
7					
8					

[a] Not visible above tunnel background.
[d] No tones visible at a J of 4.2 or at windmill.

TABLE II

(j) Tunnel Mach number, 0.65; propeller advance ratio, 3.5; power coefficient, 1.85; propeller speed, 5400 rpm; helical tip Mach number, 0.862.

1 (BPF)	126.0	128.0	124.0	117.0	122.0
2	(a)	(a)	(a)	(a)	(a)
3	↓	↓	↓	↓	↓
4					
5					
6					
7					
8					

[a] Not visible above tunnel background.

TABLE II

(k) Tunnel Mach number, 0.65; propeller advance ratio[d], 3.9; power coefficient, 1.22; propeller speed, 4881 rpm; helical tip Mach number, 0.831.

1 (BPF)	(a)	118.5	(a)	(a)	(a)
2	↓	↓	↓	↓	↓
3					
4					
5					
6					
7					
8					

[a] Not visible above tunnel background.

[d] No tones visible at a J of 42 or at windmill.

TABLE II

(1) Tunnel Mach number[e], 0.60; propeller advance ratio[f], 3.5; power coefficient, 1.87; propeller speed, 5087 rpm; helical Mach number, 0.807.

1 (BPF)	119.0	119.0	118.5	115.0	112.5
2	(a)	(a)	(a)	(a)	(a)
3	↓	↓	↓	↓	↓
4					
5					
6					
7					
8					

[a] Not visible above tunnel background.

[e] No tones were visible at tunnel Mach numbers of 0.55 and 0.50.

[f] No tones visible at a J of 3.9, 4.2 or at windmill.

TABLE III. - SR-6 AT 64°.

(a) Tunnel Mach number, 0.85; propeller advance ratio, 3.5; power coefficient, 2.04; propeller speed, 6971 rpm; helical tip Mach number, 1.138.

Harmonic	Transducer				
	A	B	C	D	E
	Sound pressure level of harmonic, SPL, dB ref 2×10^{-5} N/m^2				
1 (BPF)	(a)	141.0	143.5	144.5	142.0
2	↓	131.0	137.5	140.0	131.0
3	↓	124.0	133.5	133.0	126.5
4	↓	(a)	128.5	131.0	123.0
5	↓	↓	125.0	128.0	120.5
6	↓	↓	120.0	122.5	115.0
7	↓	↓	117.0	120.5	112.5
8	↓	↓	(a)	116.5	(a)

[a] Not visible above tunnel background.

TABLE III

(b) Tunnel Mach number, 0.85; propeller advance ratio, 3.9; power coefficient, 1.26; propeller speed, 6298 rpm; helical tip Mach number, 1.098.

1 (BPF)	(a)	139.0	138.0	141.5	131.5
2	↓	125.0	132.5	134.5	126.5
3	↓	(a)	126.5	125.0	(a)
4	↓	↓	123.5	120.5	↓
5	↓	↓	120.0	117.5	↓
6	↓	↓	(a)	116.5	↓
7	↓	↓	↓	(a)	↓
8	↓	↓	↓	(a)	↓

[a] Not visible above tunnel background.

TABLE III

(c) Tunnel Mach number, 0.80; propeller advance ratio, 3.5; power coefficient, 2.38; propeller speed, 6580 rpm; helical tip Mach number, 1.074.

1 (BPF)	133.5	147.0	142.0	146.0	143.5
2	(a)	136.0	129.5	132.0	126.5
3	↓	126.5	126.0	130.5	126.5
4		(a)	123.5	128.0	122.0
5		↓	122.0	123.5	119.0
6			119.5	120.5	115.5
7			116.5	(a)	(a)
8			(a)	(a)	(a)

[a] Not visible above tunnel background.

TABLE III

(d) Tunnel Mach number, 0.80; propeller advance ratio, 3.9; power coefficient, 1.74; propeller speed, 5968 rpm; helical tip Mach number; 1.033.

1 (BPF)	132.5	144.0	137.5	140.5	130.0
2	(a)	133.5	127.0	130.5	(a)
3	↓	127.0	(a)	(a)	↓
4	↓	122.0	↓	↓	↓
5	↓	(a)	↓	↓	↓
6	↓	↓	↓	↓	↓
7	↓	↓	↓	↓	↓
8	↓	↓	↓	↓	↓

[a] Not visible above tunnel background.

TABLE III

(e) Tunnel Mach number, 0.75; propeller advance ratio, 3.5; power coefficient, 2.52; propeller speed, 6254 rpm; helical tip Mach number, 1.009.

1 (BPF)	137.5	147.5	143.5	139.5	129.0
2	(a)	136.5	133.0	132.5	126.0
3	↓	132.0	129.5	126.0	126.0
4		128.5	126.0	123.0	120.0
5		124.0	122.0	120.0	(a)
6		120.0	118.5	(a)	↓
7		116.0	115.5	(a)	
8		(a)	(a)	(a)	

[a] Not visible above tunnel background.

TABLE III

(f) Tunnel Mach number, 0.75; propeller advance ratio, 3.9; power coefficient, 1.85; propeller speed, 5602 rpm; helical tip Mach number, 0.964.

Harmonic	Transducer				
	A	B	C	D	E
	Sound pressure level of harmonic, SPL, dB ref 2×10^{-5} N/m^2				
1 (BPF)	(a)	138.0	134.0	127.0	127.5
2	↓	130.5	(a)	↓	↓
3	↓	127.5	↓	↓	↓
4	↓	122.0	↓	↓	↓
5	↓	118.5	↓	↓	↓
6	↓	(a)	↓	↓	↓
7	↓	(a)	↓	↓	↓
8	↓	(a)	↓	↓	↓

[a] Not visible above tunnel background.

TABLE III

(g) Tunnel Mach number, 0.70; propeller advance ratio, 3.5; power coefficient, 2.48; propeller speed, 5878 rpm; helical tip Mach number, 0.943.

1 (BPF)	134.5	138.0	137.5	136.5	126.5
2	(a)	(a)	126.5	127.5	(a)
3	↓	↓	(a)	(a)	↓
4			↓	↓	
5					
6					
7					
8					

[a] Not visible above tunnel background.

TABLE III

(h) Tunnel Mach number, 0.70; propeller advance ratio, 3.9; power coefficient, 1.84; propeller speed, 5263 rpm; helical tip Mach number, 0.902.

1 (BPF)	123.5	(a)	127.5	127.5	120.5
2	(a)	↓	(a)	(a)	(a)
3	↓		↓	↓	↓
4					
5					
6					
7					
8					

[a] Not visible above tunnel background.

TABLE III

(i) Tunnel Mach number, 0.60; propeller advance ratio, 3.5; power coefficient, 2.45; propeller speed, 5120 rpm; helical tip Mach number, 0.814.

1 (BPF)	121.5	124.5	118.0	124.0	114.0
2	(a)	(a)	(a)	(a)	(a)
3	↓	↓	↓	↓	↓
4					
5					
6					
7					
8					

[a] Not visible above tunnel background.

TABLE III

(j) Tunnel Mach number, 0.60; propeller advance ratio, 3.9; power coefficient, 1.88; propeller speed, 4579 rpm; helical tip Mach number, 0.777.

1 (BPF)	(a)	114.0	115.0	114.5	115.0
2	↓	↓	↓	↓	↓
3					
4					
5					
6					
7					
8					

[a] Not visible above tunnel background.

TABLE IV. - SR-6 AT 59°.

(a) Tunnel Mach number, 0.85; propeller advance ratio, 3.06; power coefficient, 1.02; propeller speed, 7963 rpm; helical tip Mach number, 1.222.

Harmonic	Transducer				
	A	B	C	D	E
	Sound pressure level of harmonic, SPL, dB ref 2×10^{-5} N/m^2				
1(BPF)	(a)[a]	140.0	147.0	147.5	145.5
2	↓	131.5	138.0	140.0	134.0
3		123.0	133.5	137.0	130.0
4		(a)	128.5	129.5	127.0
5		↓	124.0	128.0	119.5
6			120.0	125.5	119.0
7			116.0	120.0	114.5
8			111.5	117.0	112.0

[a] Not visible above tunnel background.

TABLE IV

(b) Tunnel Mach number, 0.80; propeller advance ratio, 3.04; power coefficient, 1.50; propeller speed, 7561 rpm; helical tip Mach number, 1.143.

1 (BPF)	131.5	141.5	145.0	147.5	143.5
2	(a)	129.5	137.0	131.0	129.0
3	↓	125.0	132.5	132.0	127.0
4	↓	(a)	128.0	127.5	122.5
5	↓	↓	124.0	125.0	119.0
6	↓	↓	120.5	121.5	116.0
7	↓	↓	117.0	116.5	111.5
8	↓	↓	113.0	114.0	109.0

[a] Not visible above tunnel background.

TABLE IV

(c) Tunnel Mach number, 0.75; propeller advance ratio, 3.06; power coefficient, 1.67; propeller speed, 7138 rpm; helical tip Mach number, 1.074.

Harmonic	Transducer				
	A	B	C	D	E
	Sound pressure level of harmonic, SPL, dB ref 2×10^{-5} N/m^2				
1 (BPF)	137.5	145.5	142.5	143.5	142.5
2	(a)	141.0	132.5	134.5	126.5
3	↓	134.5	129.0	131.0	125.5
4		131.0	128.0	127.0	124.0
5		127.5	125.5	125.0	117.5
6		122.5	119.5	119.0	114.5
7		119.0	117.0	113.0	113.5
8		115.0	114.0	112.0	109.0

[a] Not visible above tunnel background.

TABLE IV

(d) Tunnel Mach number, 0.70; propeller advance ratio, 3.06; power coefficient, 1.68; propeller speed, 6672 rpm; helical tip Mach number, 1.001.

1 (BPF)	138.5	148.5	139.0	141.0	131.5
2	129.0	136.0	133.5	133.5	126.0
3	(a)	129.0	127.5	125.5	122.0
4	↓	125.5	123.5	119.5	(a)
5		123.0	121.0	118.0	↓
6		120.0	117.5	114.0	
7		116.0	113.5	(a)	
8		113.0	111.0	(a)	

[a] Not visible above tunnel background.

TABLE IV

(e) Tunnel Mach number, 0.60; propeller advance ratio, 3.06; power coefficient, 1.69; propeller speed, 5836 rpm; helical tip Mach number, 0.86.

Harmonic	Transducer				
	A	B	C	D	E
	Sound pressure level of harmonic, SPL, dB ref 2×10^{-5} N/m^2				
1 (BPF)	128.5	127.5	128.0	125.0	126.5
2	(a)	122.5	(a)	(a)	(a)
3	↓	(a)	↓	↓	↓
4		↓			
5					
6					
7					
8					

[a] Not visible above tunnel background.

TABLE V. - SR-6 AT 61°.

(a) Tunnel Mach number 0.85; propeller advance ratio, 3.04; power coefficient, 1.64; propeller speed, 7980 rpm; helical tip Mach number, 1.220.

Harmonic	Transducer				
	A	B	C	D	E
	Sound pressure level of harmonic, SPL, dB ref 2×10^{-5} N/m^2				
1 (BPF)	(a)	140.0	145.0	149.5	149.0
2	↓	130.0	137.5	144.5	133.0
3	↓	(a)	134.0	138.0	134.0
4	↓	↓	128.5	136.0	126.0
5	↓	↓	123.5	131.0	123.5
6	↓	↓	118.5	127.5	120.5
7	↓	↓	(a)	123.5	118.0
8	↓	↓	(a)	120.0	112.0

[a] Not visible above tunnel background.

TABLE V

(b) Tunnel Mach number 0.80; propeller advance ratio, 3.18; power coefficient, 1.86; propeller speed, 7284 rpm; helical tip Mach number, 1.131.

1 (BPF)	(a)	145.5	144.5	147.5	147.5
2	↓	134.5	133.5	135.0	131.5
3		125.0	133.5	132.0	124.0
4		120.0	129.0	129.5	124.5
5		(a)	123.0	124.5	119.0
6		↓	120.5	121.0	115.0
7			117.0	116.5	(a)
8			113.0	112.5	(a)

[a] Not visible above tunnel background.

TABLE V

(c) Tunnel Mach number 0.75; propeller advance ratio, 3.09; power coefficient, 2.17; propeller speed, 7051 rpm; helical tip Mach number, 1.068.

Harmonic	Transducer				
	A	B	C	D	E
	Sound pressure level of harmonic, SPL, dB ref 2×10^{-5} N/m^2				
1 (BPF)	138.0	146.5	145.0	148.5	147.5
2	(a)	139.5	133.5	133.5	130.0
3	↓	135.0	130.0	129.5	126.5
4		131.0	128.5	128.5	124.5
5		127.0	126.0	123.5	117.5
6		122.0	122.0	119.0	115.0
7		118.5	117.5	115.0	114.5
8		114.5	115.0	(a)	109.5

[a] Not visible above tunnel background.

TABLE V

(d) Tunnel Mach number 0.70; propeller advance ratio, 3.06; power coefficient, 2.22; propeller speed, 6701 rpm; helical tip Mach number, 1.006.

1 (BPF)	138.5	147.0	141.0	141.0	135.0
2	130.5	134.5	129.5	136.5	125.0
3	(a)	129.5	127.5	127.0	123.5
4	↓	128.5	124.5	120.5	117.5
5		123.0	119.0	119.5	114.5
6		118.5	116.0	114.0	111.5
7		114.5	114.5	112.0	(a)
8		(a)	112.0	(a)	(a)

[a] Not visible above tunnel background.

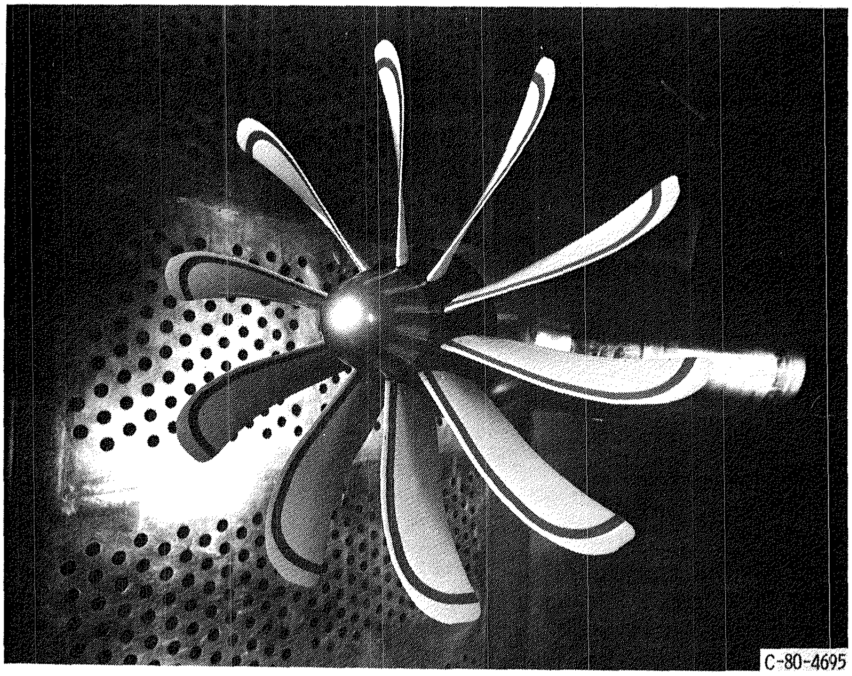
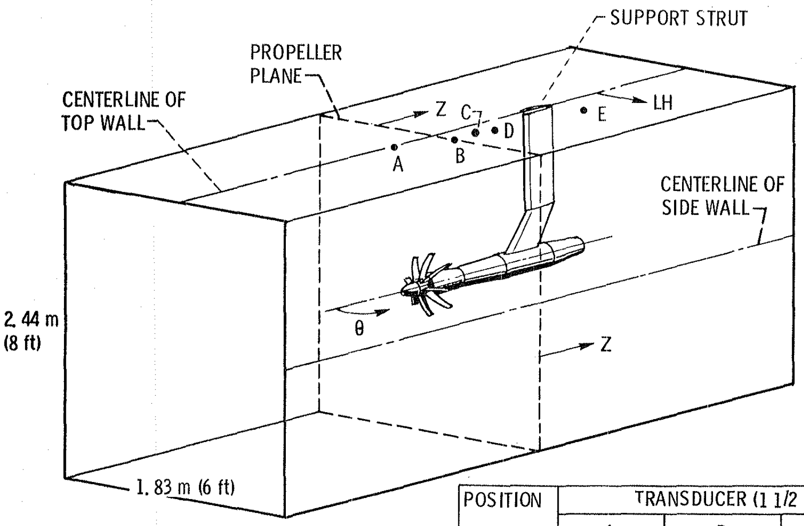
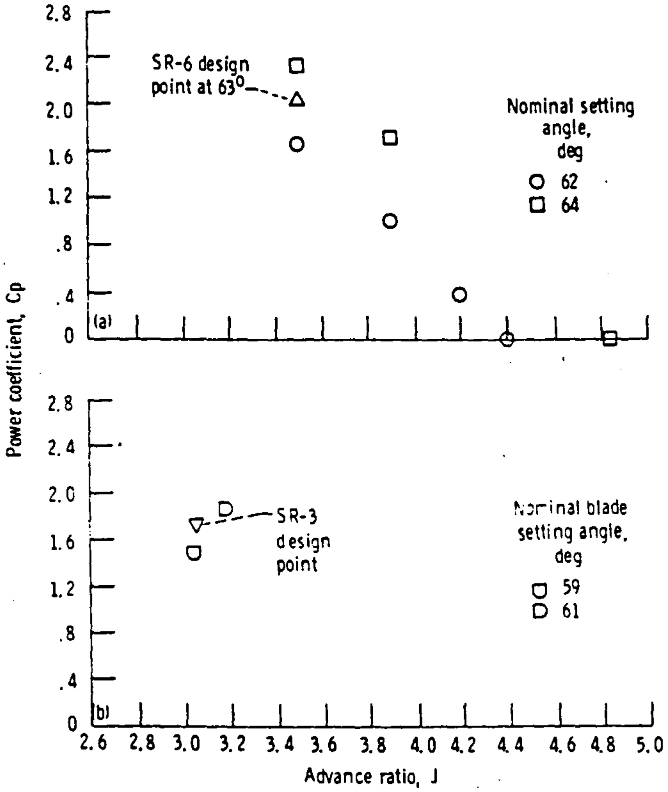

C-80-4695

Figure 1. - High speed SR-6 turboprop model installed in the Lewis 8-by 6-foot SWT.



POSITION	TRANSDUCER (1 1/2 DIAMETER FROM TIP)				
	A	B	C	D	E
	TRANSDUCER POSITION, cm (in.)				
Z	33.0(13.0)	0.953(0.375)	23.9(9.4)	45.2(17.8)	107.4(42.3)
LH	4.83(1.9)	10.2(4.0)	2.54(1.0)	7.62(3.0)	31.5(12.4)
NOMINAL ANGLE, θ, deg.	75	90	101	110	131

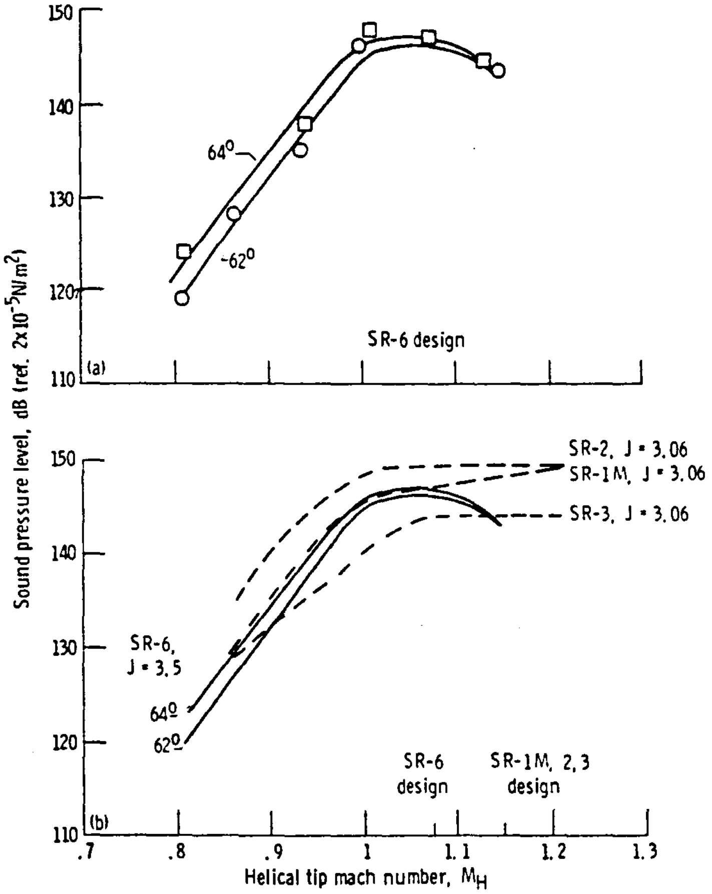
Figure 2. - Pressure transducer positions.



(a) Operation at 62 and 64 degrees, near SR-6 design.

(b) Operation at 59 and 61 degrees, near SR-3 design point.

Figure 3. - Power coefficient variation with advance ratio at tunnel mach number of 0.8.



(a) 62 and 64 degree setting angles at a nominal advance ratio of 3.5.

(b) Comparison of SR-6 with SR-1M, SR-2, and SR-3.

Figure 4. - Maximum blade passing tone variation with helical tip mach number.

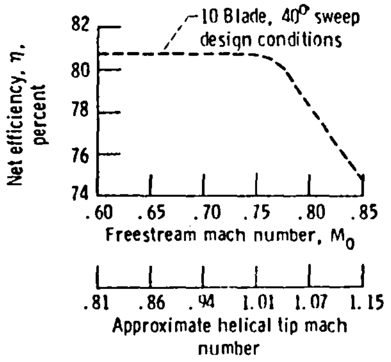
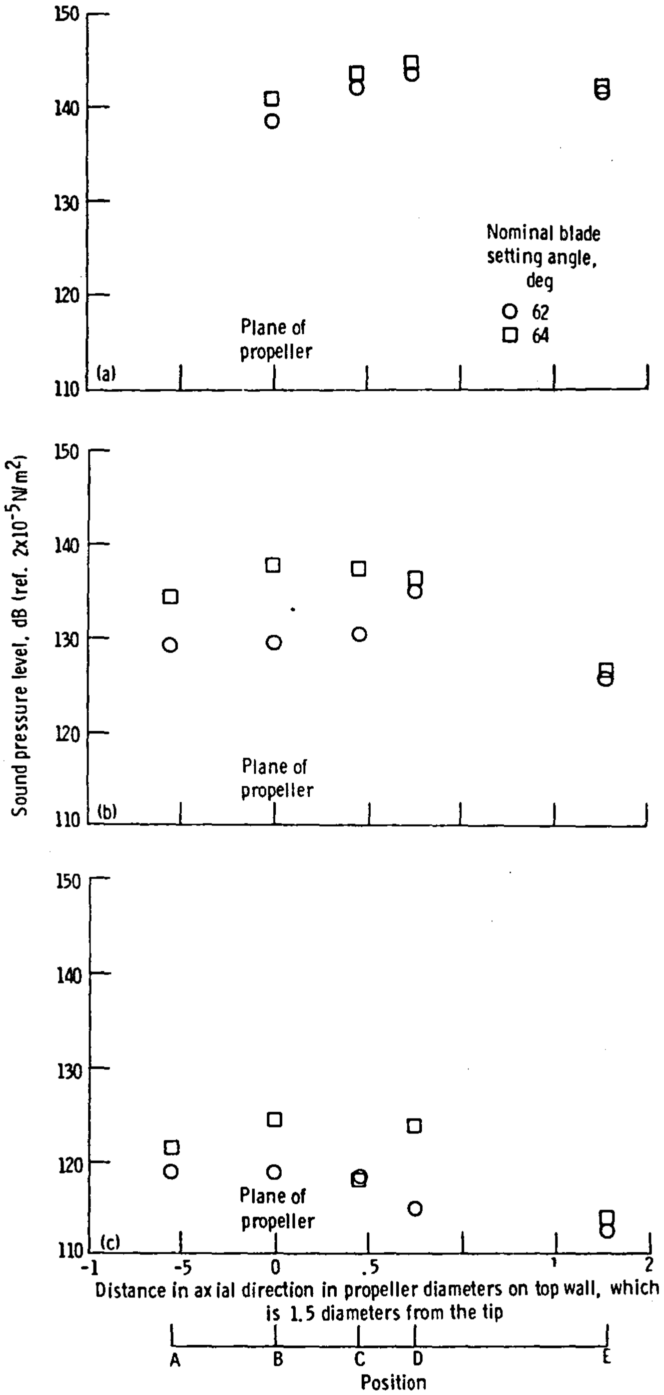


Figure 5. - SR-6 performance.

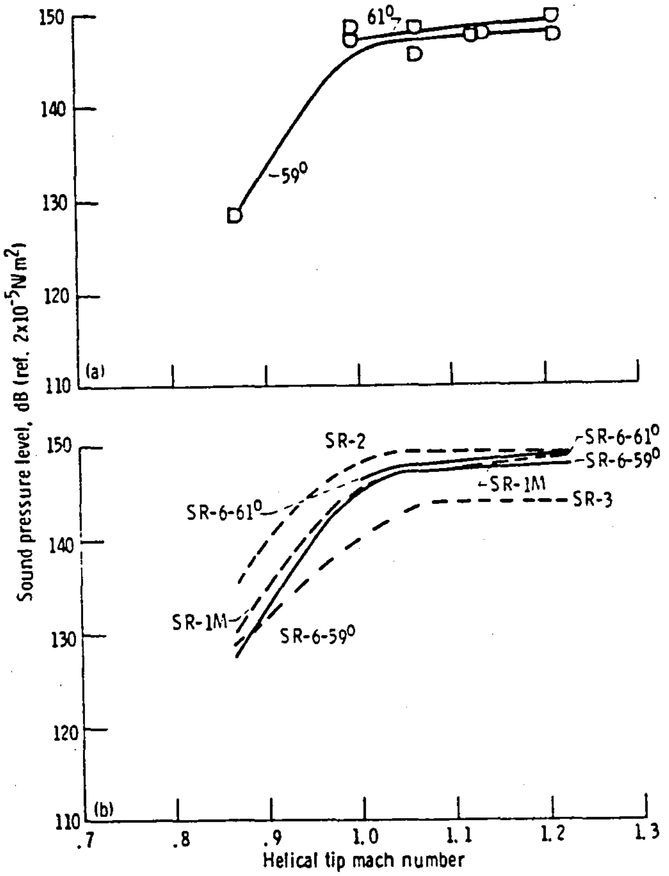


(a) Tunnel mach number = 0.85. Helical tip mach number approximately 1.15.

(b) Tunnel mach number = 0.70. Helical tip mach number approximately 0.94.

(c) Tunnel mach number = 0.60. Helical tip mach number approximately 0.81.

Figure 6. - Sideline directivity of blade passing tone.



(a) 59 and 61 degree setting angles at a nominal advance ratio of 3.06

(b) Comparison of SR-6 with SR-1M, SR-2 and SR-3 at a nominal advance ratio of 3.06

Figure 7. - Maximum blade passing tone variation with helical tip mach number for SR-6 operating near SR-3 design.

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16. Abstract

The noise generated by supersonic helical-tip-speed propellers is a likely cabin environment problem for future airplanes powered by these propellers. Three propeller models with different tip sweeps, SR-1M, SR-2, and SR-3, designed for 244 m/sec (800 ft/sec) tip speed at a flight Mach number of 0.8 were previously tested in the NASA Lewis 8- by 6-Foot Wind Tunnel. In order to investigate another design point condition, the SR-6 propeller was designed for 213 m/sec (700 ft/sec) tip speed at a flight Mach number of 0.8. The noise data from this propeller are reported herein. Curves of blade passing frequency noise versus tip Mach number (at constant advance ratio) showed that the SR-6 propeller behaved similarly to the SR-1M propeller. The noise of the SR-6 propeller at its design condition, helical tip Mach number of 1.07, is approximately 3 dB quieter than the SR-2 propeller at its higher design helical tip Mach number of 1.15, but about 2.5 dB noisier than SR-3 at its design condition. The helical tip Mach number shift of the steep noise rise followed the same progression as the blade sweep angle for all of the propellers. When operated at the SR-3 design point, the SR-6 propeller was approximately 1.5 dB quieter than SR-2 and 4 dB noisier than SR-3.

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