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A COMPARISON BETWEEN AN EXISTING PROPELLER NOISE THEORY AND WIND TUNNEL DATA

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SUMMARY

The noise of three supersonic helical tip speed propellers, measured in the NASA Lewis 8- by 6-Foot Wind Tunnel were compared with the noise predicted by an existing noise theory. Comparisons of the peak blade passage tones showed fairly good agreement between theory and experiment at the lower helical tip Mach numbers tested, 0.86 and 1.00. However, at higher helical tip Mach numbers, the theory predicted higher noise levels than measured. At the design cruise condition, helical tip Mach number of 1.14, the theoretical peak blade passage tone was about 6 decibels higher than measured.

When the differences among the propellers were considered the theory and measurement showed fairly good agreement. Both the theory and experiment showed roughly the same noise difference between the propellers at the cruise condition. Directivity measurements, in general, showed that the measured blade passage tone data peaked further downstream than the theory predicted. In addition, the harmonic content of the data and theory appeared different. At the cruise design condition the harmonics appeared to fall off faster in the data than the theory indicated.

The difference which exist between the predicted and measured noise may not be totally the fault of the prediction method as one might first assume, since the tunnel noise data were taken under less than ideal conditions. There is no attempt in this report to indicate which is in error, but rather to point out the difference between theory and experiment and to indicate where more effort may be needed to bring them into agreement.

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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 the airplane forward speed and the propeller rotational speed would result in supersonic helical velocities over the outer portions of the propeller blades. As a result of these supersonic blade sections, the propellers may create a cabin noise environment problem for the airplane at cruise.

To obtain a preliminary indication of the noise from this type of propeller, three 0.622-meter- (24.5-in.-) diameter propellers were tested in the NASA Lewis 8- by 6-Foot Wind Tunnel (refs. 1 and 2). This wind tunnel does not have acoustic damping material on its walls and is, therefore, not an ideal location for taking noise data. However, upon examination, it was felt that useful data had been obtained. This was particularly true for the purpose of ascertaining the noise differences among the three propellers.

A number of theoretical noise prediction models for these types of propellers have been developed. The most recent of these are the models of Farassat (refs. 3 to 5) and Hanson (refs. 6 and 7). These noise models represent a significant extension of propeller noise prediction into the transonic and supersonic helical tip speed regions. The Farassat prediction model was used to predict the noise from these three propellers for comparison with the tunnel data. The predictions were performed using Dr.

Farassat's computer program on the NASA Langley CDC 6600 computer and his assistance was appreciated.

It should be noted that discrepancies which exist between the predicted noise and that measured in the wind tunnel may not be totally the fault of the prediction method as one might normally assume. It is possible that the tunnel data, taken under less than ideal conditions, may be the cause of part of the discrepancy. The purpose of this report is to point out where discrepancies exist between the experiment and theory.

DATA AND THEORY

Tunnel Noise Data

Three eight-bladed propellers designed for blade tip supersonic helical velocity at 0.8 Mach number cruise were tested in the 8- by 6-Foot Wind Tunnel to obtain noise data (refs. 1 and 2). The propellers were nominally 0.622 meter (24.5 in.) in diameter and a photograph of the three individual blades is shown in figure 1. The three blades have been designated SR-2, SR-1M, and SR-3. The SR-2 blade is similar to a conventional straight propeller blade but with a long chord and a relatively low thickness-to-chord ratio at the tip. The SR-1M blade has some sweep built into the outboard section. This sweep was primarily aerodynamic for the purpose of reducing losses on the blade and amounted to about 30° of sweep at the tip. The SR-3 blade was an attempt to incorporate sweep both for aerodynamics and noise control. The tip sweep for SR-3 was about 45°. Further design details of the three propellers can be found in references 6, 8, and 9, and a comparative listing of the propeller characteristics is found in table I.

The acoustic tests were performed in the Lewis 8- by 6-Foot Wind Tunnel. A plan view of this tunnel is shown in figure 2(a) and a picture of the SR-3 propeller in the test section is shown in figure 2(b). Pressure transducers were installed in plugs placed in the tunnel bleed holes visible in figure 2(b). The four transducers used for the comparison with theory are located on the top wall and a sketch showing the location of the transducers is found in figure 3. The tunnel noise data used for the comparison were made at the design setting angle for each blade. The tunnel Mach numbers for the comparisons are $M = 0.6$, 0.7, 0.75, 0.80, and 0.85. The propeller rpm was adjusted at each tunnel Mach number so as to maintain a nominal advance ratio at the design value of approximately 3.06.

Theoretical Noise Model

The noise prediction method used in this comparison was developed by Farassat (refs. 3 to 5). The starting point of this analysis is the Ffowcs Williams-Hawkings equation (ref. 10). The formulation without the quadrupole term is used and the form of the equation used by Farassat is repeated below:

$$\frac{1}{c^2}\frac{\partial^2 p'}{\partial t^2} - \nabla^2 p' = \frac{\partial}{\partial t}\Big[\rho_o V_N |\nabla f| \delta(f)\Big] - \frac{\partial}{\partial X_i}\Big[L_i |\nabla f| \delta(f)\Big] \tag{1}$$

where C is the speed of sound and ρ_0 is the density in the undisturbed medium, P' is the acoustic pressure, V_N is the local velocity normal to the surface of the blade. The blade is described by $f(x,t) = 0$. The local force on the fluid (per unit area) at the surface of the blade is denoted by L_i and $\delta(f)$ is the Dirac delta function. The first term on the right of the equation represents the volume displacement effect and is typically referred to as the thickness term. The second term represents the force exerted on the air and is typically referred to as the loading term.

The solution to this equation has been published by Farassat in references 3 and 4. This solution has been programmed on the Langley CDC 6600 computer and this computer program was exercised to obtain the predictions used in this report. The computer program requires both geometric and loading inputs for its operation. Subroutines were already in existence for the three propeller geometries tested. Those subroutines were adjusted to achieve the same blade angles of attack as those tested in the wind tunnel. Lift coefficients at various hub to tip locations were already provided for those three blades from the design information. These were the lift coefficients at the design cruise condition (tunnel Mach number = 0.8, advance ratio = 3.06). Section lift coefficients were not measured during the propeller testing; however, the horsepower per blade was obtained from the testing. In order to provide equivalent loading conditions, the program lift coefficients were all multiplied by a common factor to obtain the same horsepower per blade for the predictions as for the test points. These changes in the lift coefficients had typically less than a 1-decibel effect on the noise prediction since the lift coefficients were generally changed less than 10 percent. General computer inputs, such as density, speed of sound, tunnel Mach number, propeller rotational velocity, were all set to correspond with the tunnel test points. The locations of the four transducers (77^o, 90^o, 110^o, and 130^o) were the primary locations where the computer program was exercised. These four positions will be referred to as the standard positions. In addition, calculations were performed at a location approximately 100^o from the inlet. This position will be referred to as the extra position. Test data does not exist at this location, but the calculations were performed to aid in the determination of the predicted directivity. The computer program predicts the free-field noise of a propeller. In order to make the calculated results comparable with those measured on the walls of the wind tunnel 6 decibels have been added to all of the predictions. No other changes to the program predictions have been made.

RESULTS AND DISCUSSION

The results of the propeller noise prediction program were compared with previously taken propeller noise data taken on the walls of the Lewwis 8- by 6-Foot Wind Tunnel at four transducer positions corresponding to roughly 77^o, 90^o, 110^o, and 130^o from the inlet direction. The computer calculations provided noise predictions at these four positions and a position corresponding roughly to 100^o from the inlet direction. The predicted and measured sound pressure levels for propellers SR-2, SR-1M, and SR-3 are tabulated in tables II, III, and IV, respectively. The levels for the first five blade passage harmonics are included in these tables for five tunnel-through flow Mach numbers, M_T, equal to 0.85, 0.80, 0.75, 0.70, and

0.60. The advance ratio was maintained at approximately 3.06 resulting in nominal blade helical tip Mach numbers of 1.21, 1.14, 1.07, 1.0, and 0.86 which correspond to the five tunnel Mach numbers.

Peak Blade Passage Tone

The two most important considerations for these propeller noise studies are the ability to determine the peak noise level of the propellers and to distinguish noise differences among the three propellers. The blade passage tone is investigated here since it is typically the highest tone in a propeller spectrum.

Magnitude. - Comparisons between the predicted and measured peak blade passage tones are plotted in figure 4, with part (a) being SR-2, (b) being SR-1M, and (c) being SR-3. These show the peak blade passage tone measured on the tunnel wall plotted versus the blade helical tip Mach number. This blade helical tip Mach number was obtained by maintaining the propeller at a constant advance ratio of approximately 3.06 while the tunnel Mach number was varied. The tunnel Mach number is indicated on these plots as a separate abscissa.

Typically the maximum levels occurred at either 90° or 110°. These positions were close enough together, that no corrections for differential distance were performed. At some of the conditions the noise at the extra position, 100°, was predicted to be higher by the theory. In those cases where it was more than 1 decibel higher than the maximum value of the four standard positions, it was also included on the plots with a separate flagged symbol.

An observation of figure 4 reveals a consistent trend for all three propellers. The peak blade passage tone predicted by the theory and that measured in the tunnel are fairly well in agreement at the lower helical tip Mach numbers (0.86 and 1.0). However, as higher Mach numbers are reached the predicted noise level continues to rise while that measured in the tunnel levels off. This results in a difference between theory and measurement of around 6 decibels near the design point of the propellers (helical tip Mach number of 1.14). The agreement between theory and experiment at the low helical tip speed is consistent with the fact that existing noise prediction techniques predict subsonic propeller noise fairly well. The subsonic propellers are typically loading noise dominated. As the helical tip Mach number is increased the thickness noise also becomes important. It is in this region that the differences between the theory and experiment start to appear. It may be that in some way this thickness term is not being predicted correctly or that other terms should be included in the theory. It is also possible that something occurred during the tunnel testing to cause the measured noise to level off artificially when it should continue to rise. In any case this supersonic helical tip speed region, particularly near the design cruise conditions, is where additional effort should be expended to bring the peak blade passage tone predicted by theory and that measured in the tunnel into agreement.

Difference among propellers. - The ability to determine the noise difference between two propellers is important particularly to enable the design of future quieter propellers. Plots of the peak noise reductions achieved by SR-1M and SR-3 from the levels of SR-2 are found in figures 5(a) and (b), respectively. These reductions are taken at the standard transducer positions. As can be observed, the predicted and measured reductions in the peak noise are in fair agreement. This is particularly true at the design cruise point (helical tip Mach number of 1.14) where the predicted and measured noise reductions are both about 1 decibel for SR-1M and both about 6 decibels for SR-3. Even though the absolute levels for the measurement and prediction are not very close at the design point it is encouraging that the measured and predicted differences between the noise levels of the propellers are so close. This gives some confidence that a propeller designed to be a certain number of decibels quieter than another propeller would indeed be that much quieter.

Directivity

Plots of the blade passage tone directivity for SR-2, SR-1M, and SR-3 are found in figures 6 to 8, respectively. On these figures part (a) is for the helical tip Mach number M_{HT}, of 1.21 (tunnel Mach number M_T, of 0.85), (b) is for $M_{HT} = 1.14$ ($M_T = 0.80$), (c) for $M_{HT} = 1.07$ ($M_T = 0.75$, (d) for $M_{HT} = 1.00$ ($M_T = 0.70$), and (e) is for $M_{HT} = 0.86$ ($M_T = 0.60$). These sound pressure levels for the positions on the tunnel wall have not been corrected for the different radial distances to each position. In the theoretical curves the extra position (100^o) has also been included.

Besides the differences in the peak noise levels between theory and experiment, differences in directivity of the blade passage tone are also observed from figures 6 to 8. At the lowest helical tip Mach number (part (e) of figs. 6 to 8), where the peak levels were well predicted, the directivity also looks fairly good. At the 130^o position the data are much higher than the theory which may indicate that this transducer is influenced by the tunnel wall reflections. At the higher helical tip Mach numbers the measured blade passage tone peaks further downstream than the theoretical peak. Also, in general, the theory falls off faster downstream of the 110^o position than does the data.

In order to further investigate this difference in directivities, the theoretical blade passage tone predictions for SR-2, SR-1M, and SR-3 have been separated into their thickness and loading components in figures 9 to 11. Here part (a) is for the lowest helical tip Mach number, $M_{HT} = 0.86$ ($M_T = 0.6$) and (b) is for the cruise design condition $M_{HT} = 1.14$ ($M_T = 0.8$). At the low helical tip Mach number of 0.86 (part (a)) where the peak tone levels were predicted fairly well (fig. 4), the theoretical blade passage tones are dominated by the loading term. At the higher helical tip Mach number, 1.14, the thickness term has become important. This thickness term dominates the prediction at the two forward transducer positions and causes the theory to peak further forward than the data. If the thickness noise were not the dominant term here, the theory would be controlled by the loading term directivity which peaks further rearward near the data peak. This would provide a closer directivity match at the higher helical tip Mach numbers. This result indicates that there may be something wrong in the thickness noise prediction. However, it should be noted that even if the thickness term were eliminated, the general conclusions of the peak magnitude curves (fig. 4) would still be valid since the remaining loading term still peaks about 5 decibels higher than the data. The seeming downstream shift of the noise data may also be a result of the convective effect of the high tunnel Mach number flow sweeping the noise downstream. If this is the case then another possibility, besides the thickness term, is that the theory is not correctly handling the convective effect on the noise. The possibility also exists that reflections from the tunnel walls may be somehow selectivity increasing the downstream noise data with respect to the upstream data.

Harmonic Content

The harmonic content of the propeller spectrum is also of concern for assessing the airplane interior noise environment. It was not possible to assess the harmonic content of all of the test data because the higher harmonic noise levels become masked by the tunnel background at some of the test conditions. Therefore, a comparison of the harmonic levels was undertaken at only one representative helical tip Mach number, 1.14, which corresponds to the cruise design point at Mach 0.8. These comparions for the three propellers, SR-2, SR-1M, and SR-3, are shown in figures 12(a), (b), and (c), respectively. These figures show the amount each harmonic is reduced from the level of the blade passage tone. On each plot the reductions are shown for the peak blade passage tone angle at the standard transducer positions.

It appears from observation of figure 12 that the harmonics fall off somewhat faster in the experiment than in the theory. This is particularly true at twice the blade passage frequency where the test data falls off faster, by 5 decibels or more, than the theory. It may be that some of the adjustments made to correct the peak noise and directivity differences will also reduce these differences.

CONCLUDING REMARKS

The noise of three supersonic helical tip speed propellers measured in the NASA Lewis 8- by 6-Foot Wind Tunnel were compared with the noise predicted by an existing propeller noise theory. Comparisons of the peak blade passage tone noise showed fairly good agreement between theory and experiment at the lower helical tip Mach numbers tested, 0.86 and 1.00. However, at higher helical tip Mach numbers, the theory predicted higher noise levels than measured. At the design cruise conditions, helical tip Mach number of 1.14, the theoretical peak blade passage tone was about 6 decibels higher than measured. This helical tip Mach number region is where the thickness noise term in the prediction method starts to become important. It may be that in some manner this thickness term is not being predicted correctly, or that other terms such as the quadrupole term should be included in the theory. It is also possible that something occurred during the tunnel testing to hold down artifically the levels measured in the tunnel.

When differences among the propellers are considered the results are more encouraging. Theoretical and experimental comparisons between SR-2 and SR-1M, at the design helical tip Mach number of 1.14 both showed SR-1M to be about 1 decibel quieter than SR-2. Similarly, comparisons between SR-3 and SR-2 both showed SR-3 to be about 6 decibels quieter. This gives some confidence that a propeller designed to be a certain amount quieter than another propeller would indeed be that much quieter.

Plots of directivity for the different propellers at the higher helical tip Mach numbers showed that the blade passage tone peaked further downstream in the wind tunnel than the theory predicted. In addition, the theoretical predictions generally fell off faster downstream. When the theoretical predictions were separated into thickness and loading components, it was seen that the thickness term was the component which caused the theory to peak further forward than the data at high helical tip Mach numbers. Reduction of the level of this thickness term would bring the theoretical and data directivity peaks closer to the same angle, but would not qualitatively change the peak magnitude comparisons. A limited number of comparison of the harmonic content of the spectrums were also made and the test harmonics generally were reduced more than the theory indicated.

It should be noted that differences between the predicted and measured noise may not be totally the fault of the prediction method as one might normally expect. It is possible that the tunnel data, taken under less than ideal conditions, may be the source of part of the differences. In either case a number of areas have been indicated where more effort is needed to bring theory and experiment into agreement.

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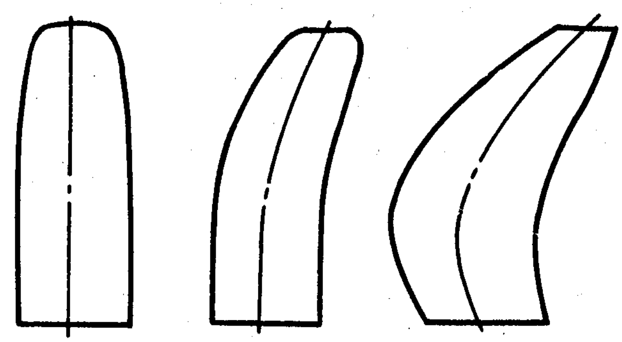
TABLE I. - COMPARISON OF PROPELLERS



	SR-2	SR-1M	SR-3
Design cruise tip speed, m/sec (ft/sec)	244 (800)	244 (800)	244 (800)
Design cruise power loading, kW/m^2 (shp/ft^2)	301 (37.5)	301 (37.5)	301 (37.5)
Number of blades	8	8	8
Tip sweep angle, deg	0	30	45
Design efficiency, %	77	79	81
Nominal diameter, D, cm (in.)	62.2 (24.5)	62.2 (24.5)	62.2 (24.5)

TABLE II. - PROPELLER SR-2 SOUND PRESSURE LEVELS

(a) Tunnel Mach number, 0.85; advance ratio, 3.07; propeller rpm, 8798; and helical tip Mach number, 1.21.

Harmonic number	Source	Transducer position				
		1	2	X	3	4
		Angle from inlet (approx.), deg				
		77	90	100	110	130
		Sound pressure level of haromonic, SPL, dB ref. 2×10^{-5} N/m^2				
[a]1BPF	Test	[b]124.5	138	-----	149.5	142
	Theory	149.4	155.1	160.3	158.8	144.9
2	Test	(c)	127.5	-----	140.5	137.5
	Theory	154.8	133.8	151.5	154.5	137.7
3	Test	(c)	(c)	-----	137	134.5
	Theory	147.5	143.7	137.4	141.2	131.0
4	Test	(c)	(c)	-----	132	127.5
	Theory	145.9	143.2	141.7	145.9	124.4
5	Test	(c)	(c)	-----	129	124.5
	Theory	142.3	147	144.1	141.0	117.7

[a]Where BPF denotes blade passage frequency.
[b]Data questionable.
[c]Not visible above tunnel background.
[d]Bad transducer.

TABLE II. - Continued.

(b) Tunnel Mach number, 0.8; advance ratio, 3.07; propeller rpm, 8328; and helical tip Mach number, 1.14.

Harmonic number	Source	Transducer position				
		1	2	X	3	4
		Angle from inlet (approx.), deg				
		77	90	100	110	130
		Sound pressure level of haromonic, SPL, dB ref. $2x10^{-5}$ N/m^2				
[a]1BPF	Test	133	141	-----	149.5	142.5
	Theory	154.7	157.3	156.7	155.1	139.4
2	Test	[b]124	137	-----	135.5	134
	Theory	151.0	148.1	150.6	152.9	127.7
3	Test	[b]122	131.5	-----	132.5	129.5
	Theory	147.7	135.8	147.7	147.1	116.6
4	Test	(c)	126.5	-----	128	126
	Theory	145.6	144.3	137.5	134.7	105.9
5	Test	(c)	122.5	-----	125	123.5
	Theory	142.3	146.0	146.6	141.7	95.1

[a]Where BPF denotes blade passage frequency.
[b]Data questionable.
[c]Not visible above tunnel background.
[d]Bad transducer.

TABLE II. - Continued.

(c) Tunnel Mach number, 0.75; advance ratio, 3.06; propeller rpm, 7876; and helical tip Mach number, 1.07.

Harmonic number	Source	Transducer position				
		1	2	X	3	4
		Angle from inlet (approx.), deg				
		77	90	100	110	130
		Sound pressure level of haromonic, SPL, dB ref. $2x10^{-5}$ N/m^2				
[a]1BPF	Test	140	148.5	-----	149	135.5
	Theory	150.0	152.0	152.2	150.2	133.3
2	Test	132.5	143	-----	136	130.5
	Theory	131.9	143.6	148.6	146.0	116.8
3	Test	124	139	-----	131	130.5
	Theory	138.7	143.1	137.1	141.0	101.2
4	Test	(c)	136	-----	128.5	125
	Theory	134.5	136.7	137.4	134.0	85.8
5	Test	(c)	133	-----	127.5	125.5
	Theory	129.5	139.3	137.1	124.7	70.8

[a]Where BPF denotes blade passage frequency.
[b]Data questionable.
[c]Not visible above tunnel background.
[d]Bad transducer.

TABLE II. - Continued.

(d) Tunnel Mach number, 0.7; advance ratio, 3.06; propeller rpm, 7413; and helical tip Mach number, 0.999.

Harmonic number	Source	Transducer position				
		1	2	X	3	4
		Angle from inlet (approx.), deg				
		77	90	100	110	130
		Sound pressure level of haromonic, SPL, dB ref. $2x10^{-5}$ N/m^2				
[a]1BPF	Test	146	145.5	-----	149.5	136
	Theory	143.5	146.7	146.8	143.7	126.5
2	Test	135	141	-----	133	129
	Theory	133.3	141.0	141.2	135.6	103.9
3	Test	130	137.5	-----	127.5	126.5
	Theory	124.5	123.6	124.2	127.7	83.6
4	Test	122.5	130	-----	124	124
	Theory	121.9	129.5	122.1	119.2	71.0
5	Test	119.5	129.5	-----	122.5	[b]118.5
	Theory	108.8	126.3	118.6	109.4	41.3

[a]Where BPF denotes blade passage frequency.
[b]Data questionable.
[c]Not visible above tunnel background.
[d]Bad transducer.

TABLE II. - Concluded.

(e) Tunnel Mach number, 0.6; advance ratio, 3.06; propeller rpm, 6491; and helical tip Mach number, 0.863.

Harmonic number	Source	Transducer position				
		1	2	X	3	4
		Angle from inlet (approx.), deg				
		77	90	100	110	130
		Sound pressure level of haromonic, SPL, dB ref. $2x10^{-5}$ N/m^2				
[a]1BPF	Test	131.5	135	------	128.5	[b]125
	Theory	130.1	133.8	133.3	129.6	111.5
2	Test	[b]122	[b]120.5	------	[b]122.5	(c)
	Theory	114.0	119.9	118.4	111.5	80.5
3	Test	(c)	(c)	------	(c)	(c)
	Theory	95.3	105.7	104.1	94.1	53.7
4	Test	(c)	(c)	------	(c)	(c)
	Theory	63.2	88.6	89.4	77.3	45.9
5	Test	(c)	(c)	------	)c)	(c)
	Theory	66.9	66.1	73.0	57.3	39.7

[a]Where BPF denotes blade passage frequency.
[b]Data questionable.
[c]Not visible above tunnel background.
[d]Bad transducer.

TABLE III. - PROPELLER SR-1M SOUND PRESSURE LEVELS

(a) Tunnel Mach number, 0.85; advance ratio, 3.07; propeller rpm, 8779; and helical tip Mach number, 1.21.

Harmonic number	Source	Transducer position				
		1	2	X	3	4
		Angle from inlet (approx.), deg				
		77	90	100	110	130
		Sound pressure level of haromonic, SPL, dB ref. 2×10^{-5} N/m^2				
[a]1BPF	Test	[b]124.5	134.5	-----	149.5	138
	Theory	150.8	155.0	159.0	156.0	141.2
2	Test	(c)	(c)	-----	137	136
	Theory	135.9	147.1	142.2	151.4	133.9
3	Test	(c)	(c)	-----	128.5	136
	Theory	131.8	139.5	145.4	140.0	128.0
4	Test	(c)	(c)	-----	129.5	127.5
	Theory	134.3	139.2	146.9	144.2	122.6
5	Test	(c)	(c)	-----	127.5	128.5
	Theory	129.1	139.5	137.1	134.3	117.3

[a]Where BPF denotes blade passage frequency.
[b]Data questionable.
[c]Not visible above tunnel background.
[d]Bad transducer.

TABLE III. - Continued.

(b) Tunnel Mach number, 0.8; advance ratio, 3.08; propeller rpm, 8347; and helical tip Mach number, 1.14.

Harmonic number	Source	Transducer position				
		1	2	X	3	4
		Angle from inlet (approx.), deg				
		77	90	100	110	130
		Sound pressure level of haromonic, SPL, dB ref. 2×10^{-5} N/m^2				
[a]1BPF	Test	131	143	-----	148	140
	Theory	150.5	156.8	155.6	152.5	137.1
2	Test	(c)	134	-----	131	129
	Theory	136.6	146.0	147.6	149.8	125.9
3	Test	(c)	130	-----	130	131
	Theory	131.5	138.6	142.1	143.9	116.1
4	Test	(c)	124.5	-----	129.5	126.5
	Theory	130.5	137.1	138.9	138.6	107.0
5	Test	(c)	120	-----	123.5	126
	Theory	125.6	134.3	136.5	136.0	98.0

[a]Where BPF denotes blade passage frequency.
[b]Data questionable.
[c]Not visible above tunnel background.
[d]Bad transducer.

TABLE III. - Continued.

(c) Tunnel Mach number, 0.75; advance ratio, 3.07; propeller rpm, 7864 and helical tip Mach number, 1.07.

Harmonic number	Source	Transducer position				
		1	2	X	3	4
		Angle from inlet (approx.), deg				
		77	90	100	110	130
		Sound pressure level of haromonic, SPL, dB ref. $2x10^{-5}$ N/m^2				
[a]1BPF	Test	137	147	-----	147.5	132
	Theory	148.9	151.9	151.1	148.6	131.4
2	Test	128	138.5	-----	131.5	129
	Theory	136.2	142.2	146.4	143.8	116.9
3	Test	(c)	133	-----	126.5	126
	Theory	143.0	138.3	139.5	138.8	106.0
4	Test	(c)	129.5	-----	128.5	122.5
	Theory	126.8	138.6	137.5	133.1	89.7
5	Test	(c)	127	-----	127.5	124
	Theory	129.7	126.7	136.1	129.7	76.7

[a]Where BPF denotes blade passage frequency.
[b]Data questionable.
[c]Not visible above tunnel background.
[d]Bad transducer.

TABLE III. - Continued.

(d) Tunnel Mach number, 0.7; advance ratio, 3.04; propeller rpm, 7404 and helical tip Mach number, 0.999.

Harmonic number	Source	Transducer position				
		1	2	X	3	4
		Angle from inlet (approx.), deg				
		77	90	100	110	130
		Sound pressure level of haromonic, SPL, dB ref. 2×10^{-5} N/m^2				
[a]1BPF	Test	140	139.5	-----	145.5	131.5
	Theory	141.3	145.5	145.3	142.4	125.8
2	Test	132.5	138.5	-----	132.5	125
	Theory	130.3	138.5	139.2	134.1	105.1
3	Test	127.5	132	-----	127	125
	Theory	119.3	128.2	132.7	127.0	86.2
4	Test	121	125	-----	[b]122.5	121.5
	Theory	120.1	128.1	125.5	119.9	68.5
5	Test	(c)	125	-----	[b]121.5	(c)
	Theory	108.0	126.9	122.5	112.7	49.6

[a]Where BPF denotes blade passage frequency.
[b]Data questionable.
[c]Not visible above tunnel background.
[d]Bad transducer.

TABLE III. - Concluded.

(e) Tunnel Mach number, 0.6; advance ratio, 3.08; propeller rpm, 6927; and helical tip Mach number, 0.857.

Harmonic number	Source	Transducer position				
		1	2	X	3	4
		Angle from inlet (approx.), deg				
		77	90	100	110	130
		Sound pressure level of haromonic, SPL, dB ref. $2x10^{-5}$ N/m^2				
[a]1BPF	Test	[b]124.5	[b]124	-----	129	[b]124.5
	Theory	127.0	130.7	130.3	126.9	110.2
2	Test	(c)	[b]122	-----	(c)	(c)
	Theory	109.2	115.8	114.8	108.3	78.1
3	Test	(c)	(c)	-----	(c)	(c)
	Theory	90.5	111.7	100.9	91.5	50.3
4	Test	(c)	(c)	-----	(c)	(c)
	Theory	64.5	84.4	86.8	75.2	38.1
5	Test	(c)	(c)	-----	(c)	(c)
	Theory	60.2	67.6	71.6	58.7	37.1

[a]Where BPF denotes blade passage frequency.
[b]Data questionable.
[c]Not visible above tunnel background.
[d]Bad transducer.

TABLE IV. - PROPELLER SR-3 SOUND PRESSURE LEVELS

(a) Tunnel Mach number, 0.85; advance ratio, 3.07; propeller rpm, 8870; and helical tip Mach number, 1.21.

Harmonic number	Source	Transducer position				
		1	2	X	3	4
		Angle from inlet (approx.), deg				
		77	90	100	110	130
		Sound pressure level of haromonic, SPL, dB ref. $2x10^{-5}$ N/m^2				
[a]1BPF	Test	(c)	136	-----	144.5	134
	Theory	137.8	151.6	153.9	154.0	144.2
2	Test	(c)	[b]126	-----	132	132
	Theory	138.5	132.3	147.9	146.9	137.9
3	Test	(c)	(c)	-----	136	135.5
	Theory	122.2	138.6	140.3	143.6	133.1
4	Test	(c)	(c)	-----	125	126
	Theory	128.8	137.8	138.7	140.4	128.9
5	Test	(c)	(c)	-----	127	127
	Theory	117.8	131.8	134.4	133.1	124.9

[a]Where BPF denotes blade passage frequency.
[b]Data questionable.
[c]Not visible above tunnel background.
[d]Bad transducer.

TABLE IV. - Continued.

(b) Tunnel Mach number, 0.8; advance ratio, 3.07; propeller rpm, 8452 and helical tip Mach number, 1.14.

Harmonic number	Source	Transducer position				
		1	2	X	3	4
		Angle from inlet (approx.), deg				
		77	90	100	110	130
		Sound pressure level of haromonic, SPL, dB ref. 2×10^{-5} N/m^2				
[a]1BPF	Test	130.5	140	------	144	135
	Theory	147.2	148.5	151.4	150.6	139.0
2	Test	(c)	129	-----	131.5	132.5
	Theory	134.6	138.8	143.8	144.7	129.2
3	Test	(c)	125.5	-----	127.5	127
	Theory	133.9	136.0	138.1	142.0	121.0
4	Test	(c)	120	-----	130	128.5
	Theory	127.5	135.4	133.4	137.5	113.5
5	Test	(c)	(c)	-----	125.5	125.5
	Theory	124.4	131.9	132.9	133.9	106.2

[a]Where BPF denotes blade passage frequency.
[b]Data questionable.
[c]Not visible above tunnel background.
[d]Bad transducer.

TABLE IV. - Continued.

(c) Tunnel Mach number, 0.75; advance ratio, 3.05; propeller rpm, 7990 and helical tip Mach number, 1.07.

Harmonic number	Source	Transducer position				
		1	2	X	3	4
		Angle from inlet (approx.), deg				
		77	90	100	110	130
		Sound pressure level of haromonic, SPL, dB ref. $2x10^{-5}$ N/m^2				
[a]1BPF	Test	133.5	140.5	-----	145	129
	Theory	141.1	146.4	147.4	146.9	131.8
2	Test	128.5	137.5	-----	136.5	133.5
	Theory	134.6	140.6	140.9	141.6	118.5
3	Test	(c)	129	-----	129	125.5
	Theory	127.7	134.1	139.2	138.1	105.9
4	Test	(c)	125.5	-----	130	122.5
	Theory	125.6	131.4	134.7	134.8	94.0
5	Test	(c)	120.5	-----	125	122
	Theory	121.7	130.1	130.9	131.3	81.3

[a]Where BPF denotes blade passage frequency.
[b]Data questionable.
[c]Not visible above tunnel background.
[d]Bad transducer.

TABLE IV. - Continued.

(d) Tunnel Mach number, 0.7; advance ratio, 3.06; propeller rpm, 7510 and helical tip Mach number, 1.0.

Harmonic number	Source	Transducer position				
		1	2	X	3	4
		Angle from inlet (approx.), deg				
		77	90	100	110	130
		Sound pressure level of haromonic, SPL, dB ref. 2×10^{-5} N/m^2				
[a]1BPF	Test	133	139.5	-----	138	135
	Theory	136.9	141.9	143.3	141.8	126.6
2	Test	133.5	136.5	-----	138	125
	Theory	129.0	135.4	136.7	134.1	107.4
3	Test	125.5	133	-----	124.5	[b]123
	Theory	120.7	130.8	133.0	128.6	90.2
4	Test	[b]121	127	-----	122	[b]120.5
	Theory	114.0	125.7	129.0	123.6	73.6
5	Test	(c)	124	-----	123	119
	Theory	114.0	124.1	124.0	118.4	55.4

[a]Where BPF denotes blade passage frequency.
[b]Data questionable.
[c]Not visible above tunnel background.
[d]Bad transducer.

TABLE IV. - Concluded.

(e) Tunnel Mach number, 0.6; advance ratio, 3.05; propeller rpm, 6538 and helical tip Mach number, 0.863.

Harmonic number	Source	Transducer position				
		1	2	X	3	4
		Angle from inlet (approx.), deg				
		77	90	100	110	130
		Sound pressure level of haromonic, SPL, dB ref. $2x10^{-5}$ N/m^2				
[a]1BPF	Test	126.5	128.5	-----	127.5	[b]124.5
	Theory	124.9	130.3	131.3	128.7	112.9
2	Test	(c)	(c)	-----	(c)	(c)
	Theory	106.9	115.2	116.5	111.8	83.9
3	Test	(c)	(c)	-----	(c)	(c)
	Theory	91.8	103.2	104,2	97.0	55.2
4	Test	(c)	(c)	-----	(c)	(c)
	Theory	75.1	90.9	92.3	82.9	38.4
5	Test	(c)	(c)	-----	(c)	(c)
	Theory	54.2	77.1	80.0	69.0	42.9

[a]Where BPF denotes blade passage frequency.
[b]Data questionable.
[c]Not visible above tunnel background.
[d]Bad transducer.

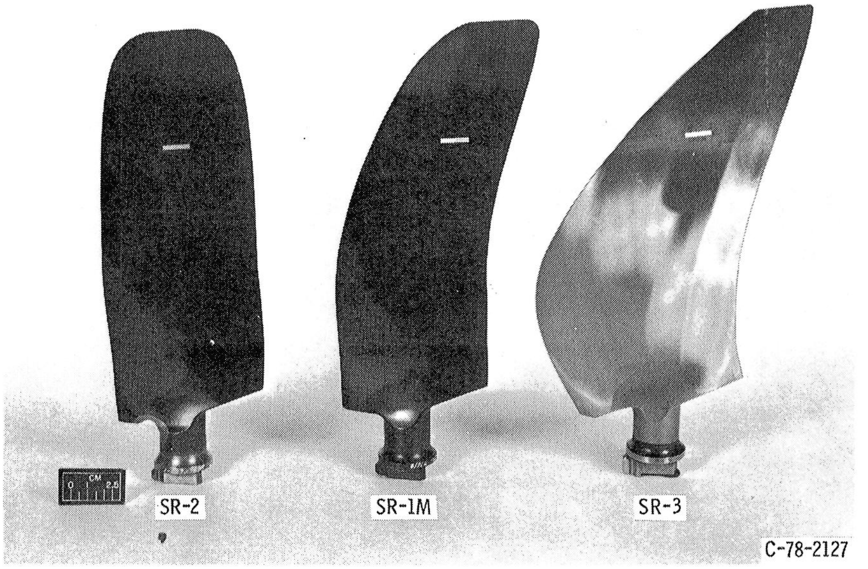
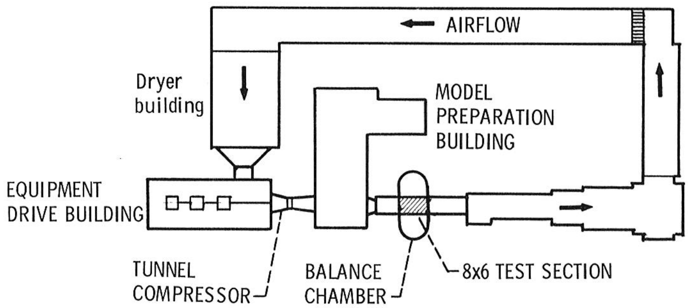
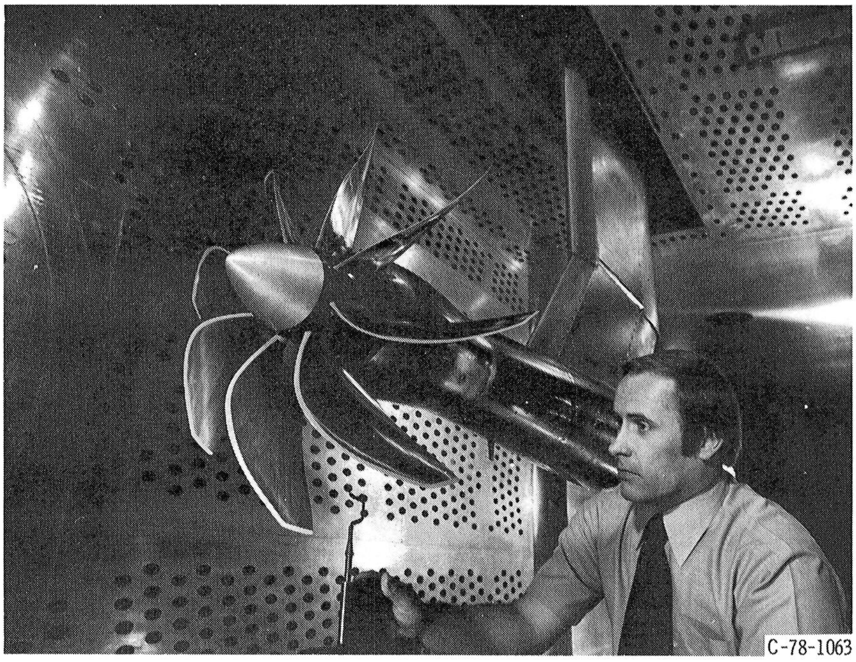


Figure 1. - Propeller blades.

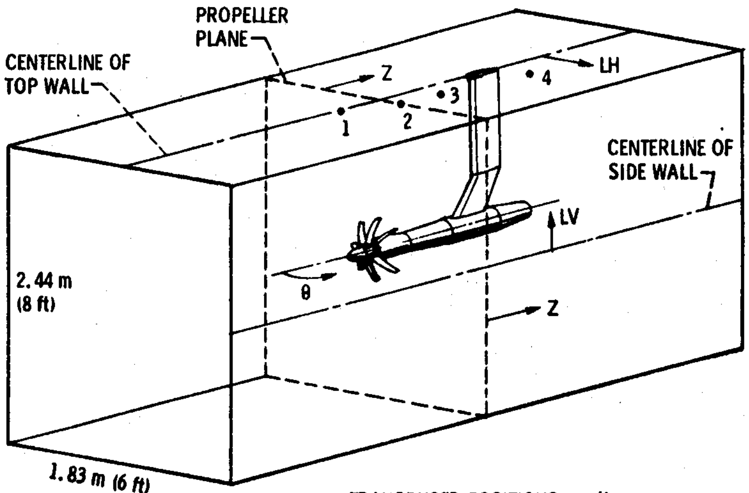


(a) PLAN VIEW OF 8x6 WIND TUNNEL.



(b) PROPELLER SR-3 IN TUNNEL.

Figure 2.



TRANSDUCER POSITIONS, cm/in.

POSITIONS	1		2		3		4	
Z	-27.7	-10.9	0.953	0.375	45.2	17.8	104.4	41.1
LH	2.54	1.0	10.2	4.0	7.62	3.0	31.5	12.4
LV	121.9	48.0	121.9	48.0	121.9	48.0	121.9	48.0
NOMINAL ANGLE, θ	77°		90°		110°		130°	

Figure 3. - Pressure transducer positions.

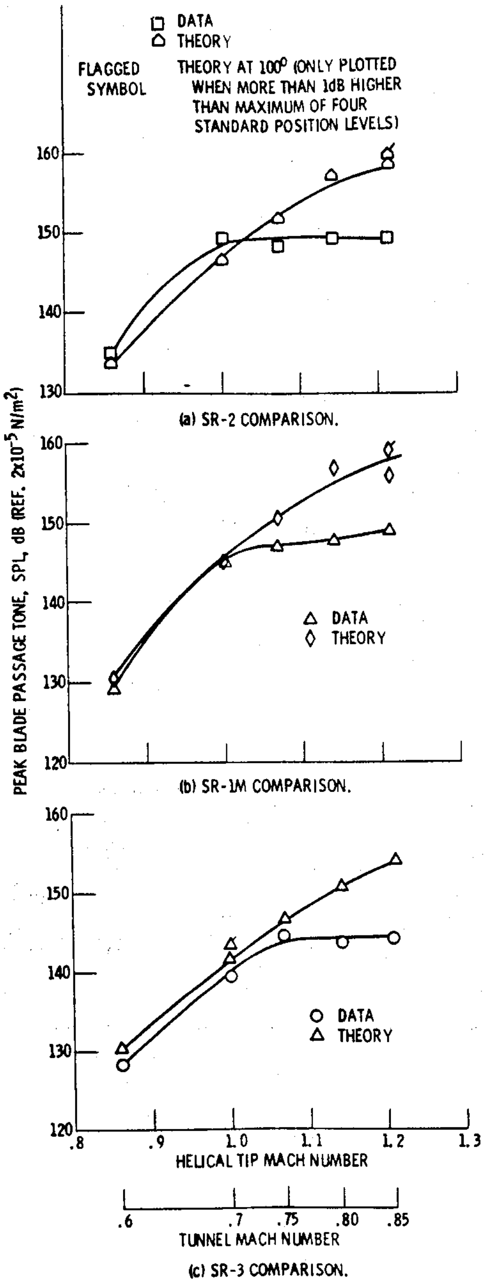
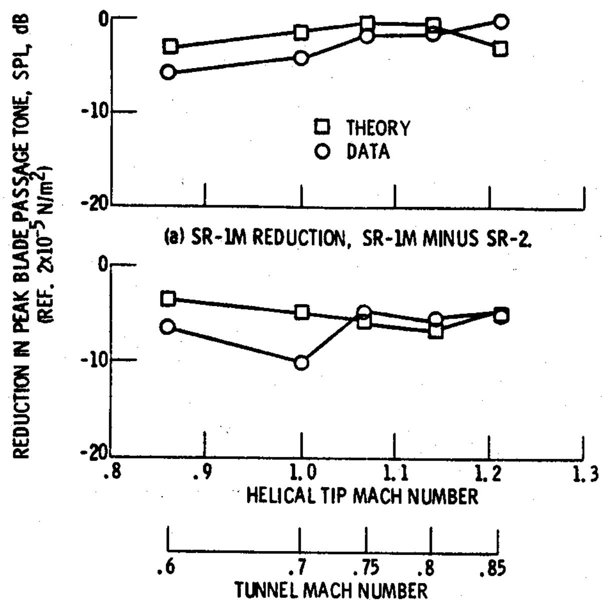
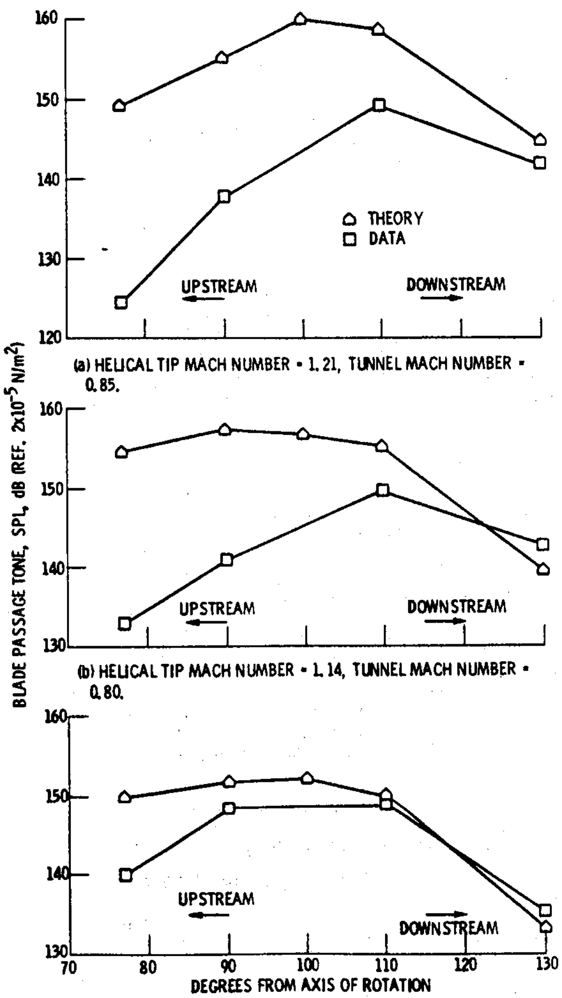


Figure 4. - Peak blade passage tone variation with helical tip Mach number.



(b) SR-3 REDUCTION, SR-3 MINUS SR-2.

Figure 5. - Reduction of noise from SR-2 level.

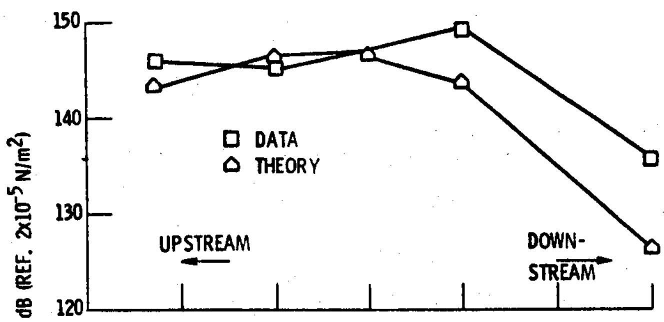


(a) HELICAL TIP MACH NUMBER = 1.21, TUNNEL MACH NUMBER = 0.85.

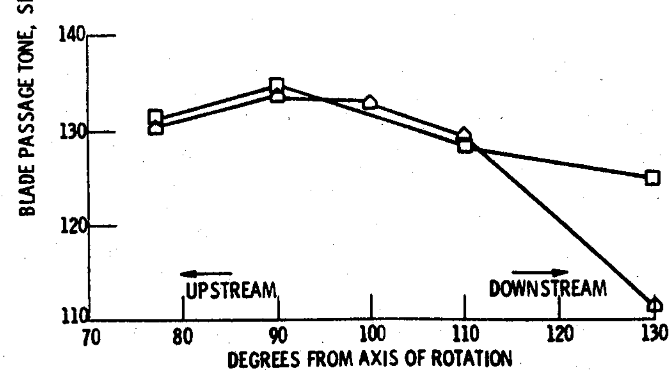
(b) HELICAL TIP MACH NUMBER = 1.14, TUNNEL MACH NUMBER = 0.80.

(c) HELICAL TIP MACH NUMBER = 1.07, TUNNEL MACH NUMBER = 0.75.

Figure 6. - Noise directivity on tunnel wall for SR-2 blade passage tone.



(d) HELICAL TIP MACH NUMBER = 0.999, TUNNEL MACH NUMBER = 0.7.



(e) HELICAL TIP MACH NUMBER = 0.863, TUNNEL MACH NUMBER = 0.6.

Figure 6. - Concluded.

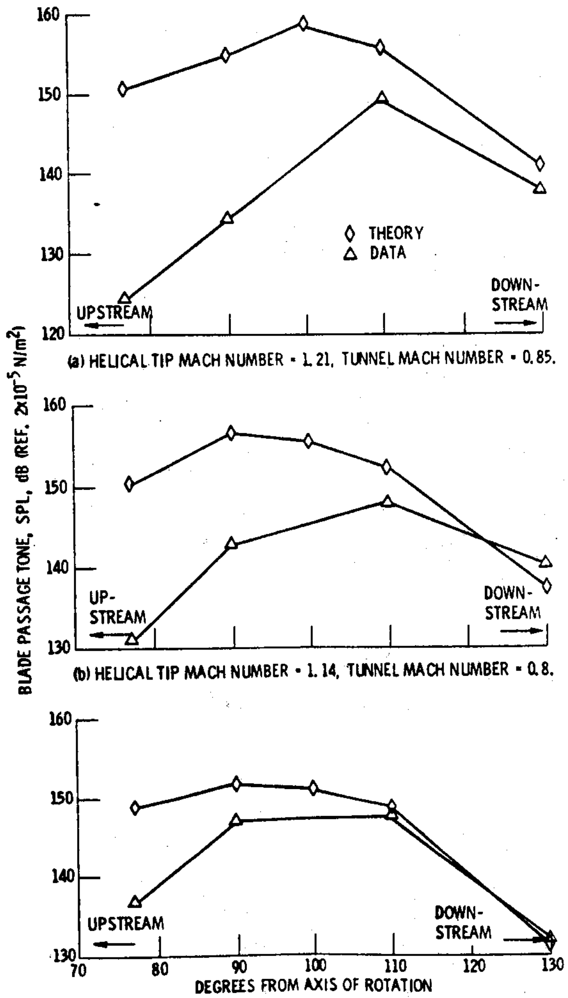
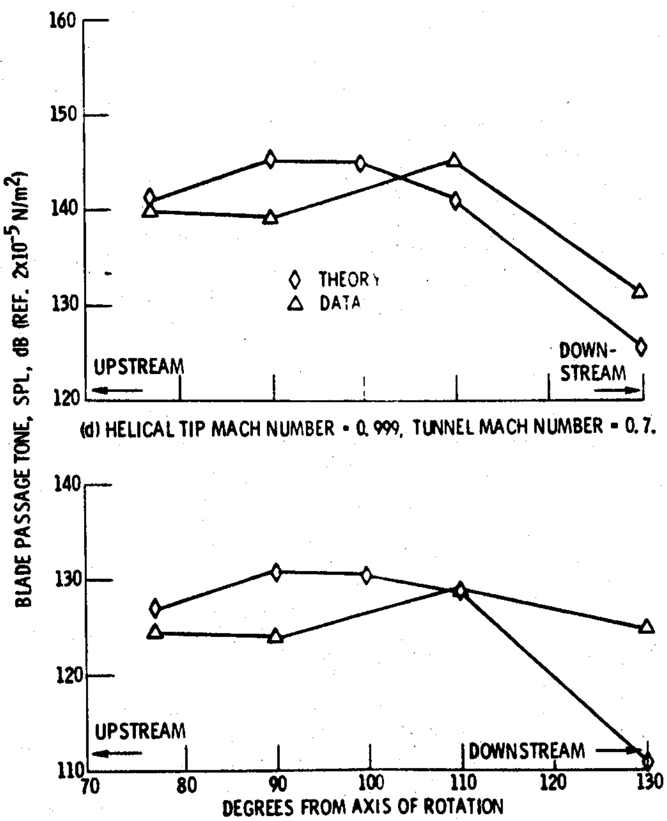


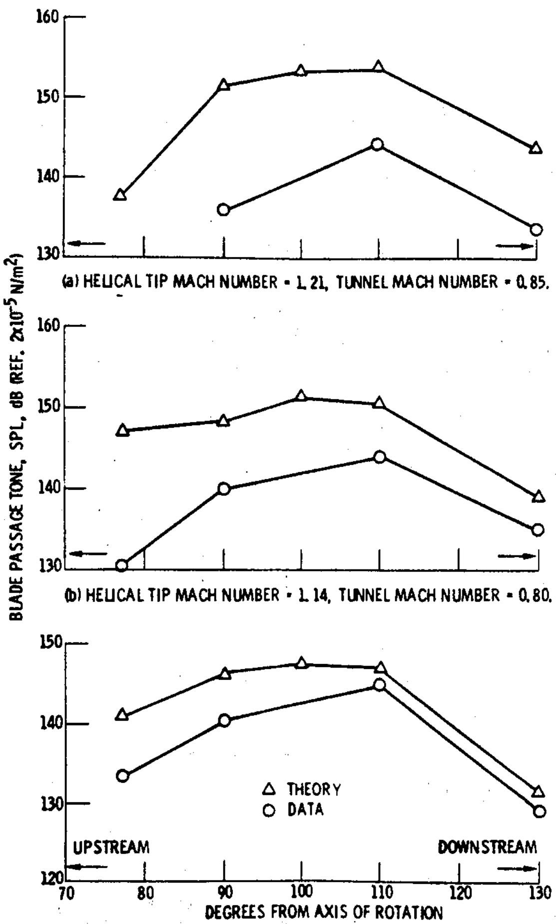
Figure 7. - Noise directivity on tunnel wall for SR-1M blade passage tone.



(d) HELICAL TIP MACH NUMBER = 0.999, TUNNEL MACH NUMBER = 0.7.

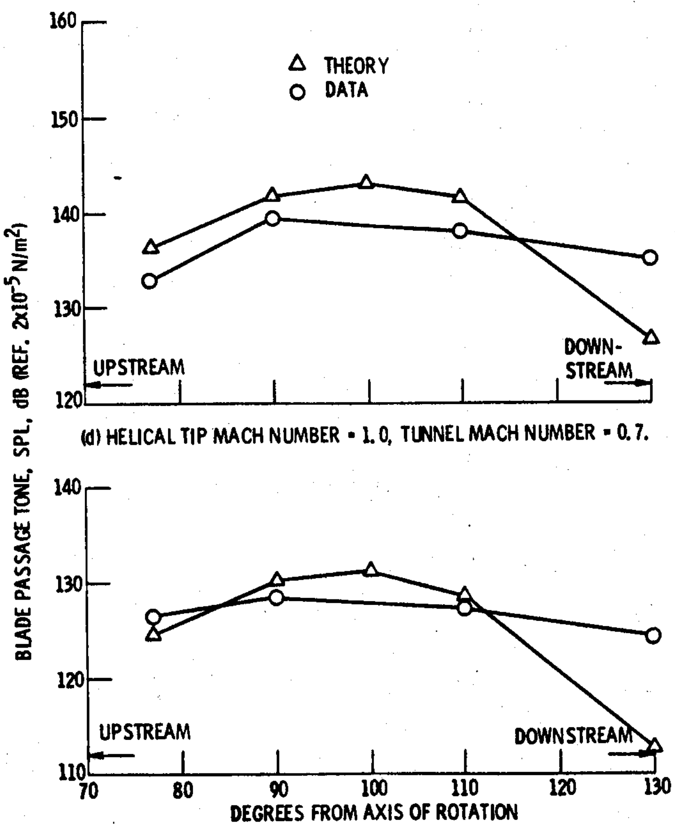
(e) HELICAL TIP MACH NUMBER = 0.857, TUNNEL MACH NUMBER = 0.60.

Figure 7. - Concluded.



(c) HELICAL TIP MACH NUMBER = 1.07, TUNNEL MACH NUMBER = 0.75.

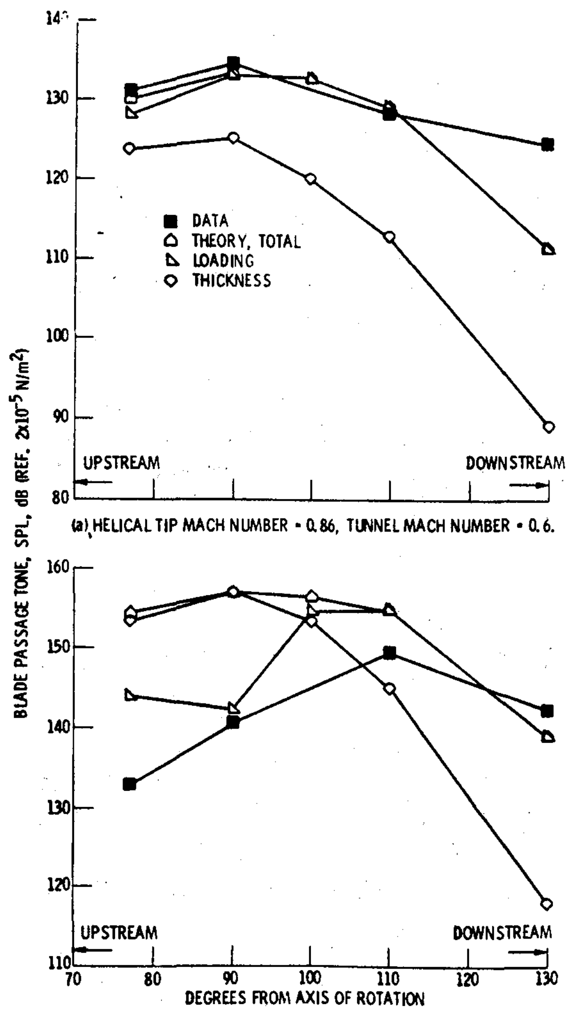
Figure 8. - Noise directivity on tunnel wall for SR-3 blade passage tone.



(d) HELICAL TIP MACH NUMBER = 1.0, TUNNEL MACH NUMBER = 0.7.

(e) HELICAL TIP MACH NUMBER = 0.863, TUNNEL MACH NUMBER = 0.6.

Figure 8. - Concluded.



(b) HELICAL TIP MACH NUMBER = 1.14, TUNNEL MACH NUMBER = 0.8.

Figure 9. - Thickness and loading contributions on SR-2.

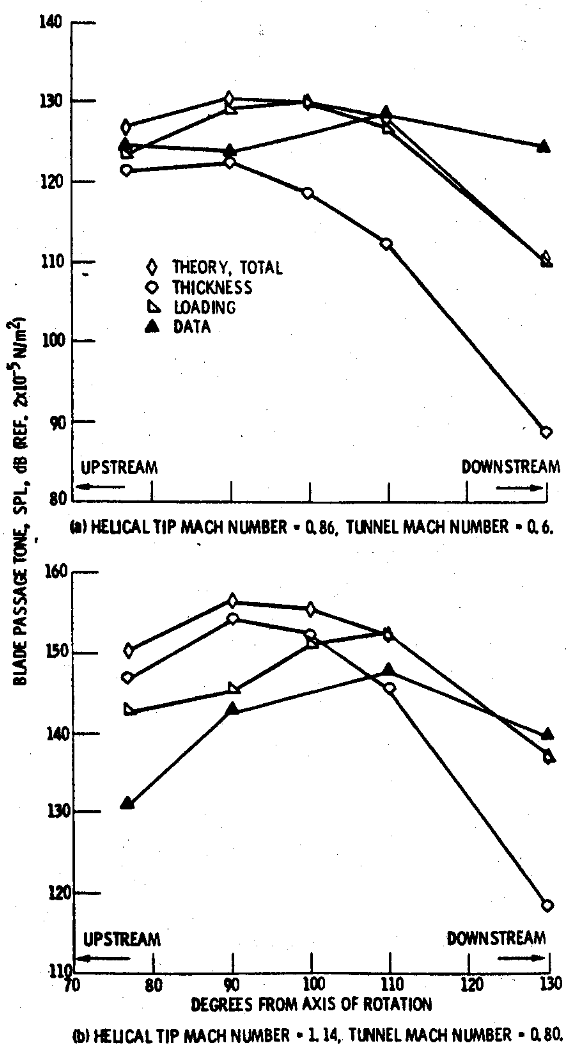


Figure 10. - Thickness and loading contributions on SR-1M.

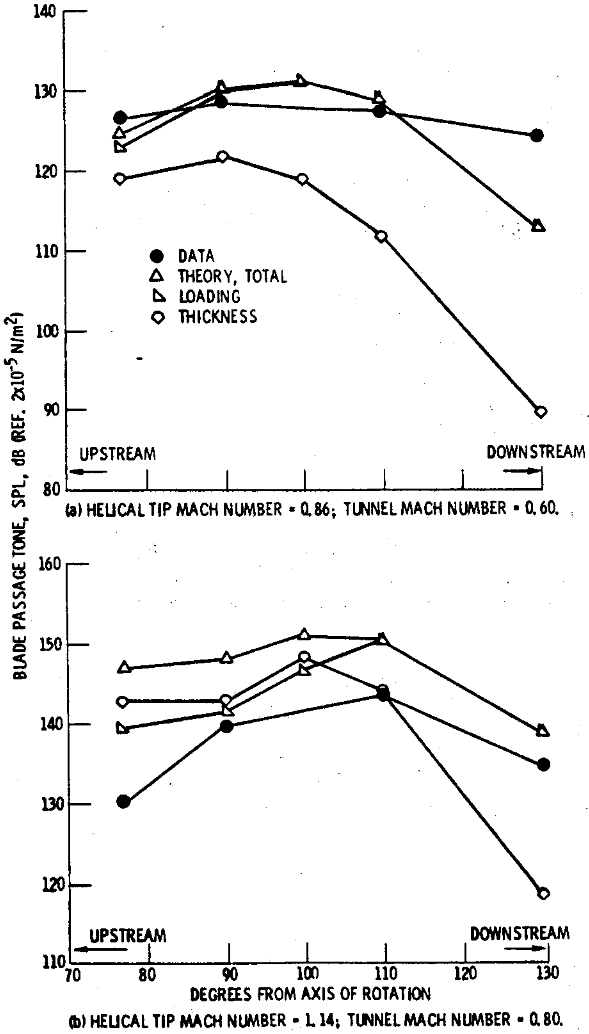
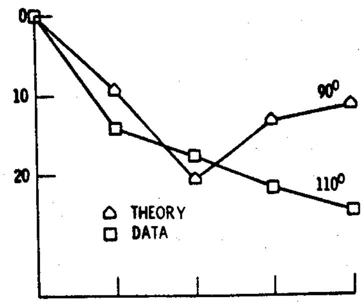
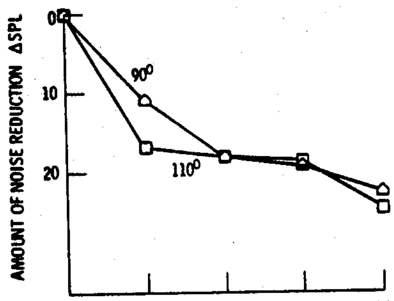


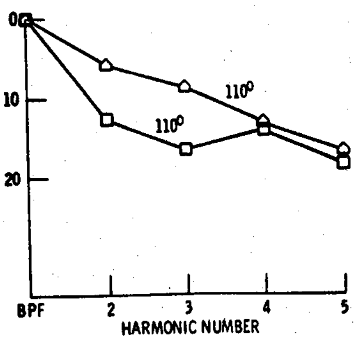
Figure 11. - Thickness and loading contributions on SR-3.



(a) SR-2, HELICAL TIP MACH NUMBER = 1.14, TUNNEL MACH NUMBER = 0.80.



(b) SR-1M, HELICAL TIP MACH NUMBER = 1.14, TUNNEL MACH NUMBER = 0.80.



(c) SR-3, HELICAL TIP MACH NUMBER = 1.14, TUNNEL MACH NUMBER = 0.80.

Figure 12. - Harmonic noise reduction, amount below blade passage tone, peak angle.

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15. Supplementary Notes

16. Abstract

The noise of three supersonic helical tip speed propellers, measured in the NASA Lewis 8- by 6-foot Wind Tunnel were compared with the noise predicted by an existing noise theory. Comparisons of the peak blade passage tones showed fairly good agreement between theory and experiment at the lower helical tip Mach numbers tested, 0.86 and 1.00. However, at higher helical tip Mach numbers, the theory predicted higher noise levels than measured. At the design cruise condition, helical tip Mach number of 1.14, the theoretical peak blade passage tone was about 6 decibels higher than measured. When the differences among the propellers were considered the theory and measurement showed fairly good agreement. Both the theory and experiment showed roughly the same noise difference between the propellers at the cruise condition. Directivity measurements in general showed that the measured blade passage tone data peaked further downstream than the theory predicted. In addition, the harmonic content of the data and theory appeared different. At the cruise design condition the harmonics appeared to fall off faster in the data than the theory indicated. The differences which exist between the predicted and measured noise may not be totally the fault of the prediction method as one might first assume, since the tunnel noise data were taken under less than ideal conditions. There is no attempt in this report to indicate which is in error, but rather to point out the differences between theory and experiment and to indicate where more effort may be needed to bring them into agreement.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
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