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THE EFFECT OF FRONT-TO-REAR PROPELLER SPACING ON THE INTERACTION NOISE OF A MODEL COUNTERROTATION PROPELLER AT CRUISE CONDITIONS

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SUMMARY

The effect of front-to-rear propeller spacing on the interaction noise of a counterrotation propeller model was measured at cruise conditions. The data taken at an axial Mach number of 0.80 behaved as expected: interaction noise was reduced with increased spacing. The data taken at $M = 0.76$ and $M = 0.72$ did not behave as expected. At some of the test conditions the noise was unchanged; others even showed noise increases with increased spacing. A possible explanation, involving the amount of downstream blade area impacted by the tip vortex, is presented.

INTRODUCTION

The noise generated by advanced fuel-conservative turboprops may create a cabin environment problem under cruise conditions. Some initial noise results for a model counterrotation propeller were presented in reference 1. An extra noise mechanism exists for counterrotation propellers that does not exist for single-rotation propellers; namely, the interactions of the forward and aft propeller flows. As discussed in reference 2 these interaction noise sources can be from the potential field interaction of the two propellers or the result of the forward propeller wakes and vortices striking the aft propeller. For the discussions in this paper the wake and vortex interactions are assumed to be stronger noise sources than the potential field interactions.

A typical spectrum from a counterrotation propeller, with different forward and aft propeller speeds or blade numbers may look as in figure 1. Each propeller exhibits a blade passage tone and its harmonics (BPF_1, $2BPF_1$, $3BPF_1$, etc., and BPF_2, $2BPF_2$, $3BPF_2$, etc.). The noise generated by the interaction mechanisms appear at sums of the blade passage frequencies of the two propellers. The first interaction tone in the spectrum occurs at $BPF_1 + BPF_2$ with others at $2BPF_1 + BPF_2$, $BPF_1 + 2BPF_2$, $3BPF_1 + BPF_2$, etc.

Reference 2 has indicated that the interaction noise of a counterrotation propeller might be reduced by increasing the spacing between the forward and aft propellers. The theoretical reductions for two of the mechanisms, wake and vortex interactions, were presented in reference 2 and are shown here in figure 2. Both mechanisms show decay with spacing with the wake decay being more rapid.

To investigate the effect of spacing on the cruise noise of a counterrotation propeller, experiments were performed in the NASA Lewis Research Center's 8- by 6-Foot Wind Tunnel. A model counterrotation propeller was tested with three forward-to-aft propeller spacings at three axial Mach numbers. This paper presents the effect of these spacing variations on the interaction tone noise.

APPARATUS AND PROCEDURE

Propeller

A counterrotation propeller model, designated F7-A7, was used for these spacing experiments. A photograph of the counterrotation test rig in the NASA Lewis 8- by 6-Foot Wind Tunnel is shown in figure 3(a), and pictures of the individual F7-A7 blades are shown in figure 3(b). The forward propeller is nominally 62.2 cm (24.5 in.) in diameter, and the aft propeller is 60.7 cm (23.9 in.) in diameter. The design characteristics of the propeller, which has eight blades in each rotor, are listed in table I. For these experiments the propeller blade angles measured with respect to the plane of rotation at the three-quarter radius location were set for the $M = 0.72$ design point with 58.5° for the forward propeller and 55.7° for the aft propeller. The design rotational tip speed (100 percent speed) is 238 m/sec (780 ft/sec).

Acoustic Measurements

The noise of the F7-A7 propeller was measured in the NASA Lewis 8- by 6-Foot Wind Tunnel using pressure transducers embedded in a plate suspended from the ceiling. The plate is able to translate up and down from the tunnel ceiling and was positioned 0.3 diameter (front propeller), or 18.7 cm (7.35 in.) above the forward propeller tips for these experiments. Figure 4(a) shows a sketch of the wind tunnel and translating plate. Figure 4(b) shows a photograph of the ceiling plate with the F7-A7 propeller.

Seventeen transducers were embedded along the centerline of the plate at the positions shown in figure 5. At the plate location tested, 11 transducers were active (1, 2, 4, 6, 8, 9, 10, 12, 14, 16, 17 of fig. 5). The plate was moved fore and aft in the wind tunnel so that transducer 9 was directly above a point halfway between the forward and aft propellers' pitch change axes. The transducer angles, measured from the forward propeller axis, ranged from 47° for transducer 1 to 133° for transducer 17. A list of these angles is presented in table II. Angular positions for each microphone are given with respect to the forward and aft propeller pitch change axis as well as the mid-point between the propellers.

Plots of the data show that the shape of the noise directivity curves or the conclusions drawn about the spacing effects are not sensitive to the choice of reference origin for the microphone location. Therefore, the data are plotted with respect to the halfway point in the same manner as they were taken.

The counterrotation propellers were operated with the forward and aft propellers turning at a 50-rpm difference in speed. This enabled the separation of the tones from the forward and aft propellers (fig. 1) using very narrow bandwidth analysis. These spectra covered a range of 80 Hz centered around the blade passage harmonics of the propellers, and had a bandwidth of 0.5 Hz.

Operating Conditions and Spacing Variations

For each of the three axial Mach numbers (0.80, 0.76, and 0.72) used in these experiments, the forward propeller was rotated at approximately its design rotational speed, and the aft propeller 50 rpm faster. Detailed aerodynamic data at the three spacings are presented in table III.

Three forward-to-aft propeller spacings were tested at each tunnel operating condition. The closest position had the pitch change axes 8.57 cm (3-3/8 in.) apart, the nominal position 10.64 cm (4-3/16 in.) apart, and the far spacing 14.92 cm (5-7/8 in.) apart. Figure 6 shows the dimensions for the three spacings and includes some axial measurements from the trailing edge of the forward propeller to the leading edge of the aft propeller.

RESULTS AND DISCUSSION

Noise data were obtained with three forward-to-aft propeller spacings at three tunnel axial Mach numbers. The interaction tone data for the first three tones (tones at BPF_{F7} + BPF_{A7}, 2 BPF_{F7} + BPF_{A7}, and BPF_{F7} + $2BPF_{A7}$) are presented in tables IV to VI for the close, nominal, and far spacings and for axial Mach numbers of 0.80, 0.76, and 0.72.

The interaction tone noise variation with spacing for an axial Mach number of 0.80 is presented first. The data for $M = 0.76$ and 0.72 are then presented along with a possible explanation for the behavior of the data.

Noise Variation with Propeller Spacing at $M = 0.80$

The interaction noise directivities for an axial Mach number of 0.80 are shown in figure 7 for the first, second, and third interaction tone (BPF_{F7} + BPF_{A7}, $2BPF_{F7}$ + BPF_{A7}, and BPF_{F7} + $2BPF_{A7}$). The data at $M = 0.80$ behave roughly as expected (fig. 2): As the spacing is increased the peak noise is reduced. This reduction occurs in going from close to nominal spacing and in going from nominal to far spacing for all three interaction tones, although the results at BPF_{F7} + $2BPF_{A7}$ are not as strong.

The observed reductions are similar to those indicated by the spacing effect on wake interaction noise (fig. 2(a)). In order to show this behavior, the forward-to-aft propeller spacing (fig. 6, dimension C) and the upstream blade chord near the tip are taken for estimation purposes. The chord of the upstream blade, C_R, is approximately 4.45 cm (1.75 in.) at this location. These dimensions then yield axial spacing parameters (X/C_R) of approximately 1.1, 1.6, and 2.6. From figure 2(a) the expected wake noise reductions would then be 3-1/4 dB in moving from close to nominal positions and 3-3/4 dB in moving from nominal to far positions for a total of 7 dB from close to far. The reduction expected for the vortex interaction (fig. 2(b)) are 1-1/2 dB for close to nominal spacing, 2-1/4 dB for nominal to far for a total of 3-3/4 dB. The distance measured along the flow direction may be a better indication of wake or vortex decay than the axial spacing distance used here. This would increase the spacing parameter values at each spacing, but in this case it does not significantly change the expected noise reductions with each spacing.

The changes in the maximum measured noise at the first interaction tone (BPF_{F7} + BPF_{A7}) can be seen in figure 7(a) or taken from tables IV to VI. In moving from close to nominal position the noise reduced 3 dB and from nominal to far 5 dB for a total of 8 dB reduction from close to far. These reductions are very similar to the wake noise reductions indicated by figure 2(a) which indicated a total of 7 dB for wake interaction noise variation with spacing. The predicted vortex interaction noise reduction was much less than measured (only about half) and this indicates the noise reduction is more probably due to reduced wake interaction noise than reduced vortex interaction noise.

Noise Variation with Propeller Spacings at M = 0.76 and 0.72

The first, second, and third interaction tone noise directivities for an axial Mach number of 0.76 are shown in figure 8(a) to (c), respectively. These data do not behave in the same manner as expected or as did the data at M = 0.80. In moving from close to nominal position, reductions in the first interaction tone are observed (fig. 8(a)). However, in moving from the nominal to the far position, the noise increases. The results at the other interaction tones are also not behaving as expected.

The noise results for the M = 0.72 axial Mach number show results that are almost opposite to those expected. Figure 9(a) shows the first interaction tone results, while figures 9(b) and (c) show the interaction tones at $2BPF_{F7}$ + BPF_{A7} and BPF_{F7} + $2BPF_{A7}$, respectively.

Figure 9(a) shows the first interaction-tone peak at nominal spacing is greater than that at close spacing. This trend, which is opposite to that expected, is also seen at the far position, where the noise is in general the same or somewhat greater than that at the nominal position. The results at the other interaction tones (figs. 9(b) and (c)) also show trends different than the expected reduction with distance.

Possible Explanation

Based on the noise reduction with propeller spacing as indicated in reference 2 (fig. 2), the behavior of the data at M = 0.76 and 0.72 was unexpected. It would appear that some other mechanism or some other behavior of the sound generation with spacing is controlling the noise. The following is an attempt to provide a possible, although not proven, explanation for the behavior of the noise with spacing.

The possible explanation lies in a variation of the spanwise extent of the downstream blade which is impacted by the tip vortex of the upstream blade. The curve drawn in figure 2(b) for vortex noise reduction with spacing was based on the assumption that the entire vortex hits the downstream blade. Then the reduction in the vortex strength with distance would translate into a noise reduction with increased spacing. If, however, the entire vortex does not hit the downstream blade at close spacing and successively hits more of the downstream blade as the spacing was increased, the noise from this mechanism would increase with spacing. One way to envision this might be as shown in figure 10. The vortex at some spacings may pass partially or completely outboard of the blade. This would be particularly possible at the closest spacing, since the downstream blade has a smaller diameter than the upstream blade by 1.5 cm (0.6 in.). As the spacing increases, the path of the vortex might move inboard and any spreading of the vortex would have the inner edge move inboard as it moved downstream. This would then have more of the downstream blade intercepting the vortex and generating more noise.

A simple scenario of how the data might be explained by this mechanism is shown in figure 11. At the M = 0.80 condition, where the first interaction tone noise data showed the expected reduction with spacing for wake controlled generation, the vortex may be missing the downstream blade at all three of the tested spacings or may only be partially hitting and not producing a major noise source. The vortex location was measured in reference 3 for a single rotation propeller and was located outboard of the tip location (fig. 12). Although a counterrotation propeller would not necessarily have the same vortex location this does indicate that it would be possible for the vortex to miss the downstream blade at all three spacings at M = 0.80 (fig. 11). If this were the case the dominant noise mechanism would then be the wake interaction mechanism, and the noise would be expected to reduce similarly to figure 2(a). Indeed, the noise at M = 0.80 did reduce in the same manner as figure 2(a).

As the axial Mach number was reduced to 0.6 in reference 3, the vortex location moved inboard (fig. 12). It may then be possible that at the lower Mach numbers the counterrotation forward propeller vortex moves inboard and hits the downstream blades or has a larger spanwise contact area at some spacing than at others. If, as shown in figure 11, the vortex only hits the blade at the far position at M = 0.76, the interaction tone data of figure 8 are explained. When going from close to nominal spacing at M = 0.76, the noise was reduced, presumably due to the wake interaction reduction with spacing. At the far position at M = 0.76 the vortex might be striking the downstream blade (fig. 11) which would result in the noise increase in going from nominal to far spacing, as shown in figure 8(a). (It may be possible that some of the vortex would hit at the nominal position also and partially counterbalance the wake noise reduction in going from close to nominal position.)

At M = 0.72 the vortex may strike the downstream blade both at the nominal and far spacings as showing in figure 11. This could account for the close position being a little quieter than the nominal position and the far position being about the same as the nominal position as shown by the data of figure 9(a).

A possible reason for the different radial vortex locations at different axial Mach numbers could be hub choking. At M = 0.80 the propeller hub might be choked, causing radial flows and moving the tip vortex outboard of the propeller tip. At lower axial Mach numbers the choking might be relieved, allowing the vortex to move inward. This might also explain the effect with spacing since increased spacing could result in hub choking relief and vortex motion inward.

Some further support of this explanation can be seen in figure 13. Here, the maximum first interaction tone noise is plotted versus axial Mach number for the three spacings. For the far spacing position at M = 0.80, the tone is at 136.5 dB. At the M = 0.76 condition, where the possible explanation of figure 11 indicates that the vortex is hitting the downstream blade, the noise jumps to 141.5 dB. At M = 0.72, where the vortex is still hitting the blade, the noise remains roughly constant at 141.0 dB.

The data at the nominal position (fig. 13) show the same trends as the figure 11 explanation. At M = 0.80 and 0.76, where the vortex does not hit the blade (fig. 11), the noise is roughly constant at 140 to 140.5 dB. The noise jumps to 144 dB at the M = 0.72 condition where the model of figure 11 indicates the vortex may be striking the blade.

At the close position the explanation of figure 11 indicates that the vortex may not be hitting at any of the Mach numbers. The close position data of figure 13 show a noise reduction with decreased Mach number, as might be expected since typically a noise generation mechanism reduces with lower velocities (ref. 2). The close position data and the explanation are then also compatible.

The variation in the spanwise area of the downstream blade that is impacted by the vortex at different spacings is a possible explanation for the behavior of the noise data. The simplified explanation shown in figure 11 has the vortex completely missing the downstream blade at some spacings and hitting at others. It is not necessary that complete missing or hitting be involved only that larger areas of impact occur at some conditions than at others. The explanation presented here does appear to fit the data presented for cruise conditions, and it might be used in explaining future data for other flight conditions.

CONCLUDING REMARKS

The effect of forward-to-aft propeller spacing on the interaction noise of a counterrotation propeller, designated F7-A7, at cruise conditions was measured in the NASA Lewis 8- by 6-Foot Wind Tunnel. Three forward-to-aft propeller spacings were tested at three tunnel axial Mach numbers. The first three interaction tones were measured, those tones at frequencies equal to $BPF_{F7} + BPF_{A7}$, $2BPF_{F7} + BPF_{A7}$, and $BPF_{F7} + 2BPF_{A7}$.

The data at an axial Mach number of 0.80 behaved as expected with the interaction noise decreasing with increased spacing. A comparison of these $M = 0.80$ data with the reduction expected from the wake interaction mechanism showed they were similar.

The data taken at $M = 0.76$ and $M = 0.72$ did not behave as expected. The noise increased with increased spacing at some conditions and decreased or remained the same at others. A possible explanation for this behavior lies with the tip vortex interaction with the downstream blade. The noise from this mechanism can increase with spacing if more of the vortex impacts the downstream blade at the larger spacings. This explanation appears to fit the data.

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3. Miller, B.A.; Dittmar, J.H.; and Jeracki, R.J.: The Propeller Tip Vortex - A Possible Contributor to Aircraft Cabin Noise. J. Aircr, vol. 19, no. 1, Jan. 1982, pp. 84-86.

TABLE I. - DESIGN CHARACTERISTICS OF COUNTERROTATION PROPELLER F7-A7

Number of blades	8 by 8
Design cruise Mach number	0.72
Nominal diameter, cm (in.)	62.2(24.5)/60.7(23.9)
Nominal design cruise tipspeed, m/sec (ft/sec)	238(780)
Nominal design advance ratio	2.82
Hub to tip ratio	0.42
Geometric tip sweep, deg	34/31
Activity factor	150/150
Design power coefficient based on annulus area	4.16

TABLE II. - TRANSDUCER ANGULAR POSITIONS

Transducer	Angle measured from point half way between propellers (all spacings), deg	Angle measured from forward propeller at spacing, deg			Angle measured from aft propeller at spacing, deg		
		Close	Nominal	Far	Close	Nominal	Far
1	46.8	49.6	50.3	51.7	44.3	43.7	42.6
2	52.0	55.2	56.0	57.7	49.1	48.4	47.1
4	59.4	63.2	64.1	66.1	55.8	55.0	53.5
6	69.3	73.8	74.9	77.1	65.1	64.1	62.3
8	81.8	86.8	88.0	90.3	77.1	76.0	73.8
9	90.0	95.0	96.1	98.4	85.0	83.9	81.6
10	98.2	102.9	104.0	106.2	93.2	92.0	89.7
12	110.7	114.9	115.9	117.7	106.2	105.1	102.9
14	120.6	124.2	125.0	126.5	116.8	115.9	113.9
16	128.0	130.9	131.6	132.9	124.8	124.0	122.3
17	133.2	135.7	136.3	137.4	130.4	129.7	128.3

TABLE III. - EXPERIMENTAL CONDITIONS

(a) Close spacing

Axial Mach number	Nominal speed, percent of design	Forward propeller				Aft propeller				Total power coefficient[a]
		Speed		Advance ratio	Helical tip Mach number	Speed		Advance ratio	Helical tip Mach number	
		rpm	Percent of design			rpm	Percent of design			
0.72	100	8148	100.6	2.789	1.084	8209	101.3	2.849	1.071	4.31
.76	100	8049	99.9	2.958	1.107	8102	100.6	3.024	1.094	3.54
.80	100	8053	100.3	3.100	1.136	8104	100.9	3.170	1.123	2.80

(b) Nominal spacing

0.72	100	8258	99.4	2.82	1.076	8306	99.9	2.88	1.063	4.21
.76	100	8155	100.2	2.95	1.108	8198	100.7	3.02	1.095	3.50
.80	100	8155	100.4	3.10	1.136	8203	101.0	3.17	1.123	2.76

(c) Far spacing

0.72	100	8153	100.9	2.78	1.086	8205	101.6	2.84	1.073	4.28
.76	100	8053	100.2	2.95	1.108	8106	100.9	3.02	1.095	3.47
.80	100	7954	99.7	3.12	1.133	8009	100.4	3.19	1.121	2.55

[a]Based on forward propeller annulus area.

TABLE IV. - PROPELLER INTERACTION TONE NOISE AT CLOSE AXIAL SPACING

(a) Axial Mach number, 0.8

Transducer	Sound pressure level, dB, of tone at frequency of -		
	$BPF_{F7} + BPF_{A7}$	$2BPF_{F7} + BPF_{A7}$	$BPF_{F7} + 2BPF_{A7}$
1	(a)	(a)	(a)
2	↓	↓	↓
4	↓	↓	↓
6	↓	↓	↓
8	137.0	129.0	123.5
9	144.5	137.5	136.0
10	144.5	128.5	131.5
12	130.0	134.0	128.5
14	135.0	135.0	134.5
16	131.0	135.0	123.0
17	136.0	133.0	127.5

(b) Axial Mach number, 0.76

1	(a)	(a)	(a)
2	(a)	↓	↓
4	128.5	↓	↓
6	131.5	↓	↓
8	138.0	133.0	129.5
9	140.0	133.0	(a)
10	143.5	(a)	(a)
12	138.0	130.0	133.0
14	128.0	132.0	131.5
16	127.5	(a)	(a)
17	130.5	135.5	130.0

(c) Axial Mach number, 0.72

1	129.5	(a)	(a)
2	132.0	125.0	125.0
4	135.0	(a)	(a)
6	135.5	131.5	126.5
8	129.5	(a)	(a)
9	135.0	132.0	128.0
10	136.0	127.0	126.0
12	139.0	136.0	136.5
14	131.5	135.5	126.5
16	136.0	140.0	134.5
17	136.0	139.0	132.0

[a]Tone not measurable above tunnel background.

TABLE V. - PROPELLER INTERACTION TONE NOISE AT NOMINAL AXIAL SPACING

(a) Axial Mach number, 0.8

Transducer	Sound pressure level, dB, of tone at frequency of -		
	$BPF_{F7} + BPF_{A7}$	$2BPF_{F7} + BPF_{A7}$	$BPF_{F7} + 2BPF_{A7}$
1	(a)	(a)	(a)
2	↓	↓	↓
4	↓	↓	↓
6	↓	↓	↓
8	135.0	130.0	123.0
9	139.5	134.0	133.0
10	141.5	129.5	127.0
12	136.5	131.0	131.0
14	134.0	129.0	133.5
16	133.5	133.5	126.5
17	136.0	124.0	124.5

(b) Axial Mach number, 0.76

1	(a)	(a)	(a)
2	126.5	↓	↓
4	(a)	↓	↓
6	129.0	↓	↓
8	136.5	132.0	127.5
9	140.0	137.5	132.5
10	137.0	131.5	(a)
12	136.5	133.5	135.0
14	128.5	125.0	135.0
16	126.5	127.5	126.0
17	130.0	128.5	131.0

(c) Axial Mach number, 0.72

1	128.5	(a)	(a)
2	131.5	(a)	↓
4	139.0	(a)	↓
6	134.5	131.5	↓
8	140.5	134.0	127.5
9	139.0	130.0	130.0
10	144.0	129.0	134.0
12	133.5	132.0	136.5
14	129.5	135.0	126.0
16	133.5	133.0	132.0
17	139.0	123.5	131.5

[a]Tone not measurable above tunnel background.

TABLE VI. - PROPELLER INTERACTION TONE NOISE AT FAR AXIAL SPACING

(a) Axial Mach number, 0.8

Transducer	Sound pressure level, dB, of tone at frequency of -		
	$BPF_{F7} + BPF_{A7}$	$2BPF_{F7} + BPF_{A7}$	$BPF_{F7} + 2BPF_{A7}$
1	(a)	(a)	(a)
2	↓	↓	↓
4	↓	↓	↓
6	↓	↓	↓
8	131.5		
9	133.5	128.5	131.5
10	136.5	128.0	127.5
12	133.0	128.5	131.0
14	135.5	125.5	132.0
16	127.5	126.0	126.0
17	136.5	125.0	125.5

(b) Axial Mach number, 0.76

Transducer	$BPF_{F7} + BPF_{A7}$	$2BPF_{F7} + BPF_{A7}$	$BPF_{F7} + 2BPF_{A7}$
1	(a)	(a)	(a)
2	(a)	↓	↓
4	(a)	↓	↓
6	131.5	↓	↓
8	137.5	132.0	125.5
9	141.5	135.0	128.5
10	133.5	134.0	132.0
12	140.0	136.0	126.0
14	134.5	123.0	133.5
16	131.5	122.0	127.5
17	131.5	(a)	134.5

(c) Axial Mach number, 0.72

Transducer	$BPF_{F7} + BPF_{A7}$	$2BPF_{F7} + BPF_{A7}$	$BPF_{F7} + 2BPF_{A7}$
1	130.5	(a)	(a)
2	135.0	129.0	125.0
4	139.0	128.5	126.5
6	136.0	137.5	(a)
8	137.5	132.0	130.0
9	141.0	136.0	130.5
10	140.5	131.0	136.0
12	139.5	128.0	129.5
14	135.0	124.0	128.0
16	131.5	124.5	132.0
17	135.0	123.5	136.5

[a]Tone not measurable above tunnel background.

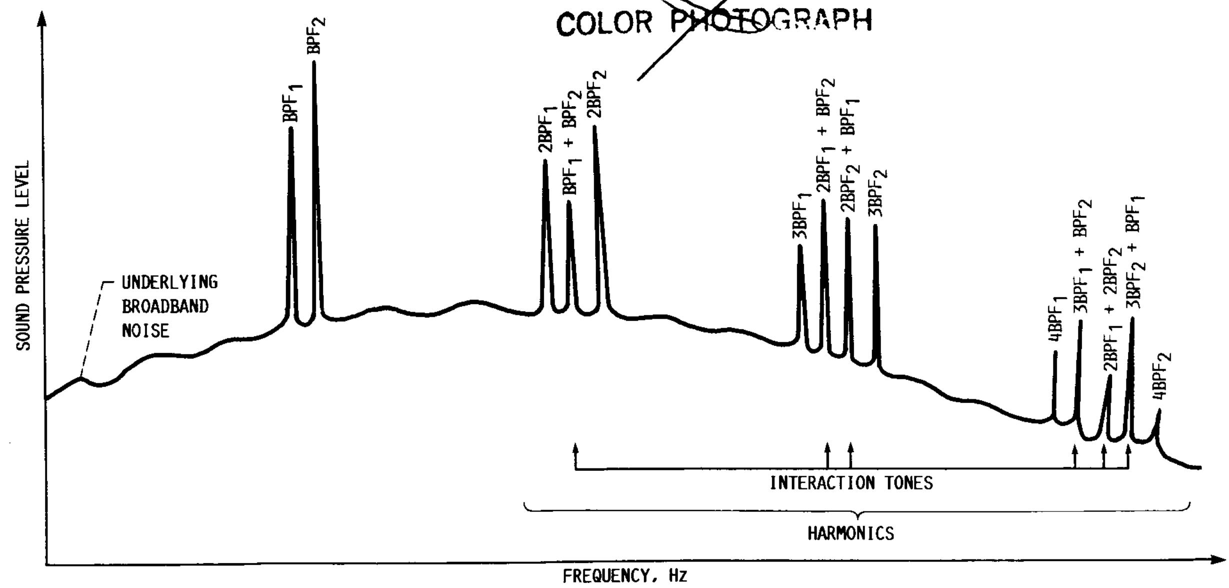
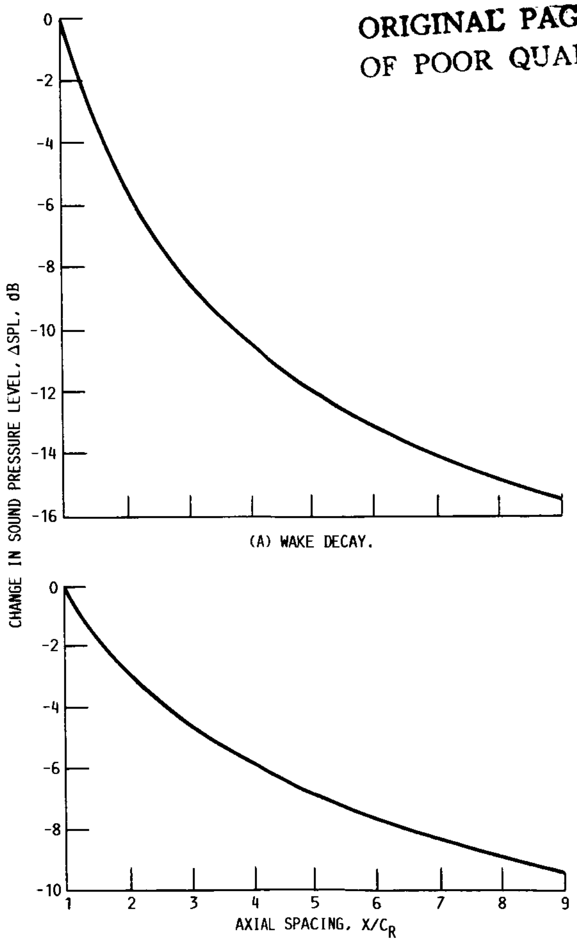


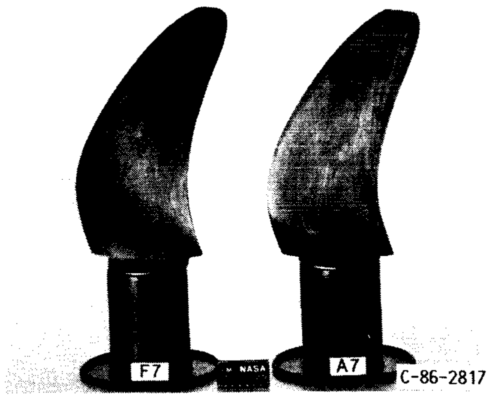
FIGURE 1. - GENERAL COUNTERROTATION PROPELLER NOISE SPECTRA.



(B) VORTEX DECAY.

FIGURE 2. - CHANGE IN SOUND PRESSURE LEVEL WITH SPACING.

(A) TEST RIG IN 8- BY 6-FT WIND TUNNEL.



(B) INDIVIDUAL F7-A7 BLADES.

FIGURE 3. - PROPELLERS.

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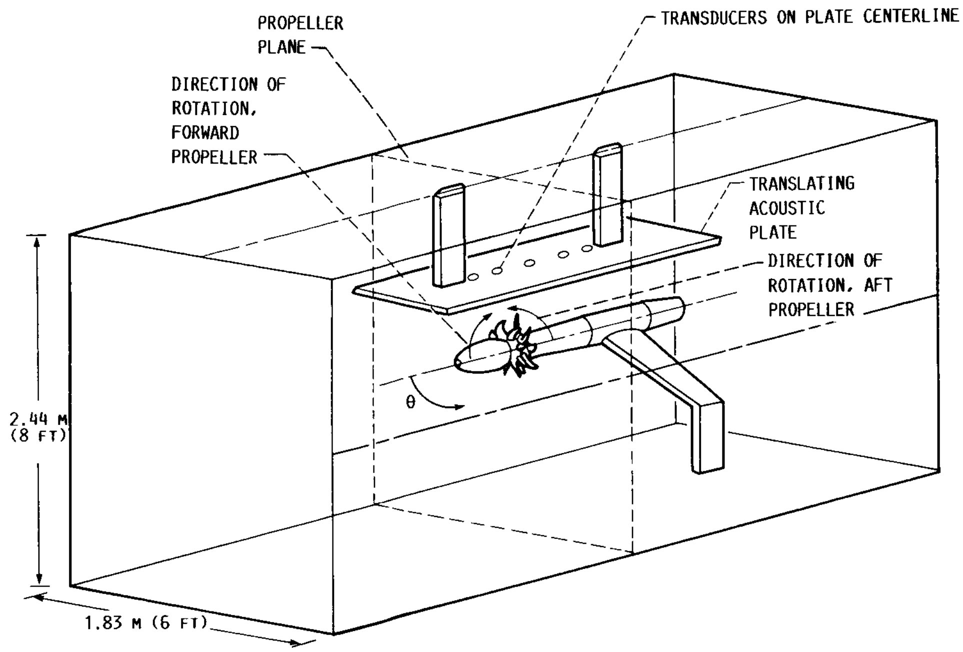


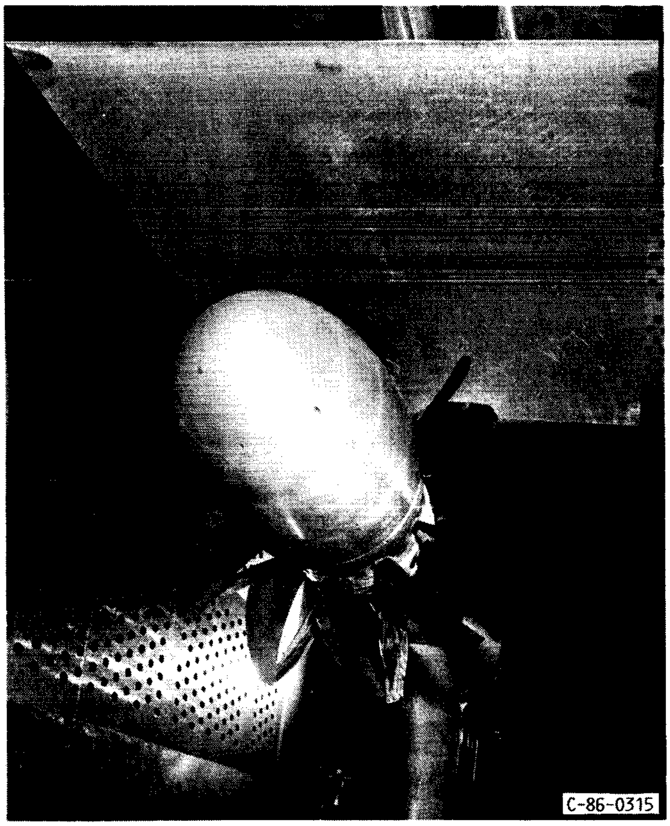
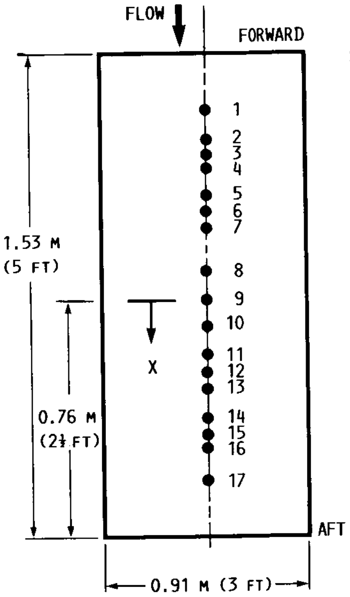
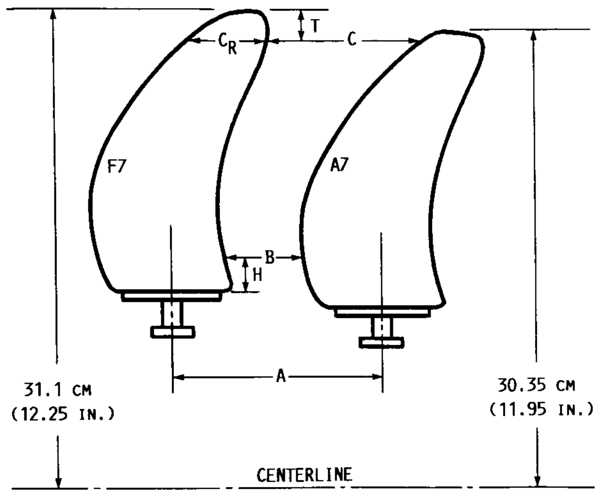


FIGURE 4. - TEST APPARATUS SHOWING TRANSLATING ACOUSTIC PLATE.



TRANSDUCER	POSITION, X	
	CM	IN.
1	-46.7	-18.4
2	-38.9	-15.3
3	-34.0	-13.4
4	-29.5	-11.6
5	-23.4	-9.2
6	-18.8	-7.4
7	-14.7	-5.8
8	-7.1	-2.8
9	0	0
10	7.1	2.8
11	14.7	5.8
12	18.8	7.4
13	23.4	9.2
14	29.5	11.6
15	34.0	13.4
16	38.9	15.3
17	46.7	18.4

FIGURE 5. - TRANSDUCER POSITIONS ON TRANSLATING ACOUSTIC PLATE (STANDING INSIDE TUNNEL, LOOKING UP).

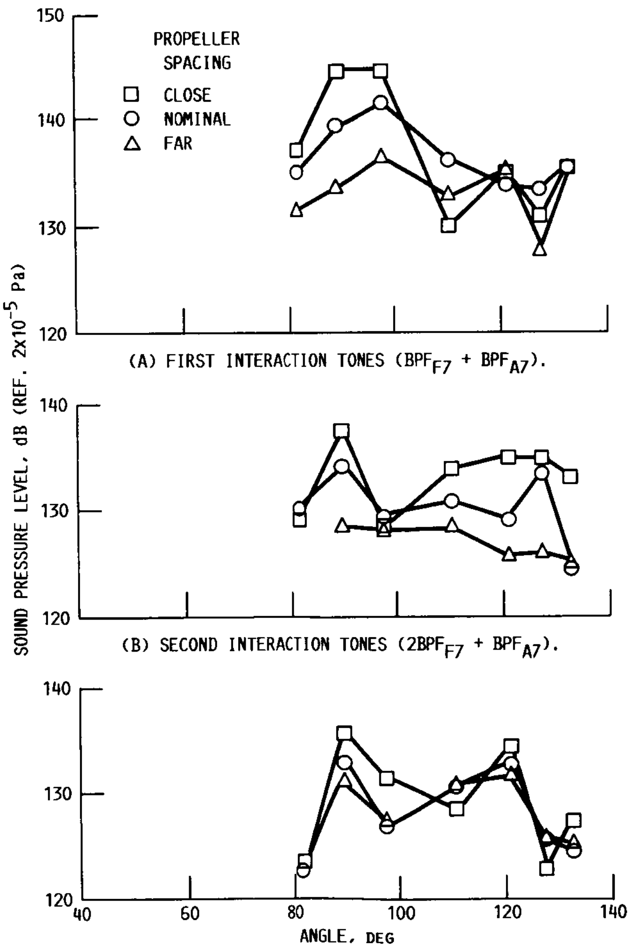


AXIAL DISTANCE		AXIAL SPACING, CM (IN.)		
		CLOSE	NOMINAL	FAR
A	DISTANCE BETWEEN F7 AND A7 PITCH CHANGE AXES	8.57 (3-3/8)	10.64 (4-3/16)	14.92 (5-7/8)
B	DISTANCE FROM F7 TRAILING EDGE TO A7 LEADING EDGE MEASURED AT LOCATION H[a]	0.79 (5/16)	2.86 (1-1/8)	7.14 (2-13/16)
C	DISTANCE FROM F7 TRAILING EDGE TO A7 LEADING EDGE MEASURED AT LOCATION T[b]	4.92 (1-15/16)	6.99 (2-3/4)	11.27 (4-7/16)

[a]LOCATION H IS 0.625 CM (1/4 IN.) UP FROM ROTOR F7 HUB.

[b]LOCATION T IS 0.938 CM (3/8 IN.) DOWN FROM ROTOR F7 TIP. THE CHORD OF F7 AT LOCATION T IS 4.45 CM (1-3/4 IN.).

FIGURE 6. - PROPELLER SPACING.



(A) FIRST INTERACTION TONES (BPF_{F7} + BPF_{A7}).

(B) SECOND INTERACTION TONES ($2BPF_{F7}$ + BPF_{A7}).

(C) THIRD INTERACTION TONES (BPF_{F7} + $2BPF_{A7}$).

FIGURE 7. - INTERACTION NOISE DIRECTIVITIES FOR MACH 0.80.

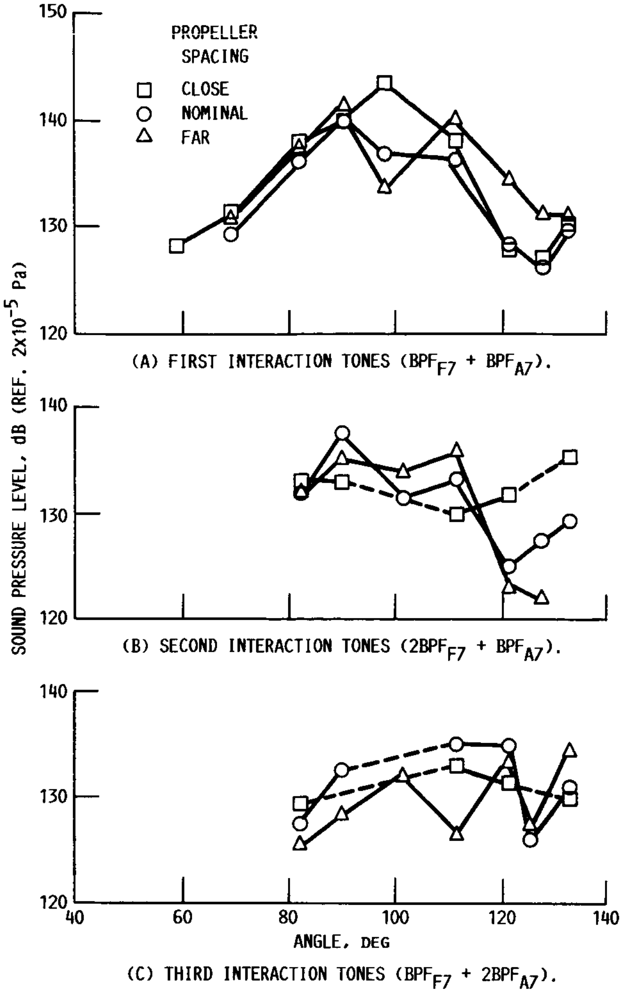


FIGURE 8. - INTERACTION NOISE DIRECTIVITIES FOR MACH 0.76.

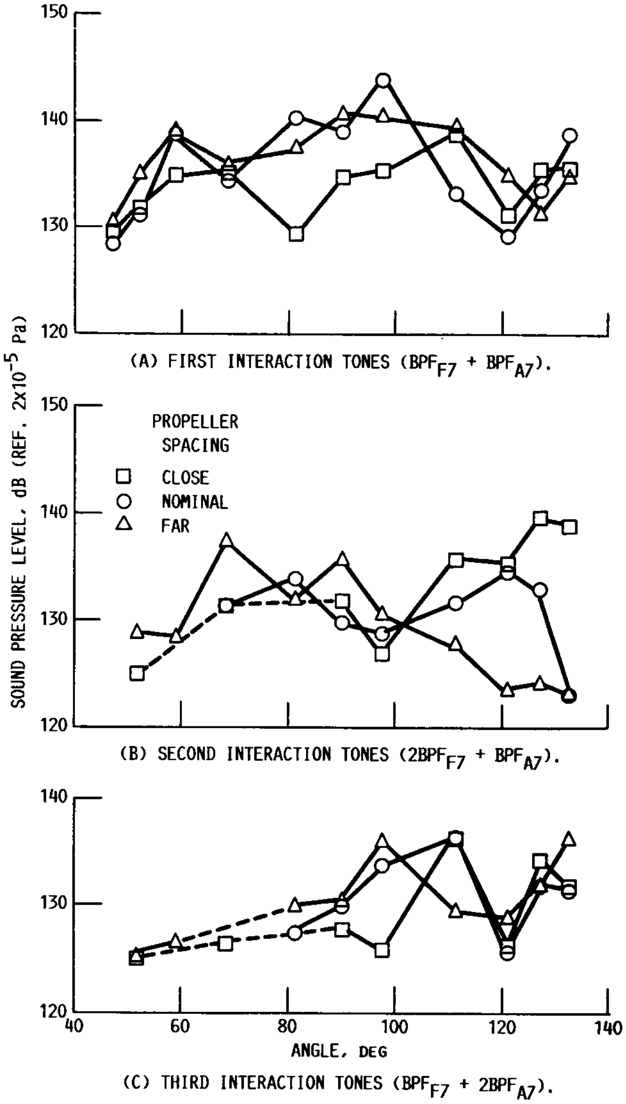


FIGURE 9. - INTERACTION NOISE DIRECTIVITIES FOR MACH 0.72.

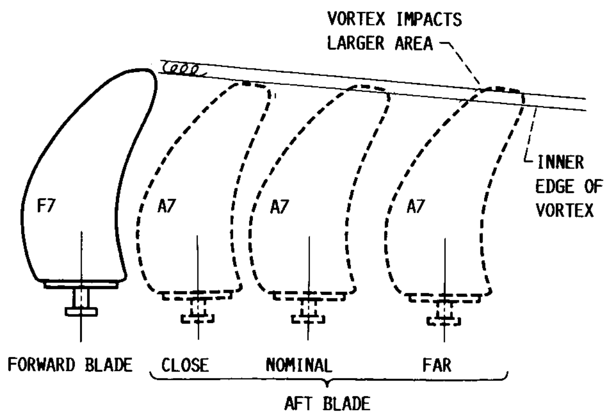


FIGURE 10. - SCHEMATIC SHOWING VORTEX MAY IMPACT LARGER BLADE AREA AT LARGER FORWARD-TO-AFT PROPELLER SPACINGS. (SPACING AND VORTEX PATH ARE NOT TO SCALE.)

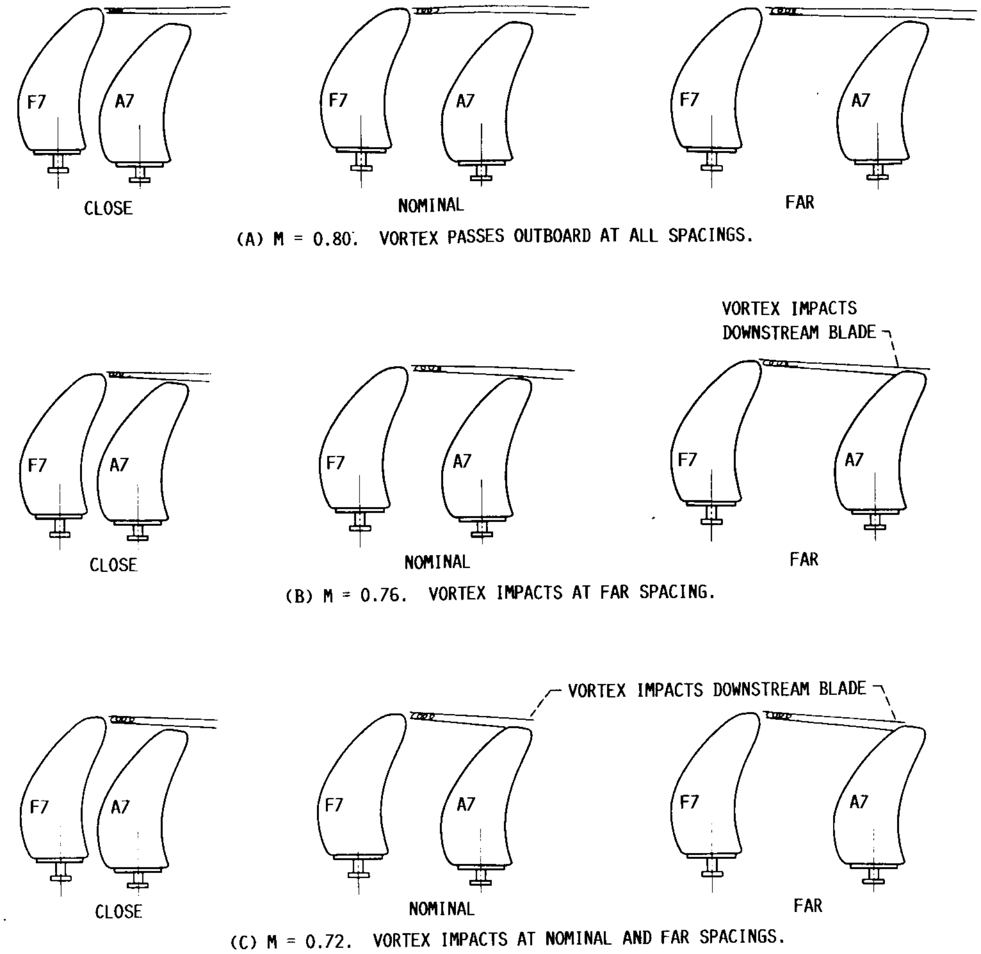


FIGURE 11. - EXPLANATION MODEL SHOWING POSSIBLE VORTEX LOCATIONS RELATIVE TO DOWNSTREAM BLADES.

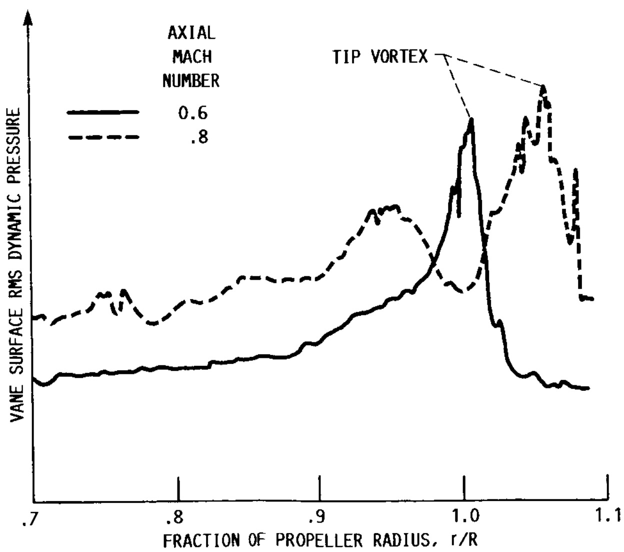


FIGURE 12. - RADIAL VARIATION OF VANE SURFACE RMS DYNAMIC PRESSURE MEASURED BEHIND PROPELLER SHOWING TIP VORTEX RADIAL POSITION (FROM REF. 3, FIG. 2).

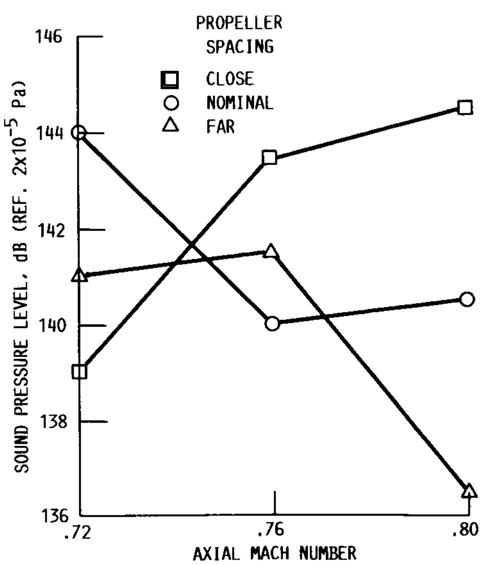


FIGURE 13. - MAXIMUM FIRST INTERACTION TONE VARIATION WITH MACH NUMBER AT THREE SPACINGS.

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15. Supplementary Notes

16. Abstract

The effect of front-to-rear propeller spacing on the interaction noise of a counterrotation propeller model was measured at cruise conditions. The data taken at an axial Mach number of 0.80 behaved as expected: interaction noise was reduced with increased spacing. The data taken at $M = 0.76$ and $M = 0.72$ did not behave as expected. At some of the test conditions the noise was unchanged; others even showed noise increases with increased spacing. A possible explanation, involving the amount of downstream blade area impacted by the tip vortex, is presented.

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