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Noise Reduction for Model Counterrotation Propeller at Cruise by Reducing Aft-Propeller Diameter

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SUMMARY

The forward propeller of a model counterrotation propeller was tested with its original aft propeller and with a reduced-diameter aft propeller. Noise reductions with the reduced-diameter aft propeller were measured at simulated cruise conditions. Reductions were as large as 7.5 dB for the aft-propeller blade passing tone and 15 dB in the harmonics at specific angles. The interaction tones, mostly the first interaction tone, were reduced, probably because the reduced-diameter aft propeller blades no longer interacted with the forward-propeller tip vortex. The total noise (sum of primary and interaction noise) at each harmonic was significantly reduced. The chief noise reduction at each harmonic came from reduced aft-propeller-alone noise, with the interaction tones contributing little to the totals at cruise. Total cruise noise reductions were as much as 3 dB at given angles for the blade passing tone and 10 dB for some of the harmonics. These reductions would measurably improve the fuselage interior noise levels and represent a definite cruise noise benefit from a reduced-diameter aft-propeller.

E-3378

INTRODUCTION

Advanced turboprop aircraft have the potential for significant fuel savings over equivalent-technology turbofan-powered aircraft. To investigate this potential the National Aeronautics and Space Administration has an ongoing Advanced Turboprop Program (ref. 1). A single-rotation turboprop design is projected to use 15 to 30 percent less fuel than turbofans, and a counterrotation design may save 8 percent more (ref. 2).

To implement these fuel savings, the new turboprop aircraft must be acceptable to the flying public. The noise from these advanced high-speed propellers is of concern since it may present a cabin environment problem for the airplane at cruise. The cruise noise of a number of single-rotation propeller models has previously been measured in the NASA Lewis 8- by 6-Foot Wind Tunnel (refs. 3 to 7). Noise measurements are presently being conducted on a counterrotation propeller for a pusher airplane (fig. 1). A generalized noise spectra for a counterrotation propeller is shown in figure 2 (from ref. 8). A tone is generated at the blade passing frequency of each propeller, and harmonics occur at multiples of these fundamental frequencies ($2BPF_1$, $2BPF_2$, etc.). Tone noise is also generated at the various summations of the two blade passing frequencies ($BPF_1 + BPF_2$, $2BPF_1 + BPF_2$, $2BPF_2 + BPF_1$, etc.). These summation tones are generated by the interactions of the two propellers, including potential field and viscous flow field interactions. Of the two interactions the viscous flow field interactions are thought to dominate. Trailing behind the forward propeller are wakes and vortices (fig. 3) that strike the aft-propeller blades and create lift fluctuations on these blades, which in turn generate noise.

To investigate these interaction noise mechanisms, a forward propeller was tested with two different aft propellers. The first aft propeller was the one originally designed to operate with the forward propeller and had approximately the same tip diameter. The second aft propeller was designed with a reduced diameter so as to miss the forward-propeller tip vortex and thus reduce the community noise. The interaction tones at takeoff are thought to dominate over the primary blade passing tones so that reductions in these interaction tones directly reduce the total noise (ref. 8).

The fundamental blade passing tones and their harmonics (BPF_1, BPF_2, $2BPF_1$, etc.) are greater at cruise than at takeoff and are thought to be larger than the interaction tones at cruise. Although reductions in the interaction noise are expected at cruise with the reduced-diameter aft propeller, reductions in the stronger aft-propeller blade passing tones should also result from the smaller diameter because of reduced tip speed. This report presents the cruise noise reductions observed with the reduced-diameter aft propeller.

APPARATUS AND PROCEDURE

Propellers

A 62.2-cm (24.5-in.) diameter forward propeller was tested with two aft propellers: the standard aft propeller, 60.7 cm (23.9 in.) in diameter; and a reduced-diameter aft propeller, 53.1 cm (20.9 in.) in diameter. The forward propeller was designated F1; the standard aft propeller, A1; and the reduced-diameter aft propeller, A3. Table I lists the general characteristics of these three blades. As shown in figure 4, the A3 aft blade, besides being shorter, was designed with a longer chord to recover the thrust lost by the shorter span while turning at the same rotational speed (rpm). The distance from the forward- to aft-propeller split lines was 10.6 cm (4-3/16 in.) for both configurations.

These counterrotation propellers were tested with nine blades in the front propeller and eight blades in the aft propeller. The forward-propeller (F1) blade setting angle was the same when tested with both aft rotors (57.2° measured at the 3/4-radius location). The standard aft propeller (A1) was set at 54.3°, and the reduced-diameter aft propeller (A3) was set at 58.0°. The aft blade angles chosen were those predicted to give equal forward- and aft-propeller torques.

Acoustic Measurements

The noise of these two propeller configurations was measured in the NASA Lewis 8- by 6-Foot Wind Tunnel by using pressure transducers embedded in a plate suspended from the tunnel ceiling (fig. 5). The plate could translate up and down from the tunnel ceiling and fore and aft in the wind tunnel. For these experiments the plate was located 0.3 forward-propeller diameter, or 18.7 cm (7.35 in.), above the forward-propeller tips. The plate contained 17 flush-mounted transducers (fig. 6). At this plate position 11 transducers were active (1, 2, 4, 6, 8, 9, 10, 12, 14, 16, and 17 of fig. 6), and the plate was positioned fore and aft in the tunnel so that transducer 9 was directly above a point halfway between the two propellers. At this plate position the transducer angles measured from the propeller axis (table II) varied from 47° for transducer 1 to 133° for transducer 17. The noise data were reduced on a narrow-band analyzer to yield 0- to 5000-Hz spectra with a 16-Hz bandwidth. The 16-Hz bandwidth was chosen so that the individual tones could be clearly separated. This allowed tones out through the fourth harmonic to be measured (as in fig. 2).

The measured thrust levels for comparable F1-A1 and F1-A3 propeller conditions differed by no more than 10 percent and were within 5 percent at the Mach 0.72, 100-percent-speed design condition. Because the thrust levels were so close, no corrections were made to the acoustic data for thrust differences.

Operating Conditions

Noise data were taken with the propeller operating at three tunnel axial Mach numbers: 0.76, 0.72, and 0.67. The propeller was operated at 100 percent of design corrected rotational speed at Mach 0.76 and 0.72. In addition, data were taken at 95- and 90-percent speed at Mach 0.76 and 0.72. At Mach 0.67 data were taken only at 95- and 90-percent speed because limited drive power prevented the apparatus from reaching 100-percent speed.

The propeller operating conditions for these cases are summarized in table III. Because the data for F1-A1 and F1-A3 were taken on two separate days and with different air temperatures, different propeller rotational speeds were required to reach a specific corrected speed.

RESULTS AND DISCUSSION

The tone noise data for the F1-A1 and F1-A3 propeller combinations are presented through the fourth harmonic in tables IV and V, respectively. The data are as measured on the translating plate, rounded to the nearest one-half decibel. The harmonics are listed in order of increasing frequency with the aft-propeller harmonics listed first since the aft propeller had fewer blades and therefore a lower blade passing frequency, as shown by the sample spectrum in figure 7.

Fundamental Blade Passing Tones and Harmonics

Comparison of forward-propeller tones. - In general the noise produced by the forward propeller did not change significantly when it was tested with the reduced-diameter aft propeller (fig. 8). The small differences shown here are typical of the other tested conditions. These small differences may be caused by the forward propeller acting differently with the reduced-diameter aft propeller or may indicate scatter in the data.

Only small differences were observed in the harmonic data (fig. 9).

Comparison of aft-propeller tones. - The blade passing tones differed significantly for the two aft propellers tested (A1 and A3), as shown in figure 10. The maximum difference of 8.5 dB occurred at transducer 9 at Mach 0.76 and 90-percent speed (fig. 10(b)). This difference does not indicate a significant trend with reduced speed since a 7.5-dB reduction was observed at the same location at Mach 0.76 and 100-percent speed (fig. 10(a)). The design condition, Mach 0.72 and 100-percent speed, seemed to show uncharacteristically small differences (fig. 10(c)); therefore data were also included at Mach 0.72 and 95-percent speed (fig. 10(d)).

The reductions in the aft-propeller tones were the result of a lower helical tip Mach number. The shorter A3 aft blades turned at the same rotational speed as the A1 blades. The tip rotational velocity with the shortened A3 blades was then lower than that for the A1 blades. The lower velocity reduced the strength of the noise-generating mechanism and resulted in lower propeller-alone noise for the A3 aft blades even though the pitch of the A3 blades was increased to produce approximately the same total thrust as the A1 blades.

These reductions in the aft-propeller passing tone are significant. If a counterrotation airplane had propellers with unequal numbers of forward and aft blades, the forward- and aft-propeller tones would be at different frequencies. This might complicate the design of the acoustic damping material needed to make an acceptable airplane interior noise level and might even increase the amount needed. Substantial reductions in the aft-propeller blade passing tone could simplify the design again and possibly reduce the amount of material needed.

The harmonic levels were also reduced with the reduced-diameter aft propeller (fig. 11). The reductions in the harmonics shown here further emphasize the effectiveness of the reduced-diameter aft propeller.

Interaction Tones

Tones $BPF_F + BPF_A$. - The first interaction tone occurred at a frequency that is the sum of the two propeller blade passing frequencies (fig. 2). The reduced-diameter aft propeller significantly reduced this interaction tone (fig. 12). At particular angles the reduction was as much as 7 to 8 dB. The Mach 0.72, 95-percent speed data are again included because they are more representative than the Mach 0.72, 100-percent speed data.

It is worth noting, although no explanation is readily apparent, that the directivity pattern of reduction seems to vary with axial Mach number. At Mach 0.76 and 100-percent speed the reduction was primarily in plane and forward. As the axial Mach number was decreased, the reductions moved toward the rear.

The reduced-diameter aft propeller was designed to reduce the vortex interaction noise at takeoff by having the vortex pass outboard of the downstream blades. This dictated the diameter reduction needed so that the vortex would miss the downstream blades. At cruise the vortex will probably be farther from the hub and the shortened aft blades will be even more likely to miss the vortex. This, combined wth reductions of 7 or 8 dB at some angles, indicates that shortening the aft blades has probably removed the vortex interaction as a noise source.

Tones at $2BPF_A + BPF_F$ and $BPF_A + 2BPF_F$. - The second interaction tones occurred at frequencies between the third harmonic of the forward propeller ($3BPF_F$) and the third harmonic of the aft propeller ($3BPF_A$) (fig. 2). The first of these tones was at a frequency equal to the sum of twice the blade passing frequency of the aft propeller and the blade passing frequency of the forward propeller ($2BPF_A + BPF_F$). The second tone was at a frequency equal to the sum of the blade passing frequency of the aft propeller and twice the blade passing frequency of the forward propeller ($BPF_A + 2BPF_F$). The reduced-diameter aft propeller decreased these tones only slightly (figs. 13 and 14). At some angles the tones increased.

A summation of these two tones ($2BPF_A + BPF_F$ and $BPF_A + 2BPF_F$) based on a pressure-squared addition (fig. 15) shows little noise reduction in these harmonics with the reduced-diameter aft propeller and increases at some angles. This may mean that the tones at these harmonics are controlled by the wake interactions at some inboard sections of the blades and not by the vortex interaction near the tip.

Tones at $3BPF_A + BPF_F$, $2BPF_A + 2BPF_F$, and $BPF_A + 3BPF_F$. - The third interaction tones in the spectrum occurred at frequencies between the fourth harmonic of the forward propeller ($4BPF_F$) and the fourth harmonic of the aft propeller ($4BPF_A$). In general the reduced-diameter aft propeller did not cause much overall change in these three interaction tones (fig. 16). Comparing the summation of these three tones (fig. 16(d)) shows a slight reduction at some angles, a slight increase at other angles, and not much change overall - an indication that the inboard sections of the blade may control the noise at these harmonics.

Total Noise Reduction

In the 9- by 8-blade configuration tested in this investigation the blade passing tones and harmonics of the two propellers appeared at different frequencies. For a counterrotation propeller with equal numbers of forward and aft blades turning at the same speed, the tones at each harmonic would occur at the same frequencies. The spectrum would appear similar to a single-rotation spectrum with tones only appearing at the blade passing frequency and its harmonics. The forward- and aft-propeller primary tones and the interaction tones at a given harmonic would occur at the same frequency and would add together to make the total tone at that harmonic. For example, in figure 2 the tones at $2BPF_1$, $BPF_1 + BPF_2$, and $2BPF_2$ would all add together. This section discusses the total noise at each harmonic and the relative importance of the various tones in these totals.

Total noise at blade passing frequencies. - Since the interaction tones only start with the second harmonic ($BPF_{F1} + BPF_{A1}$, etc.), the total blade passing tone is obtained by adding the primary blade passing tone for the forward propeller to that for the aft propeller.

At Mach 0.76 and 100-percent speed the forward propeller (F1) peaked around 90° (transducer 9) and the aft propeller (A1) around 98° (transducer 10) (fig. 17(a)). The peaks were at approximately the same level. The tones added together to give approximately a 3-dB increase at the peak. In general the forward noise was controlled by the forward propeller and the aftward noise by the aft propeller.

With the reduced-diameter aft propeller (A3) (fig. 17(b)) the aft-propeller tone was significantly decreased and the summation was smaller. This resulted in the total blade passing tone being reduced.

The total blade passing tone reductions were significant (fig. 18). Because the Mach 0.72, 100-percent-speed condition showed the least total noise reduction, the Mach 0.72, 95-percent-speed results were included as being more typical of the data. As much as a 3-dB reduction was observed at this condition at the peak (fig. 18(c)). This level of total blade passing tone reduction with the reduced-diameter aft propeller could have an effect on the interior noise level of advanced counterrotation-propeller-powered aircraft. The overall effect from reducing the aft-propeller diameter would be even more powerful for a counterrotation propeller where the aft-propeller tones dominated the spectrum.

Total noise at twice blade passing frequency. - The total noise at twice blade passing frequency includes the two primary tones ($2BPF_F$ and $2BPF_A$) and the first interaction tone ($BPF_F + BPF_A$). With the original aft propeller (fig. 19(a)) the two primary tones ($2BPF_{F1}$ and $2BPF_{A1}$) had about the same peak level near the plane of rotation, but the interaction tone ($BPF_{F1} + BPF_{A1}$) had a much lower peak and was only of the same magnitude as the primary tones when the propeller axis was approached. Theory says that the primary tones should have their peak somewhere near the plane of rotation and should decrease toward the axis and that the interaction tones remain high on the axis (see fig. 4 of ref. 8). These results are then consistent with the trend expected from theory. The results shown here for Mach 0.76 and 100-percent speed were typical of the other conditions.

Comparing the total noise at twice blade passing frequency for the two propeller combinations (fig. 20) shows significant reductions with the reduced-diameter aft propeller - as much as 10 dB at some conditions for aft angles.

For this experiment noise was measured as far forward as 47° and as far aft as 133°. Nowhere in this range did the interaction tones dominate. At some angle closer to the axis the interaction tone may dominate. However, for the angular range where the data were measured, the change in the interaction tones did not have much effect on the total noise. Most of the change in total noise at twice blade passing frequency at cruise resulted from reduction in the aft-propeller blade passing tone. The interaction noise is expected to be larger relative to the propeller-alone tones at takeoff conditions than at the cruise conditions tested herein. Therefore the reductions in the interaction tone may have a larger effect on the total noise reduction at takeoff.

Total tone at three times blade passing frequency. - The total noise at three times blade passing frequency includes the two primary tones ($3BFP_F$ and $3BPF_A$) and two interaction tones ($2BPF_F + BPF_A$ and $BPF_F + 2BPF_A$). This noise was significantly reduced with the reduced-diameter aft propeller (fig. 21). As for the total noise at twice blade passing frequency the reductions were from decreases in the aft-propeller primary tone at this harmonic. This was the result of the interaction tone not contributing much to the F1-A1 total at most angles and the small observed reductions in the interaction tones (fig. 15).

Total tone at four times blade passing frequency. - The total noise at four times blade passing frequency includes the two primary tones ($4BPF_F$ and

$4BPF_A$) and three interaction tones ($3BPF_F + BPF_A$, $2BPF_F + 2BPF_A$, and $BPF_F + 3BPF_A$). This noise was significantly reduced with the shortened aft blades (fig. 22). As before, the reductions were from the reduction in the aft-propeller primary tone at this harmonic.

CONCLUDING REMARKS

The forward propeller of a counterrotation propeller was tested with two different aft propellers - the one originally designed for the forward propeller, and one designed with a reduced diameter so as to avoid interaction with the forward-propeller tip vortex. The reduced-diameter aft propeller was designed to give less interaction noise at takeoff conditions. Noise reductions, in both interaction tones and propeller-alone tones, were observed with this propeller operating at simulated cruise conditions. All comparisons were made at approximately equal total thrust (within 10 percent), and this required a larger blade angle on the reduced-diameter aft propeller.

The propeller-alone tones of the forward propeller, the blade passing tone, and the harmonics showed little change when the reduced-diameter aft propeller was substituted for the original aft propeller. What changes were observed may be the result of slight differences in the forward-propeller aerodynamics when it was operating with the reduced-diameter aft propeller.

The aft-propeller-alone tones were significantly reduced with the reduced-diameter aft propeller - reductions of the order of 7.5 dB in the blade passing tone and 15 dB in the harmonics. Reductions of this magnitude could significantly enhance the acceptability of cabin noise in counterrotation-propeller-powered airplanes.

The interaction tones were also reduced - mostly in the first interaction tone, with only slight reductions at the higher harmonics. The reductions in the first interaction tone at some angles were enough to indicate that they probably were the result of the reduced-diameter aft propeller no longer interacting with the tip vortex from the forward propeller.

The total noise at each harmonic was computed. This involved summing the primary and interaction tones at each harmonic. As much as 3-dB total noise reduction was observed in the blade passing tone as a result of the reduced aft-propeller blade passing tone. The higher harmonics were also reduced - as much as 10 dB at some conditions. These reductions resulted primarily from the reduced aft-propeller blade harmonics since the interaction tones did not contribute greatly to the total tone levels at the measurement angles. At more forward or aft angles the interaction noise reduction might dominate. Most of the reductions were to the rear so that cabin noise reductions would not be as large for an aft-mounted propeller as they would be for a wing-mounted one.

The noise reductions at cruise with the reduced-diameter aft propeller were significant and would measurably improve cabin noise levels.

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TABLE I. - DESIGN CHARACTERISTICS OF PROPELLERS

[Design Mach number, 0.72.]

Propeller	Diameter		Chord at 50-percent span		Tip sweep, deg	Design advance ratio	Activity factor
	cm	in.	cm	in.			
F1	62.2	24.5	7.39	2.91	33.4	2.81	150
A1	60.7	23.9	7.39	2.91	29.9	2.81	150
A3	53.1	20.9	9.49	3.74	22.0	[a]3.29	[a]243

[a]Based on tip diameter with all propellers (F1, A1, and A3) rotating at the same speed in revolutions per minute.

TABLE II. - ANGULAR POSITIONS OF TRANSDUCERS USED IN EXPERIMENT

[Translating plate 0.3 propeller diameter from propeller tip.]

Transducer	Angle measured from forward-propeller axis (fig. 5), θ, deg
1	47
2	52
4	59
6	69
8	82
9	90
10	98
12	111
14	121
16	128
17	133

TABLE III. - EXPERIMENTAL CONDITIONS

General description		Specific conditions								Total power coefficient[a]
Axial Mach number	Nominal speed, percent of design	Forward propeller				Aft propeller				
		Speed		Advance ratio	Helical tip Mach number	Speed		Advance ratio	Helical tip Mach number	
		rpm	percent of design			rpm	percent of design			
F1-A1 propeller										
0.76	100	8005	99.96	2.966	1.1063	8054	100.58	3.031	1.0938	3.13
	95	7604	94.98	3.125	1.0781	7650	95.56	3.194	1.0665	2.45
	90	7205	89.97	3.293	1.0490	7255	90.6	3.363	1.0387	----
.72	100	8054	100.16	2.807	1.0809	8103	100.77	2.868	1.0680	4.07
	95	7655	95.15	2.951	1.0506	7701	95.73	3.016	1.0386	3.57
	90	7257	90.24	3.113	1.0224	7307	90.86	3.179	1.0118	2.92
.67	95	7654	94.72	2.757	1.0141	7705	95.35	2.816	1.0021	4.69
	90	7256	89.79	2.905	.9842	7306	90.40	2.967	.9732	4.12
F1-A3 propeller										
0.76	100	8301	100.47	2.948	1.1088	8352	101.09	3.438	1.0278	3.39
	95	7849	95.04	3.120	1.0780	7902	95.68	3.637	1.0038	2.80
	90	7449	90.27	3.291	1.0521	7497	90.85	3.837	.9836	2.16
.72	100	8296	100.20	2.807	1.0814	8356	100.93	3.270	.9991	4.13
	95	7851	94.81	2.960	1.0482	7897	95.37	3.452	.9718	3.64
	90	7450	89.99	3.121	1.0208	7505	90.65	3.635	.9509	3.07
.67	95	7899	94.69	2.756	1.0137	7949	95.29	3.214	.9349	4.51
	90	7501	89.93	2.911	.9867	7550	90.52	3.394	.9139	3.94

[a]Based on forward-propeller annulus area.

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TABLE IV. - TONE NOISE FOR PROPELLER F1-A1

(a) Mach 0.76

Transducer	BPF_{A1}	BPF_{F1}	$2BPF_{A1}$	BPF_{A1} + BPF_{F1}	$2BPF_{F1}$	$3BPF_{A1}$	$2BPF_{A1}$ + BPF_{F1}	BPF_{A1} + $2BPF_{F1}$	$3BPF_{F1}$	$4BPF_{A1}$	$3BPF_{A1}$ + BPF_{F1}	$2BPF_{A1}$ + $2BPF_{F1}$	BPF_{A1} + $3BPF_{F1}$	$4BPF_{F1}$
	Blade passing frequency — Sound pressure level, dB													
	100-Percent speed													
1	142.0	144.0	[a]131.5	[b]133.5	[b]132.0	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)
2	143.0	142.0	135.0	[b]133.0	[b]132.0	↓	(a)	(a)	(a)	↓	↓	↓	↓	↓
4	146.0	144.0	135.0	134.0	134.5	↓	(a)	(a)	(a)	↓	↓	↓	↓	↓
6	143.0	156.5	[b]132.0	137.5	143.0	↓	[b]129.5	131.0	131.0	↓	↓	↓	↓	↓
8	156.0	162.5	144.5	145.0	153.5	136.0	136.5	139.0	148.0	138.5	131.5	132.5	137.0	143.5
9	162.0	163.0	153.0	145.5	154.5	148.0	139.0	144.0	153.5	143.5	136.5	135.0	141.0	147.5
10	164.0	162.5	154.5	147.0	153.0	153.0	139.5	133.0	150.5	147.0	137.0	133.5	140.0	146.5
12	158.5	147.0	152.0	140.0	141.0	150.0	134.0	132.0	139.0	148.5	129.0	128.0	137.0	134.0
14	143.5	143.0	143.0	137.0	142.0	132.0	137.0	135.0	133.0	137.0	137.5	[b]126.5	136.0	134.0
16	152.5	151.0	137.5	132.5	135.0	133.5	130.5	134.5	136.5	137.0	132.5	129.0	133.5	131.0
17	150.5	149.0	138.0	135.5	135.5	137.0	133.0	137.0	131.5	133.5	132.0	[b]126.0	133.0	132.0
	95-Percent speed													
1	141.5	143.0	[b]132.0	135.0	[b]131.0	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)
2	147.0	148.0	[b]132.0	136.0	134.0	↓	↓	↓	↓	↓	↓	↓	↓	↓
4	151.5	151.0	[b]132.5	136.5	136.0	↓	↓	↓	↓	↓	↓	↓	↓	↓
6	152.5	148.0	136.0	138.5	137.0	↓	↓	↓	↓	↓	↓	↓	↓	↓
8	151.0	161.5	142.5	140.5	151.5	135.0	135.0	135.5	148.5	136.0	130.0	131.5	133.0	144.0
9	159.5	162.0	149.0	136.0	148.5	147.0	136.5	137.5	153.0	143.0	134.5	132.0	134.0	138.0
10	159.5	157.5	148.5	145.5	151.0	148.0	133.0	135.0	144.0	144.5	129.0	128.0	137.5	147.0
12	150.0	146.0	145.0	134.0	142.0	134.0	130.5	129.5	140.0	145.0	134.0	128.5	134.5	130.5
14	150.0	151.0	133.0	137.5	134.0	133.0	134.0	137.0	132.5	133.5	136.0	[b]127.0	129.0	135.5
16	145.0	150.5	133.0	135.0	135.0	132.0	(a)	134.0	134.5	133.0	(a)	(a)	133.0	134.5
17	138.5	148.0	136.5	132.0	135.5	134.0	131.5	128.0	135.0	136.0	129.0	(a)	131.5	132.5
	90-Percent speed													
1	145.0	145.0	[b]133.0	[b]134.0	[b]135.0	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)
2	140.5	151.5	136.5	135.5	139.0	↓	↓	↓	↓	↓	↓	↓	↓	↓
4	142.0	154.5	[b]132.5	134.5	137.0	↓	↓	↓	↓	↓	↓	↓	↓	↓
6	144.0	152.0	134.0	133.0	135.5	↓	↓	↓	↓	↓	↓	↓	↓	↓
8	155.5	158.5	141.0	142.0	150.0	133.0	131.0	133.0	147.0	134.0	128.0	128.5	134.0	140.5
9	159.0	158.0	147.5	140.0	148.5	146.0	133.0	138.0	149.0	140.0	132.0	129.0	134.5	146.0
10	158.5	149.0	154.0	145.0	148.0	139.0	136.0	136.0	137.0	138.5	136.5	128.5	134.5	142.0
12	147.0	149.5	136.0	139.5	136.0	136.0	133.0	134.5	134.5	135.0	133.0	131.5	134.0	135.5
14	145.0	140.5	132.5	133.0	137.0	131.0	129.5	131.0	136.0	129.0	135.5	[b]126.5	133.5	127.0
16	140.5	135.0	137.0	130.5	133.5	132.5	(a)	129.5	136.0	133.0	(a)	(a)	133.0	129.0
17	139.5	139.0	136.0	136.0	132.0	129.5	131.0	132.5	133.5	130.0	129.0	(a)	129.0	128.5

[a]Tone not visible above tunnel background.
[b]Tone only slightly above tunnel background.

TABLE IV. - Continued.

(b) Mach 0.72

Transducer	Blade passing frequency													
	BPF_{A1}	BPF_{F1}	$2BPF_{A1}$	BPF_{A1} + BPF_{F1}	$2BPF_{F1}$	$3BPF_{A1}$	$2BPF_{A1}$ + BPF_{F1}	BPF_{A1} + $2BPF_{F1}$	$3BPF_{F1}$	$4BPF_{A1}$	$3BPF_{A1}$ + BPF_{F1}	$2BPF_{A1}$ • $2BPF_{F1}$	BPF_{A1} + $3BPF_{F1}$	$4BPF_{F1}$
	Sound pressure level, dB													
100-Percent speed														
1	146.0	148.5	136.0	138.5	136.5	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)
2	151.0	146.0	135.5	141.0	136.0	(a)	(a)	(a)	(a)	↓	↓	↓	↓	↓
4	148.0	145.5	136.5	136.0	137.5	132.0	131.5	131.5	132.0	↓	↓	↓	↓	↓
6	156.0	150.0	139.5	145.5	138.5	130.0	136.0	135.0	131.5	↓	↓	↓	↓	↓
8	150.0	161.5	147.0	141.0	154.0	140.1	136.0	137.0	149.0	138.0	133.0	131.0	138.5	145.0
9	157.0	162.5	153.0	138.0	154.5	150.0	138.0	134.0	151.0	147.0	140.0	130.5	139.0	147.0
10	159.5	158.0	155.5	142.5	154.0	153.0	133.0	138.0	145.0	146.5	134.5	135.0	137.0	147.0
12	156.0	145.5	152.5	141.5	148.5	146.0	137.0	132.0	141.0	148.5	133.0	133.0	137.0	133.0
14	156.0	153.0	140.0	137.5	136.0	141.5	137.0	142.5	133.0	134.5	132.5	129.5	132.0	134.5
16	148.0	149.5	137.5	133.0	139.0	134.0	136.0	134.0	133.0	138.0	128.5	132.0	138.0	134.0
17	143.0	149.5	135.5	138.5	136.0	135.0	131.5	130.0	129.5	139.0	129.0	128.5	132.5	136.0
95-Percent speed														
1	140.0	147.0	135.0	136.5	134.0	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)
2	146.0	153.5	134.5	135.5	135.5	↓	(a)	(a)	(a)	↓	↓	↓	↓	↓
4	149.5	151.5	136.5	137.0	136.5	↓	(a)	(a)	(a)	↓	↓	↓	↓	↓
6	148.5	155.5	139.5	142.0	143.5	↓	132.5	137.0	133.5	↓	↓	↓	↓	↓
8	157.5	160.0	146.0	135.5	150.0	142.0	135.5	132.0	149.0	137.0	132.5	128.5	130.0	145.0
9	160.5	160.0	147.5	140.0	151.0	149.0	131.0	136.0	150.5	146.0	131.5	128.5	129.5	145.0
10	160.5	156.5	149.5	141.5	148.5	151.5	134.0	135.0	140.0	146.0	132.0	128.5	136.0	142.5
12	154.0	154.5	146.0	135.0	141.0	145.0	133.0	138.0	135.0	144.0	136.0	[b]127.0	139.0	128.5
14	155.0	146.0	141.0	131.5	139.0	133.0	130.5	137.0	134.0	132.0	[b]126.0	[b]127.0	139.0	133.0
16	150.0	144.5	137.5	134.0	135.0	132.0	130.0	131.0	130.5	136.5	[b]126.0	128.0	137.0	130.0
17	150.0	141.0	140.5	139.5	135.0	131.5	131.0	135.0	132.0	132.0	130.0	[b]127.0	132.0	(a)
90-Percent speed														
1	151.0	147.5	141.0	136.0	135.5	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)
2	149.0	144.5	138.5	133.5	139.0	↓	(a)	(a)	(a)	↓	↓	↓	↓	↓
4	146.0	151.5	138.0	137.0	138.5	↓	(a)	(a)	(a)	↓	↓	↓	↓	↓
6	145.0	149.5	135.0	136.5	141.5	↓	130.0	131.0	134.5	↓	↓	↓	↓	↓
8	156.0	160.0	144.5	142.0	152.0	139.0	135.0	135.0	146.0	133.0	↓	↓	132.0	144.0
9	158.5	157.5	151.0	141.0	151.0	144.0	133.0	132.5	145.0	140.0	130.5	130.0	135.5	146.0
10	157.5	154.0	152.5	134.5	148.0	139.0	136.0	134.0	140.0	145.0	130.5	128.0	138.0	138.5
12	150.0	143.0	144.5	136.0	142.0	139.0	129.5	134.5	137.0	129.0	129.0	[b]126.0	143.0	135.0
14	136.5	146.0	133.5	132.5	136.0	131.0	130.5	139.0	137.0	[b]127.0	(a)	(a)	139.5	134.0
16	141.5	139.5	135.5	134.0	138.0	(a)	130.0	135.0	131.0	[b]127.0	(a)	(a)	131.0	128.5
17	143.0	142.0	135.5	136.5	135.5	(a)	134.0	136.0	133.5	(a)	[b]127.0	(a)	130.0	126.0

[a]Tone not visible above tunnel background.
[b]Tone only slightly above tunnel background.

TABLE IV. - Concluded.

(c) Mach 0.67

Transducer	Blade passing frequency													
	BPF_{A1}	BPF_{F1}	$2BPF_{A1}$	BPF_{A1} + BPF_{F1}	$2BPF_{F1}$	$3BPF_{A1}$	$2BPF_{A1}$ + BPF_{F1}	BPF_{A1} + $2BPF_{F1}$	$3BPF_{F1}$	$4BPF_{A1}$	$3BPF_{A1}$ + BPF_{F1}	$2BPF_{A1}$ + $2BPF_{F1}$	BPF_{A1} + $3BPF_{F1}$	$4BPF_{F1}$
	Sound pressure level, dB													
95-Percent speed														
1	148.5	143.0	139.0	133.0	140.0	133.0	129.5	133.5	130.0	(a)	(a)	(a)	(a)	(a)
2	149.0	148.0	137.0	139.5	138.5	132.0	131.0	132.0	130.5	(a)	(a)	(a)	(a)	(a)
4	146.5	149.0	140.0	137.0	143.5	132.0	133.0	132.5	133.0	129.0	128.0	129.0	127.5	130.0
6	153.0	154.0	143.0	139.5	144.5	135.0	131.5	131.5	143.0	132.0	129.0	128.0	128.0	137.0
8	158.0	159.5	147.5	142.0	152.5	142.0	133.5	135.0	146.5	140.5	129.5	129.0	128.5	146.0
9	160.0	159.5	150.0	141.0	152.0	148.0	130.5	133.0	144.0	146.0	134.0	130.0	136.5	147.5
10	160.5	160.0	151.5	134.5	146.5	148.0	128.0	138.0	140.5	146.0	138.5	132.0	138.5	140.0
12	156.0	146.5	149.5	137.5	141.0	139.5	135.0	136.5	135.0	136.5	129.0	127.0	146.0	136.0
14	142.0	147.5	136.0	134.5	137.5	129.5	130.0	144.0	137.0	131.5	128.0	127.0	143.0	133.0
16	148.5	145.0	133.0	137.0	140.0	129.0	136.0	139.0	133.0	130.0	129.5	128.5	136.5	133.0
17	149.5	148.0	132.5	139.0	137.0	127.0	140.0	142.5	137.5	128.0	129.5	126.0	133.0	129.0
90-Percent speed														
1	147.5	146.0	138.5	[b]133.0	137.0	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)
2	145.0	145.5	142.5	136.0	137.0	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)
4	136.5	150.5	139.0	[b]134.0	137.0	133.5	131.0	(a)	135.0	130.5	129.0	(a)	128.5	130.0
6	149.5	156.0	139.5	138.5	150.0	136.0	131.0	134.0	144.0	128.0	(a)	(a)	131.0	137.0
8	155.5	158.0	145.0	141.5	150.5	138.0	134.0	134.0	143.0	135.0	[b]127.0	129.5	130.0	142.0
9	156.5	155.0	147.5	137.0	150.5	144.0	128.5	135.5	141.0	143.5	[b]126.5	130.5	138.0	139.5
10	155.0	151.5	148.0	[b]134.0	146.5	142.0	133.0	139.5	134.0	140.0	[b]126.0	[b]125.5	143.5	128.0
12	150.5	138.5	139.5	[b]129.5	140.0	134.5	135.5	142.5	133.0	132.0	130.0	128.0	145.0	135.0
14	146.0	143.5	140.0	[b]130.0	138.0	129.5	130.0	144.0	132.0	130.5	128.0	127.0	139.0	131.0
16	139.0	141.5	137.0	[b]131.0	137.5	(a)	132.0	142.0	133.0	128.0	128.0	[b]125.0	133.0	127.0
17	135.0	141.0	137.5	[b]131.0	136.5	130.5	136.0	142.0	134.0	127.5	127.0	[b]124.0	135.0	(a)

[a]Tone not visible above tunnel background.
[b]Tone only slightly above tunnel background.

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TABLE V. - TONE NOISE FOR PROPELLER F1-A3

(a) Mach 0.76

Transducer	BPF_{A3}	BPF_{F1}	$2BPF_{A3}$	BPF_{A3} + BPF_{F1}	$2BPF_{F1}$	$3BPF_{A3}$	$2BPF_{A3}$ + BPF_{F1}	BPF_{A3} + $2BPF_{F1}$	$3BPF_{F1}$	$4BPF_{A3}$	$3BPF_{A3}$ + BPF_{F1}	$2BPF_{A3}$ + $2BPF_{F1}$	BPF_{A3} + $3BPF_{F1}$	$4BPF_{F1}$
	Blade passing frequency: Sound pressure level, dB													
	100-Percent speed													
1	138.0	144.5	(a)	[b]131.0	[b]132.5	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)
2	139.5	143.0	[b]130.0	[b]131.5	[b]131.5	↓	↓	(a)	(a)	↓	↓	↓	↓	↓
4	142.0	147.0	[b]132.0	[b]131.5	136.5	↓	↓	(a)	(a)	↓	↓	↓	↓	↓
6	140.5	155.5	[b]131.0	133.0	141.0	↓	↓	128.5	130.0	↓	↓	↓	↓	↓
8	149.0	161.5	140.0	140.0	152.0	132.0	133.0	135.5	147.5	137.0	130.0	131.0	133.0	143.0
9	155.0	162.5	150.5	142.0	154.5	145.0	137.0	141.5	152.0	139.5	137.0	132.0	136.5	148.5
10	158.5	161.5	154.5	142.5	152.0	149.0	138.0	131.0	151.0	145.0	138.0	131.0	140.0	146.0
12	156.0	145.5	143.0	142.0	140.0	132.5	136.0	133.0	134.0	129.5	131.0	129.0	138.0	131.5
14	140.0	144.0	143.0	135.0	139.0	134.0	135.0	134.0	134.0	127.0	137.0	128.0	139.5	133.0
16	148.5	151.5	137.5	132.0	134.0	132.0	133.0	133.5	134.5	132.0	128.0	127.5	135.0	131.5
17	147.5	147.5	134.0	132.0	135.5	135.0	132.0	135.0	131.0	132.5	129.5	128.0	136.0	131.5
	95-Percent speed													
1	138.0	142.5	(a)	(a)	[b]132.5	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)
2	144.5	148.0	(a)	134.5	137.0	↓	↓	↓	↓	↓	↓	↓	↓	↓
4	145.5	151.5	(a)	136.0	139.0	↓	↓	↓	↓	↓	↓	↓	↓	↓
6	147.5	148.5	132.5	137.0	139.0	↓	↓	↓	↓	↓	↓	↓	↓	↓
8	146.5	161.5	140.0	134.5	143.0	131.0	133.0	132.0	147.0	135.0	130.0	130.0	131.0	143.0
9	153.0	162.0	148.0	136.0	151.0	141.0	135.0	134.0	152.0	138.0	130.5	130.0	134.0	139.0
10	155.0	157.0	150.0	137.5	151.0	144.0	133.0	135.0	145.0	140.0	128.0	130.0	134.0	146.0
12	151.0	143.0	140.0	134.0	141.5	132.0	134.0	129.5	139.0	130.5	135.5	[b]126.0	130.0	133.0
14	147.5	150.0	131.5	132.5	133.0	129.0	134.0	134.5	132.0	128.0	133.5	[b]125.0	127.5	135.0
16	139.5	150.0	131.0	131.0	136.0	130.0	(a)	133.0	131.5	135.0	129.5	(a)	130.0	132.0
17	136.0	148.0	132.0	130.5	135.0	132.5	129.5	129.5	132.5	132.0	[b]126.0	(a)	129.0	130.5
	90-Percent speed													
1	136.5	144.0	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)
2	136.5	150.0	[b]131.5	[b]132.0	137.0	↓	↓	↓	↓	↓	↓	↓	↓	↓
4	138.5	153.5	[b]131.5	[b]131.0	136.5	↓	↓	↓	↓	↓	↓	↓	↓	↓
6	138.0	152.5	[b]132.0	[b]130.0	[b]133.5	↓	↓	↓	↓	↓	↓	↓	↓	↓
8	148.0	159.5	138.5	133.0	149.5	130.5	131.0	133.0	146.5	131.0	128.0	128.5	127.5	139.5
9	150.5	159.0	145.0	136.0	148.0	139.0	129.5	133.5	149.0	137.0	129.0	128.0	129.5	146.0
10	151.0	152.5	144.5	136.5	147.0	140.0	133.0	133.0	135.0	132.5	134.0	128.5	130.0	144.0
12	144.5	151.5	134.5	132.0	137.5	(a)	132.0	136.0	133.0	128.0	132.0	(a)	136.0	134.0
14	143.0	143.0	129.5	129.0	135.0	129.5	(a)	133.5	133.5	127.5	133.0	↓	134.5	126.0
16	136.0	139.5	131.0	128.5	131.0	130.0	130.0	130.0	133.0	129.0	128.0	↓	132.0	128.5
17	136.0	141.5	131.0	130.0	129.5	131.0	131.5	133.0	132.0	127.0	128.0	↓	128.5	129.5

[a]Tone not visible above tunnel background.
[b]Tone only slightly above tunnel background.

TABLE V. - Continued.

(b) Mach 0.72

Transducer	BPF_{A3}	BPF_{F1}	$2BPF_{A3}$	BPF_{A3} + BPF_{F1}	$2BPF_{F1}$	$3BPF_{A3}$	$2BPF_{A3}$ + BPF_{F1}	BPF_{A3} + $2BPF_{F1}$	$3BPF_{F1}$	$4BPF_{A3}$	$3BPF_{A3}$ + BPF_{F1}	$2BPF_{A3}$ + $2BPF_{F1}$	BPF_{A3} + $3BPF_{F1}$	$4BPF_{F1}$
	Blade passing frequency													
	Sound pressure level, dB													
100-Percent speed														
1	142.5	149.0	132.5	136.0	133.0	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)
2	147.0	149.5	133.5	138.5	135.0	(a)	(a)	(a)	(a)	↓	(a)	(a)	(a)	↓
4	148.5	148.0	135.5	136.5	138.5	129.0	129.5	130.0	131.5	↓	(a)	(a)	(a)	↓
6	155.0	149.0	137.0	144.0	137.5	(a)	137.0	135.0	131.0	↓	[b]127.0	130.5	129.0	↓
8	144.5	162.0	142.5	140.5	152.5	139.0	133.5	138.0	149.5	136.5	130.0	130.0	137.5	145.0
9	154.0	163.0	151.0	136.5	152.5	149.0	139.0	139.0	152.0	142.0	136.0	134.0	139.0	145.0
10	156.5	159.0	152.0	139.0	152.5	149.5	139.0	139.0	143.5	140.0	131.0	134.0	140.0	145.0
12	155.0	148.0	136.0	139.5	145.5	144.0	137.0	133.0	139.0	133.0	136.0	128.0	139.0	131.0
14	154.0	151.0	134.0	135.5	137.5	131.0	135.0	144.5	129.5	133.0	129.0	130.5	139.5	132.5
16	144.0	150.5	136.5	133.0	137.5	131.5	131.0	141.0	133.0	137.0	136.5	128.5	137.0	132.0
17	144.5	149.5	131.0	135.0	137.0	137.0	131.0	135.0	132.0	135.0	130.5	[b]126.0	133.0	137.5
95-Percent speed														
1	137.5	146.0	133.0	134.0	134.5	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)
2	140.5	152.5	135.0	133.0	137.5	↓	↓	(a)	(a)	↓	↓	↓	↓	↓
4	141.5	151.5	136.0	133.0	137.0	↓	↓	(a)	(a)	↓	↓	↓	↓	↓
6	150.0	155.0	135.0	137.0	143.0	↓	↓	133.0	130.0	↓	↓	↓	↓	↓
8	151.5	158.5	141.5	139.5	150.5	138.0	134.0	134.0	148.0	134.0	129.0	128.5	130.5	143.0
9	155.0	159.0	148.0	134.5	151.5	143.5	132.0	139.0	150.0	140.0	130.0	130.0	129.0	145.0
10	156.0	154.0	147.5	135.5	148.5	144.0	134.0	136.0	139.5	139.0	134.0	129.0	135.0	139.5
12	153.0	152.5	137.5	131.5	143.0	133.0	134.5	136.5	134.0	133.0	134.0	128.0	136.0	130.5
14	149.5	147.0	133.0	129.5	137.5	128.5	128.0	136.5	135.0	130.0	[b]126.5	(a)	137.0	133.5
16	142.0	140.5	133.0	129.5	135.0	133.0	132.5	132.5	135.0	130.0	129.0	(a)	134.0	132.0
17	141.0	141.0	132.0	137.0	132.5	132.0	134.5	135.0	136.0	127.0	133.0	[b]127.5	127.0	(a)
90-Percent speed														
1	145.5	146.5	135.5	133.0	134.0	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)
2	145.5	146.5	136.0	134.5	136.5	↓	↓	↓	↓	↓	↓	↓	↓	↓
4	142.5	151.5	134.5	134.5	140.5	↓	↓	↓	↓	↓	↓	↓	↓	↓
6	140.5	151.5	[b]132.5	135.0	143.0	↓	↓	↓	↓	↓	↓	↓	↓	↓
8	151.5	158.0	140.0	137.5	150.0	136.0	131.0	129.5	143.5	131.5	128.0	127.5	129.5	143.0
9	154.0	156.0	145.0	135.5	150.5	143.0	131.0	129.0	143.5	138.0	129.0	128.0	135.0	145.0
10	153.0	152.5	146.0	129.5	146.0	141.0	133.0	133.0	139.5	136.5	129.0	[b]125.0	134.0	136.0
12	147.5	146.0	139.5	[c]129.0	140.0	132.0	130.0	133.0	133.0	[b]125.0	129.0	[b]125.0	142.0	135.0
14	137.0	145.0	(a)	130.0	133.0	(a)	130.0	138.0	134.0	[b]125.0	[b]125.0	(a)	138.0	135.0
16	136.5	143.5	131.0	130.0	134.5	127.0	134.0	133.0	130.0	[b]126.0	[b]127.0	(a)	133.0	128.0
17	138.5	144.5	128.5	129.5	132.0	128.0	136.0	133.0	130.5	(a)	130.5	(a)	[b]126.0	125.0

[a]Tone not visible above tunnel background.
[b]Tone only slightly above tunnel background.
[c]Tone almost not visible above tunnel background.

TABLE V. - Concluded.

(c) Mach 0.67

Transducer	Blade passing frequency													
	BPF_{A3}	BPF_{F1}	$2BPF_{A3}$	BPF_{A3} + BPF_{F1}	$2BPF_{F1}$	$3BPF_{A3}$	$2BPF_{A3}$ + BPF_{F1}	BPF_{A3} + $2BPF_{F1}$	$3BPF_{F1}$	$4BPF_{A3}$	$3BPF_{A3}$ + BPF_{F1}	$2BPF_{A3}$ + $2BPF_{F1}$	BPF_{A3} + $3BPF_{F1}$	$4BPF_{F1}$
	Sound pressure level, dB													
95-Percent speed														
1	151.0	145.0	137.0	134.0	139.0	132.0	129.0	133.0	131.0	(a)	(a)	(a)	(a)	(a)
2	151.5	146.5	135.0	137.5	138.0	129.0	131.0	136.0	133.0	(a)	(a)	(a)	(a)	(a)
4	151.5	149.0	135.5	138.5	144.5	131.0	129.5	131.5	134.5	(a)	127.0	127.5	127.0	129.0
6	150.5	154.0	139.5	139.5	146.5	130.5	130.5	131.0	143.5	127.0	[b]126.0	[b]126.0	129.0	137.0
8	157.0	158.5	139.5	140.0	152.0	130.5	134.0	131.0	146.0	133.0	128.0	129.0	132.0	145.0
9	157.5	159.5	142.0	137.5	151.5	136.0	132.0	137.0	145.0	139.0	132.5	134.0	139.0	146.0
10	157.0	158.0	142.5	131.5	146.5	140.0	134.0	139.5	138.5	141.5	136.0	127.0	141.0	140.0
12	151.5	147.5	138.5	129.0	141.5	133.0	133.5	140.0	136.0	[b]126.0	132.0	[b]125.0	148.5	135.0
14	138.5	148.0	127.5	129.5	141.0	128.0	133.0	145.0	137.0	[b]126.0	[b]126.0	[b]124.5	144.5	130.5
16	143.0	146.0	130.0	134.5	143.5	132.0	136.0	144.0	133.0	[b]126.0	128.0	[b]124.0	138.0	132.0
17	144.5	148.5	128.5	137.0	138.5	128.5	136.0	145.0	136.0	[b]123.0	134.0	129.0	127.0	127.0
90-Percent speed														
1	141.0	146.5	[b]132.0	[b]131.5	134.5	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)
2	141.0	147.0	134.5	[b]133.0	138.5	(a)	(a)	(a)	(a)	↓	↓	↓	(a)	(a)
4	135.5	148.5	135.0	134.0	139.0	(a)	(a)	129.5	137.0	↓	↓	↓	127.0	130.0
6	144.5	156.0	[b]131.5	136.0	148.0	130.0	129.0	128.0	142.5	↓	↓	↓	128.0	136.0
8	152.0	157.0	138.0	136.0	149.0	134.0	133.0	134.0	143.0	130.0	126.5	127.0	132.0	142.0
9	152.5	155.0	138.0	138.0	150.0	138.0	134.0	135.0	142.0	134.0	129.0	128.0	136.0	140.0
10	151.5	152.5	138.0	[b]129.5	144.5	134.0	129.0	136.5	134.0	129.5	128.0	[b]125.0	141.0	129.0
12	146.0	138.5	[b]131.0	133.0	138.5	127.0	128.0	139.0	129.0	(a)	133.0	[b]126.0	144.0	134.0
14	140.0	143.5	[b]130.0	130.5	138.5	128.0	132.0	140.0	132.0	126.0	[b]125.0	[b]123.0	138.0	133.0
16	134.0	140.0	[b]129.0	[b]129.5	135.5	128.0	133.0	140.0	132.5	(a)	129.0	[b]122.0	128.5	128.0
17	131.0	140.5	[b]129.0	131.0	136.5	128.5	137.0	139.0	136.0	(a)	129.5	(a)	135.0	(a)

[a]Tone not visible above tunnel background.
[b]Tone only slightly above tunnel background.

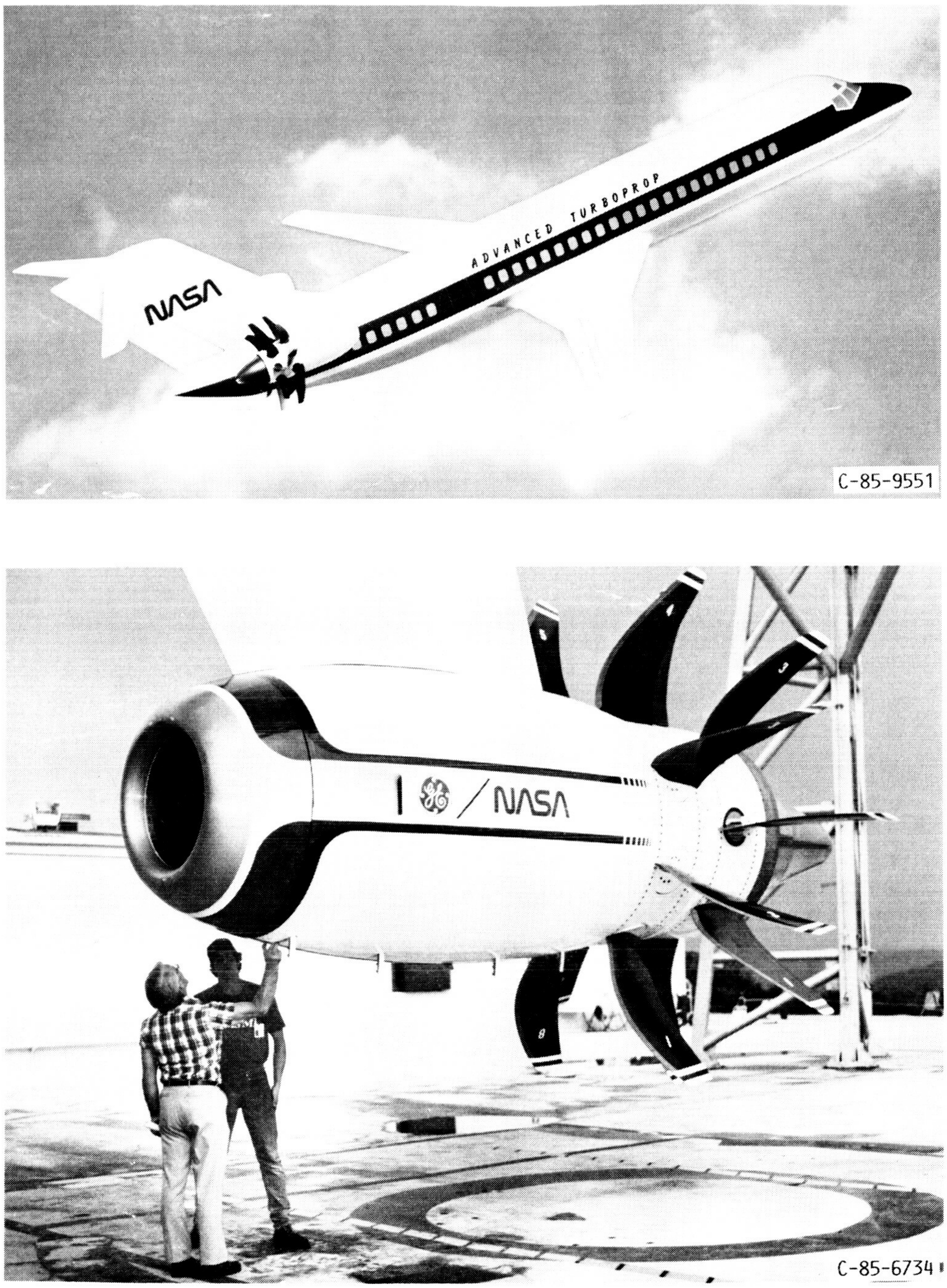


FIGURE 1. - COUNTERROTATION PUSHER AIRPLANE AND ENGINE.

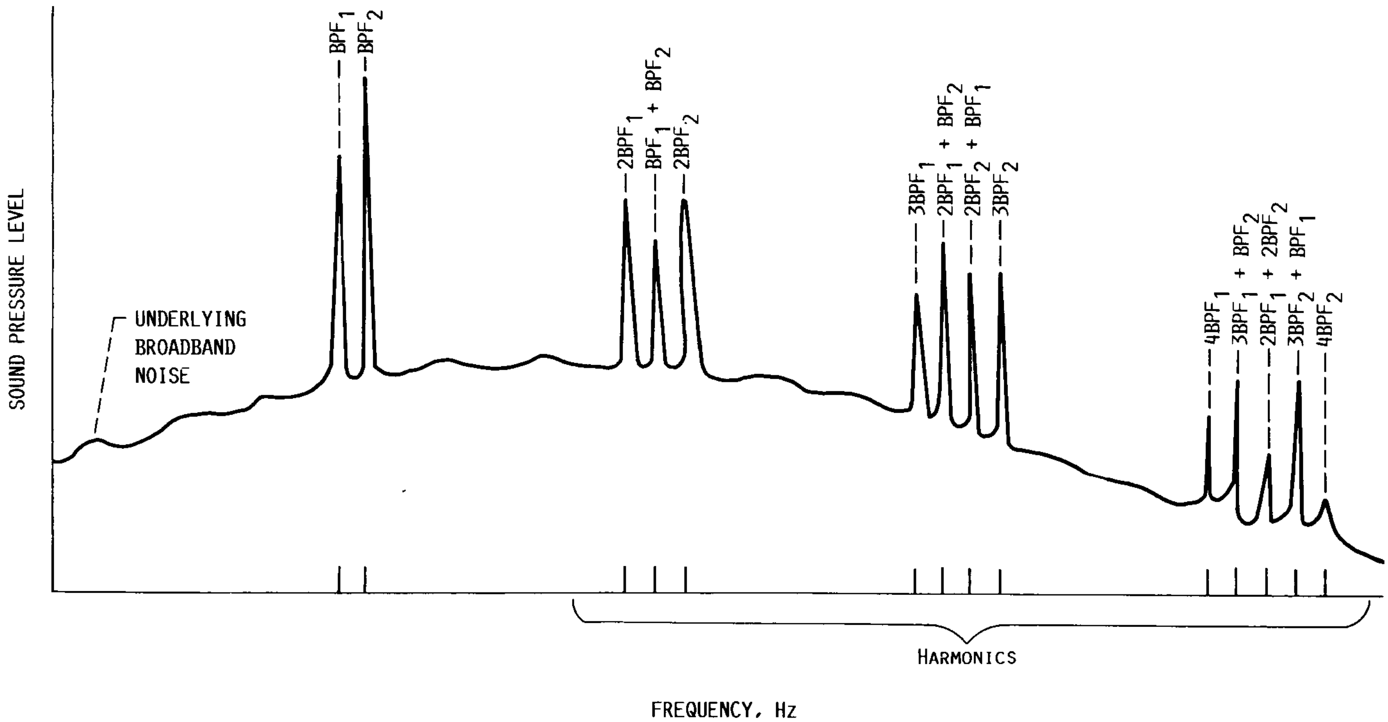
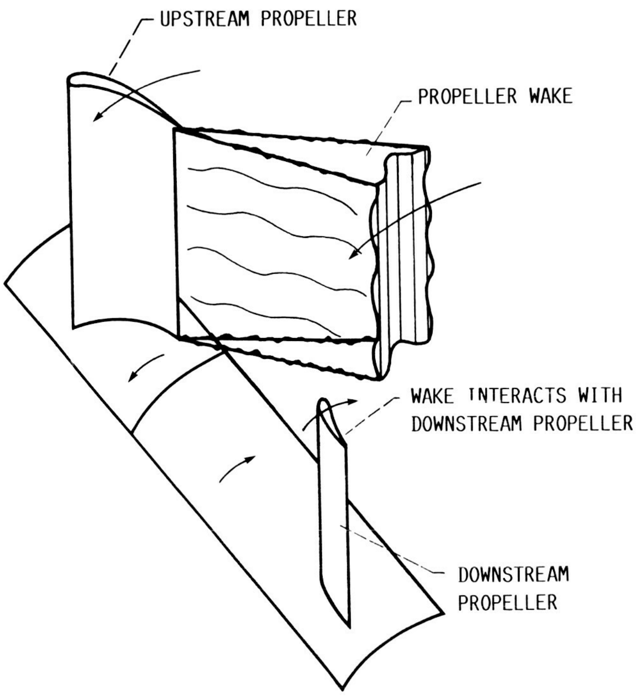
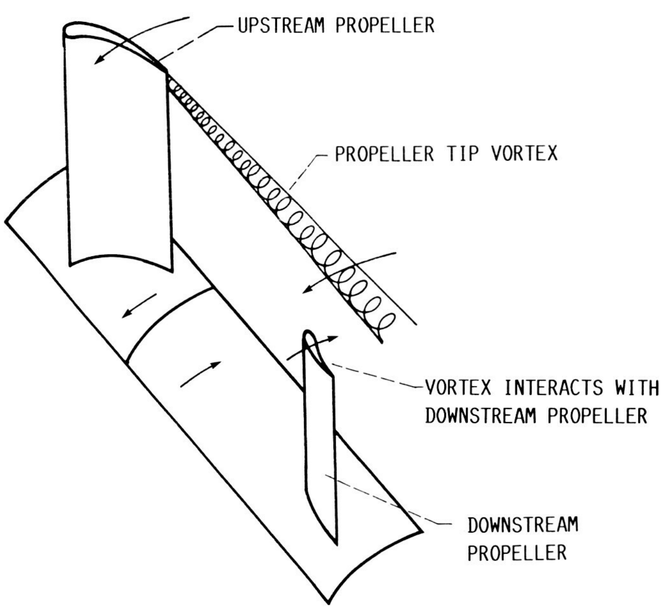


FIGURE 2. - GENERAL NOISE SPECTRUM OF COUNTERROTATING PROPELLER.



(A) WAKE INTERACTION.



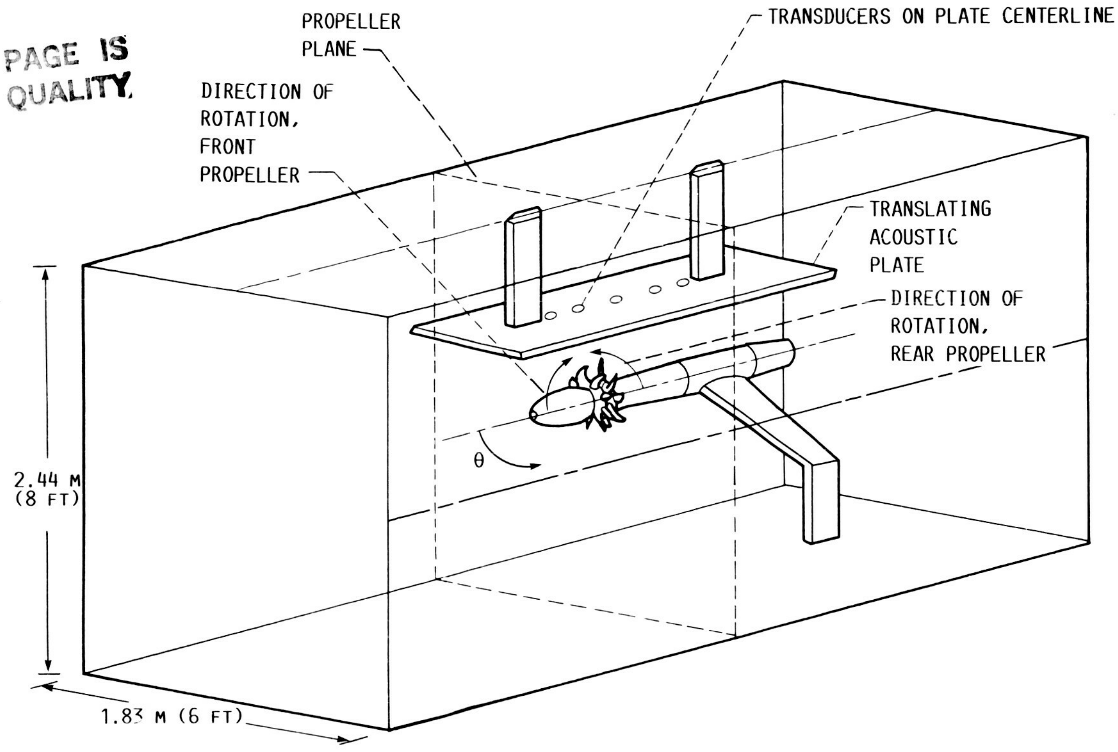
(B) VORTEX INTERACTION.

FIGURE 3. - NOISE MECHANISMS.

(A) F1-A1, ORIGINAL AFT PROPELLER.

(B) F1-A3, REDUCED-DIAMETER AFT PROPELLER.

FIGURE 4. - PROPELLER CONFIGURATIONS.



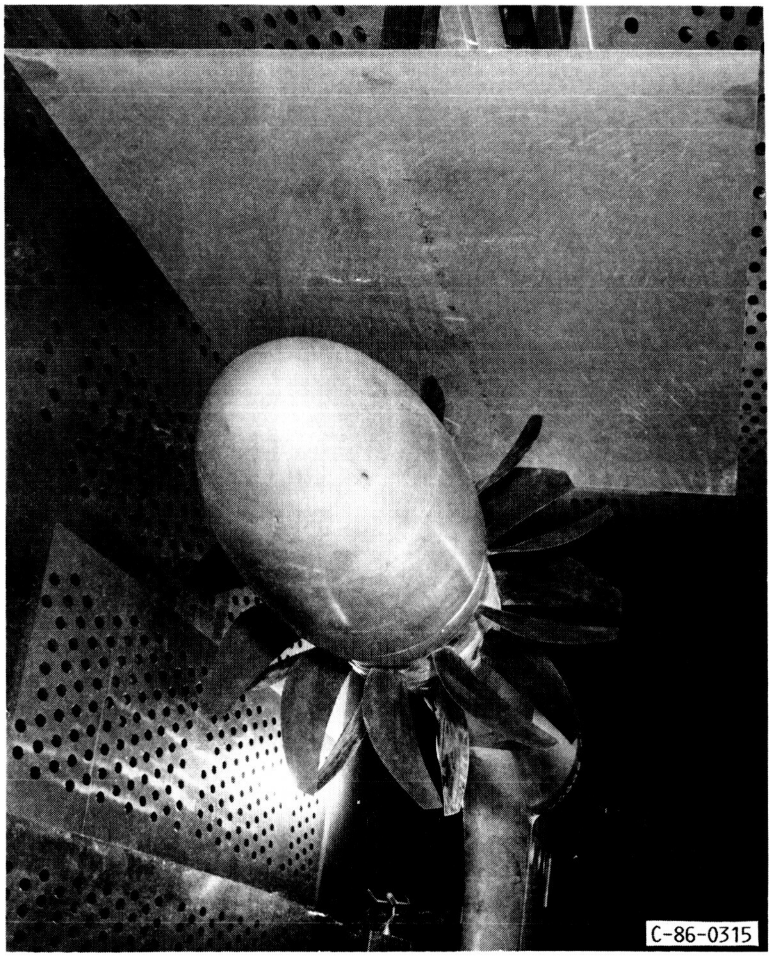
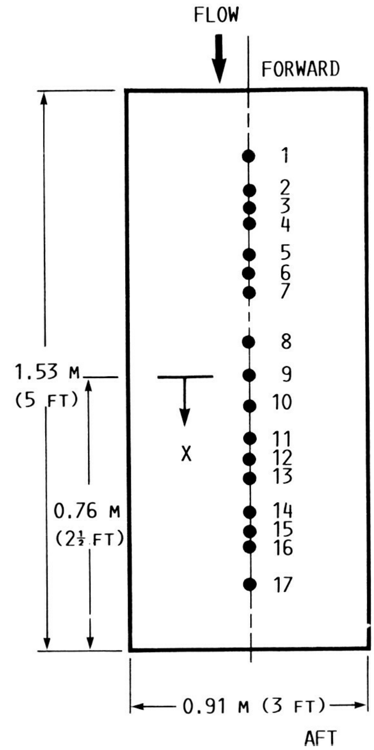


FIGURE 5. - TEST APPARATUS SHOWING TRANSLATING ACOUSTIC PLATE.



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

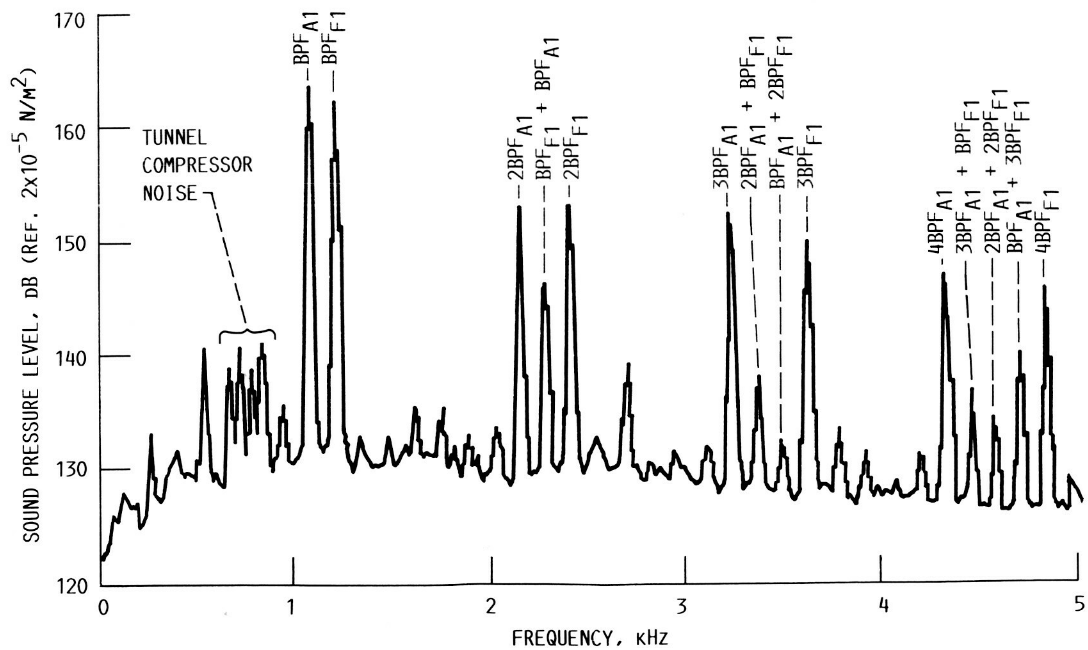
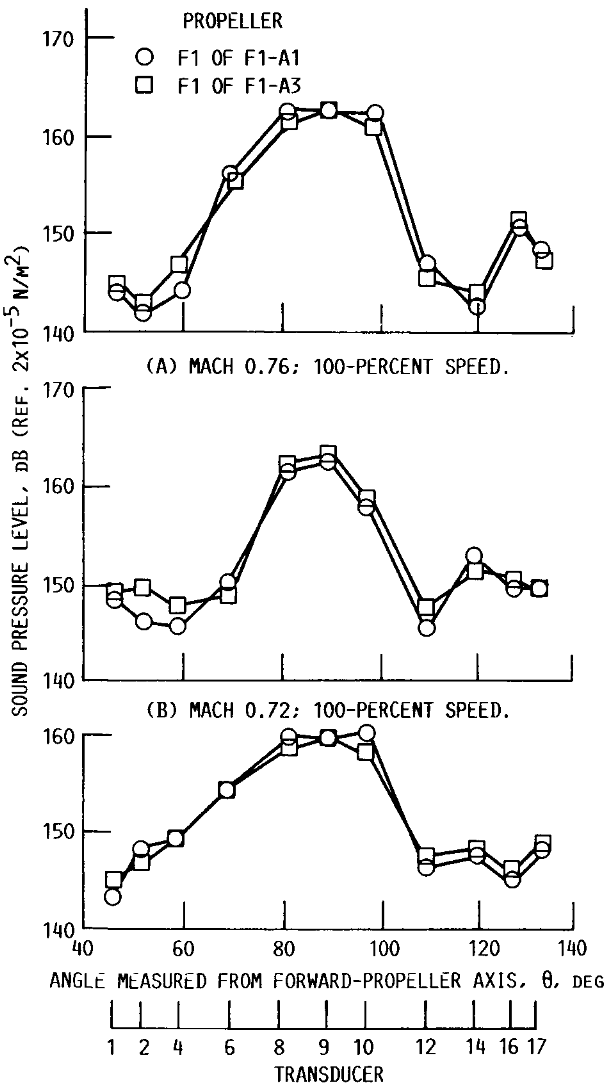
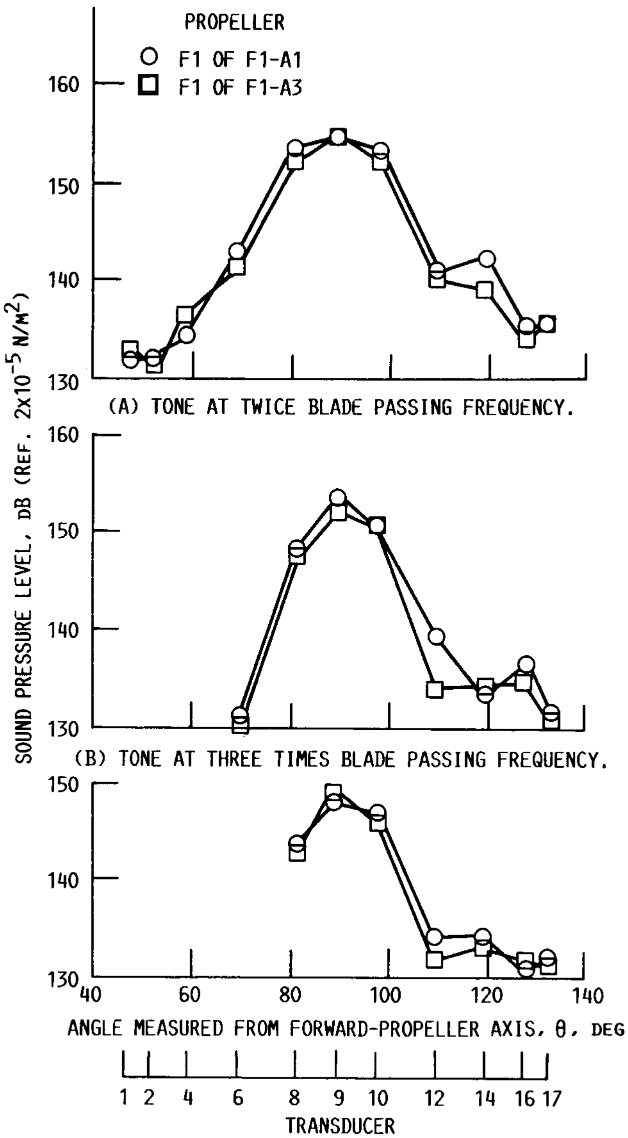


FIGURE 7. - NOISE SPECTRUM FOR PROPELLER F1-A1 (TRANSDUCER 10) AT MACH 0.76 AND 100-PERCENT SPEED.



(C) MACH 0.67; 95-PERCENT SPEED.

FIGURE 8. - FORWARD-PROPELLER PRIMARY BLADE PASSING TONES.



(C) TONE AT FOUR TIMES BLADE PASSING FREQUENCY.

FIGURE 9. - FORWARD-PROPELLER PRIMARY TONES AT HIGHER HARMONICS. MACH 0.76; 100-PERCENT SPEED.

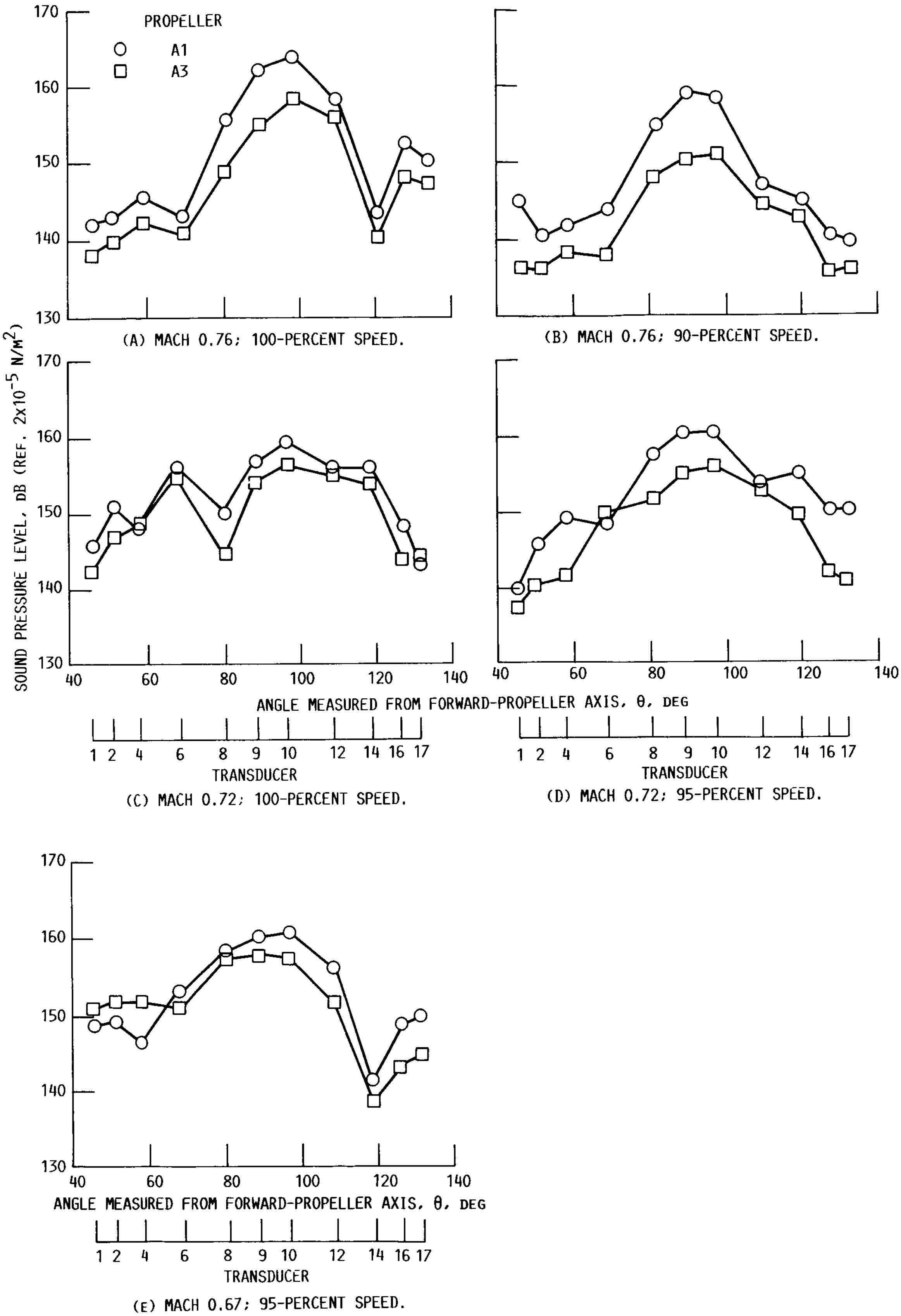


FIGURE 10. - AFT-PROPELLER PRIMARY BLADE PASSING TONES.

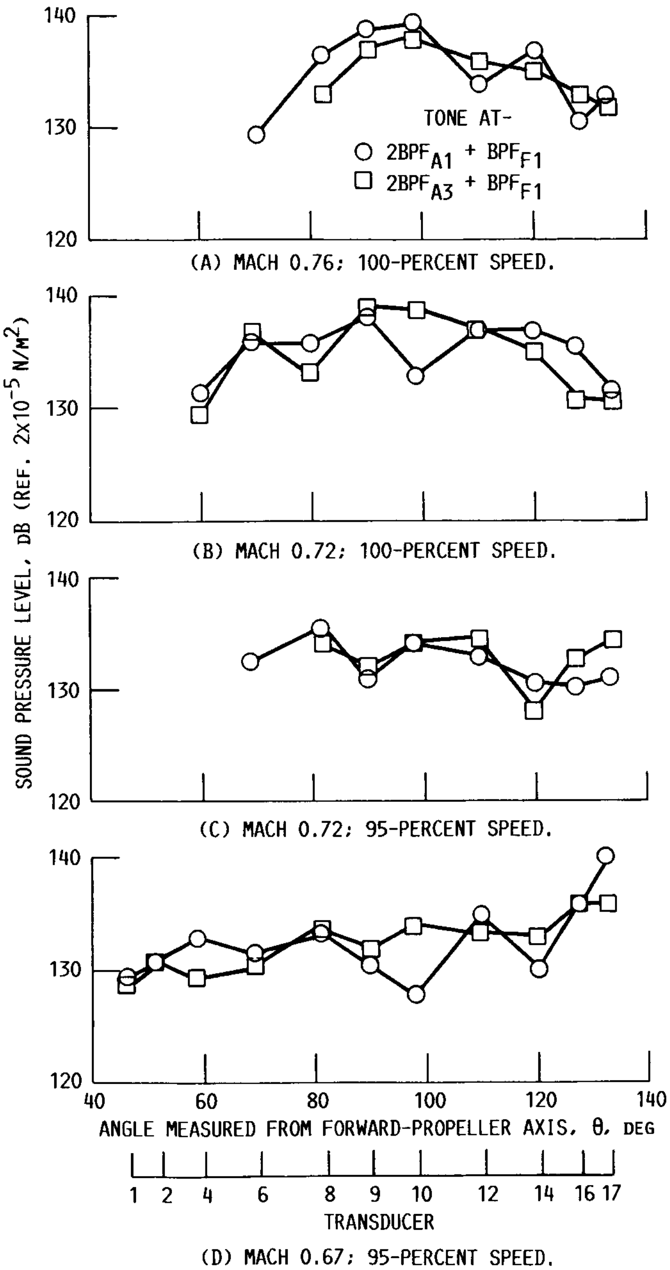


FIGURE 13. - INTERACTION TONES AT TWICE AFT-PROPELLER BLADE PASSING FREQUENCY PLUS FORWARD-PROPELLER BLADE PASSING FREQUENCY.

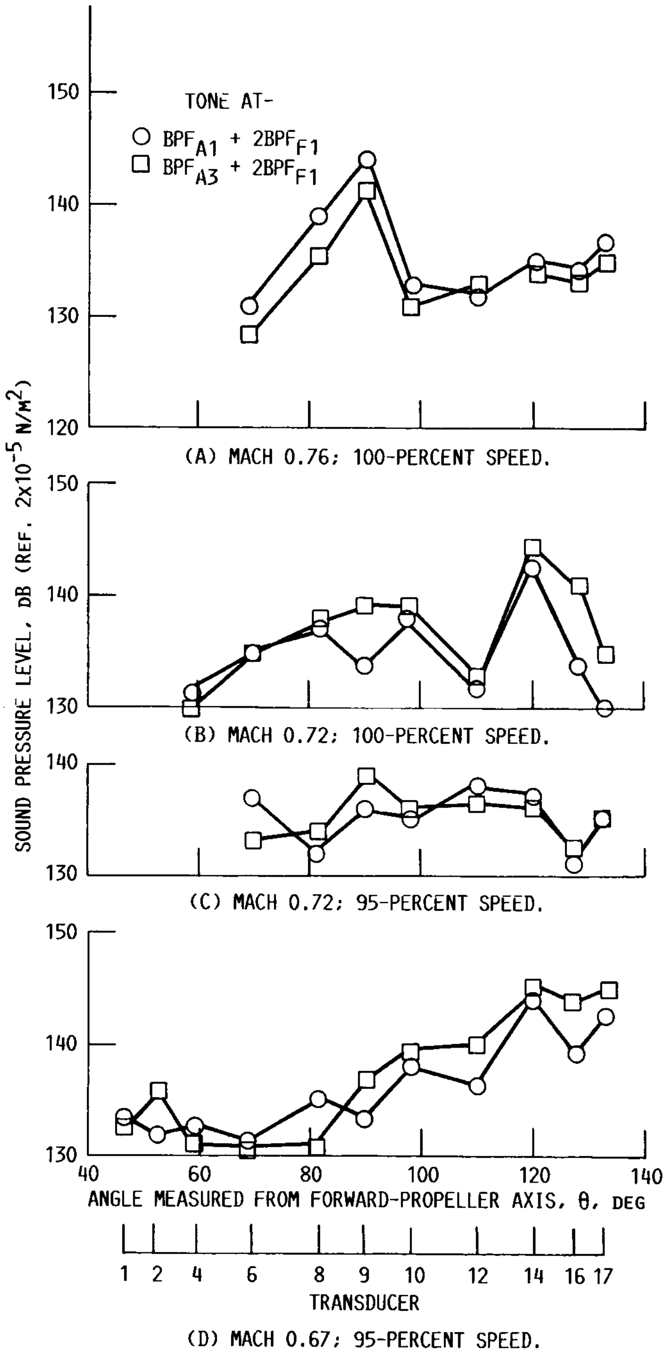
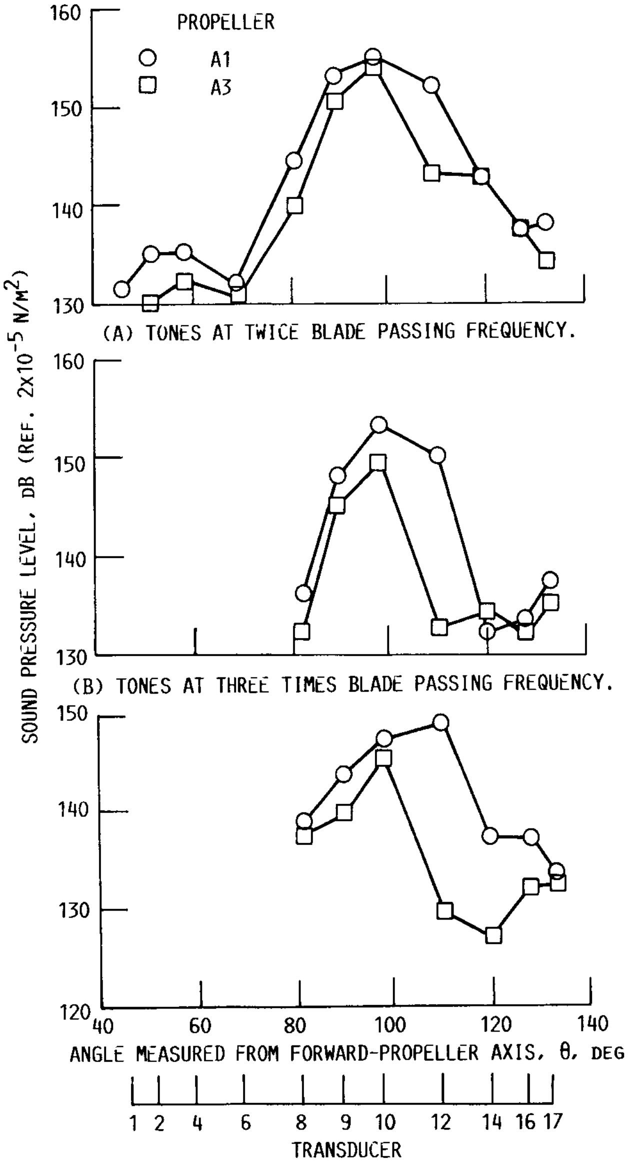


FIGURE 14. - INTERACTION TONES AT AFT-PROPELLER BLADE PASSING FREQUENCY PLUS TWICE FORWARD-PROPELLER BLADE PASSING FREQUENCY.

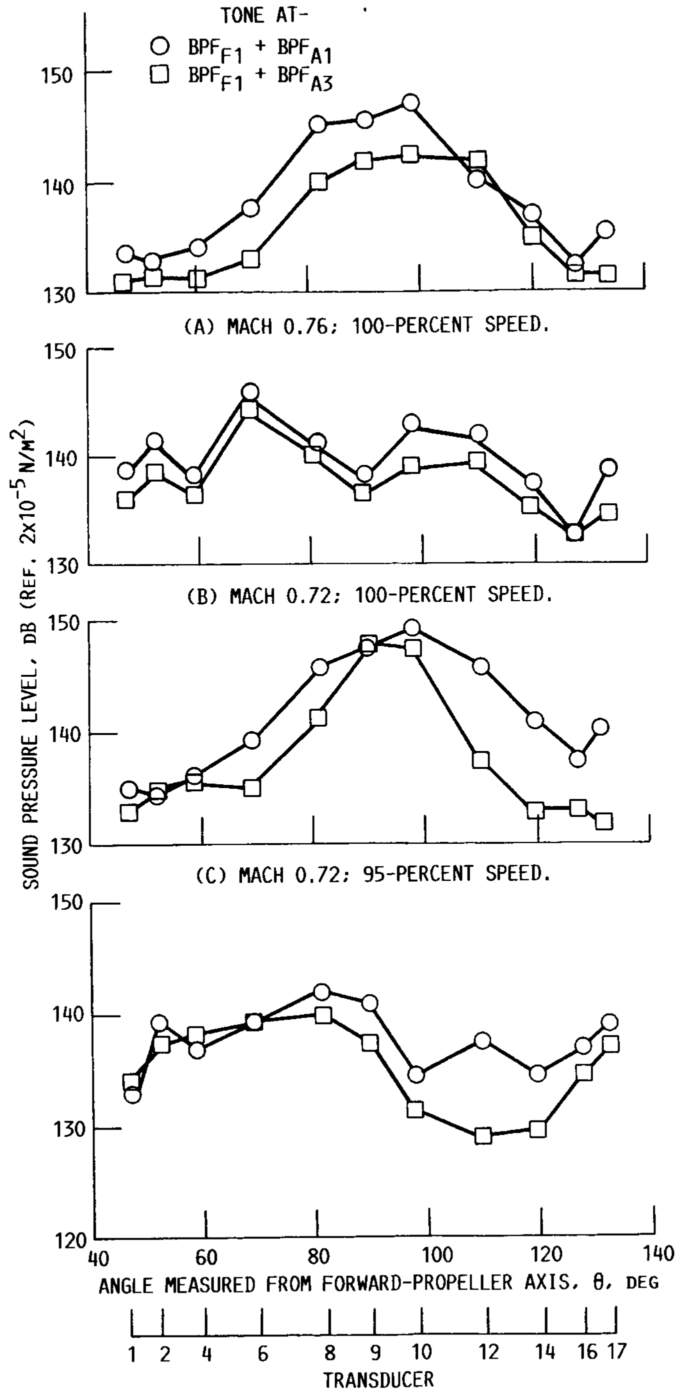


(A) TONES AT TWICE BLADE PASSING FREQUENCY.

(B) TONES AT THREE TIMES BLADE PASSING FREQUENCY.

(C) TONES AT FOUR TIMES BLADE PASSING FREQUENCY.

FIGURE 11. - AFT-PROPELLER PRIMARY TONES AT HIGHER HARMONICS. MACH 0.76; 100-PERCENT SPEED.



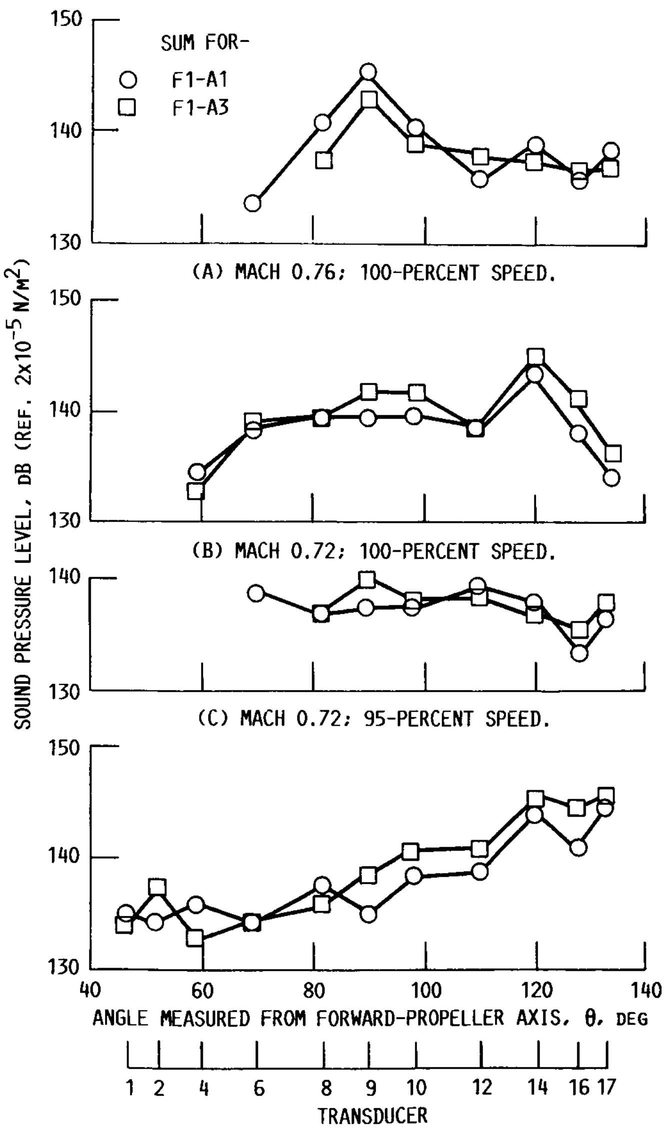
(A) MACH 0.76; 100-PERCENT SPEED.

(B) MACH 0.72; 100-PERCENT SPEED.

(C) MACH 0.72; 95-PERCENT SPEED.

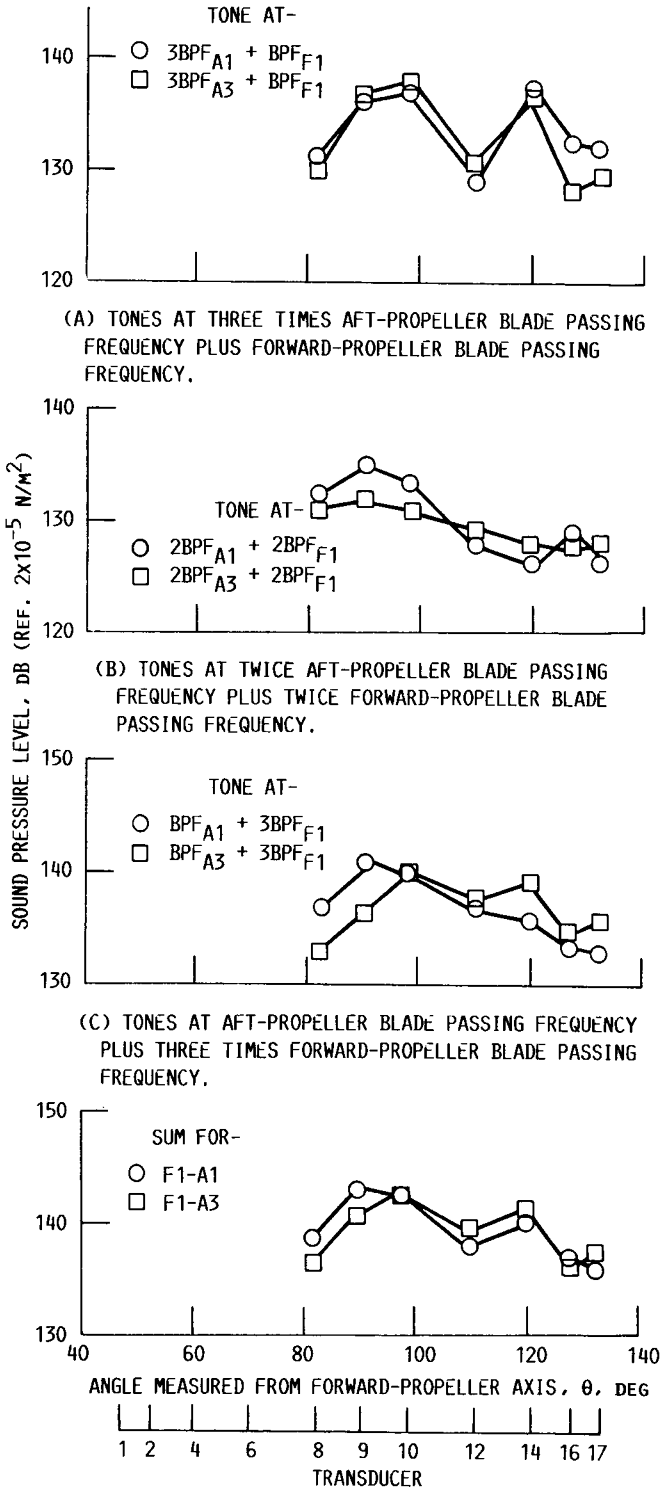
(D) MACH 0.67; 95-PERCENT SPEED.

FIGURE 12. - FIRST INTERACTION TONES (TONE AT SUM OF TWO BLADE PASSING FREQUENCIES.



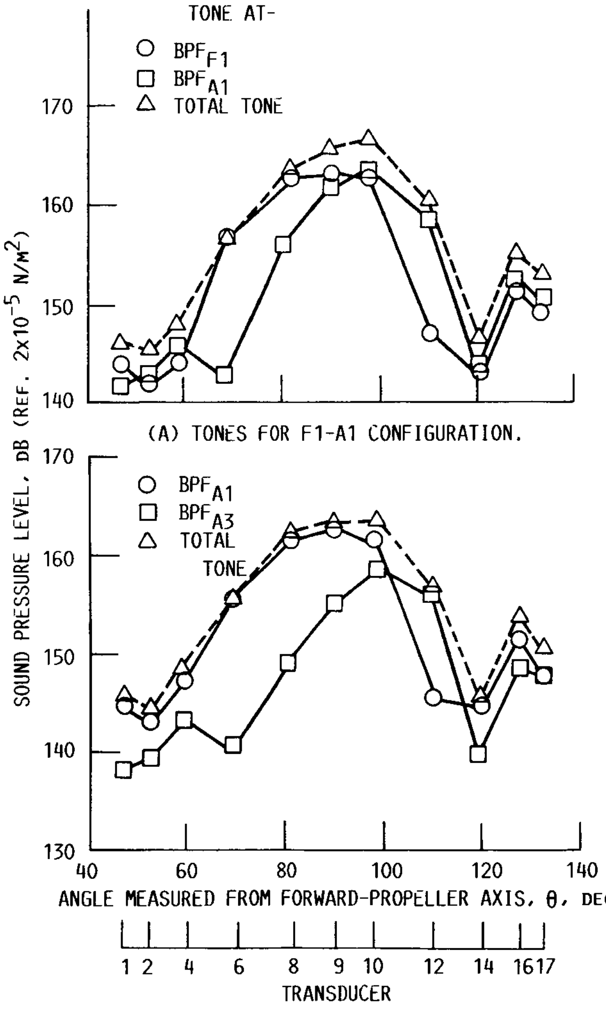
(D) MACH 0.67; 95-PERCENT SPEED.

FIGURE 15. - SUMMATION OF INTERACTION TONES OCCURRING BETWEEN TWO THIRD-HARMONIC PRIMARY TONES (TONES AT $2BPF_A + BPF_F$ SUMMED WITH TONES AT $BPF_A + 2BPF_F$).



(D) SUMMATION OF THREE TONES AT $3BPF_A + BPF_F$, $2BPF_A + 2BPF_F$, AND $BPF_A + 3BPF_F$.

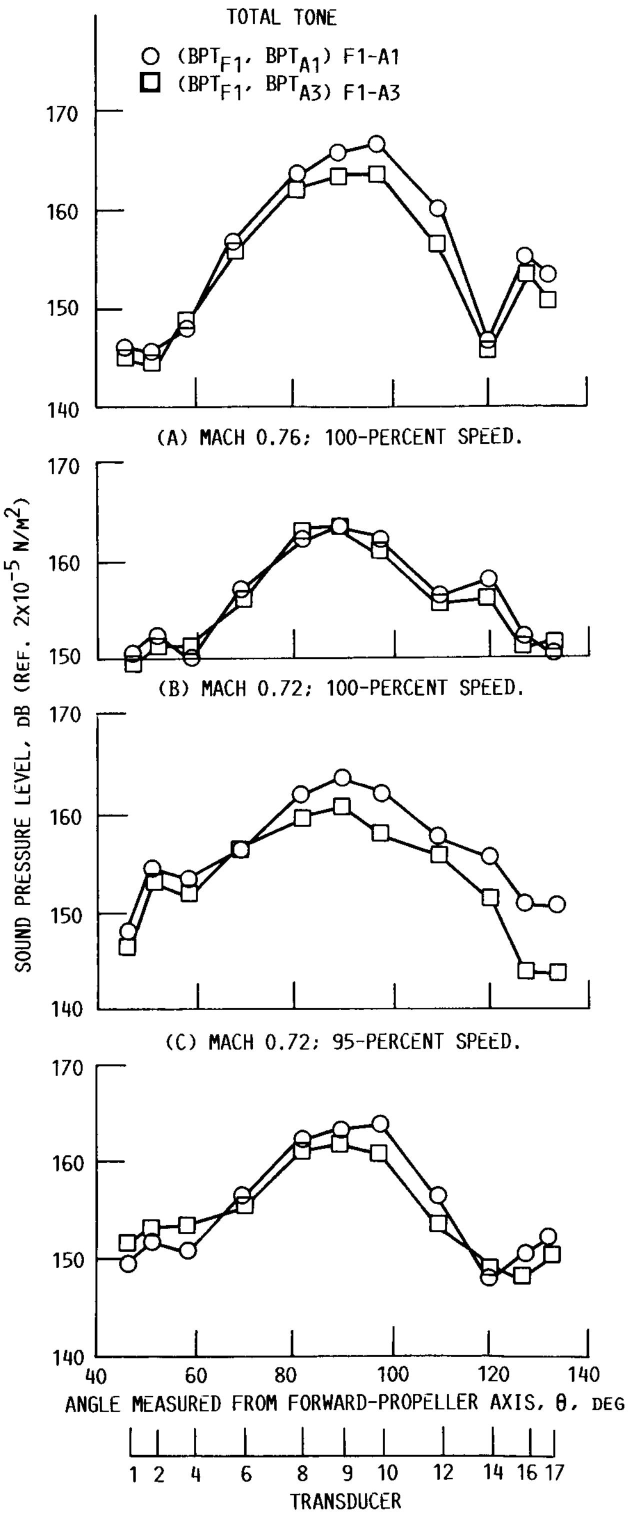
FIGURE 16. - INTERACTION TONES OCCURRING BETWEEN FOURTH-HARMONIC PRIMARY TONES. MACH 0.76 AND 100-PERCENT SPEED.



(A) TONES FOR F1-A1 CONFIGURATION.

(B) TONES FOR F1-A3 CONFIGURATION.

FIGURE 17. - SUMMATION OF TWO PRIMARY TONES AT PROPELLER BLADE PASSING FREQUENCIES. MACH 0.76 AND 100-PERCENT SPEED.



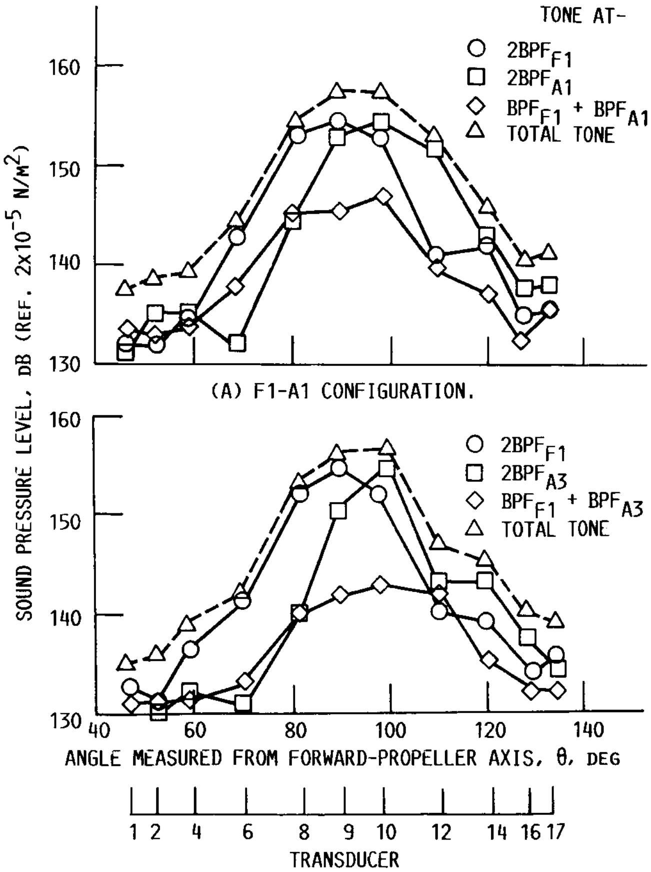
(A) MACH 0.76; 100-PERCENT SPEED.

(B) MACH 0.72; 100-PERCENT SPEED.

(C) MACH 0.72; 95-PERCENT SPEED.

(D) MACH 0.67; 95-PERCENT SPEED.

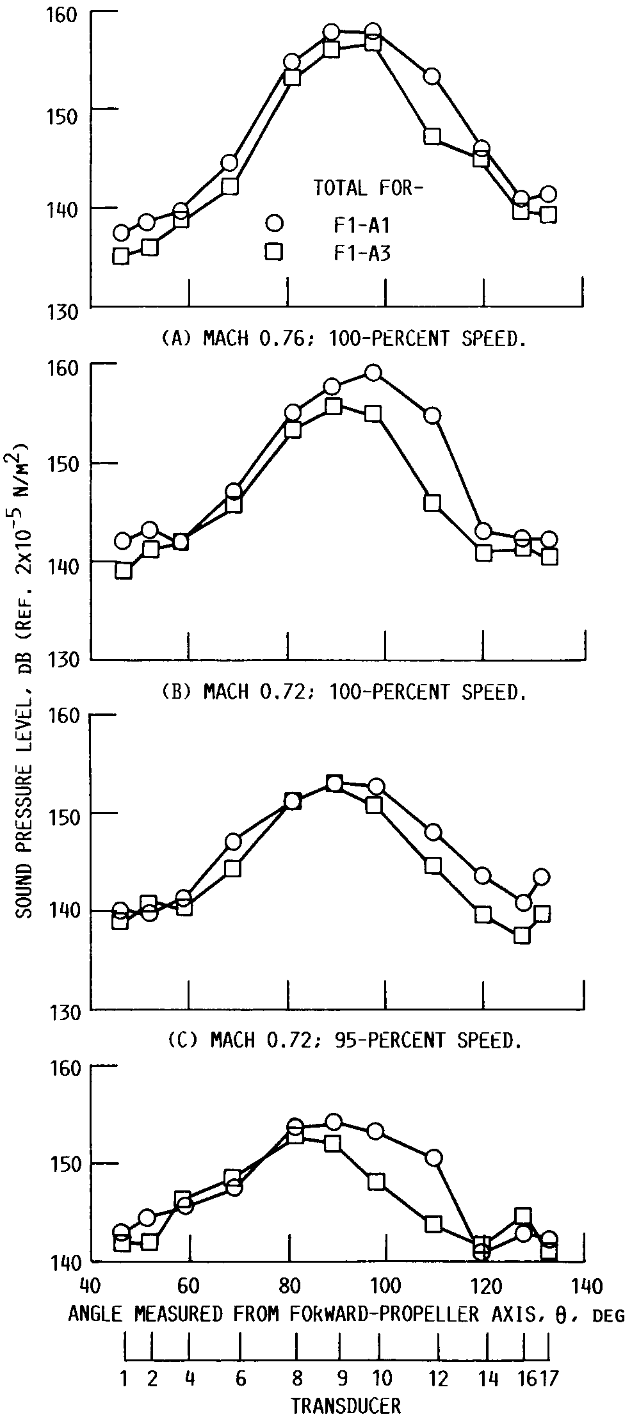
FIGURE 18. - TOTAL BLADE PASSING TONES.



(A) F1-A1 CONFIGURATION.

(B) F1-A3 CONFIGURATION.

FIGURE 19. - SUMMATION OF TONES AT TWICE BLADE PASSING FREQUENCY. MACH 0.76 AND 100-PERCENT SPEED.



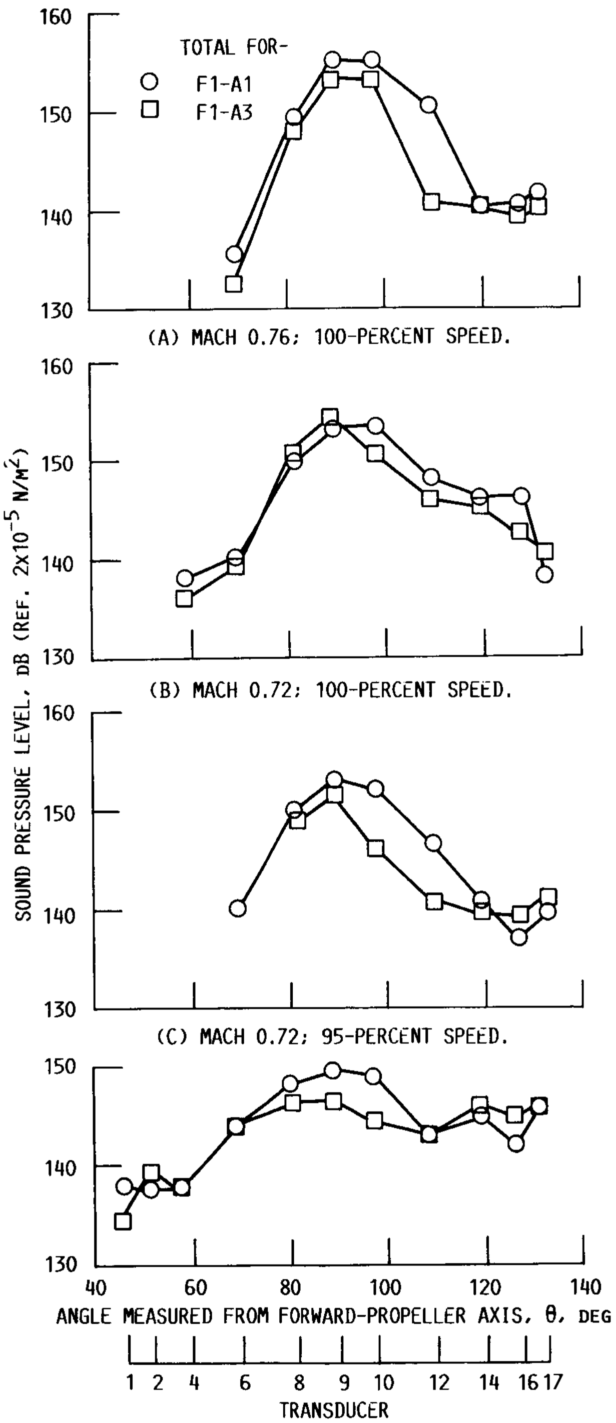
(A) MACH 0.76; 100-PERCENT SPEED.

(B) MACH 0.72; 100-PERCENT SPEED.

(C) MACH 0.72; 95-PERCENT SPEED.

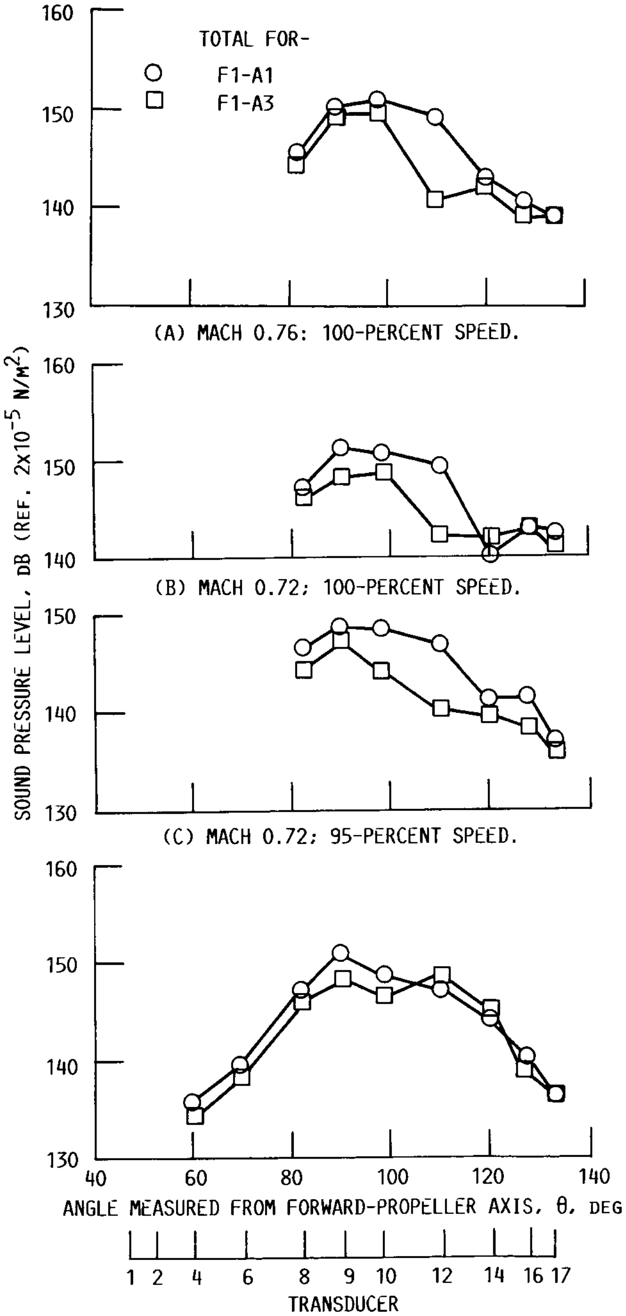
(D) MACH 0.67; 95-PERCENT SPEED.

FIGURE 20. - TOTAL TONES AT TWICE BLADE PASSING FREQUENCY.



(D) MACH 0.67; 95-PERCENT SPEED.

FIGURE 21. - TOTAL TONES AT THREE TIMES BLADE PASSING FREQUENCY.



(D) MACH 0.67; 95-PERCENT SPEED.

FIGURE 22. - TOTAL TONES AT FOUR TIMES BLADE PASSING FREQUENCY.

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7. Author(s) James H. Dittmar and David B. Stang		8. Performing Organization Report No. E-3378
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15. Supplementary Notes

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16. Abstract

The forward propeller of a model counterrotation propeller was tested with its original aft propeller and with a reduced-diameter aft propeller. Noise reductions with the reduced-diameter aft propeller were measured at simulated cruise conditions. Reductions were as large as 7.5 dB for the aft-propeller passing tone and 15 dB in the harmonics at specific angles. The interaction tones, mostly the first tone, were reduced probably because the reduced-diameter aft-propeller blades no longer interacted with the forward-propeller tip vortex. The total noise (sum of primary and interaction noise) at each harmonic was significantly reduced. The chief noise reduction at each harmonic came from reduced aft-propeller-alone noise, with the interaction tones contributing little to the totals at cruise. Total cruise noise reductions were as much as 3 dB at given angles for the blade passing tone and 10 dB for some of the harmonics. These reductions would measurably improve the fuselage interior noise levels and represent a definite cruise noise benefit from using a reduced-diameter aft-propeller.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Propeller noise; Counterrotation; Vortex interaction noise	Unclassified - unlimited STAR Category 71

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