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# Preliminary Measurement of the Noise From the 2/9 Scale Model of the Large-Scale Advanced Propfan (LAP) Propeller, SR-7A

James H. Dittmar
*Lewis Research Center*
*Cleveland, Ohio*



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# PRELIMINARY MEASUREMENT OF THE NOISE FROM THE 2/9 SCALE MODEL OF THE LARGE-SCALE ADVANCED PROPFAN (LAP) PROPELLER, SR-7A

James H. Dittmar
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

## SUMMARY

Noise data on the Large-scale Advanced Propfan (LAP) propeller model SR-7A were taken in the NASA Lewis 8- by 6-Foot Wind Tunnel. The maximum blade passing tone decreases from the peak level when going to higher helical tip Mach numbers. This noise reduction points to the use of higher propeller speeds as a possible method to reduce airplane cabin noise while maintaining high flight speed and efficiency. Comparison of the SR-7A blade passing noise with the noise of the similarly designed SR-3 propeller shows good agreement as expected. The SR-7A propeller is slightly noisier than the SR-3 model in the plane of rotation at the cruise condition.

Projections of the tunnel model data are made to the full-scale LAP propeller mounted on the test bed aircraft and compared with design predictions. The prediction method is conservative in the sense that it overpredicts the projected model data.

## INTRODUCTION

Advanced turboprop-powered 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. One element of this program is the Large-scale Advanced Propfan Program (ref. 1) which includes the design, fabrication, and ground tests of a 2.74-m-(9-ft-) diameter propeller. This propeller will later be flown on a test bed Gulfstream II aircraft as shown in figure 1. Under the LAP program an aeroelastically scaled model of this propeller, designated SR-7A, has been constructed in 62.2-cm (24.5-in.) size to enable the early determination of the aeroelastic characteristics of the 2.74-m (9-ft) design and for later measurement of the aerodynamic and acoustic performance over the range of flight conditions. The noise from these advanced high speed propellers is also of present concern since it may be a cabin environment problem for the airplane at cruise. Therefore, while the SR-7A model was in the NASA 8- by 6-Foot Wind Tunnel for initial aeroelastic testing, some preliminary noise measurements were also taken. A number of other propellers have been tested in this tunnel (refs. 2 to 5). This report presents the results of the acoustic measurements taken on the SR-7A propeller and compares its noise against that of the previously tested SR-3 propeller. Comparisons with a semi-empirical prediction method for the design cruise condition are also included. More detailed measurements of the noise of this propeller model are planned.

## APPARATUS AND PROCEDURE

The SR-7A propeller, which is nominally 0.622 m (24.5 in.) in diameter, was tested for acoustics in the NASA Lewis 8- by 6-Foot Wind Tunnel. Table I shows some of the characteristics of this propeller compared with those from the previously tested SR-3 propeller (refs. 2, 3, and 5). The SR-7A propeller is similar to the SR-3 propeller, and is designed, as is the SR-3, to have the hub-to-tip sweep distribution tailored to provide noise cancellation from the different sections. In order to provide an aeroelastically stable full-scale propeller, a somewhat different blade sweep distribution was used for SR-7A. A comparison of the two blade profiles in figures 2(a) and (b) shows the blade sweep for the two blades. The blade sweeps are measured relative to the local streamline when they are in the deflected position corresponding to the cruise condition. As can be seen, SR-3 has more sweep over most of the span but SR-7A has slightly more sweep at the tip. The SR-7A propeller was also designed with less power loading at the cruise condition. (See table I.) One of the purposes of this experiment was to determine any noise differences that might result from variations in the two designs.

A plan view of the wind tunnel is shown in figure 3(a), and a photograph of the SR-7A propeller in the test section is shown in figure 3(b). To measure the propeller noise, pressure transducers were installed, flush with the tunnel ceiling, through the bleed holes visible in figure 3(b) at the locations shown in figure 4. Tests were conducted with the propeller at its design blade setting angle of 57.3°. The propeller was operated at its design advance ratio of 3.06, and the wind tunnel was operated for a Mach number of 0.5 to a Mach number of 0.9 in steps of 0.05.

The signals from the five pressure transducers were recorded on magnetic tape and narrowband spectra were obtained for each of the test points. At most of the conditions, the narrowband range was from 0 to 10 000 Hz with a band width of approximately 26 Hz. However, because the propeller blade passing frequency is so close to the wind tunnel compressor tones at the lower Mach numbers, some higher resolution spectra (0 to 1000 Hz with approx. a 2.6 Hz bandwidth.) were used to isolate the propeller tone.

## RESULTS AND DISCUSSION

The tone levels were read from the narrowband spectra, and a compilation of the first eight harmonics is given in table II. In this table the propeller tone levels are tabulated for the conditions where the tones are sufficiently above the tunnel background. For those harmonies where the tone is not sufficiently above the tunnel background the table is left blank.

### Variation with Helical Tip Mach Number

SR-7A. - The variation of the maximum blade passage noise versus helical tip Mach number (vector sum of axial and rotational Mach numbers) has been determined for a number of other propellers (refs. 2 to 5). These previous tests, performed at constant advance ratio for helical tip Mach numbers ($M_{ht}$) from 0.72 to 1.20, showed a sharp rise in noise from $M_{ht}$ = 0.72 to 1.0 and then leveled off above 1.0. It has been suggested that the blade passage noise may decrease at helical tip Mach numbers above 1.2. Such a reduction in noise at higher speeds has been observed in the multiple pure-tone noise of supersonic fans (ref. 6). Therefore, the range of the experiments on SR-7 was extended out to a helical tip Mach number of 1.29. Figure 5(a) shows the maximum blade passing tone levels measured on the wind tunnel ceiling as a function of the helical tip Mach numbers for the SR-7A propeller. As observed, the noise does show a reduction, from the peak, at the higher helical tip Mach numbers. This observation points to the use of faster rotating propellers as a possible method of reducing the noise incident on the airplane fuselage while retaining both high flight speed and propeller efficiency.

It should be noted that the maximum noise measured at the $M_{ht} = 1.29$ condition occured at transducer position D, and that the transducer at position E was not functioning. (See table II.) It is possible that the maximum noise at $M_{ht} = 1.29$ may be at a more aft location and be higher than indicated. However, since the noise at microphone E for $M_{ht} = 1.00$ to 1.14 is at least 8 dB lower than at microphone D, microphone E would probably still measure less than microphone D at $M_{ht} = 1.20$ and 1.29. Thus, the decreasing trend in the noise levels above 1.20 is probably real.

Comparison with SR-3. - The blade passing noise versus helical tip Mach number curve for SR-7A is compared with that for SR-3 in figure 5(b). The data for SR-3 were obtained from reference 3 and 6 dB were added to these data to account for the calibration error identified in reference 5. The validity of these SR-3 data with this 6 dB recalibration was demonstrated in reference 7 by comparison with data taken on the Jetstar airplane.

As observed in figure 5(b), the variation of SR-7A noise with helical tip Mach number is very similar to the SR-3 noise levels. At most of the tested conditions the slight differences in the measured noise are within the general data scatter. The maximum noise measured at the design condition ($M_{ht} = 1.14$) shows the SR-7A data point to be a couple of decibels higher than the equivalent SR-3 data point. However, the SR-7A data point lies almost exactly on the curve that was previously faired through all of the SR-3 data. Therefore, it is concluded, that the maximum blade passing tone levels, as a function of helical tip Mach number, are virtually the same for SR-7A and SR-3. As expected, at least for design $M_{ht}$ and below, the similar designs of SR-7A and SR-3 have yielded essentially the same fundamental peaktone noise characteristics.

## Directivity

SR-7A. - Blade passing tone levels for the SR-7A propeller are shown as a function of the angular position of the transducer (fig. 6). At most of the conditions above an axial Mach number of $M = 0.65$ and helical tip Mach number of $M_{ht} = 0.93$ (fig. 6(f)), the data show a strong directivity pattern. As indicated in reference 8, this strong directivity is believed to be one of the reasons valid fundamental-tone acoustic data are obtainable in this wind tunnel. The lobed pattern observed in the SR-3 data at the cruise condition (ref. 2) also occurs in the SR-7A data (fig. 6(c)), and has significance for the type and placement of acoustic treatment in the cabin wall. Below an axial Mach number of $M = 0.65$ ($M_{ht} = 0.93$), the directivity plots are flat. Again, as indicated in reference 8, this may mean that the data at the lower Mach numbers are being effected by tunnel wall reflections.

Comparisons with SR-3. - Comparisons of the directivities measured for the SR-7A and SR-3 propellers at helical tip Mach numbers of 1.14, 1.00, and 0.86 (axial Mach numbers of 0.8, 0.7, and 0.6) are shown in figure 7. In general, the directivity shapes for the two propellers are similar. The blade passing tone noise for SR-7A at cruise is higher than the SR-3 noise at most angles (fig. 7(a)), with the largest difference being in the plane of rotation (90°). At lower speeds there is less difference in noise levels.

## Airplane Projections

SR-7A. - The noise measured in the wind tunnel can be projected to flight conditions by using corrections for differences in altitude, size, and distance. The acoustic pressure is assumed to vary inversely with the distance squared, and directly with the square of the propeller diameter and the ambient pressure (ref. 7). Correcting a tunnel operating pressure of $76.5 \times 10^3$ $N/m^2$ (11.1 psi) at cruise condition to a flight altitude of 10.7 km (35 000 ft) yields a decrease of 10 dB. The tunnel ceiling is 1.5 diameter from the propeller tip, and the airplane fuselage is at 0.6 diameters from the tip. The size and distance correction yields an increase of 5.9 dB. The net correction from tunnel to flight conditions is then -4.1 dB. The distance correction in this flight projection is 1.5 dB more than the distance correction used in reference 7, where levels were assumed to decrease with 15 log of the distance. A plot of the full-scale propeller blade passing tone on the Gulfstream II airplane fuselage at cruise ($M_{ht}$ = 1.14, M = 0.80) is shown in figure 8. This is projected from the wind tunnel data for the SR-7A propeller model.

Comparison with prediction. - A graphical method for predicting the noise of the full-scale SR-7 propeller is presented in reference 9. Figures 8, 16, and 22(a) of reference 9 are used to predict the free field SR-7 propeller on the Gulfstream II Airplane. Six decibels are added to these free-field numbers to account for the pressure doubling effects of the airplane fuselage. These predictions are also shown in figure 8.

No corrections were applied to wind tunnel projected data to account for boundary-layer refraction. Reference 5 experimentally investigated this effect and found little or no boundary-layer refraction at or behind the plane of rotation.

The comparison of the predicted blade passing noise at cruise with that projection from the model data is shown in figure 8. The predicted curve shape is from figure 16 of reference 9.

As can be seen, the maximum predicted level is somewhat higher than that projected from the model data. Since, as mentioned before, the boundary-layer refraction is not effecting the data at the aft angles, it should be a good comparison. The prediction peak lies between the measured points.

Although boundary-layer refraction does not effect the noise at the aft angles, it does effect the noise measured at the forward angles in the 8- by 6-Foot Wind Tunnel data (ref. 5). This may account for the projected levels being lower than the predicted in the front figure 8. However, a shift in directivity of the predicted data would also improve the comparison.

The relative levels of the harmonics with respect,to the fundamental are also of interest. A comparison of the predicted levels with the measured data at the maximum noise position at cruise (see table II (c), transducer D) are shown in figure 9. The predictions were taken from figure 22(a) of reference 9 and the values are shown as differences from the level of the fundamental. The harmonics relative to the fundamental are lower than those predicted. The drop seems to occur from the fundamental to the second harmonic. In general, the predictions are higher than the model data projections. These comparisons indicate the predictions are conservative in the sense that they predict higher levels than the noise projected from the model data for both the fundamental blade passing tone and the harmonics, respectively.

## CONCLUDING REMARKS

Noise data on the Large-scale Advanced Propfan propeller model, SR-7A, were taken in the NASA Lewis 8- by 6-Foot Wind Tunnel. A plot of the maximum blade passage tone versus helical tip Mach number ($M_{ht}$) at constant advance ratio showed a rise in noise from $M_{ht} = 0.72$ to $M_{ht} = 1.0$. The noise started to level off above $M_{ht} = 1.0$, and then showed a lower value at $M_{ht} = 1.29$ than at the noise peak which occured at $M_{ht} = 1.14$. This noise reduction at higher helical tip Mach numbers points to the use of faster rotating propellers as a possible method to reduce cabin noise while maintaining high flight speed and efficiency. Comparison of the maximum SR-7A blade passing tone levels with those from the similarly designed SR-3 propeller show similar results as expected.

Directivity plots show the SR-7A noise data to have a highly directive and lobed pattern at cruise. Comparisons show good agreement with the SR-3 directivities, but indicate that SR-7A is noisier in the plane of the propeller.

Projections for the blade passing noise of the full scale 2.74-m-(9-ft-) diameter propeller, to be flown on the Gulfstream II test bed aircraft, were made from the wind tunnel model data. These projections were compared with a semi-empirical prediction of the noise. The prediction method indicated higher peak noise level than the projected data, and that the peak occured between the peaks of the measured data. The predicted levels of the harmonics were also found to be higher. The prediction method was conservative in the sense that it overpredicted the projected model data.

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TABLE I. - PROPELLER DESIGN CHARACTERISTICS

| | Propeller | |
|---|---|---|
| | SR-3 | SR-7A |
| Diameter, cm (in.) | 62.2 (24.5) | 62.2 (24.5) |
| Number of blades | 8 | 8 |
| Design Mach number | 0.80 | 0.80 |
| Design to speed, m/sec (ft/sec) | 244 (800) | 244 (800) |
| Design advance ratio | 3.06 | 3.06 |
| Design power coefficient | 1.7 | 1.45 |
| Design power loading, $kW/m^2$ ($hp/ft^2$) | 301 (37.5) | 257 (32.0) |
| Integrated design lift coefficient | 0.214 | 0.202 |
| Activity factor | 235 | 227 |
| Design efficiency, percent | 78 | 79 |

TABLE II. - SR-7A SOUND PRESSURE LEVELS

(a) Tunnel Mach number, 0.90; propeller speed, 9344 rpm; helical tip Mach number 1.29.

| Harmonic number | Transducer | | | | |
|---|---|---|---|---|---|
| | A | B | C | D | E |
| | Sound pressure level of harmonic, SPL, dB, ref. $2 \times 10^{-5}$ N/m$^2$ | | | | |
| 1 (BPF) | (a) | 139.0 | 143.0 | 145.5 | (b) |
| 2 | ↓ | 128.5 | 134.5 | 133.0 | ↓ |
| 3 | ↓ | (a) | 129.0 | 133.0 | ↓ |
| 4 | ↓ | ↓ | 125.0 | 131.5 | ↓ |
| 5 | ↓ | ↓ | (a) | (a) | ↓ |
| 6 | ↓ | ↓ | ↓ | ↓ | ↓ |
| 7 | ↓ | ↓ | ↓ | ↓ | ↓ |
| 8 | ↓ | ↓ | ↓ | ↓ | ↓ |

(b) Tunnel Mach number, 0.85; propeller speed, 8922 rpm; helical tip Mach number 1.22.

| Harmonic number | A | B | C | D | E |
|---|---|---|---|---|---|
| 1 (BPF) | (a) | 149.0 | 145.5 | 149.0 | (b) |
| 2 | ↓ | 136.0 | 138.0 | 144.5 | ↓ |
| 3 | ↓ | 127.5 | 134.5 | 130.0 | ↓ |
| 4 | ↓ | (a) | 127.0 | 134.0 | ↓ |
| 5 | ↓ | ↓ | (a) | 124.5 | ↓ |
| 6 | ↓ | ↓ | ↓ | 125.0 | ↓ |
| 7 | ↓ | ↓ | ↓ | (a) | ↓ |
| 8 | ↓ | ↓ | ↓ | (a) | ↓ |

[a]Not visible above wind tunnel background.
[b]Transducer malfunction.

TABLE II. - Continued

(c) Tunnel Mach number, 0.80; propeller speed, 8458 rpm; helical tip Mach number 1.14.

| Harmonic number | Transducer | | | | |
|---|---|---|---|---|---|
| | A | B | C | D | E |
| | Sound pressure level of harmonic, SPL, dB, ref. $2 \times 10^{-5}$ N/$m^2$ | | | | |
| 1 (BPF) | 136.0 | 151.0 | 145.5 | 151.5 | 136.0 |
| 2 | (a) | 135.5 | 137.0 | 138.0 | 133.0 |
| 3 | ↓ | 130.5 | 133.5 | 135.0 | 126.0 |
| 4 | ↓ | 127.0 | 132.5 | 128.0 | 126.5 |
| 5 | ↓ | (a) | 128.5 | 130.0 | (a) |
| 6 | ↓ | ↓ | 125.0 | 126.0 | ↓ |
| 7 | ↓ | ↓ | 124.0 | (a) | ↓ |
| 8 | ↓ | ↓ | (a) | (a) | ↓ |

(d) Tunnel Mach number, 0.75; propeller speed, 7982 rpm; helical tip Mach number 1.07.

| | | | | | |
|---|---|---|---|---|---|
| 1 (BPF) | 135.5 | 148.5 | 147.5 | 147.5 | 138.0 |
| 2 | 133.0 | 145.0 | 138.0 | 138.0 | 134.5 |
| 3 | 129.0 | 135.0 | 131.5 | 132.0 | 128.0 |
| 4 | (a) | 131.0 | 127.0 | 126.0 | (a) |
| 5 | ↓ | 127.5 | 128.0 | 125.0 | ↓ |
| 6 | ↓ | 124.5 | 128.0 | 127.0 | ↓ |
| 7 | ↓ | 121.5 | 123.5 | 123.0 | ↓ |
| 8 | ↓ | (a) | 121.0 | 120.5 | ↓ |

[a]Not visible above wind tunnel background.

TABLE II. - Continued

(e) Tunnel Mach number, 0.70; propeller speed, 7496 rpm; helical tip Mach number 1.00.

| Harmonic number | Transducer | | | | |
|---|---|---|---|---|---|
| | A | B | C | D | E |
| | Sound pressure level of harmonic, SPL, dB, ref. $2 \times 10^{-5}$ $N/m^2$ | | | | |
| 1 (BPF) | 140.5 | 142.5 | 136.0 | 144.5 | 136.0 |
| 2 | 131.0 | 144.0 | 138.5 | 135.0 | 129.0 |
| 3 | 131.5 | 139.0 | 138.0 | 131.0 | 128.0 |
| 4 | (a) | 131.0 | 129.0 | (a) | 125.0 |
| 5 | ↓ | 129.0 | (a) | ↓ | (a) |
| 6 | ↓ | 125.0 | ↓ | ↓ | ↓ |
| 7 | ↓ | 122.5 | ↓ | ↓ | ↓ |
| 8 | ↓ | 120.5 | ↓ | ↓ | ↓ |

(f) Tunnel Mach number, 0.65; propeller speed, 6996 rpm; helical tip Mach number 0.93.

| | | | | | |
|---|---|---|---|---|---|
| 1 (BPF) | 137.5 | 139.0 | 140.5 | 141.5 | 134.5 |
| 2 | 133.5 | 135.5 | 129.0 | 131.0 | (a) |
| 3 | (a) | 131.0 | 129.0 | (a) | ↓ |
| 4 | ↓ | 126.5 | (a) | ↓ | ↓ |
| 5 | ↓ | (a) | ↓ | ↓ | ↓ |
| 6 | ↓ | ↓ | ↓ | ↓ | ↓ |
| 7 | ↓ | ↓ | ↓ | ↓ | ↓ |
| 8 | ↓ | ↓ | ↓ | ↓ | ↓ |

[a]Not visible above wind tunnel background.

TABLE II. - Continued

(g) Tunnel Mach number, 0.60; propeller speed, 6506 rpm; helical tip Mach number 0.86.

| Harmonic number | Transducer | | | | |
|---|---|---|---|---|---|
| | A | B | C | D | E |
| | Sound pressure level of harmonic, SPL, dB, ref. $2 \times 10^{-5}$ N/m$^2$ | | | | |
| 1 (BPF) | 133.0 | 135.0 | 135.0 | 131.5 | 127.5 |
| 2 | (a) | 130.0 | (a) | (a) | (a) |
| 3 | ↓ | (a) | ↓ | ↓ | ↓ |
| 4 | | ↓ | | | |
| 5 | | | | | |
| 6 | | | | | |
| 7 | | | | | |
| 8 | | | | | |

(h) Tunnel Mach number, 0.55; propeller speed, 5980 rpm; helical tip Mach number 0.79.

| | | | | | |
|---|---|---|---|---|---|
| 1 (BPF) | 126.5 | 131.0 | 128.0 | 132.5 | 125.0 |
| 2 | (a) | (a) | (a) | (a) | (a) |
| 3 | ↓ | ↓ | ↓ | ↓ | ↓ |
| 4 | | | | | |
| 5 | | | | | |
| 6 | | | | | |
| 7 | | | | | |
| 8 | | | | | |

[a]Not visible above wind tunnel background.

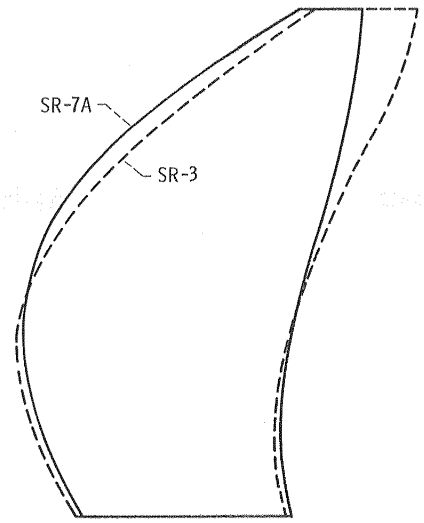
TABLE II. - Concluded

(i) Tunnel Mach number, 0.5; propeller speed, 5442 rpm; helical tip Mach number 0.72.

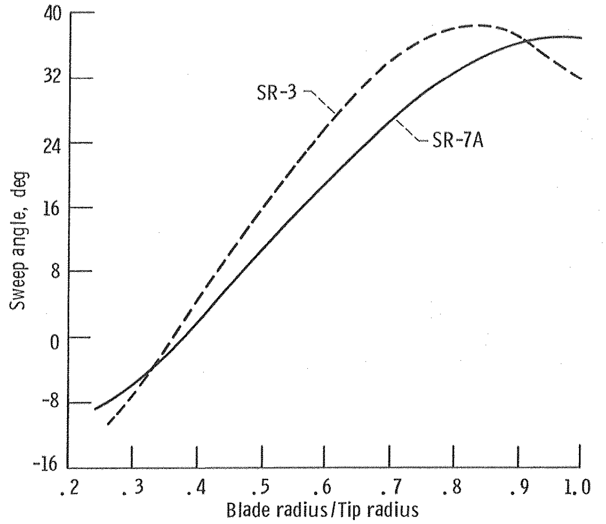
| Harmonic number | Transducer | | | | |
|---|---|---|---|---|---|
| | A | B | C | D | E |
| | Sound pressure level of harmonic, SPL, dB, ref. $2\times10^{-5}$ N/m$^2$ | | | | |
| 1 (BPF) | 122.0 | 123.5 | 121.0 | 122.0 | 124.5 |
| 2 | (a) | (a) | (a) | (a) | (a) |
| 3 | ↓ | ↓ | ↓ | ↓ | ↓ |
| 4 | | | | | |
| 5 | | | | | |
| 6 | | | | | |
| 7 | | | | | |
| 8 | | | | | |

[a]Not visible above wind tunnel background.


Figure 1. - Large-scale advanced propfan on test bed aircraft.

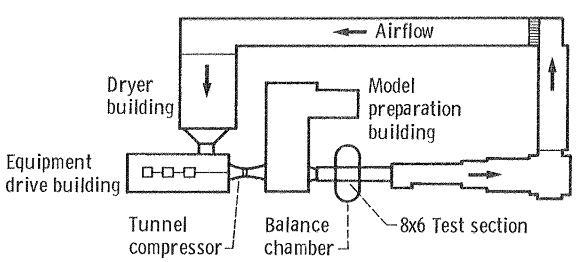



(a) Planform comparison.



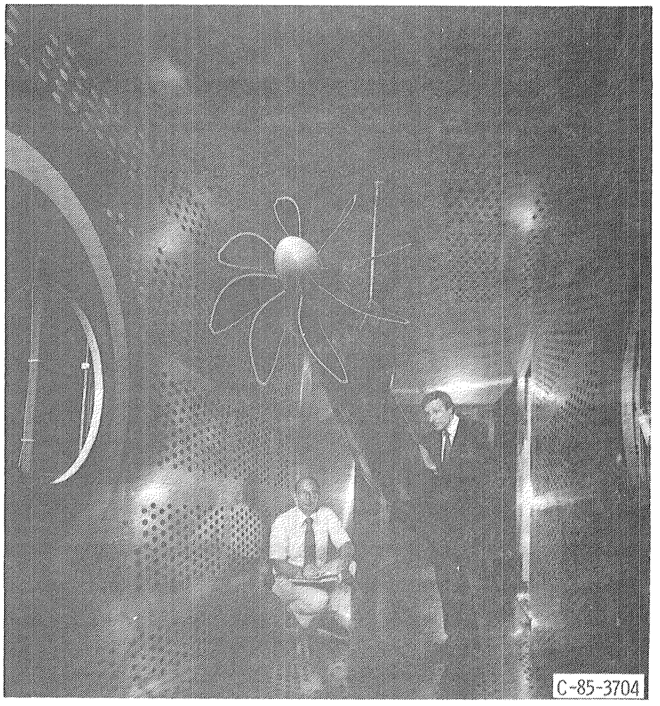

(b) Blade sweep relative to local streamline for the design cruise-deflected condition.

Figure 2. - SR-7A - SR-3 Blade shapes.



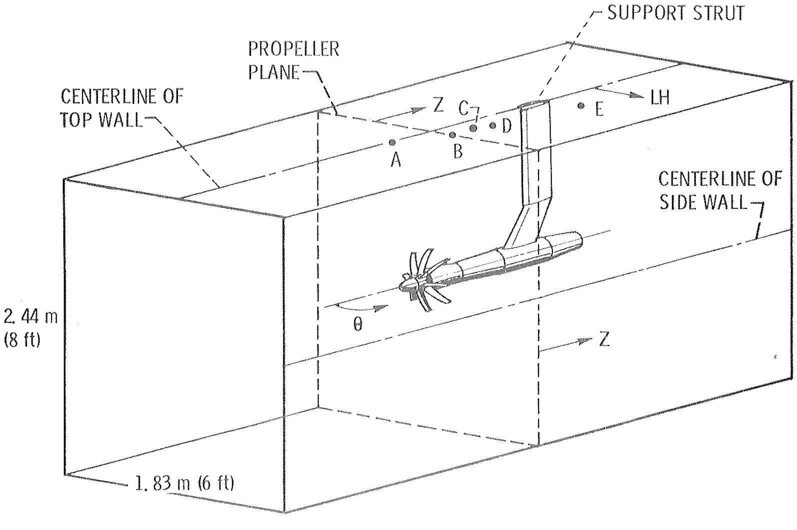

(a) Plan view of 8- by 6-Foot Wind Tunnel.

Figure 3. - Wind tunnel and propeller installation.




(b) SR-7A in test section.

Figure 3. - Concluded.




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

Figure 4. - Pressure transducer positions.

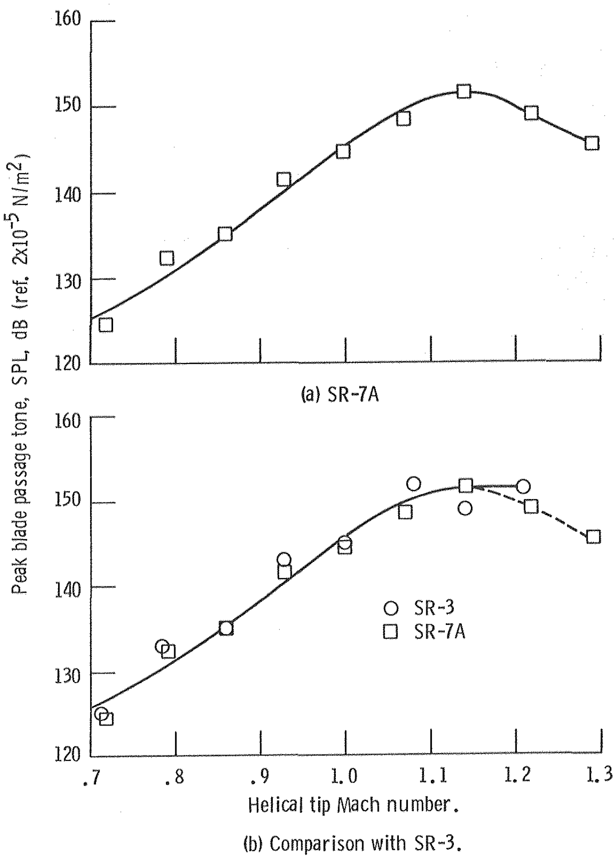



Figure 5. - Maximum blade passing tone variation with Helical tip Mach number.

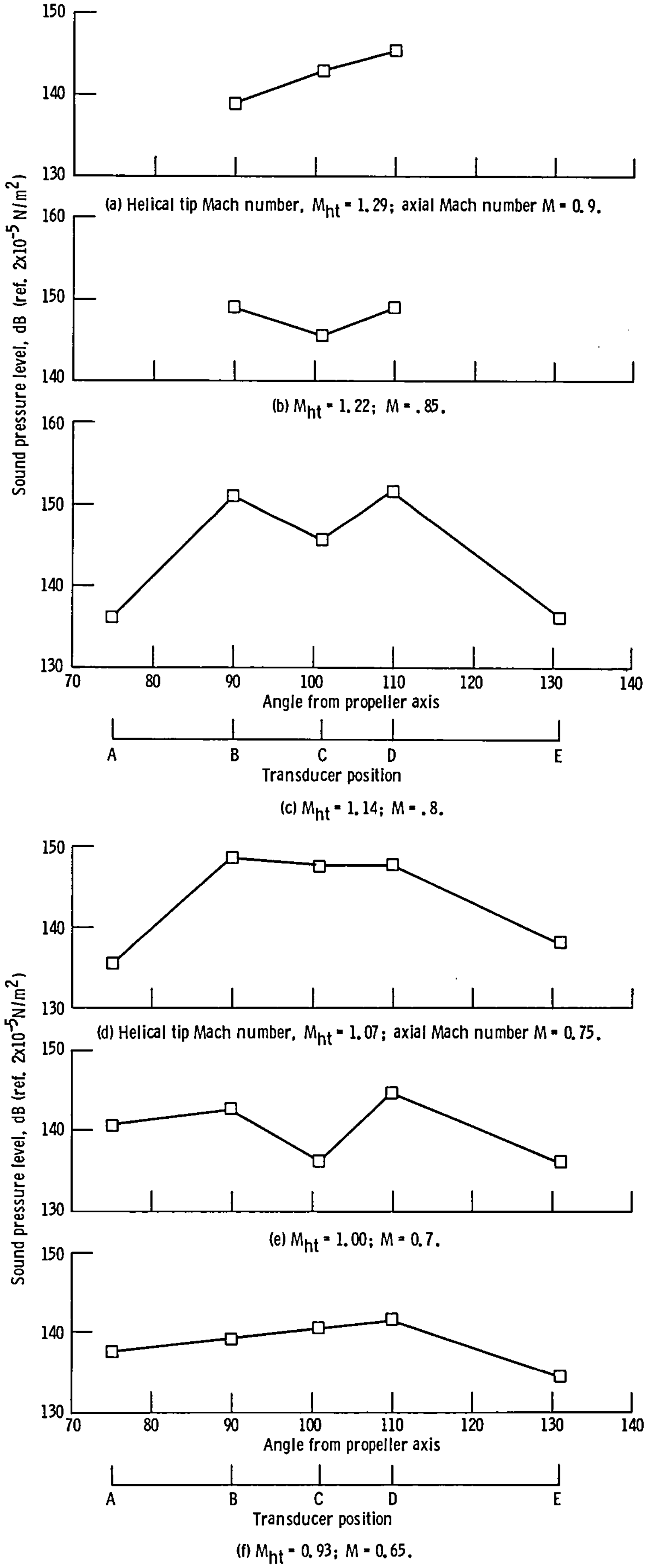
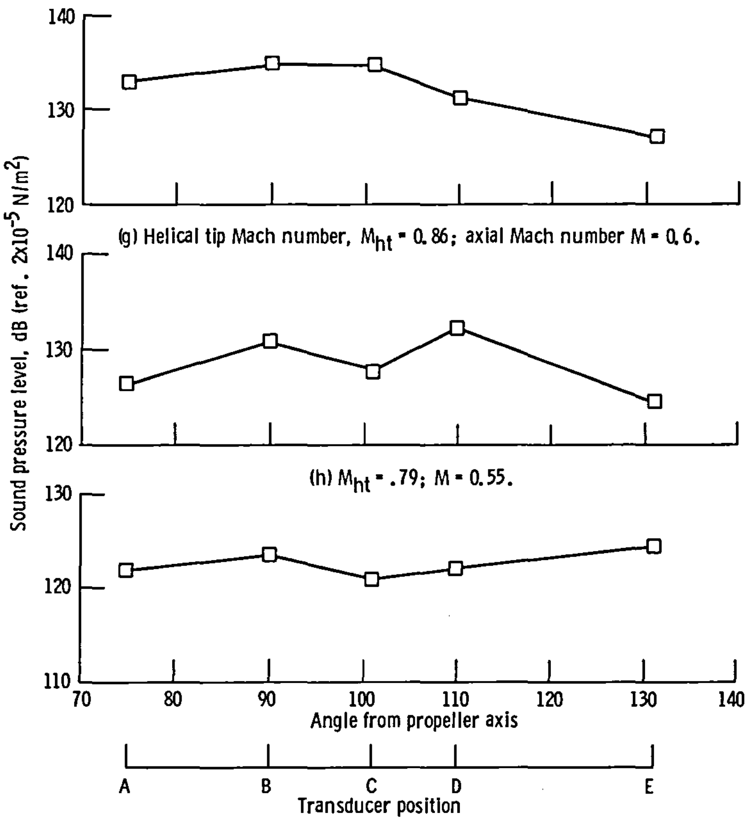



Figure 6. - Sideline directivity of blade passing tone.




(i) $M_{ht}$ = 0.72; M = 0.5.

Figure 6. - Concluded.

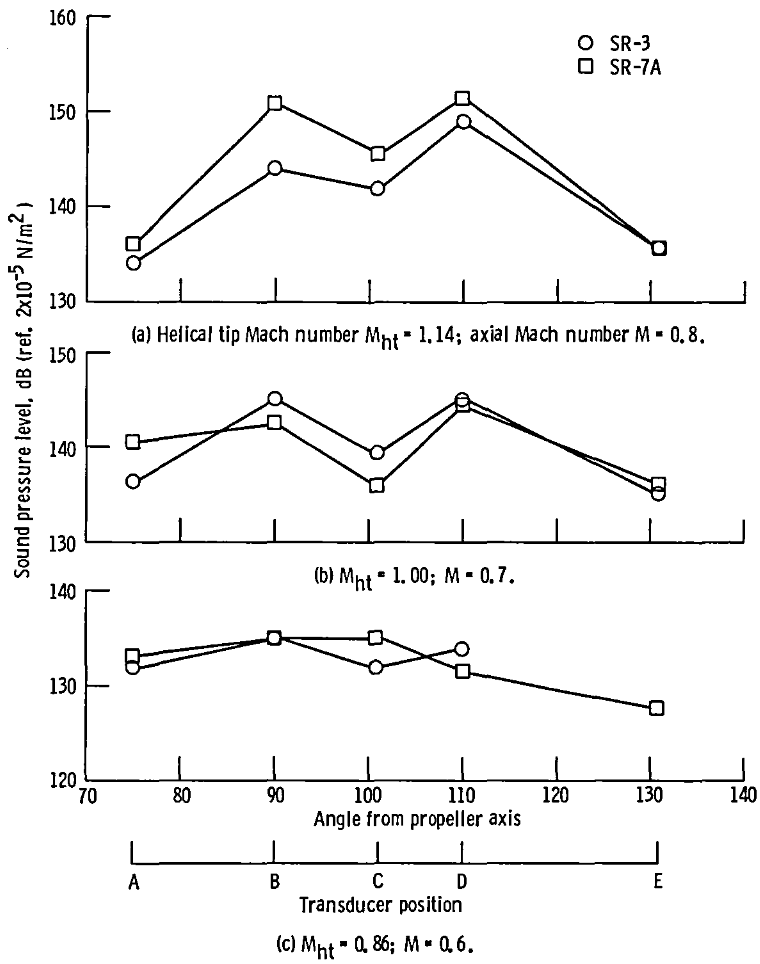



Figure 7. - Comparisons of blade passing tone directivities.

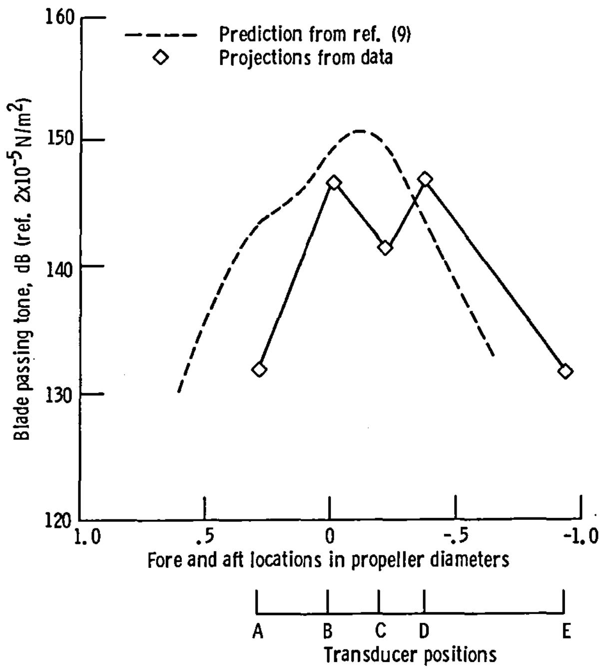



Figure 8. - Blade passing tone on airplane fuselage at cruise condition ($M_{ht}$ = 1.14, M = 0.8, 10.7 Km (35 000 ft) altitude).

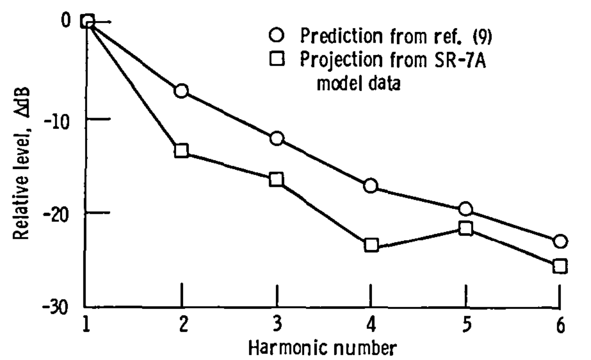



Figure 9. - Level of blade passage frequency harmonics relative to fundamental at maximum noise location for cruise condition of full-scale propeller.

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Preliminary Measurement of the Noise From the 2/9 Scale Model of the Large-Scale Advanced Propfan (LAP) Propeller, SR-7A

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James H. Dittmar

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16. Abstract
Noise data on the Large-scale Advanced Propfan (LAP) propeller model SR-7A were taken in the NASA Lewis 8- by 6-Foot Wind Tunnel. The maximum blade passing tone decreases from the peak level when going to higher helical tip Mach numbers. This noise reduction points to the use of higher propeller speeds as a possible method to reduce airplane cabin noise while maintaining high flight speed and efficiency. Comparison of the SR-7A blade passing noise with the noise of the similarly designed SR-3 propeller shows good agreement as expected. The SR-7A propeller is slightly noisier than the SR-3 model in the plane of rotation at the cruise condition. Projections of the tunnel model data are made to the full-scale LAP propeller mounted on the test bed aircraft and compared with design predictions. The prediction method is conservative in the sense that it over-predicts the projected model data.

17. Key Words (Suggested by Author(s))
Propeller noise; Noise; Supersonic tip speed

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