Cruise Noise of the 2/9 Scale Model SR-7A Propeller

James H. Dittmar*
NASA Lewis Research Center, Cleveland, Ohio
and
David B. Stang†
Sverdrup Technology, Inc., Cleveland, Ohio

Noise data on the 2/9 scale model SR-7A propeller were taken in the NASA Lewis Research Center 8×6 ft wind tunnel. The maximum blade passing tone noise first rises with increasing helical tip Mach number to a peak level, then remains the same or decreases from its peak level when going to higher helical tip Mach numbers. This trend was observed for operation at both constant advance ratio and approximately equal thrust. This noise reduction, or leveling out at high helical tip Mach numbers, points to the use of higher propeller tip speeds as a possible method to limit airplane cabin noise while maintaining high flight speed and efficiency. Projections of the tunnel model data are made to the full scale and compared with predictions. The prediction method is found to be somewhat conservative in that it slightly overpredicts the projected model data at the peak.

Introduction

ADVANCED turboprop-powered aircraft have the potential for significant fuel savings over equivalent core technology turbofan-powered aircraft. To investigate this potential, NASA has an ongoing Advanced Turboprop Program. One element of this program is the Large-scale Advanced Propfan Program (LAP),[1] which includes the design, fabrication, and ground tests of a 2.74 m (9.0 ft) diam propeller. This propeller has been tested statically under the Propfan Test Assessment (PTA) Program,[2] and is being flown on a test bed Gulfstream II aircraft. Under the LAP program, an aeroelastically-scaled model of the 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 full-scale design and for the measurement of the propeller aerodynamic and acoustic performance over a range of flight conditions in wind-tunnel tests. There is concern that the noise from these advanced high-speed propellers may be a cabin environment problem for the airplane at cruise.

Preliminary noise measurements of this propeller were made in the NASA Lewis 8×6 ft wind tunnel using five transducers embedded in the tunnel ceiling.[3] The present SR-7A acoustic testing was done using a plate suspended from the tunnel ceiling. The plate contained 12 transducers, which enabled a better angular resolution of the acoustic data. More accurate forward arc data were obtainable[4] on the plate because of a thinner boundary layer. The testing envelope was expanded from that of the preliminary test. Three propeller blade setting angles and a number of advance ratios were tested at each tunnel Mach number. This report presents the results of the detailed acoustic measurements taken on the SR-7A propeller and compares the measured noise with a semiempirical prediction for the design cruise condition.

Presented as Paper 87-2717 at the AIAA 11th Aeroacoustics Conference, Palo Alto, CA, Oct. 19–21, 1987; received Nov. 9, 1987; revision received Jan. 20, 1988.

*Senior Research Engineer. Member AIAA.
†Research Engineer.

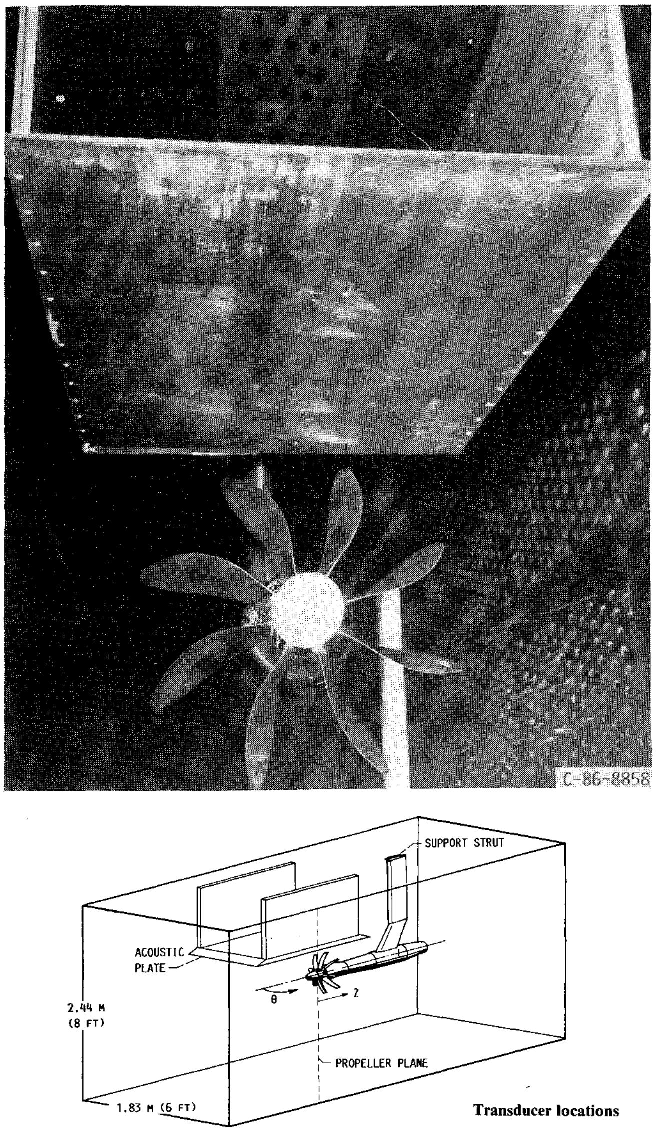
Apparatus and Procedure

The SR-7A propeller, which is normally 62.2 cm (24.5 in.) in diameter, was tested for acoustics in the NASA Lewis 8×6 ft wind tunnel. Table 1 shows some of the design characteristcs of this propeller. The propeller was tested with three design setting angles, measured at the 3/4 radius location of 57.7, 60.1, and 63.3 deg. The 60.1 deg angle was the design cruise blade setting angle at $M=0.8$. The preliminary noise report[3] indicated that 57.3 deg was the design angle, but the present aerodynamic testing showed that the 60.1 deg angle really produced the design conditions. The propeller was operated at these blade setting angles for various advance ratios and tunnel Mach numbers.

A plate was mounted from the tunnel ceiling 0.3 propeller diam from the propeller tip, and transducers were installed flush with the plate surface to measure the noise of the propeller. A photograph of this plate is shown in Fig. 1a, and a sketch of the installed plate is shown in Fig. 1b. Twelve transducers were installed on the plate centerline which was directly above this propeller centerline. The transducer locations are shown in Fig. 1b. The signals from the pressure transducers were recorded on magnetic tape and narrowband spectra were obtained for each of the test points. Typically, the narrowband range was 0 to 10,000 Hz with a bandwidth of 32 Hz. However, because the propeller blade passing frequency was so close to the wind tunnel compressor tones at some of the test conditions, some higher resolutions (0 to 2500 Hz with an 8 Hz bandwidth) were performed to isolate the propeller tone.

Table 1 SR-7A propeller design characteristics

Diameter, cm (in.)	62.2 (24.5)
Number of blades	8
Design Mach number	0.80
Design speed, m/s (ft/s)	244 (800)
Design advance ratio	3.06
Design power coefficient	1.45
Design power loading, kW/m^2 (hp/ft)^2	257 (32.0)
Integrated design lift coefficient	0.202
Activity factor	227
Design efficiency, %	79



POSITION	TRANSDUCER (PLATE 0.3 DIAMETER FROM TIP)											
	1	2	3	4	5	6	7	8	9	10	11	12
	TRANSDUCER POSITION, CM (IN.)											
Z	-46.7 (-18.4)	-41.7 (-16.4)	-30.5 (-12.0)	-16.0 (-6.3)	-8.9 (-3.5)	0.8 (0.3)	8.9 (3.5)	12.4 (4.9)	18.0 (7.1)	25.0 (9.9)	28.7 (11.3)	42.4 (16.7)
	ANGLE FROM UPSTREAM, DEG											
θ	46.8	50.0	58.5	72.2	80	90.9	100	104	110	116.8	120	130.4

Fig. 1 Acoustic plate.

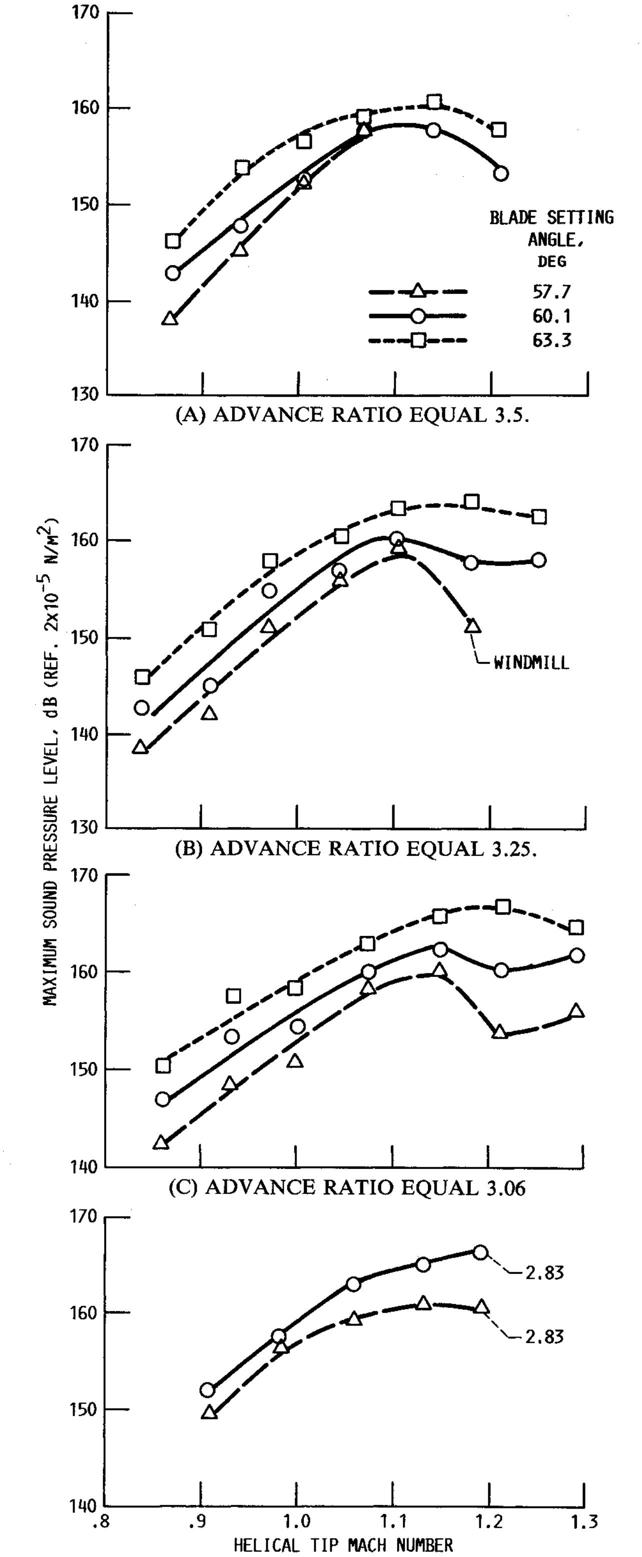


Fig. 2 Maximum blade passing tone variation with helical tip Mach number at constant advance ratio.

Results and Discussion

Peak Blade Passing Tone Variations

It has been indicated in Ref. 3 that the peak blade passing tone noise first increases with increasing helical tip Mach number, and then the noise may decrease from the peak when going to higher helical tip Mach numbers. During this previous testing[3] all of the acoustic transducers were not operating, so some question of that conclusion was possible. The present data allow a more detailed look at this variation of peak tone level with helical tip Mach number.

Variations with Helical Tip Mach Number, Constant Advance Ratio

The propeller blade setting angle was manually set before each test and the tunnel operated at various axial Mach numbers. Curves of peak blade passing tone noise measured on the plate were plotted vs helical tip Mach number in Fig. 2. These plots are at constant advance ratio, and each tunnel axial Mach number tested yields the helical tip Mach number variation. Data for four advance ratios were obtained.

Figure 2a is for an advance ratio $J = 3.5$, Fig. 2b for $J = 3.25$, Fig. 2c for $J = 3.06$, and Fig. 2d for $J = 2.75$. Where available, data for all three propeller blade setting angle are shown. As can be seen, the data does show a peak tone level at a helical tip Mach number of about 1.15 with the noise leveling off or reducing at helical tip Mach numbers above the peak.

The blade loading increases with blade setting angle. As can be seen from these curves, the noise at subsonic helical tip

Mach numbers increases with increasing blade setting angle almost as if the curves were just uniformly shifted higher. This is probably the result of increased loading noise. In the subsonic portion of the curves, the noise increases approximately as the square of the input power ratio.

Figure 2c presents the peak blade passing tone variations with helical tip Mach number at the design advance ratio of 3.06. At the highest blade setting angle of 63.3 deg, the noise peaks around a helical tip Mach number of 1.2 and then reduces at the higher helical tip Mach numbers. The data at the design angle $\beta = 60.1$ deg and the lower $\beta = 57.7$ deg both show a peak around $M_{ht} = 1.15$, a reduction around $M_{ht} = 1.2$ and then a noise increase from the $M_{ht} = 1.2$ level to the $M_{ht} = 1.29$ condition. This humped shape to the curve is present for both of these lower loaded blade angles. The hump around $M_{ht} = 1.5$ may represent a different noise mechanism. Possibilities for this mechanism include "quadrupole noise"[5] and the shock wave pressure rise.[6] As the loading is increased from the 57.7 deg angle case to the $\beta = 60.1$ deg case, the hump is reduced, and the hump disappears at the highest loaded case $\beta = 63.3$ deg. This may indicate that the noise from this mechanism can be seem at the lower loading conditions $\beta = 57.7$ deg and 60 deg, but the loading noise dominates at higher blade angles.

Comparison with Previous Data

The previous data,[3] using five ceiling transducers, were taken with a blade setting angle of 57.3 deg. These data were adjusted to the plate position using 20 log of the distance from the propeller centerline. This resulted in 8 dB being added to the previous data. Figure 3 shows the previous plot of noise vs helical tip Mach number from Ref.3 compared with that obtained with a 57.7 deg blade setting angle. As can be seen in Fig. 3, the comparison of the peak noise variation with helical tip Mach number for the two sets of data are very good, particularly when the difference in angular resolution and the small difference in blade setting angles are considered.

Variations with Helical Tip Mach Number at Approximately Equal Thrust

The experiments reported herein were performed by testing at fixed advanced ratios at different tunnel Mach numbers. Three blade setting angles were tested. Although the tests were not structured to provide this comparison, available combinations of blade seting angle and advance ratio can be used to cross plot the data and obtain the variation of peak noise with helical tip Mach number at approximately equal thrust. Figure 4 shows these plots of peak blade passing noise vs helical tip Mach number at approximately equal thrust. Figure 4a is for an axial Mach number of 0.85. Data taken with the 60.1 deg angle at $J = 3.25$, 63.3 deg angle at $J = 3.75$, and 57.7 deg angle at $J = 3.06$ are plotted in this figure. These points are at approximately 50% thrust. The thrust at the 57.7 deg angle at $J = 3.06$ point was not available, but at $M = 0.75$ and $M = 0.80$, the thrust was 52 and 50% respectively, thus the thrust at $M = 0.85$ was taken to be approximately 50%. As observed, the noise reduces at the higher helical tip Mach numbers.

Figure 4b is for an axial Mach number of 0.8. Data were again taken from the three blade setting angles with the goal of constructing a curve at approximately 85% thrust. Data were available at the 57.7 deg and 63.3 deg setting angles at approximately 85% thrust but not at 60.1 deg. Therefore, two data points are shown for the 60.1 deg angle—one at 100% thrust and the other at 73% thrust. The assumption here being that the 85% noise data would lie somewhere in between. As can be seen from this figure, the noise again appears to peak and then level off or reduce from that peak as the helical tip Mach number is increased.

It should be noted here that the reductions from the peak are occurring at the 57.7 deg case, which was somewhat off design. It may be possible to show even more of a noise reduction if a propeller blade were actually designed for this higher helical tip Mach number.

Peak Tone Contours

Propeller operating maps showing the curves of power coefficient against advance ratio are shown in Fig. 5. Attempts have been made to draw contours of constant peak blade passing tone sound pressure level on these operating maps. These curves at $M = 0.9$, 0.8, 0.7, and 0.6, show an overall acoustic "picture" of the effect of blade operating parameters on peak passing tone levels.

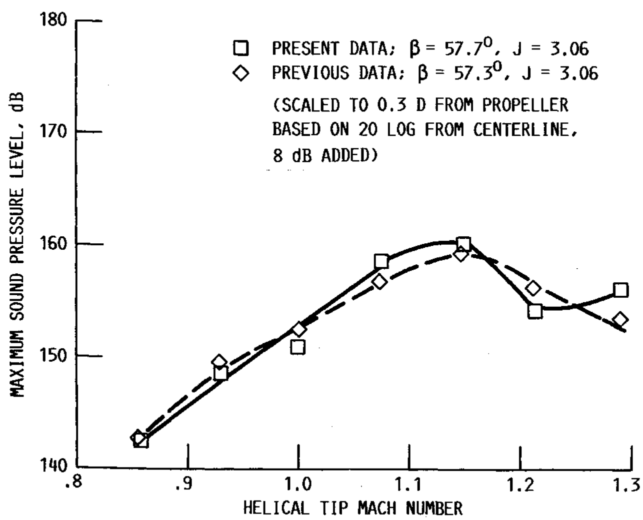


Fig. 3 Comparison of maximum blade passing tone variation from previous data with present data.

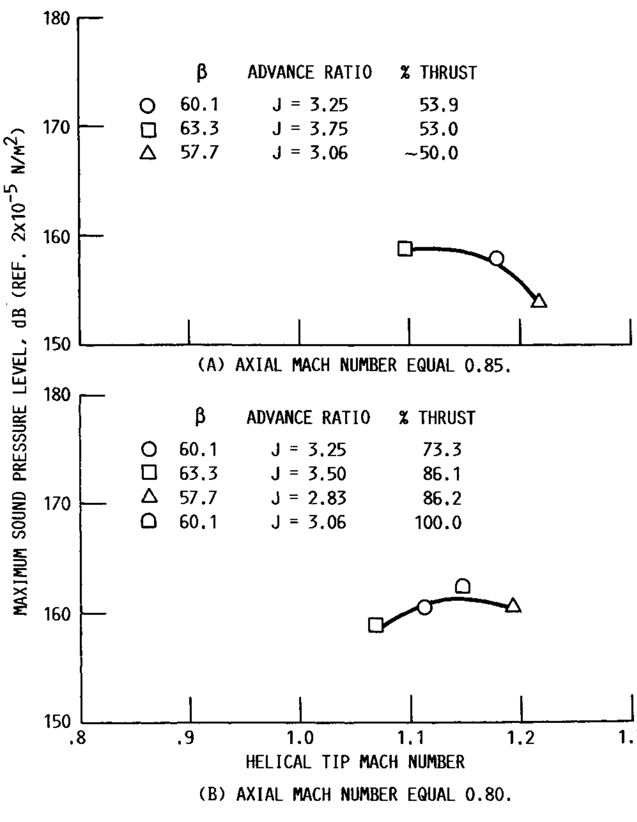


Fig. 4 Maximum blade passing tone variation with helical tip Mach number at approximately constant thrust.

These contour plots indicate that changes in propeller tip speed have a larger effect on noise than do changes in blade setting angle. An increase in tip speed at constant blade setting angle results in tracing a performance curve toward lower advance ratios. Since the noise contours are close to normal to the performance curves, large noise increase are observed. Increases in blade angle at constant tip speed result in going between performance curves at constant advance ratio, since this movement is close to parallel with the noise contours only a small noise increase occurs.

Directivities

Blade passing tone levels for the SR-7A propeller are shown as a function of angular poosition in Fig. 6. Directivities are shown in Fig. 6 for the design advance ratio ($J = 3.06$) condition at the seven Mach numbers tested.

Each Mach number figure shows the data for the three blade setting angles tested. As can be seen, the curves are similar in shape for the different blade setting angles. The peak levels have been shifted with the higher loading (higher blade angle) cases showing more noise. The levels toward the

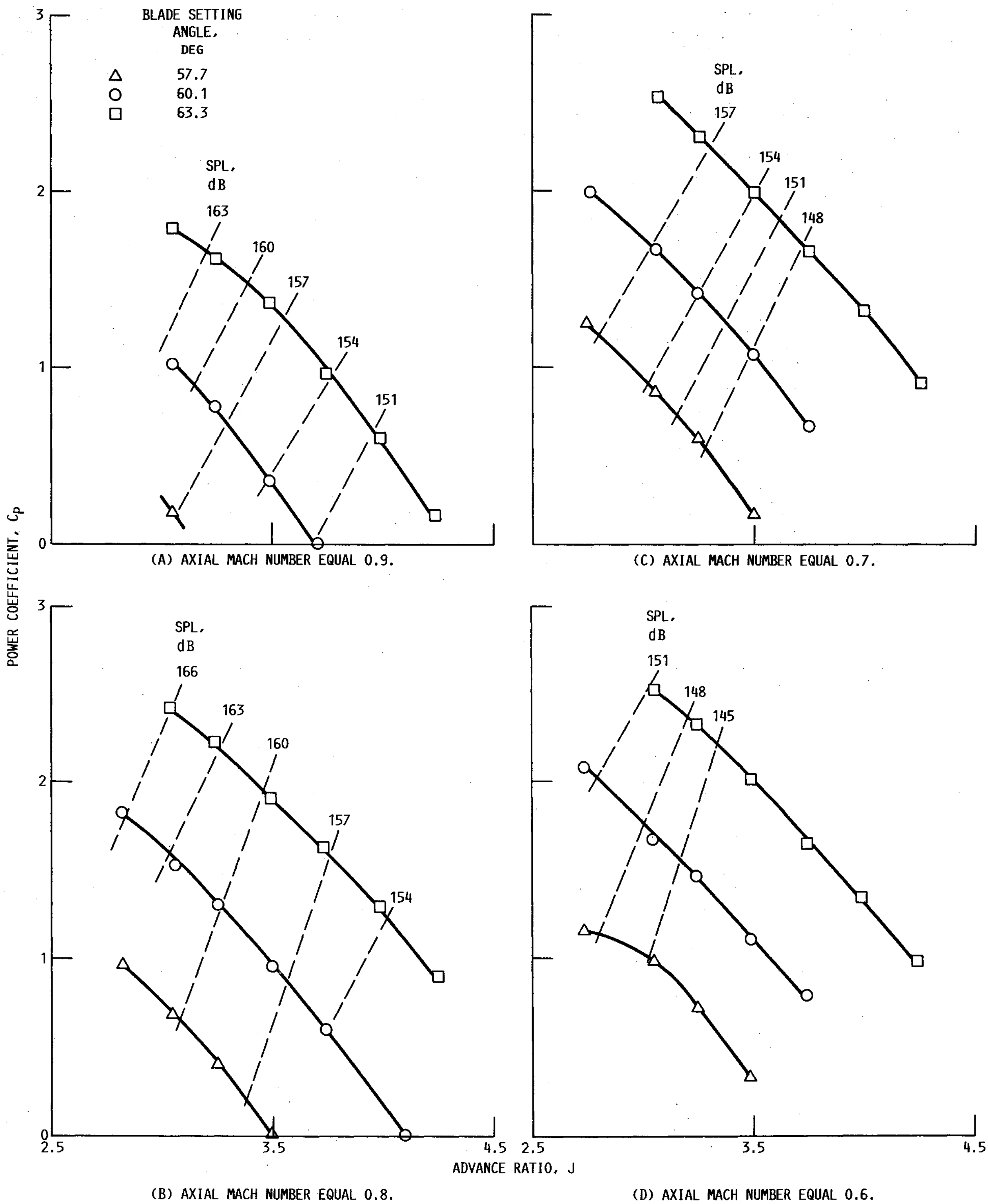


Fig. 5 Maximum blade passing tone levels on propeller operating map.

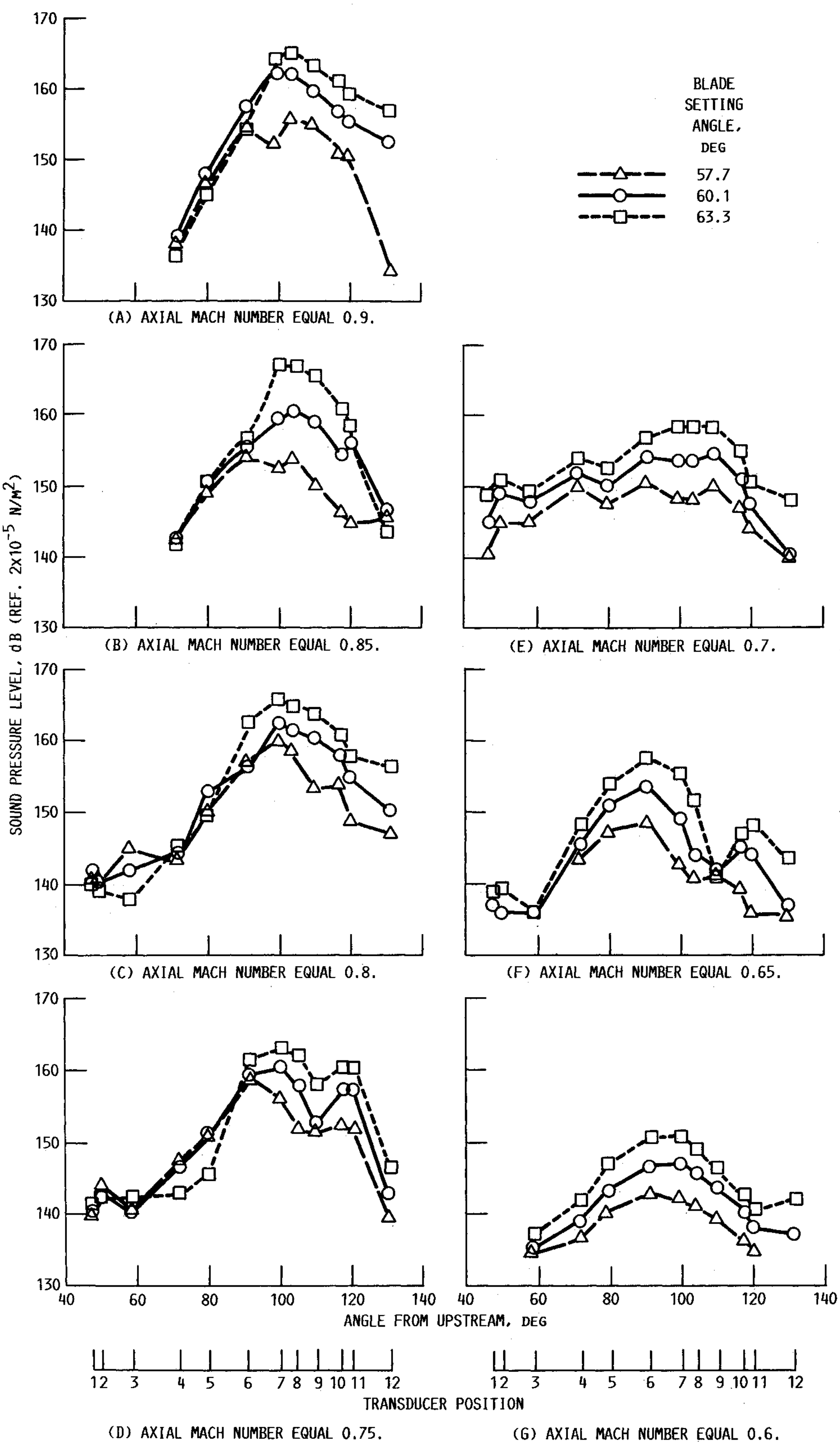


Fig. 6 Blade passing tone directivities at an advance ratio of 3.06.

front are closer together than at the peak, particularly at the higher Mach numbers (Figs. 6a-6d). This may be an indication that the forward noise may not be controlled by the blade loading.

The directivities at most of the Mach numbers are also similar in shape with the noted exception of the data at $M=0.7$. Here the directivity is much flatter than at other Mach numbers. The forward noise is higher at $M=0.7$ than at either $M=0.65$ or $M=0.75$, and the noise at the forwardmost positions around 50 deg is higher here than at any other Mach number. The helical tip Mach number at $M=0.7$ is approximately 1.0, so it may be that this is some transient transonic effect. Since the far-forward levels are higher here than at any other Mach number, this may represent a cabin noise peak at the far-forward angles as the airplane is accelerated to $M=0.8$ cruise conditions.

Previous directivities at $M=0.65$ and $M=0.60$ taken on the tunnel ceiling indicated problems with the data being contaminated with tunnel wall reflections.[3,7] The data taken here at 0.3 diam on the plate rather than on the tunnel wall do not appear to suffer those signal to noise problems.

Airplane Projections

Data Adjustments

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.[8] Correcting a tunnel operating pressure of 76.5×10^3 n/m^2 (11.1 psi) at cruise conditions to a flight altitude of 10.7 km (35,000 ft) yields a decrease of 10 dB.

The acoustic plate is 0.3 diam from the propeller tip and the airplane fuselage is 0.6 diam from the tip. Based on the distance from the propeller centerline the size and distance correction yields a decrease of 3 dB. The net reduction from tunnel to flight conditions is then 13 dB.

A plot of the projected full-scale propeller blade passing tone on the Gulfstream II airplane fuselage at cruise ($M_{ht} = 1.14$, $M = 0.08$, $\beta = 60.1$, $J = 3.06$) is shown in Fig. 7.

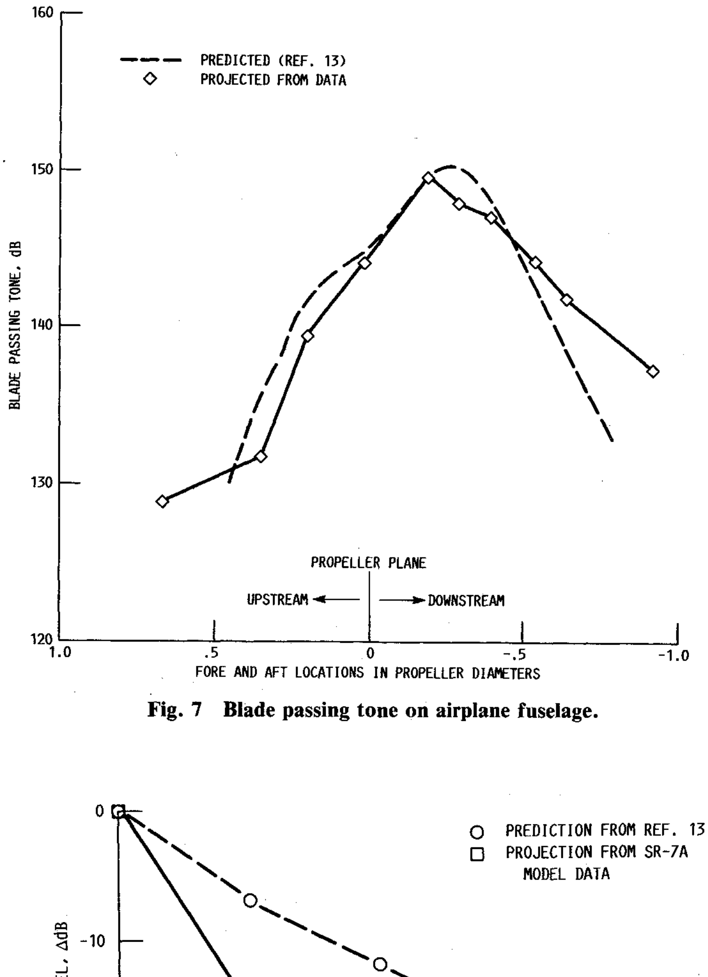


Fig. 7 Blade passing tone on airplane fuselage.

Comparison with Prediction

A graphical method for predicting the noise of the full-scale SR-7 propeller is presented in Ref. 9. This method is based on theoretical calculation procedures, and the computer results have been generalized for the SR-7 propeller. Figures 8, 16, and 22a of Ref. 9 were used to predict the free-field SR-7 propeller on the Gulfstream II airplane. Six decibels were added to these free-field numbers to account for the pressure doubling effects of the airplane fuselage.

The prediction method of Ref. 9 locates its fore and aft positions from the peak overall noise level location. The prediction is placed here on Fig.7 by aligning the predicted curve base location with the location of the measured position of maximum overall noise.

As can be seen the prediction compares very well with the projected data. The peak noise level is slightly overpredicted, and the level aft of the propeller is slightly underpredicted. In general, the comparisons in level and directivity are very good.

The relative levels of the blade passing tone harmonics with respect to the fundamental are also of interest. A comparison of the predicted levels with measured data at the maximum noise position at cuise is shown in Fig. 8. The predictions for this position are also shown. The measured harmonics relative to the fundamental are mostly lower than predicted with only the fourth hamonic being the same. These comparisons indicated the predictions are somewhat higher than the noise projected from the model data for both the fundamental blade passing tone and the harmonics at the peak location.

Concluding Remarks

Noise data on a model of the LAP propeller SR-7A were taken in the NASA Lewis 8×6 ft wind tunnel. The propeller was tested at three blade angles. Plots of the maximum blade passing tone vs helical tip Mach number at constant advance ratio first rise with increasing Mach number to a peak level then remain the same or reduce from the peak when going to higher helical tip Mach numbers. Some limited curves of maximum blade passing tone vs helical tip Mach number, taken at approximately equal thrust, showed the same reduction from the peak noise level when going to higher helical tip Mach numbers. This noise reduction, or leveling out at high helical tip Mach numbers, points to the use of faster rotating propellers as a possible method to limit cabin noise while maintaining high flight speed and efficiency.

Projections for the blade passing noise of the full scale 2.74-m (9-ft) diam propeller, to be flown on the Gulfstream II test bed aircaft, were made from the wind-tunnel model data. These projections were compared with a semiempirical prediction of the noise. The predicted blade passage tone generally compared very well with the projected data both in level and directively. The prediction did slightly overestimate the blade passage tone at the peak, and the predicted levels of the har-

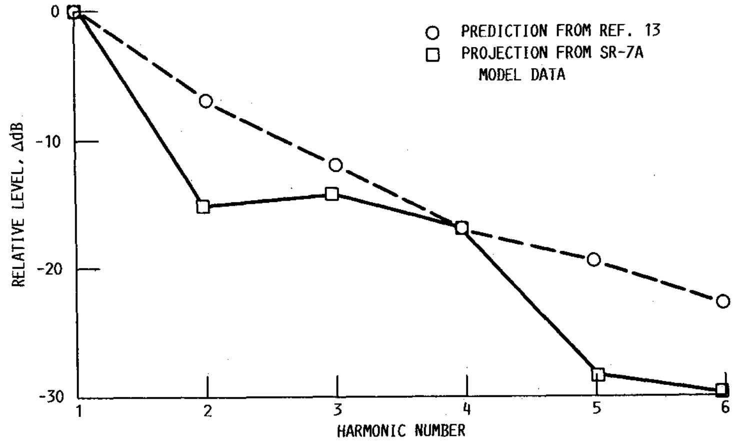


Fig. 8 Level of blade passage frequency harmonics relative to fundamental at maximum noise location for cruise condition of full-scale propeller.

monics were somewhat higher than the projected data. The prediction method was found to be somewhat conservative in the sense that it ovepredicted the projected model data at the peak.

References

[1]Sagerser, D.A. and Ludemann, S.G., "Large Scale Advance Propfan (LAP) Program Progress Report," AIAA Paper 85-1187, July 1985.

[2]Withers, C.C. "Static Tests of the PTA Propulsion System," AIAA Paper 87-1728, July 1987.

[3]Dittmar, J.H., "Preliminary Measurement of the Noise from the 2/9 Scale Model of the Large-Scale Advanced Propfan (LAP) Propeller, SR-7A," NASA TM-87116, Dec. 1985.

[4]Dittmar, J.H., Burns, R.J., and Leciejewski, D.J., "An Experimental Investigation of the Effect of Boundary Layer Refraction on the Noise from a High Speed Propeller," NASA TM-83764, Sept. 1984.

[5]Hanson, D.B. and Fink, M.R., "The Importance of Quadruple Sources in Prediction of Transonic Tip Speed Propeller Noise," *Journal of Sound and Vibration,* Vol. 62, No. 1, Jan. 1979, pp. 19–38.

[6]Dittmar, J.H. and Rice, E.J., "A Shock Wave Approach to the Noise of Supersonic Propellers," NASA TM-82752, Dec. 1981.

[7]Dittmar, J.H., "Why Credible Propeller Noise Measurements are Possible in the Acoustically Untreated NASA Lewis 8-by-6 Foot Wind Tunnel," *Journal of the Acoustical Society of America,* Vol. 75, June 1984, pp. 1913–1914.

[8]Dittmar, J.H., "Further Comparison of Wind Tunnel and Airplane Acoustic Data for Advanced Design High Speed Propeller Models," NASA TM-86935, April 1985.

[9]Parzych, D., Cohen, S., and Shenkman, A., "Large-Scale Advanced Propfan (LAP) Performance, Acoustic, and Weight Estimation," NASA CR-174782, Feb. 1985.