1-9-91
E5809

NASA Technical Memorandum 103635

Potential Reduction of En Route Noise From an Advanced Turboprop Aircraft

James H. Dittmar
Lewis Research Center
Cleveland, Ohio

December 1990

NASA

POTENTIAL REDUCTION OF EN ROUTE NOISE FROM AN ADVANCED TURBOPROP AIRCRAFT

James H. Dittmar
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135-3191

E-5809

SUMMARY

When the en route noise of a representative aircraft powered by an eight-blade SR-7 propeller was previously calculated, the noise level was cited as a possible concern associated with the acceptance of advanced turboprop aircraft. Some potential methods for reducing the en route noise were then investigated and are reported herein. Source noise reductions from increasing the blade number and from operating at higher rotative speed to reach a local minimum noise point were investigated. Greater atmospheric attenuations for higher blade passing frequencies were also indicated. Potential en route noise reductions from these methods were calculated as 9.5 dB (6.5 dB(A)) for a 10-blade redesigned propeller and 15.5 dB (11 dB(A)) for a 12-blade redesigned propeller.

INTRODUCTION

Advanced turboprop-powered aircraft have the potential for significant fuel savings over technologically equivalent turbofan-powered aircraft. To investigate this potential, NASA conducted the Advanced Turboprop Program (ref. 1). In this program a single-rotation turboprop design was projected to use 15 to 30 percent less fuel than turbofans.

For these fuel savings to be implemented, however, the new turboprop aircraft must be acceptable to the public. Scale models of these advanced propellers have been investigated for community noise around airports during takeoff and landing (ref. 2) and for cabin noise levels during cruise (refs. 3 to 6). Recently the en route noise, the noise under the aircraft flightpath, was identified as a possible concern associated with the advanced turboprop at cruise. Reference 7 shows that the peak sound pressure level for a representative two-engine, single-rotation aircraft may be approximately 67.5 dB, which yields 58.5 dB on the A-weighted scale. The A-weighted scale provides a measure of the way the human ear perceives noise. The study explored some variations in the gross propeller design parameters that show potential for reducing en route noise and evaluated the predicted reductions.

PROCEDURE

Reference 7 used scale-model propeller noise measured in a wind tunnel (data from ref. 5) to estimate the en route noise of a representative two-engine, single-rotation advanced turboprop aircraft. A hypothetical narrow-body, 100-passenger aircraft with two engines was sized in reference 8. The aircraft was to cruise at Mach 0.8 at 9144 m (30 000 ft) and had 3.78-m (12.4-ft) diameter propellers with a tip speed of 244 m/sec (800 ft/sec).

Projection to Flight

The single-rotation, scale-model data on the eight-blade SR-7 propeller model were previously taken by five transducers on the wall of the NASA Lewis Research Center's 8- by 6-Foot Supersonic/Transonic Wind Tunnel (ref. 5). The preliminary data on this propeller were obtained with a blade setting angle of 57.3 °. In order to project the tunnel data to flight, adjustments were made in the study of reference 7 to account for distance, thrust, atmospheric conditions, and the pressure amplification at the measuring surfaces. The thrust was assumed to be proportional to the propeller diameter squared with a thrust noise correction of 10 times the logarithm of the thrust ratio. The noise was assumed to decay with distance as 20 times the logarithm of the distance ratio. At the same relative distance, measured in propeller diameters, the thrust and distance adjustments from tunnel to full scale cancelled out. The 8- by 6-Foot Supersonic/Transonic Wind Tunnel operates at a pressure of 76.5×10^3 N/m^2 (11.1 psi), and the pressure at 9144-m (30 000-ft) altitude is approximately 30.3×10^3 N/m^2 (4.4 psi). Using 20 times the logarithm of the pressure ratio yields a reduction of 8 dB from the tunnel data. Another 6 dB was subtracted from the tunnel levels to account for the pressure doubling on the measurement surface in the tunnel. The tunnel data for one propeller were then reduced by a total of 14 dB to convert the noise level to a free-field level at the arbitrary reference plane, 1.5 diameters from the propeller tip.

More extensive noise and performance data have been taken on the SR-7 propeller model. These data were reported in reference 9 (aerodynamic) and reference 6 (acoustic). In reference 6 the noise data were taken with 12 transducers embedded in a plate 0.3 diameter from the propeller tip (fig. 1). This new experimental setup enabled both a larger angular range than the wall measurements and a better angular definition. In aerodynamic testing (ref. 9) the 60.1° blade setting angle yielded performance more equivalent to the design conditions than did the 57.3° angle used previously in reference 5. The combination of the change in design blade setting angle and the more detailed acoustic data justifies the calculation of a new "baseline" en route noise estimate for use in this study. In the following paragraphs the data from reference 6 are used to calculate this baseline.

The data from reference 6, at the 60.1° blade setting angle, were taken 0.3 diameter from the propeller tip. These data were translated to the tunnel wall position by using 20 times the logarithm of the distance ratio from the propeller centerline. This yielded an 8-dB reduction in the reference 6 data to translate them to the wall position. This 8-dB adjustment was then added to the 14-dB adjustment from the wall sideline to flight, described earlier, to provide a total reduction of 22 dB from the reference 6 data. The projected free-field noise levels at cruise, at a 1.5-diameter sideline from the propeller tip, are shown in table I for the first two harmonics. Also in this table are the levels previously used in reference 7 from the five transducers on the tunnel ceiling when the propeller was operated at the 57.3° blade setting angle. Only the first two harmonics were used because reference 7 showed that the higher harmonics do not contribute to the A-weighted noise level. As can be seen in table I the new levels, at the greater blade setting angle (60.1°), are slightly higher than the previous data at 57.3°. The data at the 60.1° blade setting angle (table I(a)) were used in this study to calculate a baseline en route noise estimate against which improved propeller en route noise levels would be compared.

Adjusting Flight Levels to Yield Ground Levels

In order to obtain an estimate of the en route noise, adjustments are needed for the distance, the atmospheric attenuation, and the number of engines. The distance adjustment, using 20 times the logarithm of the distance ratio, indicated that the flight noise should be reduced by 61.5 dB when it reaches the ground. Because it was assumed that the sources are not coherent, 3 dB should be added to the single-propeller data of table I to get values for the two-engine aircraft. The net result of these two adjustments is a reduction of table I numbers by 58.5 dB. An estimate of the atmospheric attenuation of the noise is not as straightforward, as discussed in the following paragraphs.

The common method of estimating atmospheric attenuation for aircraft noise is given in reference 10. The amount of atmospheric attenuation depends on the humidity and temperature of the air and the frequency of the sound. In reference 7 the humidity was assumed to be constant with altitude at 72 percent and the temperature to vary from 59 °F on the ground to -45 °F at altitude. In this en route noise estimate the temperature variation used was the same as the standard-atmosphere variation used in reference 7, but a relative humidity variation with altitude was also used to improve the prediction. Table II shows the temperature and humidity variations with altitude that were used in the en route noise estimates presented in this report.

As a result of the varying temperature and humidity along the path from the aircraft to the ground, an atmospheric attenuation was obtained by an integration process. The vertical distance was divided into 1524-m (5000-ft) increments, and the average humidity and temperature for each increment were used to determine the attenuation.

The baseline propeller on the representative aircraft emitted noise with a blade passing frequency of 163 Hz and had harmonics at 326, 489, etc. Because of the Mach 0.8 velocity of the aircraft a Doppler shift in these frequencies would be observed on the ground. The frequency observed on the ground would be some multiplier of the frequency emitted. This ratio is expressed as

$$\frac{\text{Frequency observed}}{\text{Frequency emitted}} = \frac{1}{1 - M \cos \theta_e}$$

where M is the aircraft Mach number and θ_e is the noise emission angle. The noise emission angle is different from the angle where the noise would be measured. This difference is the result of the aircraft velocity. The noise emission angle is expressed as

$$\theta_e = \theta_m - \sin^{-1}(M \sin \theta_m)$$

where θ_m is the measured angle. The atmospheric attenuations were calculated by using the Doppler-shifted frequencies and the distance along the noise path calculated by using the noise emission angle.

The tables in reference 10 for atmospheric attenuation only go as low as -17 °C (1 °F). As can be seen from table II the temperatures at altitudes above 4572 m (15 000 ft) were below -18 °C (0 °F). In order to approximate the attenuations at such temperatures, it must be assumed that the attenuation varies symmetrically with temperature about the peak attenuation. The attenuations below −18 °C (0 °F) are small relative to the peak, and any slight variations from symmetry probably do not materially affect the results. The atmospheric attenuations estimated for the aircraft flyover with the baseline propeller are presented in table III.

En Route Noise Levels

The attenuations listed in table III were applied to the data of table I. When the adjustments for distance, number of engines, and atmospheric attenuation were applied, the baseline en route noise was estimated for 12 θ_m's (table IV(a)). The maximum sound pressure level was 68.5 dB at $\theta_m = 116.8°$.

The A-weighted sound pressure level for each θ_m is shown in table IV(b). The maximum A-weighted sound pressure level was 59 dB(A) at θ_m=110°. These noise levels are free-field levels at the ground plane and would be increased by whatever pressure amplification would occur on the surface where the noise would be measured. The levels shown here, 68.5 dB and 59 dB(A), are slightly higher than those obtained in reference 7 (67 dB and 58.5 dB(A)), primarily because the 60.1° blade angle data are noisier than the 57.3° data.

The values in table IV were used as a baseline estimate of the en route noise for the representative aircraft. The en route noise levels for the improved propellers discussed in this report were compared with the baseline estimate to determine the amount of improvement.

POTENTIAL NOISE REDUCTION

This section discusses some variations in gross propeller parameters that could reduce en route noise. First, possible source noise reductions are addressed, then increased atmospheric attenuation and the effects of the A-weighted noise scale.

Reduced Source Noise

At the Mach 0.8 design cruise condition the propeller noise is composed primarily of loading and thickness noise components. The thickness noise depends primarily on the volume displacement of the blade and the blade velocity. The loading noise depends also on the blade velocity and the forces imposed on the air by the blade. The relative strength of the two components for the SR-7 blade may be inferred from figure 2. The plot of maximum blade passing tone noise versus helical tip Mach number is taken from reference 6. The three curves are for three blade setting angles, which represent different amounts of loading. The middle curve is for the 60.1° blade setting angle used for the baseline noise in this report. The curves are roughly parallel up through a helical tip Mach number of 1.14; then they show different trends depending on the blade setting angle. The more highly loaded 63.3° blade was noisier than the baseline 60.1° blade, and the more lightly loaded 57.7° blade was quieter than the baseline curve.

At the same helical tip Mach number the thickness noise component of the SR-7 propeller blade should be approximately the same for the three blade setting angles tested. If the thickness noise were dominant, the three curves would have the same noise level. Since the curves from reference 6 are not the same and vary directly with the loading, it was assumed that the loading noise is dominant. It was therefore assumed in this study that the loading noise was dominant on the representative propeller and that reductions in the loading noise would directly reduce the propeller noise.

A redesigned propeller, in order to propel the representative aircraft, must maintain the same thrust as the baseline propeller. Therefore, reductions in total loading, like those that occur with a change in blade setting angle as in figure 2, would not be possible. However, the loading noise is reduced when the loading per blade is reduced. Increasing the number of blades while maintaining the same total thrust is then a method of reducing the propeller source noise through a variation in a gross propeller parameter.

Experimental results on conventional propellers have indicated conservatively that the noise is reduced at approximately 20 times the logarithm of the blade number ratio. This assumption has been incorporated in the noise prediction technique of reference 11. This technique for predicting the effect of increasing the blade number was used in this study to estimate improvements in en route noise. Calculations were also made using a Gutin type of noise prediction for the effect of increasing the blade number (ref. 12). These Gutin calculations yielded even more noise reduction than the method that used 20 times the logarithm of the blade number ratio. In this study 20 times the logarithm of the blade number ratio was used because it gave a conservative estimate of the noise reduction.

The ability to increase blade number is limited by physical constraints. As the number of blades is increased, the solidity is also increased and flow problems start to develop. For example, hub choking was observed in the 10-blade SR-6 propeller (ref. 13). Although some of the hub choking could be relieved by hub redesign, a 12-blade, single-rotation propeller may present a reasonable limit to the number of blades possible. Therefore, in this study, only 10- and 12-blade redesigns were considered. By using 20 times the logarithm of the blade number ratio, the tone level of the 10-blade design would be reduced 2 dB relative to the 8-blade SR-7 propeller, and the tone level of the 12-blade design would be reduced 3.5 dB.

Figure 2 also shows another possible way that source noise might be reduced by varying a gross propeller parameter. Normally noise is thought to increase with helical tip Mach number, but the curves for the SR-7 model propeller and other curves for different advanced propellers (refs. 3 and 4) show that the noise at a given blade setting angle bends over and appears to reach a local minimum. For the baseline SR-7 propeller at the 60.1° angle, this minimum occurred at a helical tip Mach number of about 1.22. The design point of the SR-7 propeller was at a helical tip Mach number of 1.14. The noise at the minimum was approximately 2 dB lower than that at the design point. A source noise reduction of 2 dB was then conservatively estimated to occur if the helical tip Mach number of the propeller design point was increased to 1.22. This 2-dB estimate was considered to be conservative because with more blades the loading per blade would be lower and the lower loading curve for the 57.7° blade setting angle shows the reduction from the peak to be greater than 2 dB.

As shown in figure 2, a reduction in rotative speed would also bring about a reduction in noise. However, at a fixed axial velocity and thrust level a lower rotative speed would probably reduce the efficiency of the propeller and increase the drag. Increasing rotative speed is then the preferred way to reduce noise.

Since the aircraft is operating at Mach 0.8 cruise, increasing the helical tip Mach number from 1.14 to 1.22 would require an approximately 11.2 percent higher propeller rotative speed. With this increase the predicted source noise reduction would be 2 dB.

The total source noise reduction is then the sum of the reductions from increasing the blade number and from increasing the rotative speed to reach the local noise minimum. This potential source noise reduction from varying gross propeller parameters would be 4 dB for the 10-blade propeller (2 dB from increasing the blade number and 2 dB from minimum-noise-point operation) and 5.5 dB for the 12-blade propeller (3.5 dB from increasing the blade number and 2 dB from minimum-noise-point operation).

Increased Atmospheric Attenuation

The amount of atmospheric attenuation depends on the air temperature and humidity and on the frequency of the sound. Typically, as the sound frequency is increased, the atmospheric attenuation increases (fig. 3). The atmospheric attenuation is plotted here in decibels per 1000 ft versus blade passing frequency in hertz from the tables of reference 10. The plot is based on average conditions from 0- to 5000-ft altitude at 50 °F and 59 percent relative humidity. As can be seen, increasing the propeller Doppler-shifted blade passing frequency would provide greater atmospheric attenuation and consequently lower en route noise.

Fortunately, the propeller redesigns outlined previously for source noise reduction, increased blade number, and higher blade rotative speed, also result in higher blade passing frequencies. Increasing the rotative speed will raise the blade passing frequency of the 10-blade design from the 8-blade SR-7 value of 163 Hz to 226.5 Hz and that of the 12-blade design to 272 Hz. The intent in this study was to calculate the increased atmospheric attenuations for these redesigned 10- and 12-blade propellers. The combinations of the source noise reductions and the increased atmospheric attenuation would then yield the potential en route sound pressure level reductions for these variations in the gross propeller parameters.

Although the atmospheric attenuation increased with frequency, resulting in reduced sound pressure levels on the ground, the trend of the A-weighted scale with frequency was the opposite. As shown in figure 4, below 1000 Hz increasing the noise frequency resulted in a higher weighting on the A scale. This negated some of the sound pressure level reductions achieved by increasing frequency. The net result should be a reduction in A-weighted noise but less of a reduction than that for the sound pressure level.

EN ROUTE NOISE ESTIMATES

The en route noise estimates for the representative aircraft with propellers redesigned for lower noise were calculated. The propeller redesigns were done by varying gross propeller parameters to reduce source noise and to increase atmospheric attenuation. The en route noise estimates were made for the 10- and 12-blade propellers.

The 10-blade propeller noise was predicted to be 2 dB lower than the baseline SR-7 propeller noise because of reduced loading noise and an additional 2 dB lower because of the change in rotative speed to operate at the minimum noise point. The total source noise reduction of 4 dB was assumed to apply at all angles. In other words, the directivity of the propeller noise was assumed to remain the same as that of the SR-7 but was reduced everywhere by 4 dB as shown in figure 5. The noise at cruise for the 10-blade propeller is shown in table V. The increased number of blades and higher propeller rotative speed resulted in a higher blade passing frequency. The higher blade passing frequency yielded greater atmospheric attenuation, as shown in table VI. When these atmospheric attenuations and the adjustments in the distance and the number of engines were applied to the cruise numbers, an estimate of the en route noise sound pressure level was obtained (table VII(a)). The maximum sound pressure level was 59.0 dB, 9.5 dB less than that for the baseline aircraft with the SR-7 propeller. This is again a free-field sound pressure level at the ground plane and would be increased by any pressure amplification on the measuring surface. Four decibels of reduction were from reduced source noise, and 5.5 dB from increased atmospheric attenuation.

The A-weighted noise levels are given in table VII(b). The maximum A-weighted level was 52.5 dB, a 6.5-dB reduction from the baseline propeller. As noted earlier, the higher frequency caused not only greater atmospheric attenuation, but also a higher weighting on the A-weighted decibel scale. The net result was still a reduction in A-weighted sound but not as much as the reduction in sound pressure level.

The same procedure was followed for the 12-blade propeller. The source noise was predicted to be reduced by 5.5 dB (fig. 5). This reduction was the sum of the loading noise reduction of 3.5 dB and the minimum-noise-point reduction of 2 dB. The cruise noise of the 12-blade propeller is shown in table VIII, the atmospheric attenuations in table IX, and the en route noise estimates in table X. The maximum en route sound pressure level was 53 dB, a 15.5-dB reduction from the baseline propeller. Five and one-half decibels of this reduction were from the reduced source noise, and 10 dB from increased atmospheric attenuation. The maximum A-weighted en route noise for the 12-blade propeller was 48 dB(A), an 11-dB reduction from the 8-blade baseline propeller. The reduction in A-weighted noise was again not as much as the sound pressure level reduction because the higher frequency was weighted more strongly by the A scale. Figure 6(a) shows the en route blade passing tone directivities for the 8-blade baseline propeller-powered aircraft and for the 10- and 12-blade redesigns. Figure 6(b) shows the directivities of the corresponding A-weighted sound pressure levels. The predicted reductions and the areas in which they were achieved are summarized in table XI. More than half the noise reduction came from increased atmospheric attenuation.

The calculated reduction in the estimated en route noise, 9.5 dB (6.5 dB(A)) for the 10-blade propeller and 15.5 dB (11 dB(A)) for the 12-blade propeller, were from simple variations in gross propeller parameters. These reductions of up to 11 dB(A) are significant as they lower the concern surrounding the en route noise of an advanced turboprop aircraft. The propeller variations studied here changed only the two gross propeller parameters that have the largest effect, and even more reductions may be possible for a complete, detailed design oriented toward reduced en route noise.

CONCLUDING REMARKS

Some variations in gross propeller parameters were explored that show potential for reducing the en route noise of advanced turboprop aircraft. A representative aircraft with eight-blade SR-7 propellers was used as the baseline. The en route noise estimate calculated for this baseline showed a maximum sound pressure level of 68.5 dB and a maximum A-weighted level of 59 dB(A).

The results of the study indicated that the source noise of an advanced turboprop propeller could be reduced by increasing the number of blades. Increases to 10 and 12 blades were considered. In addition, increasing the propeller rotative speed to reach a local minimum on the noise-versus-helical-tip-Mach-number curve indicated the potential for source noise reduction. These changes to the baseline propeller were estimated to yield source noise reductions of 4 dB for the 10-blade propeller and 5.5 dB for the 12-blade propeller.

Atmospheric attenuation along the path from altitude to ground depended on the frequency of the sound. Increasing the frequency increased the amount of attenuation and reduced the en route noise on the ground. The 10- and 12-blade propellers designed for reduced source noise also provided a significant increase in blade passing frequency over the baseline 8-blade propeller. This increase in frequency came from both the increase in blade number and the increase in rotative speed. Therefore, these 10- and 12-blade propellers were carried through the atmospheric attenuation calculations to estimate the en route noise. The 10-blade design reduced the maximum en route sound pressure level by 9.5 dB, and the 12-blade design by 15.5 dB. Lowering the sound pressure level also decreased the A-weighted en route noise. The 10-blade propeller showed a reduction of 6.5 dB(A); and the 12-blade design, 11 dB(A). The A-weighted reductions were lower than the linear sound pressure level eductions, since the A-scale weights the higher frequencies more strongly.

Source noise reductions were achieved by varying the gross propeller parameters of blade number and rotative speed. The higher frequencies of these propellers resulted in more atmospheric noise attenuation, with the net result being up to a 15.5-dB reduction in sound pressure level en route noise. The potential reduction in annoyance from these changes was estimated to be 11 dB(A). The propeller variations proposed here were only on the two gross propeller parameters that have the largest effect, and even more reduction may be possible for a complete, detailed design oriented toward reduced en route noise. The reductions shown here were significant as they lowered the concern surrounding advanced turboprop en route noise.

REFERENCES

1. Whitlow, J.B., Jr.; and Sievers, G.K.: Fuel Savings Potential of the NASA Advanced Turboprop Program. NASA TM-83736, 1984.

2. Woodward, R.P.: Measured Noise of a Scale Model High Speed Propeller at Simulated Takeoff/Approach Conditions. AIAA Paper 87-0526, Jan. 1987 (also NASA TM-88920).

3. Dittmar, J.H.; Jeracki, R.J.; and Blaha, B.J.: Tone Noise of Three Supersonic Helical Tip Speed Propellers in a Wind Tunnel. NASA TM-79167, 1979.

4. Dittmar, J.H.; and Jeracki, R.J.: Additional Noise Data on the SR-3 Propeller. NASA TM-81736, 1981.

5. 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, 1985.

6. Dittmar, J.H.; and Stang, D.B.: Cruise Noise of the 2/9 Scale Model of the Large-Scale Advanced Propfan (LAP) Propeller, SR-7A. AIAA Paper 87-2717, Oct. 1987 (also NASA TM-100175).

7. Dittmar, J.H.: An Estimate of the Enroute Noise of an Advanced Turboprop Airplane. NASA TM-87302, 1986.

8. Revell, J.D.; Balena, F.J.; and Koval, L.R.: Analytical Study of Interior Noise Control by Fuselage Design Techniques on High-Speed Propeller-Driven Aircraft. (LR-29382, Lockheed California Co.; NASA Contract NAS1-15427), NASA CR-159222, 1980.

9. Stefko, G.L.; Rose, G.E.; and Podboy, G.G.: Wind Tunnel Performance Results of an Aeroelastically-Scaled 2/9 Model of the PTA Flight Test Propfan. AIAA Paper 87-1893, June 1987 (also NASA TM-89917).

10. Standard Values of Atmospheric Absorption as a Function of Temperature and Humidity. SAE ARP-866A, 1975.

11. Prediction Procedure for Near-Field and Far-Field Propeller Noise. SAE AIR-1407, 1977.

12. Richards, E.J.; and Mead, D.J.: Noise and Acoustic Fatigue in Aeronautics. John Wiley & Sons, 1968, p. 189.

13. Dittmar, J.H.; Stefko, G.L.; and Jeracki, R.J.: Noise of the 10-Bladed, 40° Swept SR-6 Propeller in a Wind Tunnel. NASA TM-82950, 1982.

TABLE I. - SR-7 PROPELLER NOISE PROJECTED TO FLIGHT

[Free-field condition, 1.5 diameters from propeller tip.]

(a) Blade setting angle, 60.1; projected from data of reference 6

Harmonic	Measured angle (angle from upstream), θ_m, deg											
	46.8	50	58.5	72.2	80	90.9	100	104	110	116.8	120	130.4
	Sound pressure level of harmonic, SPL, dB (ref. 2×10^{-5} N/m^2)											
1 (BPF)	120	118.5	120	122.5	131	134.5	140.5	139.5	138.5	136.0	133.0	128.5
2	(a)	(a)	(a)	(a)	116	126	125.5	129.0	132.0	130.5	128.5	116.5

(b) Blade setting angle, 57.3°, used previously in reference 7; projected from data of reference 5

Harmonic	Measured angle (angle from upstream), θ_m, deg				
	75	90	101	110	131
	Sound pressure level of harmonic, SPL, dB (ref. 2×10^{-5} N/m^2)				
1 (BPF)	122	137	131.5	137.5	122
2	(a)	121.5	123	124	119

[a]Tone not visible above tunnel background.

TABLE II. - TEMPERATURE AND HUMIDITY VARIATIONS WITH ALTITUDE

	Altitude, m (ft)						
	0	1524 (5000)	3048 (10 000)	4572 (15 000)	6096 (20 000)	7620 (25 000)	9144 (30 000)
Temperature, °C (°F)	15 (59)	5 (41.2)	-5 (23.3)	-15 (5.5)	-31 (-24.6)	-35 (-30.2)	-45 (-48)
Relative humidity, percent	70	48	35	27	23	22	21

TABLE III. - ESTIMATED ATMOSPHERIC ATTENUATIONS FOR REPRESENTATIVE AIRCRAFT WITH EIGHT-BLADE BASELINE PROPELLER

Measured angle (angle from upstream), θ_m, deg	Noise emission angle, θ_e, deg	Doppler-shifted blade passing frequency, Hz	Attenuation at harmonic, dB	
			1 (BPF)	2
46.8	11.1	758	(a)	(a)
50	12.2	747	(a)	
58.5	15.5	712	116.0	
77.2	22.6	624	80.5	
80	28.0	555	51.0	104.5
90.9	37.8	443	30.0	64.5
100	48.0	351	19.0	42.0
104	53.1	314	17.5	39.0
110	61.3	265	12.5	27.5
116.8	71.2	220	9.0	19.5
120	76.2	184	8.0	14.5
130.4	92.9	155	6.5	14.0

[a]Attenuation was over 150 dB, greater than the maximum level emitted by the aircraft.

TABLE IV. - ESTIMATED EN ROUTE SOUND PRESSURE LEVELS FOR REPRESENTATIVE AIRCRAFT WITH EIGHT-BLADE BASELINE PROPELLER

(a) Sound pressure levels

Harmonic	Measured angle (angle from upstream), θ_m, deg											
	46.8	50	58.5	72.2	80	90.9	100	104	110	116.8	120	130.4
	Sound pressure level of harmonic, SPL, dB (ref. 2×10^{-5} N/m^2)											
1 (BPF)	(a)	(a)	(a)	(a)	21.5	46.0	63.0	63.5	67.5	68.5	66.5	63.5
2	(a)	(a)	(a)	(a)	(a)	3.0	25.0	31.5	46.0	52.5	55.5	44.0

(b) A-weighted sound pressure levels

Sound pressure level, dB(A)											
(a)	(a)	(a)	(a)	18.5	41.0	56.5	57.0	59.0	58.0	57.0	50.0

[a]Correction larger than original tone level.

TABLE V. - ESTIMATED PROPELLER NOISE AT CRUISE FOR REPRESENTATIVE AIRCRAFT WITH 10-BLADE REDESIGNED PROPELLER

[Free-field condition; 1.5 diameters from propeller tip.]

Harmonic	Measured angle (angle from upstream), θ_m, deg											
	46.8	50	58.5	72.2	80	90.9	100	104	110	116.8	120	130.4
	Sound pressure level of harmonic, SPL, dB (ref. 2×10^{-5} N/m^2)											
1 (BPF)	116.0	114.5	116.0	118.5	127.0	130.5	136.5	135.5	134.5	132.0	129.0	124.5
2	(a)	(a)	(a)	(a)	112.0	122.0	121.5	125.0	128.0	126.5	124.5	112.5

[a]Tone not visible above tunnel background.

TABLE VI. - ESTIMATED ATMOSPHERIC ATTENUATIONS FOR REPRESENTATIVE AIRCRAFT WITH 10-BLADE REDESIGNED PROPELLER

Measured angle (angle from upstream), θ_m, deg	Noise emission angle, θ_e, deg	Doppler-shifted blade passing frequency, Hz	Attenuation at harmonic, dB	
			1 (BPF)	2
46.8	11.1	1053	(a)	(a)
50	12.2	1038	(a)	
58.5	15.5	988	(a)	
77.2	22.6	866	102.5	
80	28.0	770	84.0	
90.9	37.8	616	50.5	101.0
100	48.0	487	32.5	66.0
104	53.1	436	23.0	49.5
110	61.3	369	18.5	45.0
116.8	71.2	305	14.5	32.5
120	76.2	280	13.0	24.5
130.4	92.9	215	8.5	18.5

[a]Attenuation was over 150 dB, greater than the maximum level emitted by the aircraft.

TABLE VII. - ESTIMATED EN ROUTE SOUND PRESSURE LEVELS FOR REPRESENTATIVE AIRCRAFT WITH 10-BLADE REDESIGNED PROPELLER

(a) Sound pressure levels

Harmonic	Measured angle (angle from upstream), θ_m, deg											
	46.8	50	58.5	72.2	80	90.9	100	104	110	116.8	120	130.4
	Sound pressure level of harmonic, SPL, dB (ref. 2×10^{-5} N/m^2)											
1 (BPF)	(a)	(a)	(a)	(a)	(a)	21.5	45.5	54.0	57.5	59.0	57.5	57.5
2	(a)	(a)	(a)	(a)	(a)	(a)	(a)	17.0	24.5	35.5	41.5	35.5

(b) A-weighted sound pressure levels

Sound pressure level, dB(A)											
(a)	(a)	(a)	(a)	(a)	19.5	42.5	49.0	52.5	52.5	49.5	46.5

[a]Correction larger than original tone level.

TABLE VIII. - ESTIMATED PROPELLER NOISE AT CRUISE FOR REPRESENTATIVE AIRCRAFT WITH 12-BLADE REDESIGNED PROPELLER

[Free-field condition; 1.5 diameters from propeller tip.]

Harmonic	Measured angle (angle from upstream), θ_m, deg											
	46.8	50	58.5	72.2	80	90.9	100	104	110	116.8	120	130.4
	Sound pressure level of harmonic, SPL, dB (ref. 2×10^{-5} N/m^2)											
1 (BPF)	114.5	113.0	114.5	117.0	125.5	129.0	135.0	134.0	133.0	130.5	127.5	123.0
2	(a)	(a)	(a)	(a)	110.5	120.5	120.0	123.5	126.5	125.0	123.0	111.0

[a]Tone not visible above tunnel background.

TABLE IX. - ESTIMATED ATMOSPHERIC ATTENUATIONS FOR REPRESENTATIVE AIRCRAFT WITH 12-BLADE REDESIGNED PROPELLER

Measured angle (angle from upstream), θ_m, deg	Noise emission angle, θ_e, deg	Doppler-shifted blade passing frequency, Hz	Attenuation at harmonic, dB	
			1 (BPF)	2
46.8	11.1	1264	(a)	(a)
50	12.2	1247	(a)	
58.5	15.5	1188	(a)	
77.2	22.6	1040	127.5	
80	28.0	926	104.5	
90.9	37.8	739	64.5	129.5
100	48.0	585	42.0	83.5
104	53.1	524	30.0	61.5
110	61.3	442	24.0	50.5
116.8	71.2	366	19.0	42.0
120	76.2	336	16.5	32.0
130.4	92.9	260	11.0	24.0

[a]Attenuation was over 150 dB, greater than the maximum level emitted by the aircraft.

TABLE X. - ESTIMATED EN ROUTE SOUND PRESSURE LEVELS FOR REPRESENTATIVE AIRCRAFT WITH 12-BLADE REDESIGNED PROPELLER

(a) Sound pressure levels

Harmonic	Measured angle (angle from upstream), θ_m, deg											
	46.8	50	58.5	72.2	80	90.9	100	104	110	116.8	120	130.4
	Sound pressure level of harmonic, SPL, dB (ref. 2×10^{-5} N/m^2)											
1 (BPF)	(a)	(a)	(a)	(a)	(a)	6	34.5	45.5	50.5	53.0	52.5	53.0
2	(a)	(a)	(a)	(a)	(a)	(a)	(a)	3.5	17.5	24.5	32.5	28.5

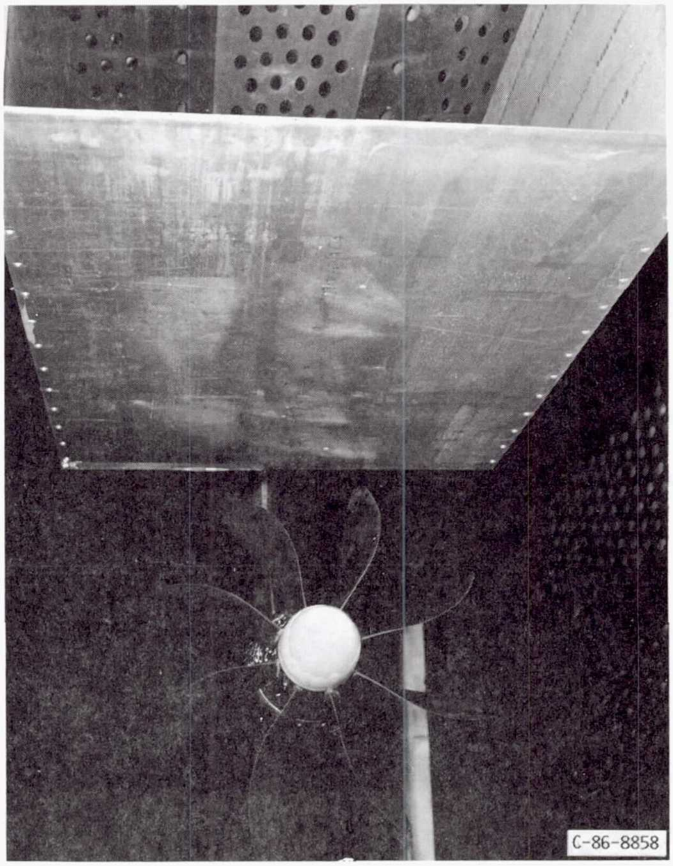
(b) A-weighted sound pressure levels

Sound pressure level, dB(A)											
(a)	(a)	(a)	(a)	(a)	4	31.5	42.5	45.5	48.0	46.0	45.0

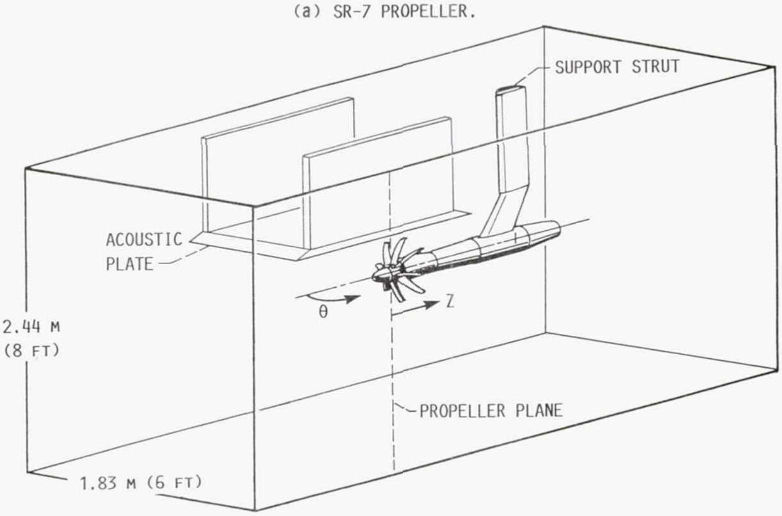
[a]Correction larger than original tone level.

TABLE XI. - NOISE REDUCTION SUMMARY

	10-Blade redesign	12-Blade redesign
	Noise reduction from baseline 8-blade propeller, ΔdB	
Source noise reduction:		
Increased blade number	2	3.5
Operation at local noise minimum	2	2
Increased atmospheric attenuation	5.5	10.0
Total en route noise reduction (source and atmospheric attenuation reductions), SPL	9.5	15.5
Total A-weighted noise reduction	6.5	11



(a) SR-7 PROPELLER.



TRANSDUCER (PLATE 0.3 DIAMETER FROM TIP)											
1	2	3	4	5	6	7	8	9	10	11	12
TRANSDUCER DISTANCE FROM PROPELLER PLANE, Z, CM (IN.)											
-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, θ, DEG											
46.8	50.0	58.5	72.2	80	90.9	100	104	110	116.8	120	130.4

(b) TRANSDUCER LOCATIONS.

FIGURE 1. - ACOUSTIC PLATE ABOVE SR-7 PROPELLER. (FROM REF. 6.)

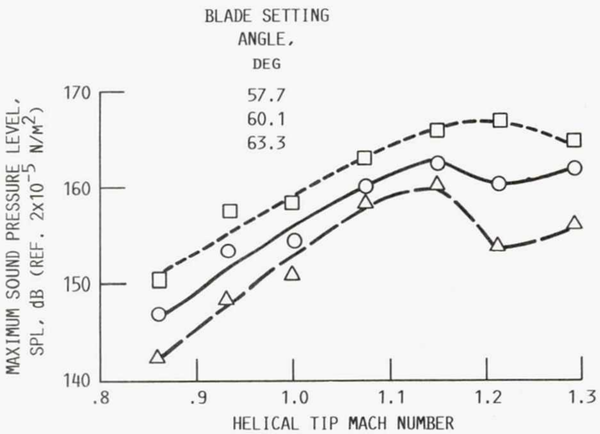


FIGURE 2. - VARIATION OF MAXIMUM BLADE PASSING TONE NOISE WITH HELICAL TIP MACH NUMBER AT CONSTANT ADVANCE RATIO OF 3.06. (FROM REF. 6.)

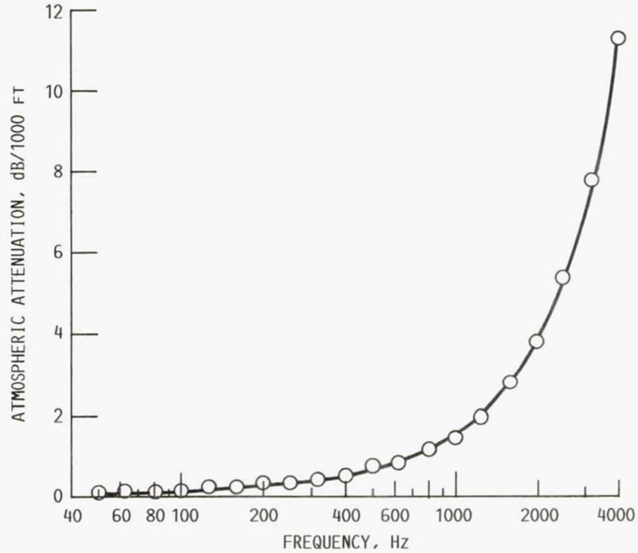


FIGURE 3. - VARIATION OF ATMOSPHERIC ATTENUATION WITH FREQUENCY FOR 50 ^{0}F, 59 PERCENT RELATIVE HUMIDITY, AND ALTITUDE RANGE OF 0 TO 5000 FT. (DATA FROM REF. 10.)

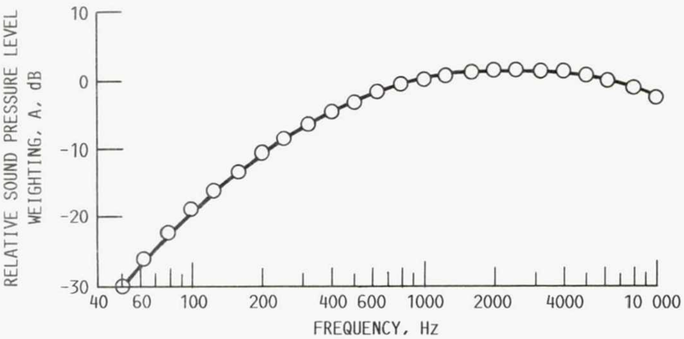


FIGURE 4. - VARIATION OF A-WEIGHTED SOUND PRESSURE LEVEL WITH FREQUENCY.

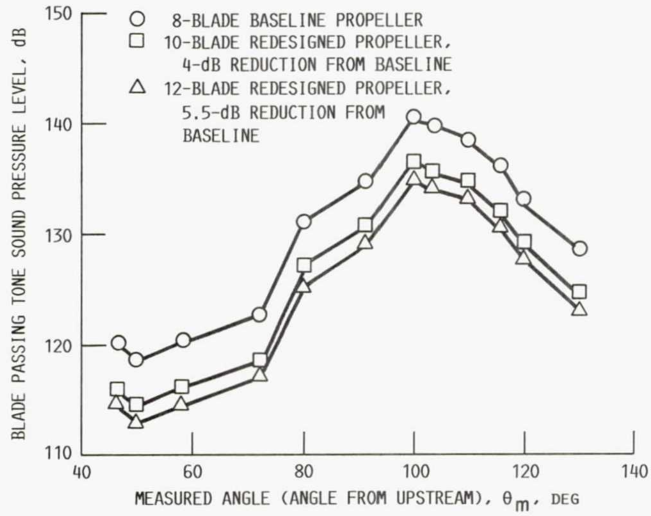


FIGURE 5. - SOURCE NOISE AT CRUISE.

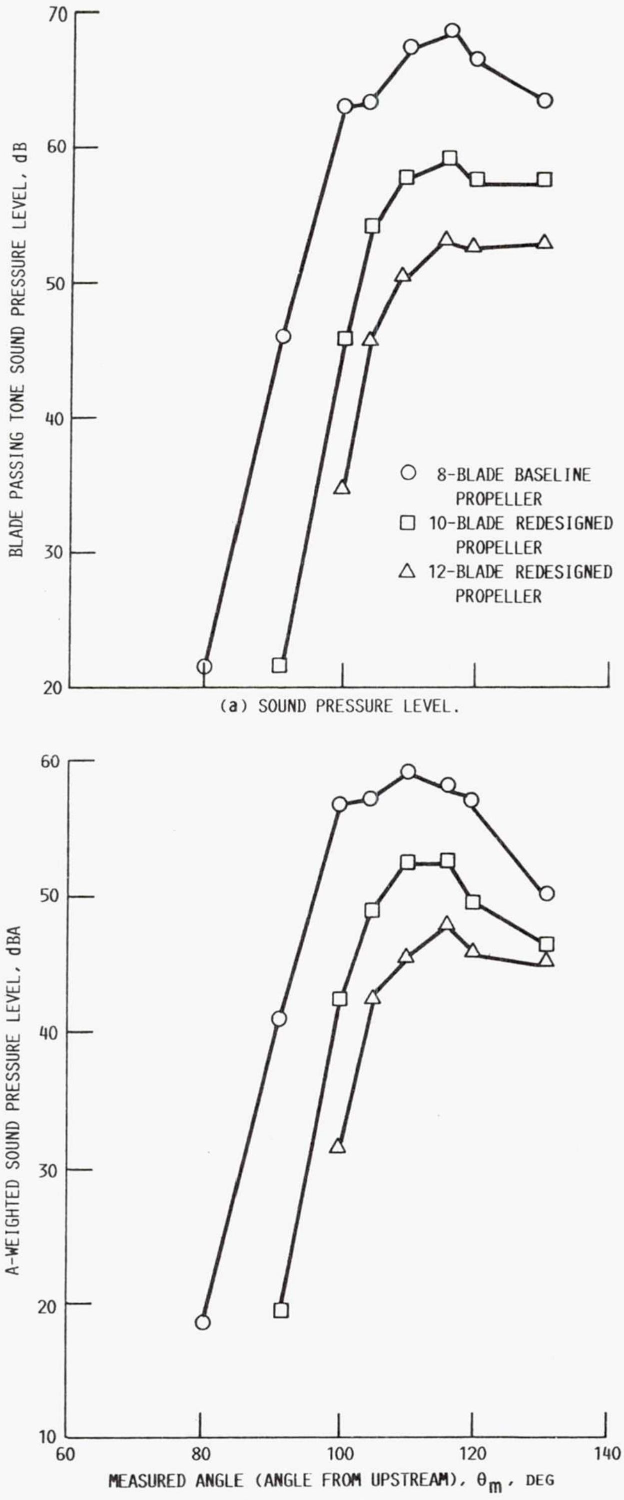


FIGURE 6. - EN ROUTE NOISE AT GROUND.

NASA
National Aeronautics and Space Administration

Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM-103635		

4. Title and Subtitle	5. Report Date
Potential Reduction of En Route Noise From an Advanced Turboprop Aircraft	December 1990
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
James H. Dittmar	E-5809
	10. Work Unit No.
	535-03-10
9. Performing Organization Name and Address	11. Contract or Grant No.
National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135-3191	
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address	Technical Memorandum
National Aeronautics and Space Administration Washington, D.C. 20546-0001	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

When the en route noise of a representative aircraft powered by an eight-blade SR-7 propeller was previously calculated, the noise level was cited as a possible concern associated with the acceptance of advanced turboprop aircraft. Some potential methods for reducing the en route noise were then investigated and are reported herein. Source noise reductions from increasing the blade number and from operating at higher rotative speed to reach a local minimum noise point were investigated. Greater atmospheric attenuations for higher blade passing frequencies were also indicated. Potential en route noise reductions from these methods were calculated as 9.5 dB (6.5 dB(A)) for a 10-blade redesigned propeller and 15.5 dB (11 dB(A)) for a 12-blade redesigned propeller.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Propeller noise En route noise Flyover noise Noise	Unclassified – Unlimited Subject Category 71

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of pages	22. Price*
Unclassified	Unclassified	18	A03

NASA FORM 1626 OCT 86

*For sale by the National Technical Information Service, Springfield, Virginia 22161