NASA Technical Memorandum 87302

An Estimate of the Enroute Noise of an Advanced Turboprop Airplane

James H. Dittmar
Lewis Research Center
Cleveland, Ohio

April 1986

NASA

AN ESTIMATE OF THE ENROUTE NOISE OF AN ADVANCED TURBOPROP AIRPLANE

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

E-3020

SUMMARY

The enroute noise of an Advanced Turboprop powered aircraft was estimated using projections of model noise data taken in the Lewis 8- by 6-Foot Wind Tunnel. The noise levels were roughly equivalent in annoyance to the noise 15.24 m (50 ft) from an automobile traveling at 80 km/hr (50 mph). It was felt that these levels would not illicit noise complaints from urban areas during the day but might be a slight annoyance in rural areas or in urban areas at night. Although it is not felt that the enroute noise is a major problem, these results indicate that a reduction in the enroute noise could improve the acceptability of advance turbo-prop airplanes.

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 (ref. 1). A single rotation turboprop design is projected to use 15 to 30 percent less fuel than turbofans (ref. 1) and a counter-rotation design may save as much as 8 percent more (ref. 2). In order to implement these fuel savings, however, the new turboprop aircraft have to be acceptable to the public.

The noise of these advanced propellers has been projected to be a possible cabin environment problem for an airplane at cruise. A number of single rotation propeller models have been tested for acoustics in the NASA Lewis 8- by 6-Foot Wind Tunnel, at simulated cruise (refs. 3 to 5) and compared with model flight data (ref. 6). These experiments have confirmed the severity of the levels to which the fuselage exterior will be subjected and have reinforced the need for large wall treatment attenuations to arrive at an acceptable cabin environment.

These advanced propellers are a noise source of such strength that some of this noise at cruise may propagate to the ground and present an enroute noise problem for the people underneath the airplane flight path. The purpose of this report is to estimate, based on projection of the wind tunnel noise data, the enroute noise of an advance turboprop airplane at cruise.

PROCEDURE

As indicated in references 3 to 6, considerable noise data have been taken on models of single rotation propellers in the Lewis 8- by 6-Foot Wind Tunnel. One of these propeller models, SR-7A (ref. 5) is a model of the Large-scale Advanced Propfan (LAP) propeller (ref. 7). This propeller is to be built in 2.74 m (9 ft) diameter size and flown on a Gulfstream II airplane (ref. 1).

It was felt that this propeller was well enough developed to be representative of the type that would be flown on a commercial airplane and projections of the tunnel data for this propeller model are used in this report. In addition a preliminary design model of a counter-rotation propeller intended for the Unducted Fan Engine (UDF) (ref. 1) was recently tested in the Lewis 8- by 6-Foot Wind Tunnel. Noise data from this model, designated F7-A7 are also used here to make an estimate of the enroute noise of a counter-rotation propeller driven airplane. This counter-rotation propeller model is not as well developed as the single rotation propellers and its noise at cruise may be a little higher than some later, more developed counter-rotation propellers. Some comments on this subject are made later in this report.

The noise data from the two propeller models taken in the wind tunnel will be presented in the "Wind Tunnel Data" section which follows. The noise of the two propellers will be adjusted to the same distance from the propeller centerline using 20 $\log_{10}$ of the distance ratio and to the same thrust level using 10 log of the thrust ratio. Some comparisons of blade passage tone directivity and harmonic content of the two propellers will also be included.

The projections to the cruise condition for a representative airplane are performed in the "Projection to Cruise" section. The noise data are projected to the airplane cruise condition using 20 $\log_{10}$ of the distance ratio measured from the propeller centerline in propeller diameters and using 10 log of the thrust ratio between model and full scale. In addition a correction equal to 20 $\log_{10}$ of the atmospheric pressure at cruise ratiod to that in the wind tunnel is applied to the data to account for different atmospheric conditions. Six decibels are subtracted from these values, which were measured on a hard surface with assumed pressure doubling, to obtain a free field noise estimate at cruise conditions.

The cruise data are then translated to the ground using 20 $\log_{10}$ of the distance ratio and are corrected for atmospheric attenuation and Doppler shift. This is performed in the section entitled "Estimate of Enroute Noise." Also included in this section is a discussion of the airplane enroute noise observability and annoyance as felt by someone on the ground. The noise estimates developed here are for the propeller noise only and do not include noise from the other propulsive or airframe sources.

WIND TUNNEL DATA

Noise Data

The noise data used for these estimates were taken in the NASA Lewis 8- by 6-Foot Wind Tunnel. The data were taken for the 8 bladed single-rotation SR-7A propeller shown in figure 1(a) and for the counter-rotation F7-A7 propeller shown in figure 1(b). A brief comparison of the design conditions for the two propellers is in table I. The noise data for the SR-7A propeller were taken by transducers installed flush with the tunnel ceiling, 1.5 propeller diameters from the blade tip. (See fig. 2(a).) The noise data for the F7-A7 propeller were taken on a translating acoustic plate which was 0.3 diameter from the propeller tip. The noise data at an axial tunnel Mach number of 0.8 are presented in table II. The SR-7A propeller was operated at approximately its design point and the F7-A7 propeller was operated at approximately where it would be expected to operate for an axial Mach number of 0.8. The F7-A7 propeller was designed for 0.72 axial Mach number cruise but was operated here at M = 0.8 by changing the blade setting angle. The SR-7A data are presented in table II(a) and have been previously reported in reference 5. The F7-A7 data are presented here for the first time and are shown in table II(b). The F7-A7 counter-rotating propeller was operated with its propellers turning at slightly different rotational speeds. Since any circumferential variation precesses rapidly past the pressure tranducers, good average noise numbers can be obtained. A narrow band frequency analysis, just wide enough (32 Hz) to capture the slightly different propeller tones in the same band was used. In other words the resultant spectra look similar to that from a single rotation propeller. Therefore only one set of tones and harmonics are shown in table II(b).

Adjustment to Single Rotation Conditions

To obtain comparable single and counter-rotation noise numbers the counter-rotation data were adjusted to the single rotation conditions. A distance correction of 20 $\log_{10}$ of the distance ratio measured from the propeller centerline results in the counter-rotation (CR) data being reduced 8 dB. From tunnel measurements of the thrust of the CR propeller and estimates of the SR-7A thrust based on the data of a similar propeller, SR-3, the counter-rotation thrust was approximately 34 percent greater.

Although the counter-rotation propeller has two propellers it also has a significantly higher hub to tip ratio which is partially why it only has 34 percent more thrust. Based on 10 log of the thrust ratio the CR data is reduced 1.3 dB. The total adjustment is then 9.3 dB which has been rounded to 9.5 dB since the data is listed in 0.5 dB increments. The adjusted data are listed in table II(c).

Comparison

The noise from a counter-rotation propeller can be thought of as containing two parts: the noise from the propellers as if they were acting alone (steady sources) and the noise caused by the interaction of the two propellers. The noise from the propellers acting alone has components at the blade passing tone of each propeller and its harmonics. The noise caused by the interaction of the propellers only occurs at frequencies which are sums of the two propeller blade passing frequencies. (See ref. 8.) For this case, where the two propeller blade passing frequencies are close enough to fall in the same narrowband, it means that the interaction noise appears in the spectrum at harmonic numbers 2 and above. Therefore the blade passage tone data will be looked at separately from the harmonic data.

Differences in directivity may affect the enroute annoyance from an Advanced Turbo-prop airplane. A comparison of the blade passage tone directivity from SR-7A and F7-A7 is shown in figure 3. In comparing the blade passing tone directivities the single rotation propeller noise seems to fall off more quickly in front of the 90° position. This is probably a secondary result of the different measurement methods in the two experiments. The single rotation data were taken on the ceiling of the wind tunnel under a much thicker boundary layer than that on the translating acoustic plate used for the counter rotation tests. Different amounts of boundary layer refraction probably explain the faster fall off of the single rotation blade passing tone in front of 90° (see ref. 9). This boundary layer refraction was shown in reference 9, to not affect the data aft of the plane of rotation. Therefore the comparison of the peak levels should be valid. Here it is seen that this counter-rotation propeller is about 6.5 dB noisier at its peak location than was SR-7A, when adjusted to the same flight conditions but not adjusted for boundary layer differences during measurement. The counter-rotation propeller also has its peak noise farther forward than the single rotation but still behind the 90° position so boundary layer refraction is not an issue. This difference in directivity may result in a different annoyance on the ground.

As was mentioned previously this counter-rotation propeller was a 0.72 Mach number design adjusted in blade setting angle to operate at a 0.8 axial Mach number. In addition this counter-rotation propeller was not swept specifically for noise reduction as was SR-7A (see ref. 5). It is felt that the majority of the peak blade passing tone noise difference is the result of these design differences.

In previous testing of single rotation propeller (ref. 3) the effect of sweep and acoustically tailored sweep were determined. Three propellers, SR-2, SR-1M, and SR-3 having respectively 0°, 30°, and 45° of tip sweep, were tested in the 8 by 6 tunnel. The SR-1M was swept only for aerodynamic purposes while SR-3 was swept to provide noise cancellation from the various hub to tip sections. The amount of peak blade passing noise plotted versus helical tip Mach number from reference 3 is repeated here in figure 4. At the $M = 0.8$ cruise condition, a helical tip Mach number of 1.14, the acoustically swept SR-3 was about 5 dB quieter than the SR-1M propeller.

As shown in reference 5, the SR-7A acoustically swept propeller generated roughly the same noise levels as the SR-3 propeller. The counter-rotation F7-A7 propeller blade sweeps are similar to the SR-1M propeller sweep in that F7-A7 has 34° of tip sweep on the front propeller and 31° on the aft and is not tailored for acoustic cancellation. It is therefore likely that the difference in peak blade passing tone noise between the F7-A7 and SR-7 is primarily the result of the counter-rotating F7-A7 not having enough sweep and not having the sweep tailored to provide a noise reduction. Furthermore it is probable that a future counter-rotation propeller used on a commercial airplane would incorporate noise reduction features and for the same thrust have roughly the same peak blade passing tone level as a SR propeller at cruise conditions.

The directivities of the blade passing tone for the single and counter-rotation propellers do show a different general shape between 90° and 110°. The single rotation propeller shows the lobed pattern typical of propeller noise while the counter-rotation propeller does not show the dip around 100°. This is probably the result of the directivity patterns from the two propellers combining to fill in the dip. The addition of the two propeller sources may also cause the noise to be slightly louder at the peak. The increase in noise for the counter-rotation propeller at the 128° position over that at the 120° position is not understood at this time and may represent an anomaly in the data.

Different harmonic content of the two types of propellers may result in different amounts of annoyance. The harmonic content comparison is also of interest because this is where the interaction noise is expected to appear in the spectra. At take-off conditions, where the propeller alone (thickness noise) is smaller, the interaction noise due to unsteady loading will probably control the harmonic levels. (See ref. 8.) At cruise conditions the propeller alone (thickness) noise is stronger than at take-off and the harmonics will not be as strongly influenced by the interaction noise. This is particularly true near the peak noise location. However, the propeller alone thickness noise is predicted to decrease toward the propeller axes while the interaction noise remains strong. Two comparisons of harmonic strength for the SR-7 and F7-A7 propellers are shown in figure 5. Part (a) is a comparison of the harmonic levels relative to the blade passage tone for the peak location. Part (b) compares the 90° single rotation point with both the 81.8° and 90° counter rotation data.

The comparison at the peak location (fig. 5(a)) shows the first few harmonics of the counter-rotation propeller to be higher than single rotation - both measured relative to the blade passage tone, but at the higher harmonics the relative levels are about the same. This shows that there might be some interaction noise contribution to the harmonics at the peak location but not a strong one.

The comparison at the angles forward of the peak, figure 5(b) shows the harmonics of the counter-rotation propeller to be consistently 6 dB above the single-rotation harmonics. Here the interaction noise is indicated as being a significant noise source. It may be that this extra harmonic content of the counter-rotation propeller will make it more annoying to the people under the flight path.

PROJECTION TO FLIGHT

In order to project this model data to flight conditions a representative airplane must be chosen. A single rotation propeller for a hypothetical narrow-body airline has already been sized in reference 10. This airplane is to cruise at M = 0.8 at 9 144 m (30 000 ft). For this airplane a 3.78 m (12.4 ft) diameter propeller with a tipspeed of 244 m/sec (800 ft/sec) was used. This was a 100 passenger airplane with two engines. For our enroute noise estimate it will be assumed that two SR-7A propellers, 3.78 m (12.4 ft) in diameter would be used on this airplane.

A counter-rotation propeller to propel this airplane would be smaller in diameter since its thrust is larger. The thrust correction has already been included in the tone noise levels of table II(c) but the frequency would be slightly higher for the smaller propeller turning with the same tip speed. This slight difference in size is neglected here since it would not result in a significantly different frequency.

For purposes of the estimate of enroute noise three propeller configurations are selected. The single rotation configuration is the SR-7A scaled to the 3.78 m (12.4 ft) diameter size. Two counter-rotation configurations are selected. The first is the F7-A7 scaled to the nominal 3.78 m (12.4 ft) diameter size. The second is an attempt to represent a counter-rotation propeller with the same level of technology as the SR-7A propeller. Such a propeller would have tailored sweep to reduce the noise and would be designed for M = 0.8 cruise. Its propeller noise signature is approximated here by taking the F7-A7 noise signature and reducing it by 6.5 dB so that its peak blade passing tone noise is the same as the single rotation propeller. It might not be possible to completely eliminate the 6.5 dB difference in an actual design since some of the extra counter-rotation noise may be from the summation of the two propeller noise signatures. However, the quieter counter-rotation propeller is probably more representative of what will be flown on a product airplane and including it provides a range within which the counter-rotation noise would probably fall.

To project the tunnel data to flight, corrections are made to account for distance, thrust, atmospheric conditions, and pressure amplification at the measuring surfaces. The thrust is assumed proportional to the propeller diameter squared with a thrust noise correction of 10 log of the thrust ratio. The noise is assumed to vary with distance as 20 log of the distance ratio. At the same relative distance, measured in propeller diameters, the thrust and distance corrections from tunnel to full size cancel out. The tunnel operates at a pressure of 76.5×10^3 n/m^2 (11.1 psi) at M = 0.8 cruise and the pressure at 9 144 m (30 000 ft) altitude is approximately 30.3×10^3 n/m^2 (4.4 psi). Using 20 log of the pressure ratio, this yields a reduction of 8 dB from the tunnel data. Another 6 dB is subtracted from the tunnel levels to account for the pressure doubling on the measurement surfaces in the tunnel. The tunnel data is therefore reduced a total of 14 dB to convert it to a free field noise level at the arbitrary reference plane 1.5 diameters from the propeller tip.

The projected noise levels at cruise for a propeller on a representative airplane are shown in table III. Part (a) contains the SR-7A levels, part (b) the F7-A7 levels and part (c) the "equivalent technology" counter-rotation noise levels (6.5 dB less than in table III(b)).

ESTIMATE OF ENROUTE NOISE

Correcting Flight Levels to Yield Ground Levels

To obtain an estimate of the enroute noise, corrections are needed for the distance, atmospheric absorption and the number of engines. The adjustment for distance uses 20 $\log_{10}$ of the distance ratio and indicates that the flight noise should be reduced 61.5 dB when it reaches the ground. For the number of engines correction it is assumed that the sources are not coherent and 3 dB should then be added to the one propeller data of table III. The net results of these two corrections is then a reduction of the table III numbers by 58.5 dB. An estimate of the atmospheric absorption of the noise is not as straight forward and a discussion of the valves used in this report follows.

The common method of estimating atmospheric absorption for airplane noise is found in reference 11. The amount of atmospheric attenuation depends on the humidity and temperature of the air and the frequency of the sound. Reference 12, table 20 indicates that the amount of water vapor in the air decreases with altitude and yields approximately constant relative humidity with altitude. For purposes of this estimation it will be assumed that the relative humidity is constant with altitude and is taken at 72 percent relative humidity. The temperature, however, varies greatly with altitude and table IV lists some of the temperatures at altitude for a standard atmosphere. Because of the varying temperature along the path from the airplane to the ground an atmospheric attenuation is obtained by an integration process. The vertical distance is divided into 1524 m (5000 ft) increments and the average temperature for that section is used to determine the attenuation.

The propeller on our representative airplane emits noise with a blade passing frequency of 163 Hz and has harmonics at 326, 489, 652, etc. Because of the 0.8 Mach number velocity of the airplane a Doppler shift in these frequencies is observed on the ground. The frequency observed on the ground is 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 airplane Mach number and θ_E is the noise emission angle.

The emitted noise angle is different than the angle where the noise would be measured. This is again the result of the airplane velocity. The emitted angle is expressed as

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

where θ_E is the emitted angle, θ_m is the measured angle and M is the airplane Mach number.

The atmospheric attenuations are calculated using the Doppler shifted frequencies and the distance along the noise path calculated using the method noise angle.

The tables in reference 11 for atmospheric absorption only go as low as -17 °C (1 °F). As can be seen from table IV the temperature at altitudes above 4 572 m (15 000 ft) is below -18 °C (0 °F). To approximate the attenuations at temperatures below -18 °C (0 °F) it is assumed that the variations of the attenuation with temperature are symmetric 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 effect the results.

The atmospheric attenuations calculated for the airplane flyover are found in table V. In this table when the attenuations were over 150 dB, which is greater than the maximum level emitted by the airplane, the table is marked with the letter "a".

Enroute Sound Pressure Levels

The total attenuations listed in table V were applied to the various harmonics of the data of table III. When all of the corrections for distance, number of engines, and atmospheric attenuation were applied, an estimate of the enroute noise was obtained and is listed in table VI. In this table, rather than include negative decibels, when the correction was larger than the original tone level the table is left blank.

As can be seen from the values in table VI, the estimated enroute sound pressure levels are high enough that they probably would be noticed on the ground. The highest sound pressure levels are at the blade passage tone and were 67 dB at 264 Hz for the single-rotation (SR-7A), 67.5 dB at 259 Hz for the projected F7-A7 counter-rotation airplane and 61 dB at 259 Hz for the "equivalent technology" counter-rotation airplane.

These levels would probably not elicit any noise complaints in a busy downtown area of a city but might be noticed in a more rural area or possibly on a quiet city street at night.

It is worth noting here that the counter-rotation F7-A7 started with a peak blade passing noise 6.5 dB louder than the single rotation SR-7A, but is only 0.5 dB higher on the ground. This is the result of the counter-rotation peak being at a more forward angle. (The peak is still behind 90° so boundary layer refraction is not an issue.) This results in a higher Doppler shifted frequency and a longer path length which both yield larger atmospheric attenuations. The "equivalent technology" counter-rotation propeller is now some 6 dB quieter than the single rotation propeller. The noise peak being farther forward for the counter-rotation propeller presents an advantage when determining the enroute noise.

Annoyance

For an evaluation of the annoyance of these airplane noise levels the "A" weighted scale was chosen. A table of the A weighted sound pressure level at each angle is found in table VII. In most cases the A weighted sound pressure level was controlled by the blade passing tone and in all cases no more than the first two harmonics were required. The single-rotation airplane showed a peak A weighted sound of 58.5 dBa. The F7-A7 counter-rotation 60.5 dBa and the equivalent technology 54 dBa. The logical comparison would be to compare these values with that of the enroute noise of a conventional turbofan powered airplane. However, a literature search was unable to obtain the enroute noise of a conventional turboprop. Therefore the advanced turboprop annoyance was compared with more conventional sources and found to be roughly equivalent to the annoyance measured 15.24 m (50 ft) from an automobile traveling at 80 km/hr (50 mph). (Ref. 13, fig. 10.1).

CONCLUDING REMARKS

The enroute noise levels for an advanced turboprop airplane were estimated. The estimates were done using data projections from single and counter-rotation model propellers tested in the Lewis 8- by 6-Foot Wind Tunnel. The counter-rotation propeller model did not incorporate noise reduction features as did the single rotation propeller. Therefore enroute noise estimates were also made for an "equivalent technology" counter-rotation airplane which had its peak blade passing tone level adjusted to be the same as the single rotation propeller.

The maximum sound pressure levels at the blade passing frequency were 67 dB for the single rotation, 67.5 dB for the projected counter rotation and 61 dB for the "equivalent technology" counter-rotation airplane. On an A weighted scale the single rotation airplane was 58.5 dBa at the peak, the projected counter-rotation airplane was 60.5 dBa and the "equivalent technology" counter-rotation airplane was 54 dBa. These noise levels compare roughly to the noise 15.24 m (50 ft) from an automobile traveling at 80 km/hr (50 mph).

It is felt that these levels would not illicit any complaints in an urban area during the day but might be reason for annoyance in a rural area or in an urban area at night. The presence of multiple flight, lower cruise altitudes, or larger and, therefore, noisier airplanes than the one used in this study might further contribute to the annoyance. Although it is not felt that the enroute noise is a major problem, these results do indicate that a reduction in the enroute noise could help improve the acceptability of advanced turboprop airplanes.

REFERENCES

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

2. Strack, W.C., et al.: Technology and Benefits of Aircraft Counter Rotation Propellers. NASA TM-82983, 1981.

3. Dittmar, J.H.; Jeracki, R.J.; and Blaha, B.J.: Tone Noise of Three Super- sonic 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.: Further Comparison of Wind Tunnel and Airplane Acoustic Data for Advanced Design High Speed Propeller Models. NASA TM-86935, 1985.

7. Sagerser, D.A.; and Ludermann, S.G.: Large-scale Advanced Propfan (LAP) Program Progress Report. AIAA Paper 85-1187, July 1985.

8. Dittmar, J.H.: Some Design Philosophy for Reducing the Community Noise of Advanced Counter-Rotation Propellers. NASA TM-87099, 1985.

9. 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, 1984.

10. 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.)

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

12. U.S. Standard Atmosphere 1976. United States Committee on Extension to the Standard Atmosphere, National Oceanic and Atmospheric Administration, U.S. G.P.O., 1976.

13. Patty, F.A., et al: Patty's Industrial Hygiene and Toxicology. 3rd ed., Vol. 1 - General Principles, John Wiley and Sons, 1978.

TABLE I. - PROPELLER DESIGN CHARACTERISTICS

	Single rotation SR-7A	Counter-rotation F7-A7
Number of blades	8	8 by 8
Design cruise Mach number	0.8	0.72
Nominal diameter, cm (in.)	62.2(24.5)	62.2(24.5)/60.7(23.9)
Nominal design cruise tipspeed, m/sec (ft/sec)	244(800)	238(780)
Nominal design advance ratio	3.06	2.82
Hub to tip ratio	0.24	0.42
Geometric tip sweep, degrees	48	34/31
Activity factor	227	150/150
Design power coefficient based on annulus area	1.97	4.16

TABLE II. - PROPELLER NOISE AT WIND TUNNEL CONDITIONS

(a) SR-7A M = 0.8, as measured

Harmonic number	Transducer position (angle from propeller axis)				
	75°	90°	101°	110°	131°
	Sound pressure level of harmonic, spl, dB (ref. 2×10^{-5} n/m^2)				
1 (BPF)	136	151	145.5	151.5	136
2	(a)	135.5	137	138	133
3		130.5	133.5	135	126
4		127	132.5	128	126.5
5		(a)	128.5	130	(a)
6			125	126	
7			124	(a)	
8			(a)	(a)	

[a]Tone not visible above tunnel background.

TABLE II. - (Concluded)

(b) F7-A7 M = 0.8, as measured

Harmonic number	Transducer position (angle from propeller axis)								
	52°	59.4°	69.3°	81.8°	90°	98.2°	110.7°	120.6°	128°
	Sound pressure level of harmonic, spl, dB (ref. 2×10^{-5} n/m^2)								
1 (BPF)	142	144.5	149	161	165.5	167.5	161.5	152.5	155.5
2	(a)	135.5	132.5	154	157	158.5	155.5	150	143
3		(a)	(a)	148	151.5	152.5	149	148	140
4				142	147	149.5	145	145	138
5				137	143	147	143	139.5	136
6				131.5	139	142.5	141.5	134.5	135
7				127	135	139	138	133	129.5
8				(a)	132	137	134.5	133	128.5

(c) F7-A7 at cruise M = 0.8 adjusted to single rotation position (1.5 D) and thrust level.

1 (BPF)	132.5	135	139.5	151.5	156	158	152	143	146
2	(a)	126	123	144.5	147.5	149	146	140.5	133.5
3		(a)	(a)	138.5	142	143	139.5	138.5	130.5
4				132.5	137.5	140	135.5	135.5	128.5
5				127.5	133.5	137.5	133.5	130	126.5
6				122	129.5	133	132	125	125.5
7				117.5	125.5	129.5	128.5	123.5	120
8				(a)	122.5	127.5	125	123.5	119

[a]Tone not visible above tunnel background.

TABLE III. - PROPELLER NOISE PROJECTED
TO FLIGHT, FREEFIELD CONDITION,
1.5 DIAMETERS FROM
PROPELLER TIP

(a) SR-7

Harmonic number	Transducer position (angle from propeller plane				
	75°	90°	101°	110°	131°
	Sound pressure level of harmonic, spl, dB (ref. 2x10-5 n/m2)				
1 (BPF)	122	137	131.5	137.5	122
2	(a)	121.5	123	124	119
3		116.5	119.5	121	112
4		113	118.5	114	112.5
5		(a)	114.5	116	(a)
6			111	112	
7			110	(a)	
8			(a)	(a)	

[a]Tone not visible above tunnel background.

TABLE III. - (Concluded)

(b) F7-A7 projected to flight

Harmonic number	Transducer position (angle measured from halfway between propeller planes)								
	52°	59.4°	69.3°	81.8°	90°	98.2°	110.7°	120.6°	128°
	Sound pressure level of harmonic, spl, dB (ref. 2×10^{-5} n/m^2)								
1 (BPF)	118.5	121	125.5	137.5	142	144	138	129	132
2	(a)	112	109	130.5	133.5	135	132	126.5	119.5
3		(a)	(a)	124.5	128	129	125.5	124.5	116.5
4				118.5	123.5	126	121.5	121.5	114.5
5				113.5	119.5	123.5	119.5	116	112.5
6				108	115.5	119	118	111	111.5
7				103.5	111.5	115.5	114.5	109.5	106
8				(a)	108.5	113.5	111	109.5	105

(c) "Equivalent technology" counter-rotation projected to flight

1 (BPF)	112	114.5	119	131	135.5	137.5	131.5	122.5	125.5
2	(a)	105.5	102.5	124	127	128.5	125.5	120	113
3		(a)	(a)	118	121.5	122.5	119	118	110
4				112	117	119.5	115	115.5	108
5				107	113	117	113	109.5	106
6				101.5	109	112.5	111.5	104.5	105
7				97	105	109	108	103	99.5
8				(a)	102	107	104.5	103	98.5

[a]Tone not visible above tunnel background.

TABLE IV. - TEMPERATURES AT ALTITUDE

Altitude, m (ft)	0	1 524 (5 000)	3 048 (10 000)	4 572 (15 000)	6 096 (20 000)	7 620 (25 000)	9 144 (30 000)
Temperature, °C (°F)	15 (59)	5 (41.2)	-5 (23.3)	-15 (5.5)	-31 (-24.6)	-35 (-30.2)	-45 (-48)

TABLE V. - ESTIMATE OF ATMOSPHERIC ATTENUATION

(a) SR-7A angles

Measured angle, θ_m	Emitted angle, θ_E	Doppler shifted blade passing frequency	Attenuation at harmonic, dB							
			1 (BPF)	2	3	4	5	6	7	8
75	24.4	600	84.7	(a)						
90	36.9	453	37.1	86.8	(a)					
101	49.3	341	18.5	46.2	77.8	103.6	139.3	(a)		
110	61.3	264	12	29	51.3	67.3	89.5	120.3	139.7	(a)
131	93.9	155	6.5	14	25.5	35	45	59	68.8	78.5

(b) Counter-rotation angles

52	12.9	740	(a)							
59.4	15.8	707	(a)							
69.3	20.9	645	98	(a)						
81.8	29.4	538	52	120.4	(a)					
90	36.9	453	37.2	86.8	131.1	(a)				
98.2	45.8	368	19.5	62.6	95.6	146.6	(a)			
110.7	62.3	259	11.9	28.8	51	66.7	88.7	119.2	(a)	
120.6	77.1	197	7.7	19.6	36.1	46.4	60.1	80.9	94.8	108.7
128	88.9	166	6.5	14	25.5	35	45	59	68.8	78.5

[a]Greater than 150 dB.

TABLE VI. - ENROUTE ESTIMATE OF NOISE

(a) Based on single rotation SR-7

Harmonic number	Transducer position (angle from propeller axis)				
	75°	90°	101°	110°	131°
	Sound pressure level of harmonic, spl, dB (ref. 2×10^{-5} n/m^2)				
1 (BPF)	(a)	41.5	54.5	67	58
2	↓	(a)	18.5	36.5	46.5
3	↓	↓	(a)	11	28
4	↓	↓	↓	(a)	19
5	↓	↓	↓	↓	(a)
6	↓	↓	↓	↓	↓
7	↓	↓	↓	↓	↓
8	↓	↓	↓	↓	↓

[a]Level below 0 dB.

TABLE VI. - (Concluded)

(b) Based on counter-rotation F7-A7

Harmonic number	Transducer position (angle from propeller axis)								
	52°	59.4°	69.3°	81.8°	90°	98.2°	110.7°	120.6°	128°
	Sound pressure level of harmonic, spl, dB (ref. 2×10^{-5} n/m^2)								
1 (BPF)	(a)	(a)	(a)	27	46.5	66	67.5	63	67
2	↓	↓	↓	(a)	(a)	14	44.5	48.5	47
3	↓	↓	↓	↓	↓	(a)	16	30	32.5
4	↓	↓	↓	↓	↓	↓	(a)	(a)	21
5	↓	↓	↓	↓	↓	↓	↓	↓	9
6	↓	↓	↓	↓	↓	↓	↓	↓	(a)
7	↓	↓	↓	↓	↓	↓	↓	↓	↓
8	↓	↓	↓	↓	↓	↓	↓	↓	↓

(c) "Equivalent technology" counter-rotation

1 (BPF)	(a)	(a)	(a)	20.5	40	59.5	61	56.5	60.5
2	↓	↓	↓	(a)	(a)	7.5	38	42	40.5
3	↓	↓	↓	↓	↓	(a)	9.5	23.5	26
4	↓	↓	↓	↓	↓	↓	(a)	10	14.5
5	↓	↓	↓	↓	↓	↓	↓	(a)	(a)
6	↓	↓	↓	↓	↓	↓	↓	↓	↓
7	↓	↓	↓	↓	↓	↓	↓	↓	↓
8	↓	↓	↓	↓	↓	↓	↓	↓	↓

[a]Level below 0 dB.

TABLE VII. - "A" WEIGHTED SOUND PRESSURE LEVEL

(a) Single rotation airplane

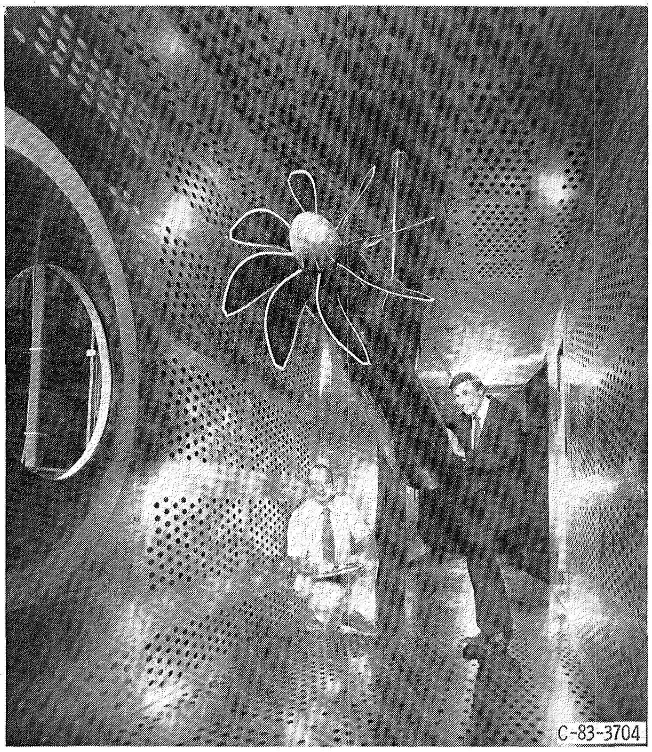
Angle	75°	90°	101°	110°	131°
A weighted sound pressure level, dB	---	37.5	48	58.5	46

(b) Counter-rotation airplane, based on F7-A7

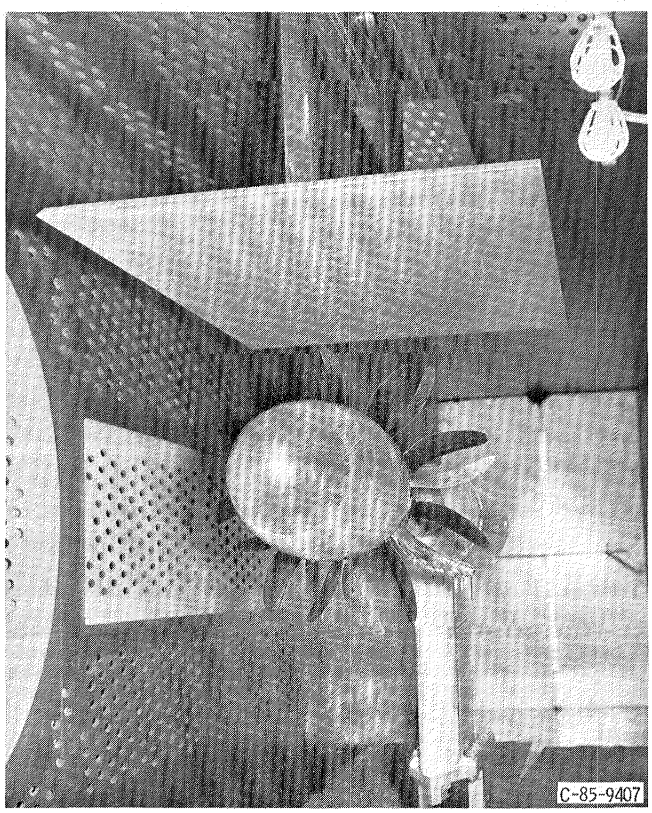
Angle	52°	59.4°	69.3°	81.8°	90°	98.2°	110.7°	120.6°	128°
A weighted sound pressure level, dB	---	-----	-----	24	42.5	60.5	59	52.5	48

(c) "Equivalent technology" counter-rotation airplane

Angle	52°	59.4°	69.3°	81.8°	90°	98.2°	110.7°	120.6°	128°
A weighted sound pressure level, dB	--	-----	-----	17.5	36	54	52.5	46	41.5

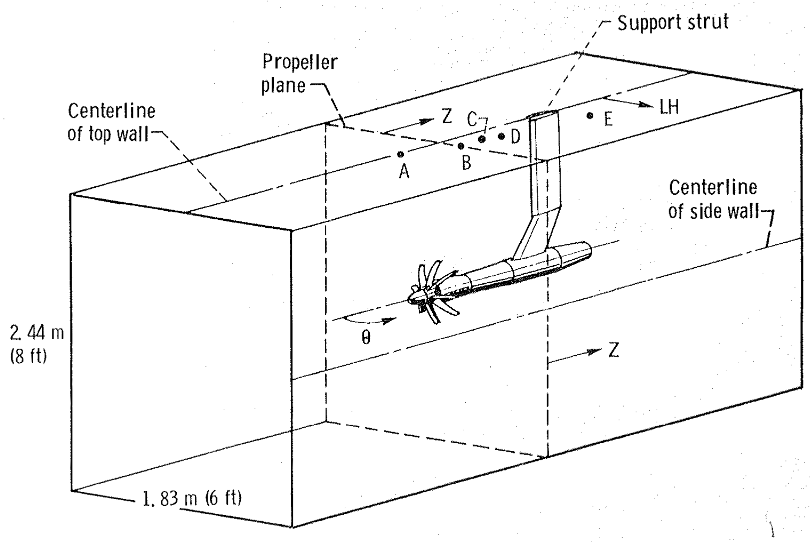


(a) SR-7A.



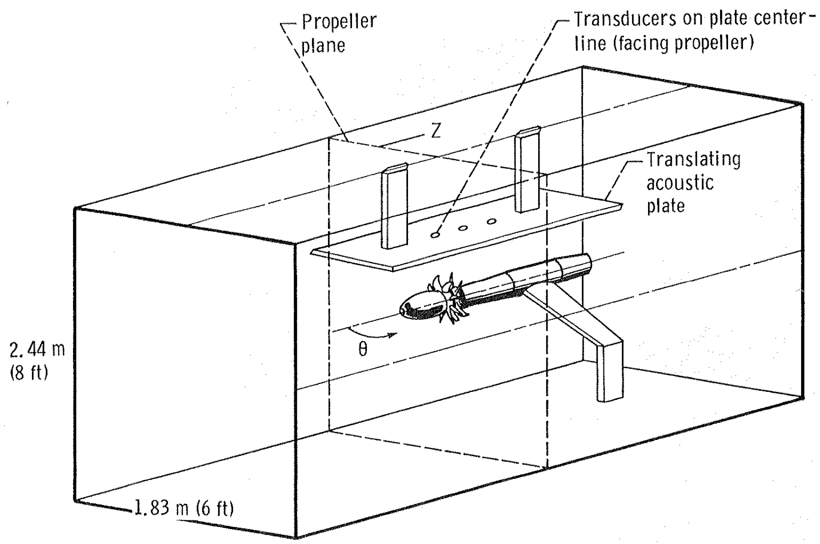
(b) F7-A7.

Figure 1. - Propellers in test section.



Trans-ducer position	Nominal angle, θ, deg
A	75
B	90
C	101
D	110
E	131

(a) SR-7A.



Trans-ducer position	Nominal angle, θ, deg
F	52
G	59.4
H	69.3
I	81.8
J	90
K	98.2
L	110.7
M	120.6
N	128

(b) F7-A7.

Figure 2. - Pressure transducer positions.

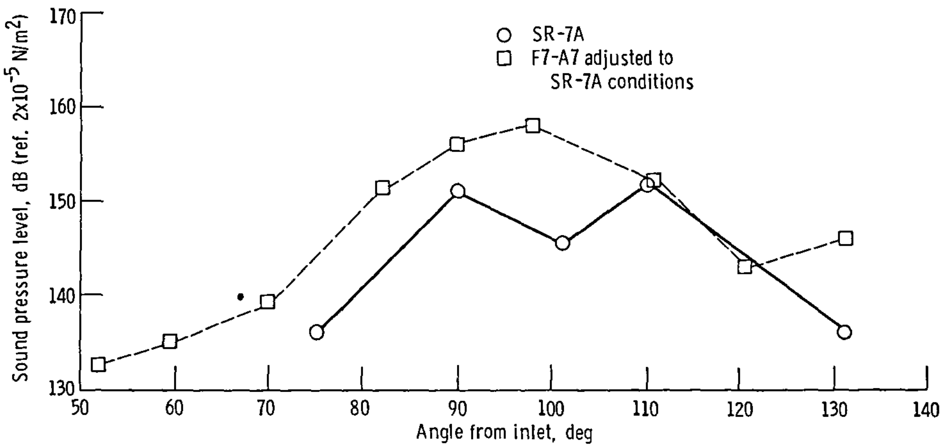


Figure 3. - Comparison of blade passage tones.

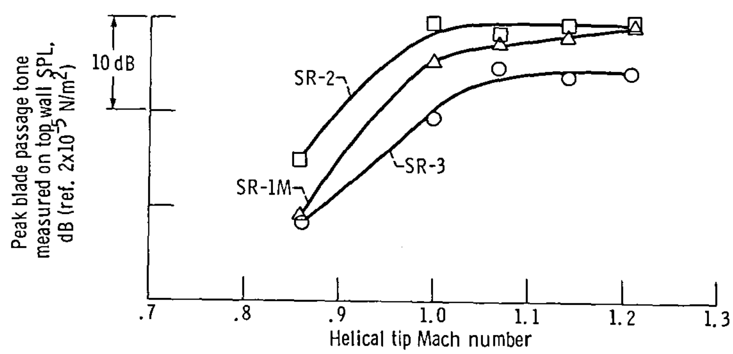
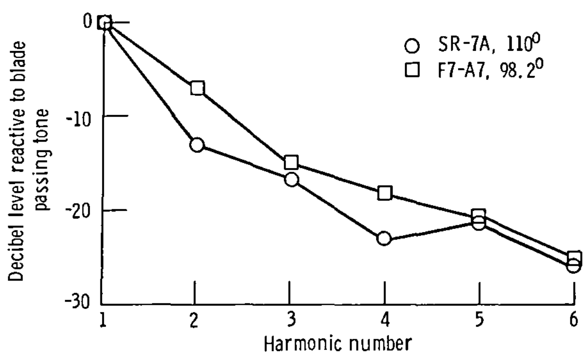
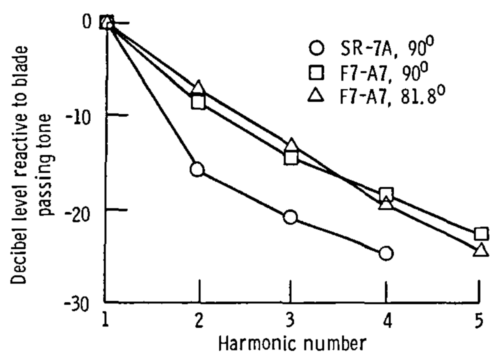


Figure 4. - Maximum blade passage tone variation with helical tip Mach number. (All at nominal advance ratio of 3.06.)



(a) Comparison at peak.



(b) Comparison formed at peak.

Figure 5. - Comparison of harmonics.

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM-87302		
4. Title and Subtitle An Estimate of the Enroute Noise of an Advanced Turboprop Airplane		5. Report Date April 1986
		6. Performing Organization Code 535-03-01
7. Author(s) James H. Dittmar		8. Performing Organization Report No. E-3020
		10. Work Unit No.
9. Performing Organization Name and Address National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135		11. Contract or Grant No.
		13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

The enroute noise of an Advanced Turboprop powered aircraft was estimated using projections of model noise data taken in the Lewis 8- by 6-Foot Wind Tunnel. The noise levels were roughly equivalent in annoyance to the noise 15.24 m (50 ft) from an automobile traveling at 80 km/hr (50 mph). It was felt that these levels would not illicit noise complaints from urban areas during the day but might be a slight annoyance in rural areas or in urban areas at night. Although it is not felt that the enroute noise is a major problem, these results indicate that a reduction in the enroute noise could improve the acceptability of advance turboprop airplanes.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Propeller noise; Enroute noise; Flyover noise; Noise	Unclassified - unlimited STAR Category 71

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

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

End of Document