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In-Flight Source Noise of an Advanced Large-Scale Single-Rotation Propeller

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A large-scale advanced single-rotation turboprop engine was installed on the left wing of a Gulfstream II aircraft for in-flight aeroacoustic tests. This program, designated propfan test assessment (PTA), involved aeroacoustic tests of the propeller over a range of flight conditions. Data was taken both near the source propeller at flight conditions and on the ground, resulting in a unique set of data which is valuable for evaluating acoustic propagation models for cruise noise ground measurements. The in-flight data reported herein was taken for seven test cases. An acoustically instrumented Learjet was flown in formation with the Gulfstream II to acquire noise measurements, and acoustic data was also acquired on the Gulfstream II aircraft. These acoustic measurements defined source levels and directivities for input into long-distance propagation models to predict en route noise. The sideline tone directivities measured by the Learjet showed maximum levels near 105 deg from the propeller upstream axis. Azimuthal directivities based on the maximum observed sideline tone levels showed highest levels below the aircraft (with a +3-deg propeller axis angle of attack). An investigation of the effect of propeller tip speed (with other engine parameters, such as thrust, shaft power, flight speed, and altitude, held constant) showed that the tone level reduction associated with reductions in propeller tip speed is more significant in the horizontal plane than below the aircraft.

Introduction

THE NASA Lewis Research Center contracted with Lockheed Aircraft to modify a Gulfstream II aircraft as a flying test bed for an advanced single-rotation propeller and related propulsive hardware.[1,2] This program, designated propfan test assessment (PTA) involved extensive aeroacoustic testing of the installed propeller, which was mounted on the left wing of the Gulfstream II aircraft. (The Gulfstream's two aft-mounted turbojet engines were used for takeoff, landing, and auxiliary cruise power.) The test propeller, designated SR-7L, was manufactured by the Hamilton Standard Division of United Technologies. The eight-blade propeller had a diameter of 2.74 m (9.0 ft). Design and performance results for the propeller and drive system may be found in Refs. 3–5.

A prime objective of the PTA test was to map the propeller source noise directivity pattern of the SR-7L propeller under actual flight conditions.[6–9] The scope of these tests included acquiring ground and Learjet stationkeeping noise measurements to obtain a data base for en route noise, as well as taking propeller blade pressure, video thermography, and structure-borne noise measurements. The results reported herein are for the in-flight noise field of the propeller as measured on the Gulfstream II aircraft and on the adjacent Learjet aircraft. Figure 1 is a photograph of the Gulfstream II and Learjet aircraft flying in formation. The Gulfstream II aircraft/SR-7L propeller was operated at seven test conditions that covered a range of propeller tip speeds and aircraft flight parameters. Reference 10 presents a comprehensive tabulation of the aeroacoustic results of this test program.

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Extensive wind-tunnel aeroacoustic tests of a 62.2-cm (24.5-in.) diameter model of the SR-7L (designated SR-7A) propeller were made at the NASA Lewis Research Center prior to these large-scale flight tests. These tests explored noise directivities at cruise conditions[11] (Mach 0.7) and takeoff/approach conditions[12] (Mach 0.2). Results of these model propeller tests are not included herein.

This article will present a synopsis of the large-scale SR-7L propeller acoustic results obtained by the Gulfstream and Learjet aircraft during these flight tests.

Test Procedure

The Gulfstream II aircraft was extensively modified by Lockheed-Georgia to accommodate the wing-mounted SR-7L propeller. As shown in Fig. 2, these modifications included increasing the structural strength of the left wing and the addition of a counterbalance weight on the right wing tip. The Gulfstream II aircraft carried instrumentation to monitor the aeroacoustic performance of the propeller as well as to record the aircraft flight conditions.

The SR-7L propeller was designed for a 0.80 cruise Mach number at 10,688-m (35,000-ft) altitude (see Table 1 and Ref. 3). The eight-blade propeller had a design tip speed of 244

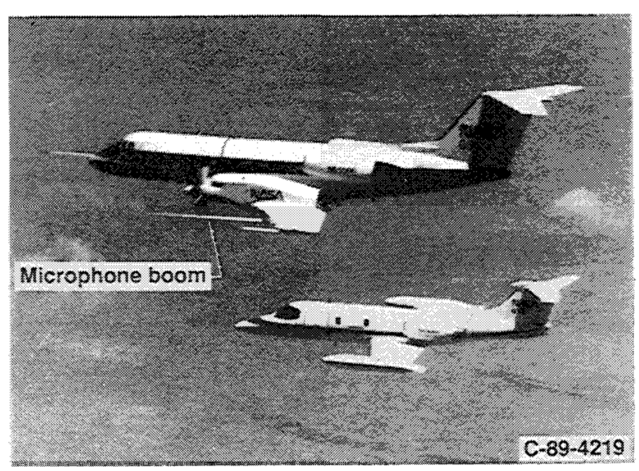


Fig. 1 In-flight photograph of PTA and Learjet aircraft.

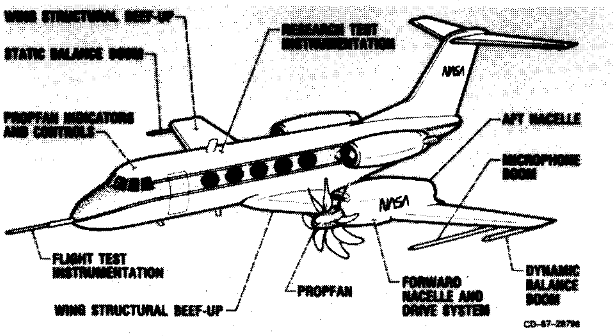


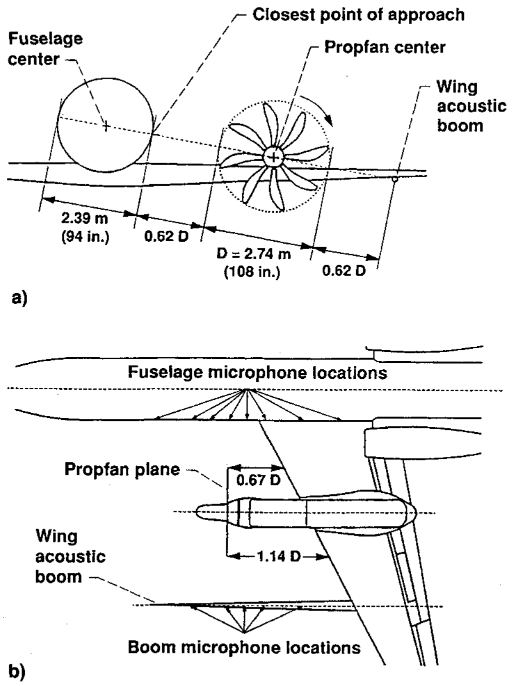
Fig. 2 Modifications of Gulfstream II aircraft to PTA configuration.

Fig. 3 SR-7L Propeller installed on Gulfstream II aircraft.

Table 1 SR-7L Propeller design parameters (cruise conditions)

Diameter, m (ft)	2.74 (9.0)
Number of blades	8
Mach number	0.80
Altitude, m (ft)	10,668 (35,000)
Tip speed, m/s (ft/s)	244 (800)
Rotational speed, rpm	1,698
Blade setting angle, ¾ span, deg[a]	57.57
Advance ratio	3.06
Power coefficient	1.45
Power loading, kW/m^2 (hp/ft^2)	257 (32.0)
Excitation factor	4.5
Power, kW (hp)	1,934 (2,592)
Thrust, N (lbf)	6,490 (1,459)

[a]Aerodynamic tests of the reduced-diameter SR-7A propeller showed that design conditions were met with a blade setting angle of 60.1 deg.



	Forward locations	Propfan plane	Aft locations
Axial distance from propfan plane, X/D	−1.00 −0.50 −0.25	0.00	0.25 0.50 1.00 1.50
Boom microphones	•	•	• • •
Fuselage microphones	• • •	•	• • • •

Fig. 4 PTA Acoustic instrumentation.

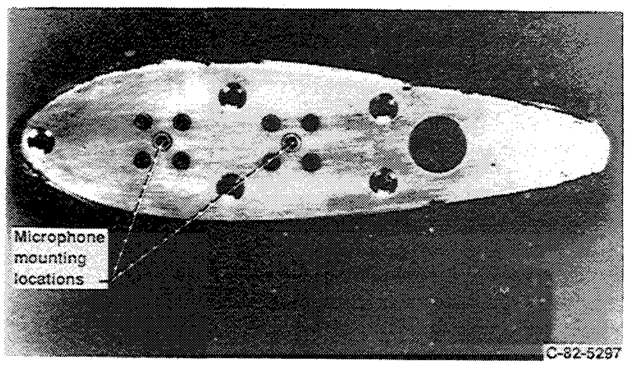


Fig. 5 Wing tip microphone mounting plate.

m/s (800 ft/s). Figure 3 is a photograph of the SR-7L propeller installed on the Gulfstream wing.

Acoustic Instrumentation

Acoustic instrumentation on the Gulfstream included flush-mounted microphones on the aircraft fuselage and on an outboard microphone boom. Figure 4 shows the locations of these microphones relative to the SR-7L propeller. The fuselage microphones were located on a lateral line of closest propeller approach. The microphone boom was located outboard of the propeller diametrically opposite the line of fuselage microphones. The plane containing the propeller axis and the axes of the two microphones arrays is tilted approximately 10 deg from the horizontal. Both the fuselage and boom microphones were at 1.12 propeller diameters from the propeller axis of rotation, or 0.62 diameters from the propeller tip. Thus, it is likely that data from these microphones include some near-field influences in the propeller noise measurements. The acoustic signals from these microphones were recorded on analog tape aboard the aircraft.

The NASA Lewis Learjet was instrumented with flush-mounted wing tip, nose, and cabin roof microphones for these tests. Two essentially adjacent microphones were located at each measurement station to provide redundant measurements, giving a total of 12 microphones on the Learjet. The wing tip microphones were mounted on a plate (Fig. 5) which replaced the navigation lights during the acoustic test flights. Figure 6 shows the locations of the Learjet microphones. The acoustic signals were monitored for data quality and recorded on magnetic tape aboard the aircraft for later analysis. The acoustic spectra of the Learjet engine noise were sufficiently different from those of the propeller to prevent data contamination. Background broadband noise levels for all of the Learjet microphones with the exception of the cabin roof microphones were about 100 dB near the fundamental and

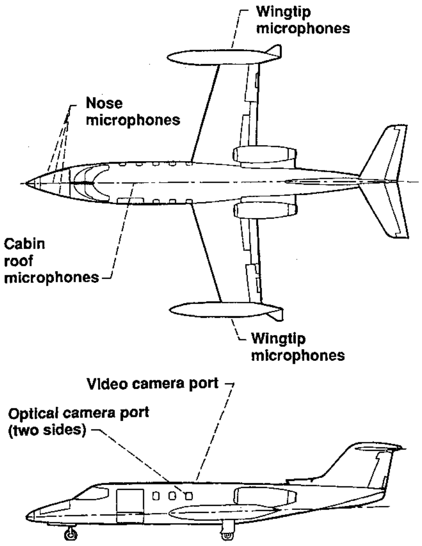


Fig. 6 Learjet acoustic instrumentation.

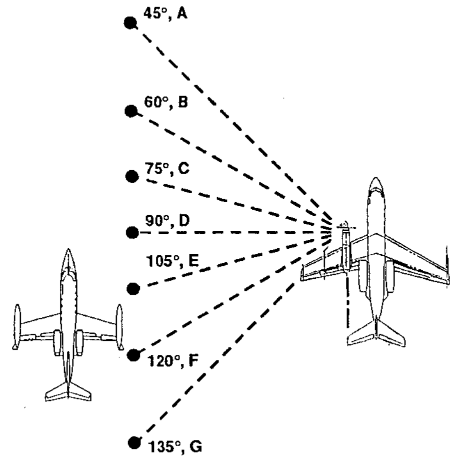
first harmonic tone frequencies. Similar levels were observed for the PTA aircraft boom and fuselage microphones (although the close proximity of these microphones to the sound source resulted in much higher tone levels relative to the broadband levels). The Learjet cabin roof microphones typically showed corresponding broadband levels of about 109 dB, with this difference presumably related to local airflow disturbances in that region of the Learjet fuselage.

Learjet Stationkeeping Positioning

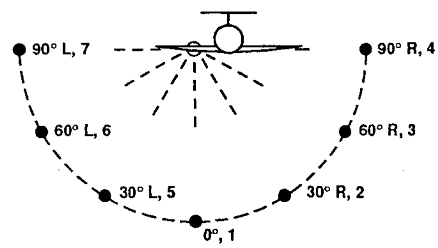
Figure 7 is a sketch showing the designations for the sideline and azimuthal stationkeeping locations used during formation flight. Two methods were used to fix the location of the Learjet relative to that of the SR-7L propeller (and Gulfstream II aircraft), with the Learjet viewing the Gulfstream either visually or with a video camera and cockpit display. Sideline surveys at 90- and 60-deg azimuthal locations were flown optically, with the Learjet pilots maintaining visual contact with the Gulfstream. Sideline surveys were initiated from behind the Gulfstream at the 135-deg or "G" location, and progressed forward as far as visual contact permitted (up to $\Theta = 45$ deg). Aircraft separation for these cases was on the order of 61 m (200 ft). A 35-mm film camera mounted on a protractor device was used to verify the sideline angle. Photographs taken at each data point were later used with an image scaling technique to determine the actual source to microphone distances. The measuring station/microphone location geometry (Fig. 9) of the Learjet were incorporated to determine the actual distance and measuring angle for each Learjet microphone.

Limited visibility of the Gulfstream from the Learjet resulted in a different positioning technique for the 30- and 0-deg azimuthal positions below the PTA aircraft. A wide-angle video camera was located such that it scanned upward through a viewing port in the Learjet cabin roof. Desired Gulfstream flight positions were then designated on viewing screens inside the Learjet. The Learjet pilots then flew the Learjet such that the Gulfstream image was at the desired data location, as shown on a display template. The video flights were flown at typical sideline separations of about 154 m (500 ft). A third "safety" aircraft was flown with the Gulfstream and Learjet for these "video" flights to ensure safe aircraft separation. The safety aircraft was flown sufficiently far away from the research aircraft to avoid signal contamination.

The aircraft formation flight (Gulfstream II and Learjet) maintained relatively stable stationkeeping positions. The angular location (sideline and azimuthal) was typically maintained within ± 1 deg, while the visual flight separation was



a) Sideline angle relative to propeller upstream axis



b) Azimuthal angle (ϕ) viewing upstream

Fig. 7 Position code for PTA-Learjet stationkeeping data. Example: position "5E" would nominally be azimuthally 30-deg L from below the propeller, and at a sideline angle of 105 deg.

typically within 3 m (10 ft) of the desired position. Based on a separation distance of 61 m (200 ft), this would give a sound level uncertainty of about 0.5 dB. The video-ranged data points may have had a somewhat higher position uncertainty; but with the greater separation distance would again have a similar 0.5 dB sound pressure level (SPL) uncertainty.

A shaft-order signal from the SR-7L propeller was transmitted from the Gulfstream II aircraft to the Learjet for inclusion in the analog data record. The plan was to use this signal for data enhancement to compensate for the increased aircraft separation distances associated with the 30- and 0-deg azimuthal locations. However, the signal enhancement technique proved unsatisfactory due to separation distances, small relative aircraft movements, etc. Subsequently, the Learjet pilots determined that some of the 30- and 0-deg azimuthal location sidelines could be flown visually at closer aircraft separation distances, with significantly greater acoustic data resolution (some upstream sideline angular positions could not be flown in this manner). The video signal for the 30- and 0-deg azimuthal locations was recorded for later source-to-microphone distance calibrations using image scaling techniques.

Results and Discussion

Propeller Aerodynamic Operating Conditions

Table 2 gives a description of the seven propeller test conditions, designated as cases 1–4, and 6–8. Average test values are given in Table 2 for the measured propeller thrust, power coefficient, and shaft power. The SR-7L propeller blade setting angle was adjusted automatically in flight to compensate for power requirements; however, values for the blade setting angle could not be obtained due to an instrumentation malfunction during the reported test program. The unavailability of the blade setting angle value during these tests introduced an additional "unknown" in data comparisons between test cases.

Table 2 SR-7L Propeller test conditions

Case number	Mach	Altitude		Propeller tangential tip speed		Thrust		C_p	Shaft power		Percent full power
		m	ft	m/s	ft/s	N	lbf		kW	hp	
1	0.70	10,668	35,000	244	800	6,230	1,400	1.35	1,790	2,400	90
2	0.70	6,096	20,000	|	|	9,920	2,230	1.43	3,210	4,300	|
3	0.50	6,096	20,000	|	|	12,721	2,860	1.27	2,820	3,780	|
4	0.59	4,267	14,000	↓	↓	13,790	3,100	1.15	3,130	4,200	↓
6	0.77	10,668	35,000	256	840	6,630	1,490	1.47	2,090	2,800	100
7	0.70	10,668	35,000	213	700	6,230	1,400	1.98	1,810	2,430	90
8	0.70	10,668	35,000	189	620	6,010	1,350	2.46	1,810	2,420	90

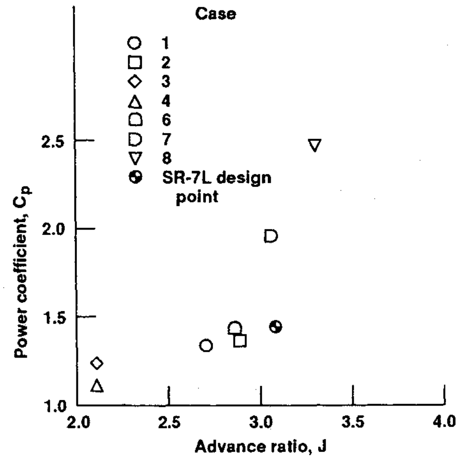


Fig. 8 Propeller operating map.

Figure 8 is a propeller operating map of the power coefficient C_p vs advance ratio J for the target operating points. Cases 1, 7, and 8 provide a parametric study of the effect of propeller tip speed (see Table 2). The propeller was operating at essentially the same thrust and shaft power for these three cases. The power coefficient, which is inversely proportional to $(\text{rpm})^3$ changes with tip speed. These three cases were flown at the design altitude of 10,688 m (35,000 ft). Case 6 performance came closest to the design point (from Table 1). However, the tip speed for this case was 256 m/s (840 ft/s) rather than the design 244 m/s (800 ft/s). Cases 2 and 3 explore performance at low flight speeds at 6096-m (20,000-ft) altitude, while case 4 was at 4267-m (14,000-ft) altitude.

Acoustic Spectra

Data samples of approximately 1-min duration were taken at designated sideline angular locations (see Fig. 7). The acoustic data presented herein are for "as-measured" angular positions. Figure 9 shows the relationship between emission and as-measured angles for the four flight speeds. These differences can be significant. For example, at Mach 0.70, a measured sideline angle of 90 deg corresponds to an emission angle of only 46 deg. (That is, the acoustic spectra which was measured at 90 deg in flight would be seen at 46 deg if there were no forward propeller velocity.) Similarly, peak emitted tone levels occurring near the propeller plane ($\Theta = 90$ deg) would be observed somewhat aft of the propeller plane.

Figure 10 shows a representative spectrum for the SR-7L propeller. This spectrum is for the 90-deg L azimuthal angle (ϕ = 90-deg L) ("L" designates left side of aircraft viewing upstream) and 118-deg sideline angle with the propeller operating at case 1 conditions (see Fig. 7 and Table 2). The spectra was acquired with a 4-Hz bandwidth, and a data sample of about 30 s. The first three propeller tone orders [$n \times$ blade passage frequency (BPF)] are easily identified in this spectrum. Broadband levels tend to be controlled by microphone "scrubbing noise" and are therefore not representative of the test propeller spectra.

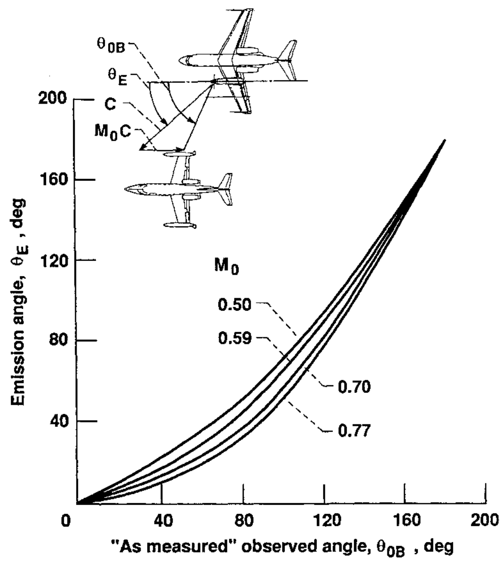


Fig. 9 Relationship between observed and emission angles. $\Theta_E = \Theta_{OB} - \sin^{-1}(M_O \sin \Theta_{OB})$.

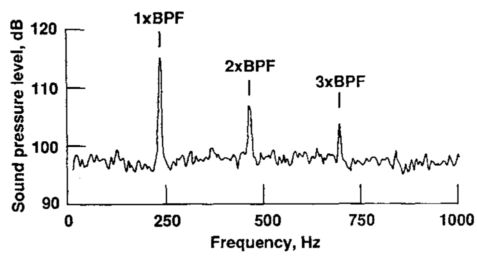


Fig. 10 Representative spectrum of PTA propeller noise. [Measured by Learjet nose microphone, 90-deg L azimuthal angle, 118-deg sideline angle, as-measured along a 54-m (178-ft) sideline, case 1 conditions, 4-Hz bandwidth.]

Free-Field Adjustments

The acoustic data presented in this article are adjusted to "free-field" conditions at a 152-m (500-ft) sideline distance relative to the propeller axis. These data adjustments are for spherical spreading [$\Delta\text{dB} = 20 \log(D_1/D_2)$], and installation effects at the microphone measurement locations.

There is considerable debate as to the best procedure to correct for scattering, boundary-layer refraction, and related flight effects at the microphone measuring location. Reference 13 presents theoretical and experimental data for free-field acoustic scattering corrections for a microphone surface mounted on an infinite cylinder of various diameters. This reference presents results for sound waves normal to the microphone surface and for a number of oblique impingement angles. These results are, however, for "no flow" conditions. The methods of Ref. 13 are applied to the acoustic data presented herein. These corrections for acoustic scattering increase with tone frequency and effective cylindrical diameter of the microphone mounting surface up to a maximum value of 6 dB (subtracted from measured data). Boundary-layer refraction effects on the acoustic data are neglected in this analysis. There is concern over the accuracy of existing analytic acoustic models for boundary-layer refraction corrections.[14]

Sideline and Azimuthal Directivities

Sideline and azimuthal directivities of blade passage and harmonic tones have been constructed from acoustic spectra measured by the Learjet at stationkeeping locations. Broadband noise at the measuring microphone and distance attenuation of the propeller noise limited data acquisition at some sideline angles. This was especially true for higher-order tones at the 30- and 0-deg azimuthal angles where video positioning with a greater separation distance was used due to safety concerns. Tone levels are only reported where they were sufficiently above adjacent broadband levels (at least 5 dB) to minimize acoustic contamination.

Sideline directivities for the Gulfstream boom and fuselage microphones are also shown on the 90-deg L sideline directivities to give some indication of distance effects (i.e., near-field/far-field). The boom microphone which was located at 0.25 propeller diameters aft of the propeller plane (Fig. 4) was inoperative during the reported test series. Again, the Gulfstream microphone boom and fuselage microphones were located at relatively close 1.12 propeller diameters from the propeller axis of rotation. The following directivities are representative of those taken during the acoustic tests. Additional directivity plots may be found in the comprehensive data report.[10]

Figures 11–16 present tone directivities for the propeller operating at case 1 conditions. Case 1 (see Table 2) was flown at 10,688-m (35,000-ft) altitude with a propeller tangential tip speed of 244 m/s (800 ft/s). Figure 11 presents the fundamental tone sideline directivity at the 90-deg L azimuthal position (ϕ = 90-deg L), which is horizontal on the propeller side of the Gulfstream II aircraft. A dashed line connects data points for the 90- and 114-deg Gulfstream II boom microphones because of the inoperative 103-deg microphone. However, microphone boom data from the earlier PTA test series, during which the 103-deg microphone was operative, showed that first- and second-order tone levels for that microphone were similar to those observed for the 90-deg microphone.

There is a consistent difference between data taken by the Learjet nose microphones and those taken by the wing tip or cabin roof microphones. This difference has been noted in previous Learjet flight noise studies[15]; however, the reason for this difference remains unexplained. Typically, the wing tip and cabin roof tone level results are slightly higher than the nose microphone tone levels. A curve has been faired through the data from either the Learjet noise or wing tip and cabin roof measuring stations for the sideline tone directivities presented herein.

The sideline directivities taken by the Learjet in Fig. 11 show a maximum tone level at a sideline angle of about 105 deg, which is the same sideline peak angular location which was observed for the model propeller at cruise conditions.[11]

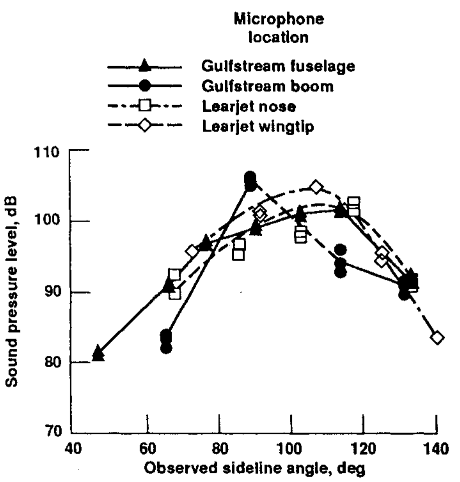


Fig. 11 PTA Aircraft 1 × BPF tone sideline directivity [90-deg L azimuthal location, Mach 0.70, 10,688-m (35,000-ft) altitude, case 1 conditions, data adjusted to 152-m (500-ft) free-field conditions].

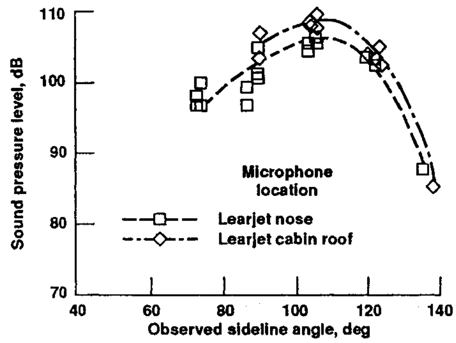


Fig. 12 PTA Aircraft 1 × BPF tone sideline directivity [0-deg azimuthal location, Mach 0.70, 10,688-m (35,000 ft) altitude, case 1 conditions, data adjusted to 152-m (500-ft) free-field conditions].

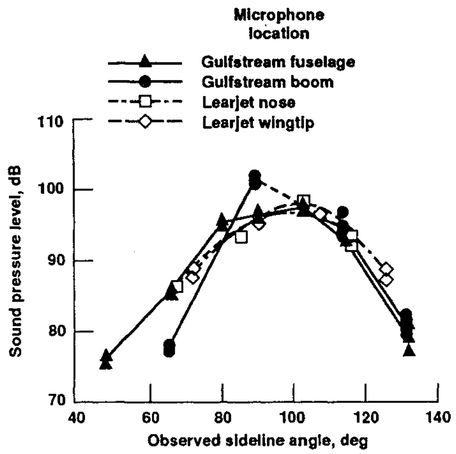


Fig. 13 PTA Aircraft 2 × BPF tone sideline directivity [90-deg L azimuthal location, Mach 0.70, 10,688-m (35,000 ft) altitude, case 1 conditions, data adjusted to 152-m (500-ft) free-field conditions].

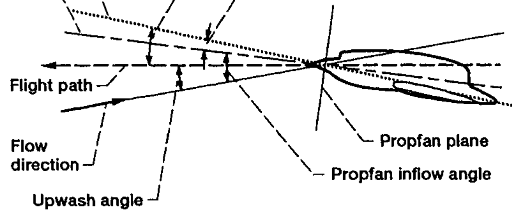


Fig. 14 Propeller installation and flow angles.

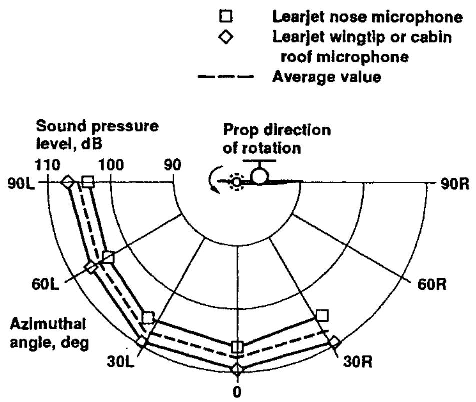


Fig. 15 PTA Aircraft 1 × BPF tone azimuthal directivity viewing upstream [Mach 0.70, 10,688-m (35,000-ft) altitude, case 1 conditions, maximum sideline tone level, data adjusted to 152-m (500-ft) sideline free-field conditions].

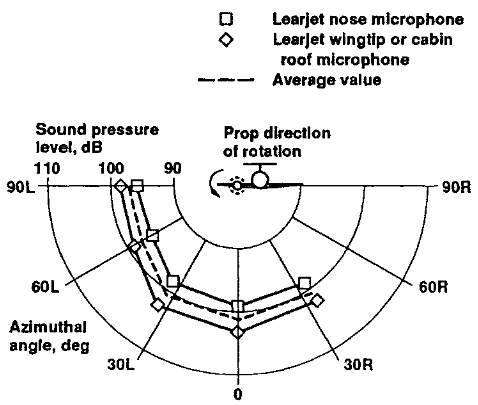


Fig. 16 PTA Aircraft 2 × BPF tone azimuthal directivity viewing upstream [Mach 0.70, 10,688-m (35,000-ft) altitude, case 1 conditions, maximum sideline tone level, data adjusted to 152-m (500-ft) sideline free-field conditions].

The unavailability of the Gulfstream boom microphone which was located 0.25 propeller diameters aft of the propeller plane (103-deg sideline angle) was unfortunate since data from that microphone should be near the maximum sideline tone level. A dashed line is used for the microphone boom directivities to denote the level uncertainty due to the missing microphone data. It is possible that data for the aft two boom microphones (located at sideline angles of 114 and 132 deg) might be affected by their proximity to the aircraft structure. The tone directivity for the microphone boom tends to peak further upstream (about 90 deg) than the corresponding directivities measured by the Learjet, followed by a more abrupt decrease in level. The reason for this difference in directivity shape is unknown.

The fundamental tone directivity measured by the PTA aircraft fuselage microphones is also shown on Fig. 11. The fuselage microphones were diametrically opposite of the boom microphones and at the same sideline distance from the propeller axis-of-rotation (see Fig. 4). However, the tone directivity for the fuselage microphones is in excellent agreement with the far-field Learjet measurements.

The Learjet took data along a number of sidelines, primarily to define the far-field data field of the SR-7L propeller for use as input to long-distance propagation models used to predict en route flyover noise. In particular, the relatively close far-field data taken by the Learjet may be used in conjunction with corresponding ground noise measurements to validate models for acoustic propagation over long distances. (Atmospheric measurements were taken concurrently with the ground fly over data acquisition for input to the acoustic propagation theory.[16]) Figure 12 shows the fundamental tone sideline directivities directly below the propeller (ϕ = 0-deg azimuthal position). Data are from the Learjet nose and cabin roof microphones. Again, curves were faired through points from each of the microphones measuring locations. These faired curves are estimates of the directivity and have some degree of uncertainty. For example, curves faired through the sideline data of Fig. 12 have a potential error of about 2 dB based on data point scatter. Maximum tone levels again occurred at about 105-deg sideline angle, and maximum tone level results for the cabin roof microphones were about 4 dB higher than those for the nose microphones.

Figure 13 shows the 90-deg L sideline tone directivities for the second harmonic propeller tone. Results for the Learjet nose and wing tip microphones are in much better agreement than was observed for the fundamental tone directivities of Fig. 11, suggesting that the aforementioned measurement differences may be related to tone frequency (and frequency related sound reflections). However, this tone frequency argument for the measuring station difference has limited validity. For example, fundamental sideline directivities at the 90-deg L position for cases 4, 6, and 7 show reasonably good agreement between data for the two Learjet measuring locations, while corresponding second harmonic data for case 8 shows nose/wing tip differences similar to those noted for case 1. The reason for these inconsistencies in the data is not known. The directivity for the second harmonic measured by the PTA fuselage microphones is in excellent agreement with the Learjet-measured directivities.

The nacelle tilt angle (the angle formed between the upstream propeller axis of rotation and the fuselage reference line) was fixed at −1.0 deg for these propeller flight tests (see Fig. 14). The upwash angle at the propfan estimated from panel method calculations[8] was about 1.0 deg, effectively canceling the nacelle tilt angle such that the measured aircraft angle-of-attack was close to the actual propeller inflow angle. Reference 17 compares SPL tone levels measured at the PTA aircraft boom and fuselage microphones with tone level predictions for several propeller angles of attack, again showing that through both theory and data there is a region of higher noise below the aircraft for propeller operation at positive rotation axis angles of attack.

Figures 15 and 16 show the azimuthal directivity of the maximum first- and second-order sideline tone level measured by the Learjet. Again, results are shown for the nose and wing tip/cabin roof microphones. The wing tip microphone results were used for the 90- and 60-deg azimuthal data, while the cabin roof (and nose top) microphones were used at 30 and 0 deg.

The fundamental azimuthal directivities of Fig. 15 show that the level difference between the Learjet microphone locations (nose and wing tip or cabin roof) is consistent and appears at all measured azimuthal locations. There is generally a higher tone level observed toward the 0-deg azimuthal location relative to the 90-deg L location. This circumferential variation is associated with propeller operation at nonzero axis angle of attack. Propeller operation at positive angles of attack (propeller upstream axis-of-rotation angles upward relative to the propeller inflow direction) would be expected to yield an azimuthal directivity with higher levels below the propeller (and lowest levels above the propeller). This is because of increased propeller blade loading during the downward portion of the rotation cycle (with the propeller axis at positive angle of attack). The loading noise radiates normal to the advancing blade, hence, increased noise level is observed below the aircraft. Takeoff (Mach 0.20) wind-tunnel noise measurements for the model SR-7A propeller[12] showed the fundamental tone level below the propeller to increase nearly 1 dB for each degree of positive angle of attack. The propeller operated with its axis of rotation at approximately 3-deg positive angle of attack at case 1 conditions, so the circumferential tone level variation observed in Fig. 15 (at cruise conditions) is expected. The propeller sideslip angle (in the horizontal plane) was typically about 0.5 deg, so this effect on the azimuthal tone directivity should be negligible.

Figure 16 shows the case 1 azimuthal directivities for the second harmonic propeller tone. These results are similar in nature to those for the fundamental tone of Fig. 15, showing a slightly higher level below the aircraft.

Figure 17 shows the case 2 azimuthal directivity for the fundamental tone as measured by the Learjet microphones. Sideline directivities for azimuthal angles from 90-deg L to 90-deg R were taken for this test case, providing more complete azimuthal directivities. Of particular interest in this figure are the sharply lower tone levels near the 90-deg R azimuthal location ("R" designates right side of aircraft viewing upstream), where Gulfstream fuselage blocking of the propeller sound path becomes significant.

Propeller Tip Speed Effects

Propeller test cases 1, 7, and 8 provided the opportunity to explore the acoustic field of the large-scale SR-7L propeller

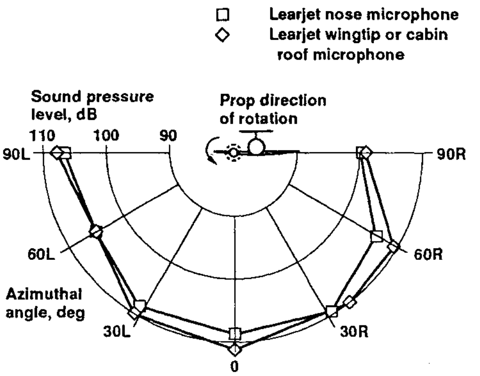


Fig. 17 PTA Aircraft 1 × BPF tone azimuthal directivity viewing upstream [Mach 0.70, 6096-m (20,000-ft) altitude, case 2 conditions, maximum sideline tone level, data adjusted to 152-m (500-ft) sideline free-field conditions].

at different tip speeds. Flight conditions remained essentially unchanged for these three test cases, including propeller operation in terms of thrust and shaft power (see Table 2). These tests were conducted at 10,688-m (35,000-ft) altitude and Mach 0.70.

Figure 18 shows fundamental tone directivities at the 90-deg L sideline as measured by the Learjet microphones. Figure 18a shows results for the nose microphones, while results for the wing tip microphones are shown in Fig. 18b. The data curves in Fig. 18 and subsequent comparison figures were faired through the individual data points as described in the discussion of Fig. 11. These sideline results show a tone level reduction associated with reduced propeller tip speed.

The effect of propeller tip speed reduction on the maximum tone level is significantly less below the propeller ($\phi = 0$ deg) as shown in Fig. 19. Also, the shape of the directivity curves (i.e., angular location of maximum tone level) showed little change for the three test cases (except for the case 8 results for the cabin roof microphones in Fig. 19b, which showed a forward shift in directivity).

Second-order tone level results measured by the Learjet were only retrievable from the data for cases 1 and 8 at the 90-deg L azimuthal location. Figure 20 shows the second harmonic sideline directivities for these two cases. Again, there is a significant tone level reduction associated with reduced propeller tip speed.

The azimuthal directivities of the maximum sideline tone levels measured by the Learjet for cases 1, 7, and 8 are presented in Fig. 21. Results are similar for the Learjet nose microphone data (Fig. 21a) and the wing tip microphones (Fig. 21b), showing that the greatest benefits of reduced propeller tip speed appear to occur toward the 90-deg L azimuthal position, with minimal benefits below the aircraft. Again, the propeller axis angle of attack was measured at about +3 deg for these three test cases, which would tend to give higher tone levels below the aircraft.

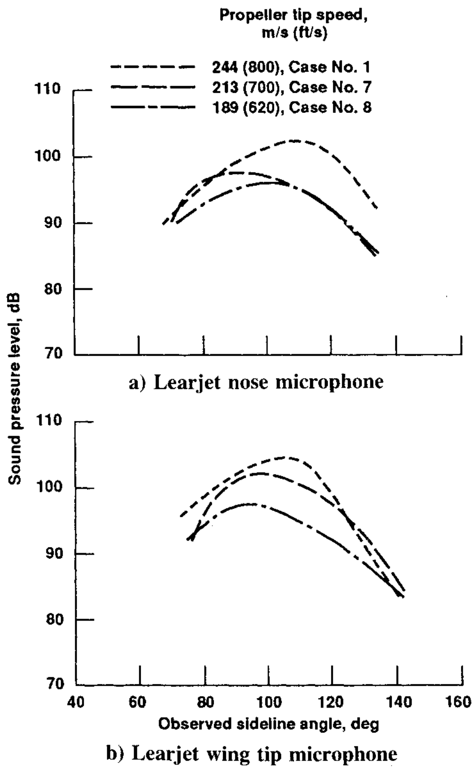


Fig. 18 1 × BPF Tone sideline directivity, effect of propeller tip speed [Mach 0.70, 10,688-m (35,000-ft) altitude, 90-deg L azimuthal angle, 152-m (500-ft) sideline].

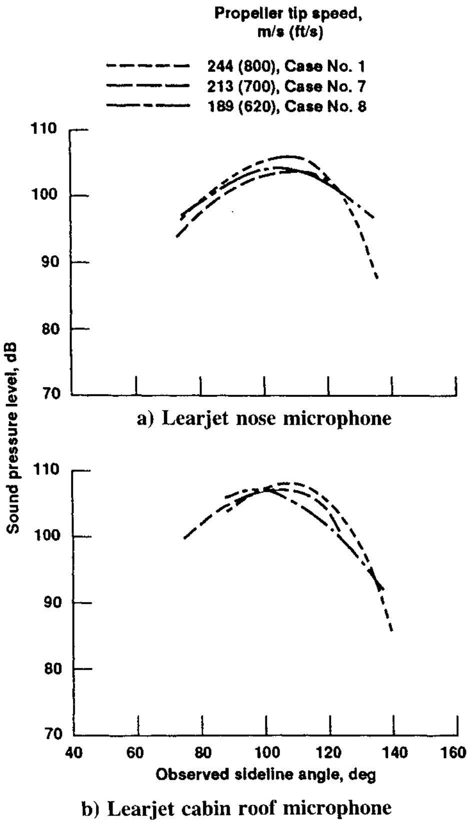


Fig. 19 1 × BPF Tone sideline directivity, effect of propeller tip speed [Mach 0.70, 10,688-m (35,000-ft) altitude, 0-deg azimuthal angle, 152-m (500-ft) sideline].

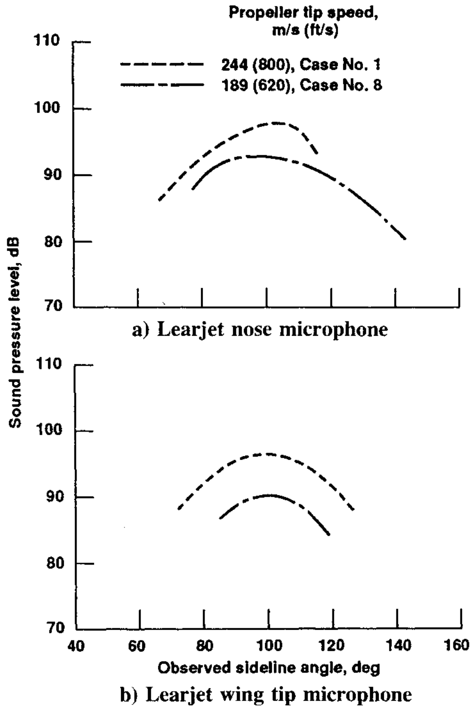


Fig. 20 2 × BPF Tone sideline directivity, effect of propeller tip speed [Mach 0.70, 10,688-m (35,000-ft) altitude, 90-deg L azimuthal angle, 152-m (500-ft) sideline].

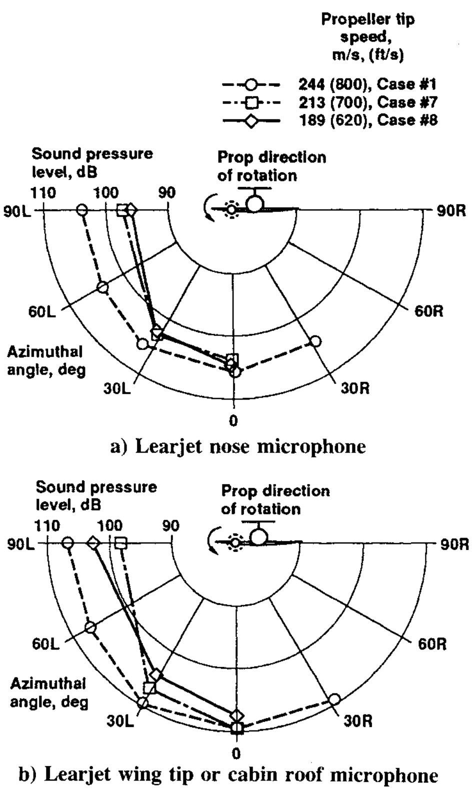


Fig. 21 1 × BPF Tone azimuthal directivity, effect of propeller tip speed [Mach 0.70, 10,688-m (35,000-ft) altitude, maximum sideline tone level, 152-m (500-ft) sideline].

Figure 22 summarizes the effect of reduced propeller tip speed for the first two propeller tone orders. Results are shown for the maximum tone levels observed along the 90-deg L and 0-deg sidelines by the Learjet nose, wing tip, and cabin roof microphones, and for the Gulfstream fuselage and boom microphones. Results for the Gulfstream microphone boom, which was located azimuthally at ϕ = 75-deg L and the Gulfstream fuselage microphones (ϕ = 105-deg R) are

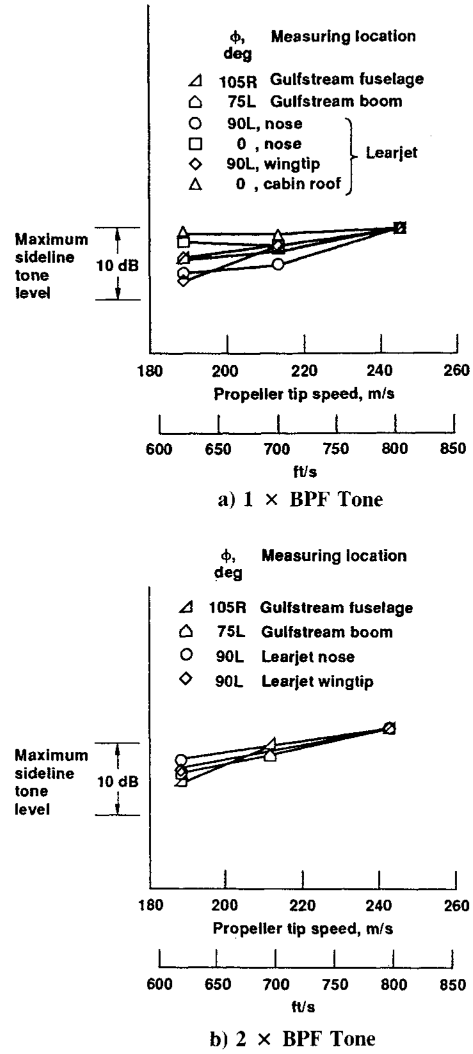


Fig. 22 Effect of propeller tip speed on maximum sideline tone level [cases 1, 7, and 8, normalized about 244 m/s (800 ft/s) tip speed].

similar to those measured by the Learjet. Again, little tone level reduction was observed below the aircraft. Level reductions with reduced tip speed for the second-order tone at the 90-deg L azimuthal position (Fig. 22b) were about the same as for the fundamental tone.

Concluding Remarks

Flight tests to define the far-field tone source were completed on the large-scale SR-7L advanced turboprop which was installed on the left wing of a Gulfstream II aircraft. This program, designated PTA, involved aeroacoustic testing of the propeller over a range of test conditions and afforded an extensive evaluation of a large-scale advanced single-rotation turboprop. This overall flight test program provided a unique set of data taken both near the source propeller at flight conditions and on the ground. These data will be valuable for refining ground-measured flight noise prediction techniques. The data reported herein were taken near the source propeller on the Gulfstream II aircraft and by an acoustically instrumented Learjet which was flown in formation with the Gulfstream II aircraft. In-flight data reported herein were taken for seven test cases. Three of these cases allowed for an investigation of the effect of propeller tip speed on tone noise at 10,688 m (35,000 ft) and Mach 0.70 flight conditions, with other parameters such as thrust and shaft power held constant. This comparison showed a decrease in the first two-tone levels with reduced tip speed, with the greatest effect observed in the horizontal plane. The sideline directivities measured by the Learjet showed maximum levels near 105 deg from the propeller upstream axis. Azimuthal directivities based on the maximum observed sideline tone levels showed highest levels below the aircraft (with +3-deg propeller axis angle of attack).

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