Measurements of Propeller Noise in a Light Turboprop Airplane

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In-flight acoustic measurements have been made on the exterior and interior of a twin-engined turboprop airplane under controlled conditions to study data repeatability. It is found that the variability of the harmonic sound pressure levels in the cabin is greater than that for the exterior sound pressure levels, typical values for the standard deviation being +2.0 and −4.2 dB for the interior vs +1.4 and −2.3 dB for the exterior. When insertion losses are determined for acoustic treatments in the cabin, the standard deviations of the data are typically ±6.5 dB. It is concluded that factors such as accurate and repeatable selection of relative phase between propellers, controlled cabin air temperatures, installation of baseline acoustic absorption even for "untreated" configurations, and measurement of aircraft attitude should be considered in order to reduce uncertainty in the measured data.

Introduction

DURING recent years, there has been considerable research activity in the field of noise control in propeller-driven aircraft.[1] This interest has been generated to a large extent by the advent of high-speed propellers designed for cruise at high-subsonic-flight Mach numbers. Since the propellers generate high sound pressure levels during cruise, there is a need to evaluate means for reducing the associated interior sound pressure levels. Other areas of interest are related to general aviation aircraft, again due to the desire for improved noise control and a reassessment of simplified prediction methods for propeller near-field noise.

There are several approaches to the design and evaluation of noise control treatments for propeller aircraft interiors. Analytical studies can be performed on candidate treatments, laboratory tests can be conducted using noise transmission suites or actual aircraft fuselages, and flight test measurements can be undertaken. While the flight test approach has the advantage that it is the most representative of actual operational conditions, the measurement of interior noise in propeller-driven aircraft poses a numer of problems in terms of data accuracy and variability. For example, it is often found that the variability of flight test data results in confusing information regarding the acoustic performance of noise control treatments. This is particularly true for treatments that provide only small changes in the interior noise levels, as is often the case at low frequencies. The problems arise because propeller noise is dominated by discrete frequency components and interior sound pressures can be influenced strongly by changes in cabin acoustic modes and uncertainties in propeller synchrophasing.

Problems of this type were evident in flight test measurements made in a general aviation turboprop airplane.[2,3] The problems were attributed, at least in part, to data variability from flight to flight, with the result that the acoustic performance of the treatment could not be evaluated accurately for low-order harmonics of the propeller blade passage frequency. A second series of flight tests was conducted with the objective of improving the understanding of the problems and exploring methods of alleviating them. Results from these flight tests are described herein; a comprehensive documentation of the data is provided in Ref. 4.

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Flight Test Procedure

Test Airplane and Conditions

The test airplane was a Gulfstream Aerospace Commander 695A, which is a high-wing business aircraft with a maximum takeoff weight of 5079 kg, pressurized cabin, and retractable landing gear (Fig. 1). The airplane was powered by two AiResearch TPE331 single-shaft, turboprop engines, with a nominal rating of 610 kW, driving Dowty Rotol three-bladed propellers with supercritical airfoil sections. The propellers had a diameter of 2.69 m and a minimum clearance between fuselage and propeller tip of 0.36 m or $0.13D$, where D denotes the propeller diameter. The maximum rotational speed of the engine was 41,800 rpm and there was a two-stage reduction gear box with an overall reduction ratio of 26.3:1 between the engine and propeller. The maximum rotational speed of the propeller was 1591 rpm and the direction of rotation was counterclockwise when viewed from the rear. Engine exhausts were located on the outboard side of each nacelle.

The fuselage structure was of conventional skin/stringer/frame construction. The thickness of the fuselage sidewall skin panels was typically 1.6 mm and the longitudinal stiffeners consisted mainly of longerons at three vertical stations. The passenger cabin contained five double-pane windows on each side. The first three flight tests were conducted with an untreated interior. All noise control and thermal treatments (fiberglass batts, interior trim, carpets, bulkhead covering, dynamic absorbers, etc.) were removed from the interior aft of the pilot and copilot seats. Prior to the fourth flight, fiberglass batts were installed throughout the cabin aft of the pilot and copilot seats. The batts had a thickness of 5 cm on the sidewalls and 7.5 cm on the cabin aft bulkhead, a density of 48 kg/m^3 and were unfaced. In addition, a simple acoustic barrier was installed between the cockpit and the cabin. This barrier consisted of a sheet of lead-impregnated vinyl (4.94 kg/m^2) and a layer of open-cell foam, 2.5 cm thick. There was no sound-absorbing material on the cabin floor. Four seats with occupants were present for all four flights; their locations relative to the microphones are indicated in Fig. 2.

Four flights were performed with the intention of repeating the same test conditions on each flight. The flights were typically 90 min in duration and were conducted at different times of day between 7.30 a.m. and 6.00 p.m. Three nominal flight altitudes were selected for the tests: 3000, 4600, and 9100 m. The 3000 m altitude was chosen for tests at zero cabin pressure differential, the 4600 m altitude for various tests including single-engine operation, and the 9100 m altitude was a typical cruise altitude.

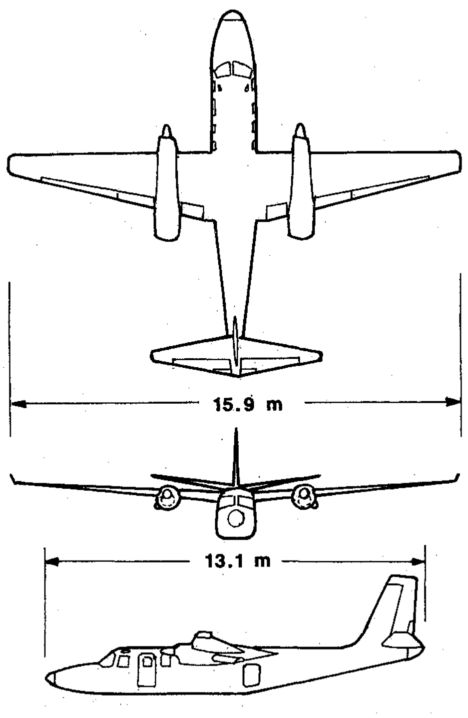

Fig. 1 Three-view diagram of test airplane.

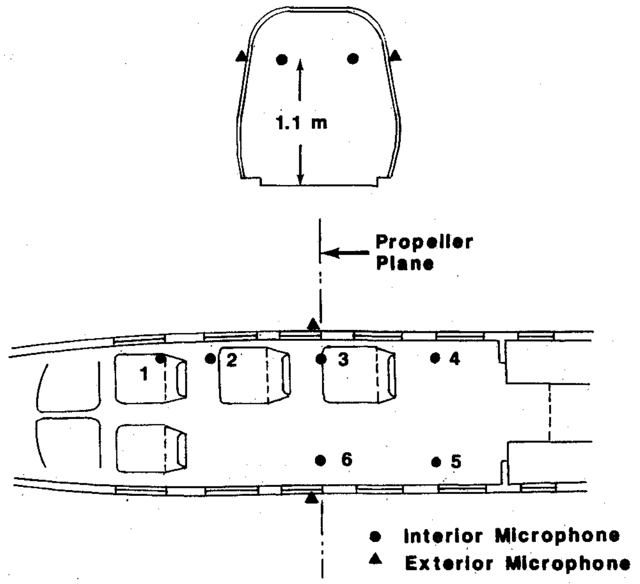

Fig. 2 Locations of interior and exterior microphones.

Propeller torque settings were selected to be typical cruise conditions and rotational speeds were chosen to be either 96 or 100% of maximum, the largest range possible with the engines. Values for torque were read from cockpit instruments as a percentage of maximum; actual values of propeller rpm were deduced from measured blade passage frequencies in the acoustic spectra. Instruments in the test airplane did not permit selection of specific relative phase angles between the two propellers. Consequently, four arbitrary settings were chosen and estimates of the actual relative phase angles determined from subsequent acoustic analysis.[4] All acoustic data were recorded during straight-and-level flight; flight through clouds was avoided and the flight condition were essentially "smooth."

Measurement Procedure

Sound pressure levels were measured at six fixed microphone locations in the cabin (Fig. 2); all microphones were positioned vertically at the approximate ear height of a seated occupant. The microphones were not moved until the end of the third flight, when they were removed to allow for installation of the acoustic treatment and then reinstalled. Exterior fluctuating pressures were measured simultaneously on the port and starboard sides of the fuselage using two condenser microphones mounted without protective grids and with diaphragms flush with the exterior surface of the skin panels. Based on available drawings, it is estimated that the flush-mounted microphones were about 5 cm below the centers of the propeller spinners (Fig. 2).

Measured harmonic and broadband sound pressure levels were analyzed in terms of mean and standard deviation values. The averaging was performed on an energy basis and the mean and standard deviations converted to decibel values. In the case of the standard deviation (SD), this was accomplished in the following manner:

$$\text{SD in dB} = 10\log(\text{energy mean} \pm \text{energy SD}) - 10\log(\text{energy mean})$$

In this format, the SD has different positive and negative values; the negative value is much more sensitive to variability in the data than is the positive value. When there was a sufficiently large number of samples, 90% confidence limits were also calculated; this occurred mainly for the exterior measurements.

Exterior Harmonic Pressure Levels

Measured Levels

The exterior pressure spectrum is composed of a series of discrete frequency components superimposed on a broadband background. Figure 3 shows two families of discrete frequency components, one associated with the starboard propeller, which was operating at 1518 rpm (blade passage frequency of 75.9 Hz), and the other with the port propeller operating at 1570 rpm (blade passage frequency of 78.5 Hz). In this case, the test was designed specifically to separate the contributions from the two propellers. Since the measurements were made on the starboard side of the fuselage, the sound pressure levels associated with the starboard propeller were much higher than those associated with the port propeller, the difference in levels being 15–20 dB.

Harmonic data for each propeller can be divided into six groups associated with the three flight altitudes and two propeller speeds. Twin-engine operation was performed with the port and starboard propellers either at the same rotational speed or at different speeds. It was possible to distinguish between the contributions from the two propellers when both propellers were at different rotational speeds, as indicated in Fig. 3, but not when they were at the same speed. However, it is reasonable to assume that measured sound levels could always be attributed to the adjacent propeller. This allowed the number of data points considered for a given flight condition to be maximized; the number varied was between 4–16, depending on flight condition. Standard deviations were calculated for all the harmonic components. On the average, standard deviations for the port propeller were higher than for the starboard propeller (+1.7, −2.3 dB vs +1.0, −1.8 dB) and, for both propellers, slightly higher for the 100% rpm condition than for 96% rpm. Another indication of the data variability is the difference between the upper and lower 90% confidence limits. On the average, the difference between the limits for the 96% rpm data was 1.3 dB for the starboard propeller and 2.6 dB for the port propeller, with little dependence on harmonic order. Corresponding values for the 100% rpm data were 2.5 and 5.9 dB, respectively, although these results might be influenced by the small number of data samples.

Mean harmonic pressure levels measured on the exterior of the fuselage were similar on the port and starboard sides for the test conditions at an altitude of 9100 m but not at lower altitudes (Fig. 4), where the harmonic levels were consistently higher on the port side, the difference increasing with harmonic order. A similar general trend was exhibited by the overall sound pressure levels, obtained from an energy sum over the 10 lowest-order harmonics (Table 1). The largest difference between port and starboard sound pressure levels occurs at an altitude of 3000 m and the smallest difference at 9600 m. Earlier tests on the same airplane, but with different pressure transducers, showed essentially the same results.

Measurements by Sulc et al.[5] on a different high-wing, turboprop airplane also showed higher harmonic levels on the port side of the fuselage than on the starboard side. In that case, measurements were made at only one altitude (3000 m) and the difference varied from 3.8 to 0 dB as the propeller power increased. However, the propeller rotation was in the opposite direction (clockwise when viewed from the rear) from that of the present test airplane. Wind-tunnel tests on a model of a third high-wing turboprop airplane[6] showed similar differences in magnitude between port and starboard harmonic pressure levels; in that case, the differences were related to fuselage angle of attack, a parameter that was not measured or controlled in the Commander tests. The propeller direction of rotation was clockwise on the wind-tunnel model and the harmonic levels were generally higher on the port side, with the difference increasing with angle of attack.

In the past, differences between harmonic levels on the two sides of the fuselage have been associated with test data that showed pressure levels to be higher when the blade was advancing than when it was retreating.[7] However, in all the test configurations referred to in the preceding discussion, the pressure transducers were in the region of the closest separation between the propeller and the fuselage skin, where it is difficult to differentiate between advancing and retreating blades.

Table 1 Comparison of exterior sound pressure levels for port and starboard propellers

Altitude, m	3000	3000	4600	4600	9100	9100
Nominal rpm, %	100	96	100	96	100	96
Port-starboard,[a] dB	4.5	3.8	3.5	3.1	0.4	−0.1

[a]Difference between port and starboard propellers.

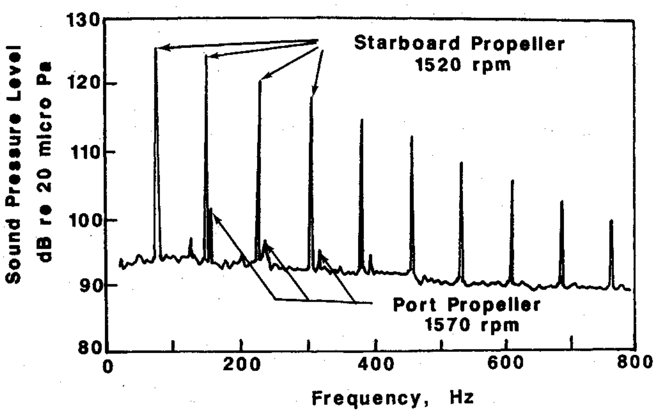

Fig. 3 Exterior narrow-band sound pressure spectrum.

Table 2 Measured and predicted propeller sound levels

Test condition	Overall sound pressure level, dB			
	Measured		Predicted	
	Port	Starboard	Ref. 8	Ref. 9
Commander (present test)				
Alt 3000 m, 96% rpm	135.7	131.9	144.1	139.5
100% rpm	136.2	131.7	144.4	140.0
4600 m, 96% rpm	134.0	130.9	144.3	139.9
100% rpm	134.9	131.4	144.4	140.4
9100 m 96% rpm	129.9	130.6	141.9	137.5
100% rpm	131.0	130.0	142.2	138.0
Commander (earlier test)				
Alt 4600 m, 96% rpm	137.6	135.1	144.5	139.5
9100 m, 96% rpm	133.4	134.6	142.5	137.5
Sulc et al.[5]				
Alt 3000 m, 96% rpm	142.5	141.5	145.7	138.0

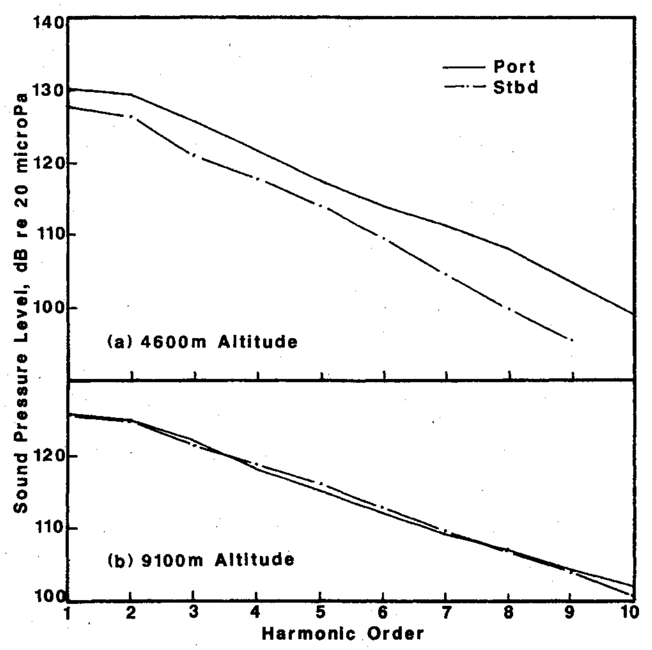

Fig. 4 Harmonic sound pressures, port and starboard propellers (96% rpm).

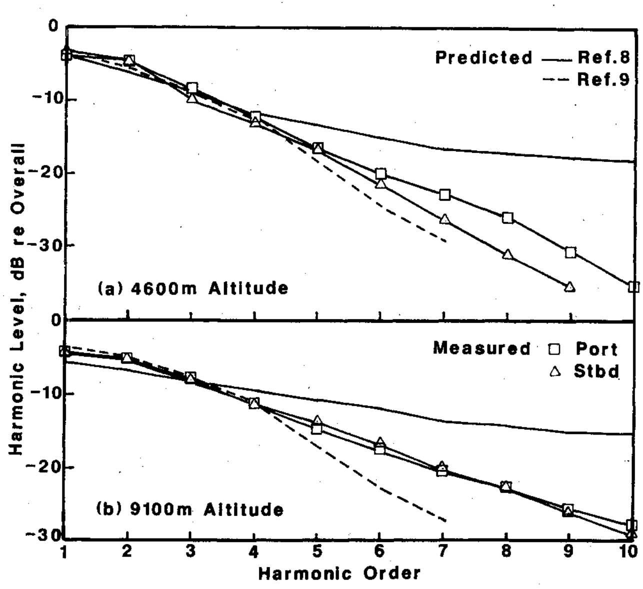

Fig. 5 Comparison of measured and predicted harmonic sound pressures (96% rpm).

Comparison with Predictions

Several simplified procedures are available for predicting propeller harmonic sound pressure levels on the exterior of a general aviation airplane fuselage. The procedures have the advantage that they require fairly rudimentary information for the propeller, significantly less detailed information than do the analytical models developed recently for general aviation and high-speed propellers, but they have been used with only limited success. Two of the methods[8,9] are used here for comparison with the flight test data.

Consider first the overall levels. The measured values are significantly lower than levels predicted by either reference, Ref. 8 consistently giving the highest overall levels (Table 2). The two prediction methods do not distinguish between port and starboard propellers, or direction of rotation. Thus, the measured levels for the port propeller are usually closer in value to the predictions than are the measured levels for the starboard propeller. Previous measurements on the same test airplane show the same trend, as indicated in Table 2. Measurements by Sulc et al.[5] show overall levels lower than predicted by Ref. 8, but higher than predicted by Ref. 9.

A comparison of measured and predicted harmonic levels can be accomplished most readily by expressing the levels relative to the overall values. In that manner, differences in overall level can be excluded and only spectrum shape considered. Figure 5 compares measured results for the port and starboard propellers with predictions based on Refs. 8 and 9. Since the prediction methods do not distinguish between port and starboard propellers, only one curve is presented for each prediction procedure. The figure shows that the measured values generally lie between the two predicted curves. Data from earlier tests on the same airplane and published data of Sulc et al.[5] show similar trends, with the harmonic levels being even closer to the values predicted by Ref. 9. Ground tests on an early model of the test airplane with reciprocating engines[10,11] have shown that Ref. 8 provides a reasonably accurate prediction of harmonic levels when the aircraft is stationary, but overpredicts the levels of the higher-order harmonics where there is forward motion of the airplane, even at the low speeds associated with taxiing.

Exterior Broadband Pressure Levels

Broadband components of the exterior pressure field were determined in terms of one-third octave band spectra in the frequency range of 25–5000 Hz. The results indicated that the broadband levels were essentially independent of propeller speed and were the same on each side of the fuselage. This conclusion was reinforced by data from single-engine operation, the broadband levels being essentially the same on both sides of the fuselage, whether or not the adjacent propeller was operating (Fig. 6). The broadband levels were higher during two-engine operation, but so was the flight speed (by a factor of about 1.3). Average broadband levels associated with the three flight altitudes decreased as altitude increased. The true airspeed was roughly the same at all three altitudes, but the freestream dynamic pressure decreased as altitude increased. Standard deviations of the one-third octave band levels about the mean were typically 1.2 and −1.7 dB.

The broadband pressure spectra can be compared with the fluctuating pressure field beneath a turbulent boundary layer. Boundary-layer pressure fluctuations have been studied experimentally by several investigators in wind tunnels, where the boundary layer could be controlled, or on jet aircraft, but little is known about the turbulent boundary layer on turboprop aircraft. Measured pressure power spectra can be nondimensionalized using various flow parameters. For the present case, boundary-layer thickness has been selected as a representative length, aircraft speed as a representative velocity, and either overall rms pressure or flight dynamic pressure as a typical pressure. All the parameters have been measured, or can be estimated, but in the case of the boundary-layer thickness an assumption has to be made regarding the origin of the turbulent boundary layer. This origin was selected rather arbitrarily to be the lower edge of the windshield. However, the result is not very sensitive to the actual choice, within the possible range from windshield to airplane nose.

Consider first the overall rms pressure obtained by integrating the measured pressure spectrum over the frequency range 25–5000 Hz. Using mean pressure levels at each altitude, the ratio of rms pressure to dynamic pressure has values in the range of 0.0038–0.0049 and the ratio of rms pressure to wall shear stress has values in the range of 1.67–2.30. These values

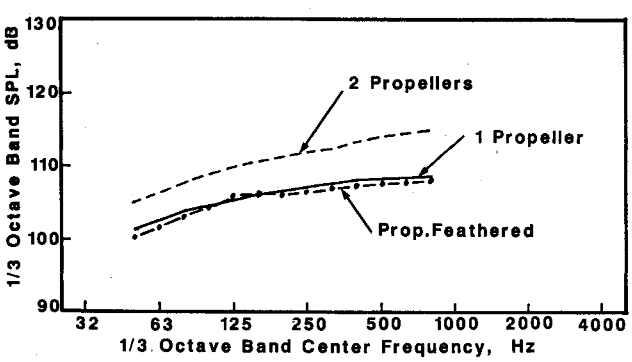

Fig. 6 Exterior broadband pressure spectra for different propeller conditions (96% rpm, 4600 m).

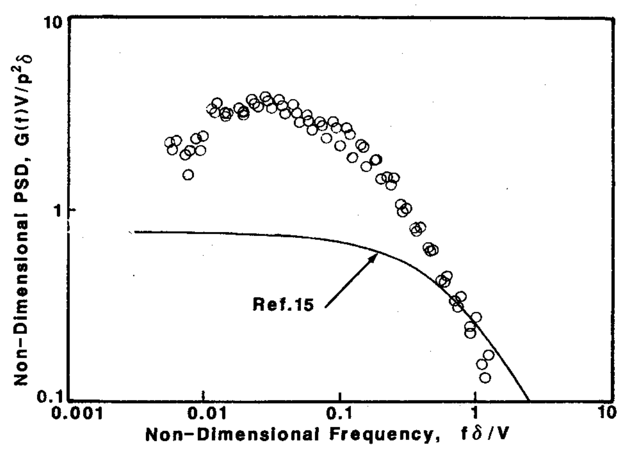

Fig. 7 Exterior broadband spectra normalized with respect to rms pressure.

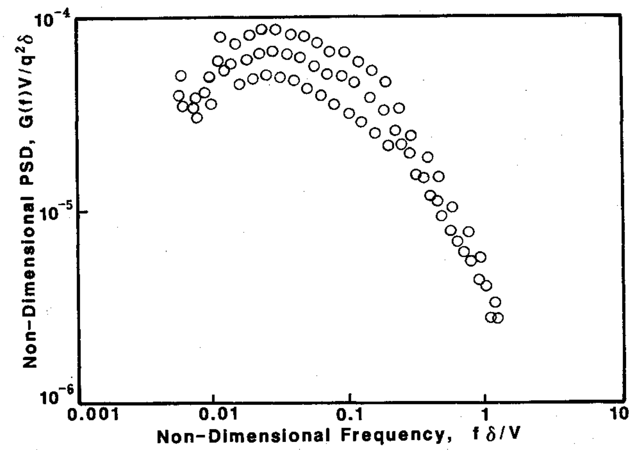

Fig. 8 Exterior broadband spectra normalized with respect to dynamic pressure.

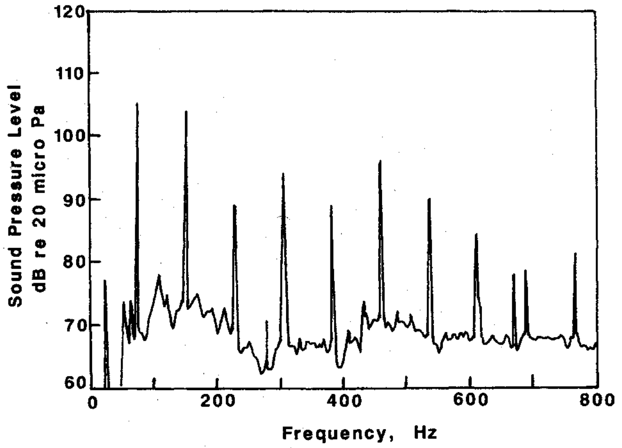

Fig. 9 Narrow-band sound pressure spectrum in cabin.

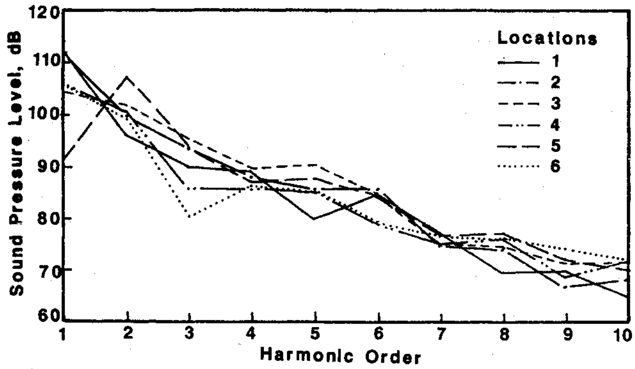

Fig. 10 Harmonic sound pressure levels at different locations in cabin (96% rpm, 4600 m).

are generally consistent with the range of published data from other tests. For example, data measured on a Boeing 737 airplane[12] show values for the ratios of approximately 0.0055 and 3.4, respectively.

Average broadband pressure spectra for two-engine operation at the three flight altitudes were nondimensionalized first using overall rms pressure as the reference. The resulting spectra show a good collapse, as indicated in Fig. 7. The data are compared to a nondimensional spectrum developed from flight test data measured on the fuselage of a Boeing 737 airplane,[12] where the boundary layer was known to be attached, although there were alternating regions of adverse and favorable pressure gradients along the fuselage. The nondimensional power spectral density for the Commander is higher (by up to 6 dB) at low frequencies and lower at high frequencies, which suggests that there is disturbed flow on the Commander fuselage. When the Commander data are nondimensionalized using flight dynamic pressure, instead of rms pressure, the data do not collapse completely, but lie in a band that is about 3 dB wide (Fig. 8). The lowest values in the band are associated with the highest altitude and vice versa. The values of the nondimensional spectral density are typically 3 dB lower at low frequencies than the corresponding values measured by Sulc et al.[5] on their test airplane. In Ref. 5, the nondimensionalized data lie within a band that is about 10 dB wide.

Interior Harmonic Sound Pressure Levels

Spectral Characteristics

A typical narrowband acoustic spectrum measured in the untreated cabin of the test airplane is shown in Fig. 9. The spectrum shows several differences with respect to the exterior pressure spectra. Interior harmonic levels vary irregularly with frequency, whereas on the exterior they decrease monotonically as frequency increases. Also, the contributions of the two propellers to the interior acoustic field can be of similar magnitudes, whereas on the exterior harmonic levels from one propeller were 15–20 dB higher than those from the other. Broadband components in the spectra also show characteristics that are different from those for the exterior pressure field; the main difference is that the relatively uniform broadband levels seen in the exterior spectra have become very irregular. The interior sound pressure levels were influenced by the structure, cabin volume, and constructive or destructive interference between acoustic signals from the two propellers.

Interior harmonic sound pressure levels for the untreated cabin were averaged for each test condition and associated standard deviations calculated. However, only three data samples were available for a given test condition. This is a smaller number than for the exterior, because the interior sound pressure levels are dependent on interior furnishings of the cabin, relative phase of the propellers, and pressure differential between the cabin and the exterior, factors that had no influence on the exterior pressures. Average standard deviations for harmonic sound pressure levels measured at a given location in the cabin are +1.6 and −2.9 dB. There is no general trend with harmonic order and standard deviations greater than −5 dB are not uncommon for some harmonics; deviations that large rarely occurred on the exterior. This is indicative of a greater variability of the data for the interior acoustic levels.

If the data were combined into extended data sets, without regard to the relative phase of the propellers, 12 data samples could be used in the averaging process. Two sets of data were averaged in this manner, one set associated with flight at 4600 m and the other at 9100 m, the propeller operating speed being 96% of maximum rpm in both cases. When averaged over all harmonics and all six measurements locations in the cabin, it is found that the standard deviations of the harmonic sound pressure levels are typically +2.0 and −4.2 dB. Corresponding average values for the exterior pressure field are +1.3 and −1.9 dB. This is another indication of the greater variability in the harmonic sound pressures measured in the cabin, compared to the corresponding exterior levels.

Harmonic spectra for a given flight condition have similar shapes at all locations in the cabin (Fig. 10), but, depending on harmonic order, the sound pressure levels can vary by 5–22 dB throughout the cabin, the largest variations occurring at the lower-order harmonics. Quite large differences in sound pressure level occurred between locations that were quite close together. For example, measured sound pressure levels for the third-order harmonic showed differences of 8–15 dB between locations 3 and 6. At this frequency, the distance between the two locations was approximately 40% of the acoustic wavelength. Differences of 6–14 dB were measured between locations 4 and 5 for the first harmonic; the distance between the two locations was only 15% of the acoustic wavelength at this frequency.

Interior sound pressure levels were measured at two cabin pressure differentials (0 and 26 KPa) during flight at an altitude of 3000 m. On the average, the harmonic sound pressure levels increased by 2.3 dB when the cabin was pressurized, but there was a large associated standard deviation of 5.7 dB. At least two phenomena influenced the results: 1) increasing the pressure differential increased the in-plane stresses in the fuselage skin and changed the response of the structure to the exterior pressure field; and 2) for a given level of vibration in the structure, the radiated acoustic pressures would be proportional to the air density in the cabin; it is estimated that this increase would be 3.3 dB. Similar results were observed by Beyer et al. in a Fairchild Merlin IVC airplane.[13]

Port and Starboard Propellers

The relative contributions of the port and starboard propellers to the interior sound pressure levels did not follow a simple pattern, as can be seen in Fig. 11 for harmonic levels measured at locations 3 and 6, in the plane of rotation of the propellers. On the port side (location 6), the levels associated with the port propeller were generally, but not always, higher than those for the starboard propeller. This is reasonable physically, since not only was the port propeller the nearer propeller, it was also generating the higher exterior sound pressure levels. On the starboard side (location 3), contributions from the two propellers were more similar in magnitude, although there were still large differences at some harmonics. Further aft in the cabin, the contributions from the two propellers differed more widely than in the plane of rotation of the propellers. In general, the port propeller made the greater contribution to the lower-order harmonics and the starboard propeller to the highest-order harmonics. In contrast, at the copilot's seat, the starboard propeller played a more important role, being the major contributor for many of the harmonics.

Figure 11 also contains mean harmonic levels associated with two-engine operation at the low-rpm (96%) condition. These levels were obtained by averaging over all combinations of relative phase between the two propellers. It is interesting to compare these results with levels obtained from a sum of the two components from the two individual propellers. Since the harmonics are essentially deterministic in character,[10,11] the combined levels could be calculated from the individual propeller contributions if both the amplitude and phase were known. If the contributions were in-phase, the amplitudes of the components would add directly and, if the components were of equal amplitude, the combined level would be 6 dB greater than either of the two components. If the components were out-of-phase, there would be destructive interference, the net effect of which would depend on the relative amplitudes of the components.

Inspection of the results indicates that the measured harmonic levels associated with two-engine operation were generally higher than the corresponding levels for either of the individual propellers. The two-engine level was lower than one of the components in only a very few cases. When one component was dominant, the two-engine operation levels were close to those of the dominant component. However, there are cases where the harmonic levels for the individual propellers were close in amplitude yet the levels associated with two-engine operation were only 1 or 2 dB higher.

The effect of relative phase on harmonic sound pressure levels measured at locations 3 and 5 in the cabin is illustrated in Fig. 12. The results indicate that, in general, the largest effects of relative phase occurred at the two lowest-order harmonics and at locations further away from the plane of rotation of the propeller. The average phase angles identified in the figure refer to the blades on the two propellers (i.e., the noise sources). The relative phase angle between specific harmonic acoustic components at a measurement location in the cabin will result from the combined effects of the phase difference between the sources and the phase differences introduced by the propagation paths.

Treatment Insertion Loss

Insertion Loss Spectra

The insertion loss provided by a treatment is computed as the difference between the cabin sound levels measured in the untreated and treated interiors. Both measurements show significant variability and the insertion loss will show even greater variation. Thus, it is appropriate to consider averaging pro-

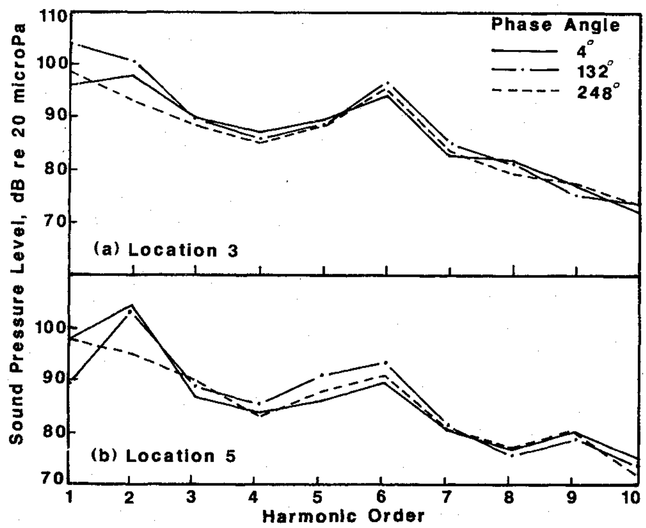

Fig. 12 Effect of propeller phase on harmonic levels in cabin (96% rpm, 4600 m).

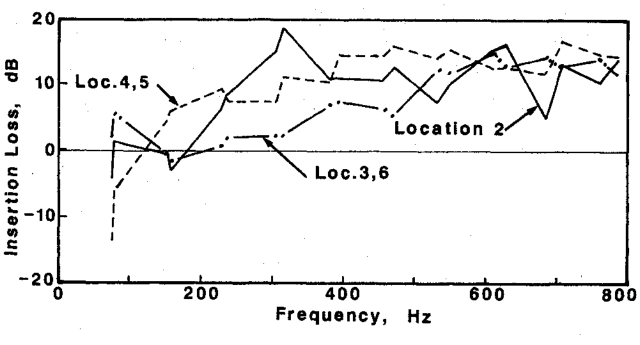

Fig. 13 Average harmonic insertion loss at different locations in cabin.

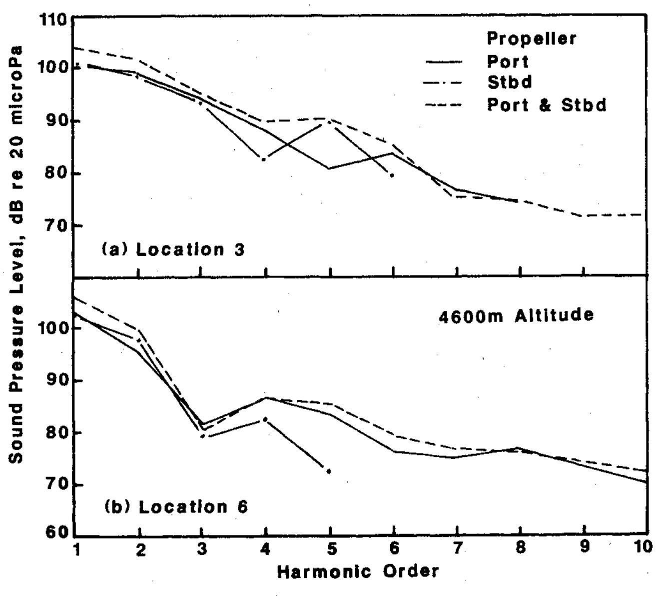

Fig. 11 Port and starboard propeller harmonics in cabin (96% rpm).

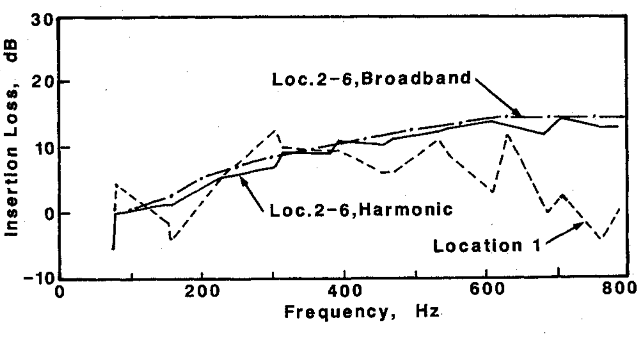

Fig. 14 Insertion loss averaged over all locations in cabin.

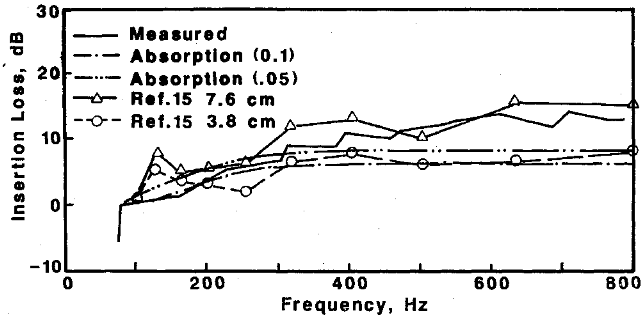

Fig. 15 Comparison of measured insertion loss with predictions and laboratory data.

cedures over flight conditions and measurement locations. It was observed in Ref. 4 that, when analyzing insertion loss data associated with locations 3 and 6 in the cabin, it was difficult to identify any influence of flight conditions on the results. Thus, measured insertion losses associated with a given location in the cabin have been averaged here over all test conditions. The resulting data associated with the propeller harmonics show large variability, with standard deviations (typically +6.5 dB) being much higher than those associated with the measured interior sound pressure levels.

Spatial averaging of insertion losses at the propeller harmonics was performed first for locations at each longitudinal station; resulting average insertion loss spectra are compared in Fig. 13. Then, the insertion losses were averaged over all locations (2–6) in the cabin and compared with insertion losses measured at location 1 in the cockpit (Fig. 14). At frequencies below about 500 Hz, the insertion losses are similiar in the cabin and cockpit; however, at higher frequencies, the insertion loss for the cockpit approaches zero, whereas in the cabin the insertion loss is greater than 10 dB. It should be remembered that there was no added treatment in the cockpit, except for the barrier between the cabin and the cockpit.

Figure 14 also contains the space-averaged, broadband insertion loss in one-third octave bands. The space-averaged harmonic and one-third octave band insertion loss spectra are very similar throughout the frequency range 100–800 Hz. However, one peculiarity has survived all the averaging process. This is associated with the blade passage frequency (76.1 Hz) at the low rpm of the propeller, where large negative insertion losses were measured at some locations. The averaged insertion loss at this frequency is approximately −6 dB, whereas the insertion losses are positive at all other frequencies in Fig. 14.

It has been speculated[2] that acoustic modal characteristics of the cabin volume could influence the measured sound pressure levels, especially when the cabin is untreated or has minimal treatment, as is the case in the present tests. There are several reasons for the speculation. First, measurements in the test airplane[2] indicate that observed harmonic sound pressure levels could be sensitive to small changes in microphone location or cabin contents, when the microphone is close to a node of an acoustic mode. Second, Lyle and Mixson[14] have shown that small changes in air temperature in the cabin can have a strong influence on the measured sound pressure levels, when measured in narrow frequency bands. Cabin air temperatures were not measured during the present flight tests, but it was subjectively observed that it was warmer in the cabin during the fourth flight when the fiberglass was installed, than during the three preceding flights when the cabin was untreated. Heated air was supplied to the cabin during all four flights by means of the cabin air conditioning system. Finally, installation of the sound-absorbing material on the sidewalls and aft bulkhead, and the introduction of the barrier between the cabin and the cockpit, could have a significant influence on cabin acoustic mode shapes.

Comparison of Predictions and Measurements

The insertion loss provided by the fiberglass batts results from the combined effects of transmission loss and absorption. An estimate of the contribution from absorption alone can be made using manufacturers' data and approximations regarding the influences of other items in the cabin, such as the chairs and occupants.[4] Two insertion loss spectra have been estimated for the effects of absorption alone, one spectrum being associated with an assumed absorption coefficient of 0.05 for the bare structure of the cabin and the other with an absorption coefficient of 0.1. These spectra are compared with the average measured insertion losses in Fig. 15. The predictions are in close agreement with flight test data in the frequency range of 100–300 Hz and lie below the measured values at higher frequencies (where treatment transmission loss would start to play a major role). Thus, the predictions and measurements are consistent.

Heitman and Mixson[15] have measured the insertion loss provided by fiberglass material installed in a small general aviation airplane in the laboratory. The airplane cabin was slightly smaller than the present test airplane and the external sound field was broadband white noise. The fiberglass was installed in two thicknesses, 3.8 and 7.6 cm as compared to 5.1 cm in the flight test airplane. Insertion losses provided by the treatments were space-averaged over the cabin volume by Heitman and Mixson. Thus, the data can be compared directly with the present flight test results, as is done in Fig. 15. It is seen that the laboratory and flight test data are consistent.

Conclusions

It is found that, under carefully controlled conditions, the variability of propeller harmonic sound pressure levels, measured on the exterior of the fuselage, is slightly greater than that for turbulent boundary-layer pressures. Standard deviations for harmonic sound pressure levels measured in the cabin are greater than those for the exterior sound field (typical values of +2.0 and −4.2 dB for the interior vs +1.4 and −2.3 dB for the exterior). When insertion losses are determined for acoustic treatments, the standard deviations of the data are typically ±6.5 dB. It is concluded that factors such as accurate and repeatable selection of relative phase between propellers, controlled cabin air temperatures, installation of baseline acoustic absorption even for "untreated" configurations, and measurement of aircraft attitude should be considered in order to reduce uncertainty in the measured data.

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