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April 1976

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16. Abstract

A field study has been conducted to examine the interior noise characteristics of a general aviation aircraft. The purposes of the study were to identify the major noise sources and their relative contribution and to establish the noise transmission paths and their relative importance. Tests were performed on an aircraft operating under stationary conditions on the ground. The results show that the interior noise level of light aircraft is dominated by broadband, low frequencies (below 1,000 Hz).

Both the propeller and the engine are dominant sources, however, the contribution from the propeller is significantly more than the engine at its fundamental blade passage frequency. The data suggests that the airborne path is more dominant than the structure-borne path in the transmission of broadband, low-frequency noise which apparently results from the exhaust.

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SOURCES AND CHARACTERISTICS OF INTERIOR NOISE IN GENERAL AVIATION AIRCRAFT

By

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INTRODUCTION
(Figure 1)

An aircraft interior noise program has been initiated at NASA Langley Research Center. The purpose of the program is to develop the technology required to reduce aircraft interior noise levels for increased operating safety, hearing protection, and comfort of crew and passengers. Previous studies (ref. 1, 2, 3) show that the levels of noise within light aircraft are high when compared to other forms of transportation and that it is desirable to reduce the interior noise levels with minimum sacrifice of aircraft performance and/or economy.

This paper describes some field studies performed on light aircraft as part of the overall aircraft interior noise program at LRC. In an initial effort to identify the noise source which contributes to the high interior noise level, both exterior and interior noise measurements as well as aircraft vibration measurements were investigated. The study was performed on stationary, single and twin engine aircraft. As outlined in figure 1, the work described in this paper has two objectives, namely, to identify the major noise sources and their relative contribution and to establish the noise transmission paths and their relative importance.

OBJECTIVES

- IDENTIFY MAJOR NOISE SOURCES AND THEIR RELATIVE CONTRIBUTION TO INTERIOR NOISE
- ESTABLISH THE NOISE TRANSMISSION PATHS AND THEIR RELATIVE IMPORTANCE

Figure 1

PHOTOGRAPH OF SINGLE ENGINE LIGHT AIRCRAFT USED IN STUDY
(Figure 2)

The photograph shows the single engine light aircraft in test position for ground runup tests. Exterior noise levels were measured from five fixed microphones beginning from the propeller hub, 10 ft apart, positioned in a straight line directly in front of the aircraft. Simultaneous noise measurements were obtained from these five outside microphones together with one microphone inside the cabin of the aircraft for each of two engine rpm settings, namely, 2,000 and 2,300 rpm. The aircraft was then turned 30° about the microphone line so as to maintain 10 ft between the first microphone and the propeller hub. This procedure was repeated to a full circle of 360° in 30° increments. The photograph shows the aircraft turned approximately 210° from the original position.

SINGLE-ENGINE LIGHT AIRCRAFT USED FOR STATIONARY TESTS

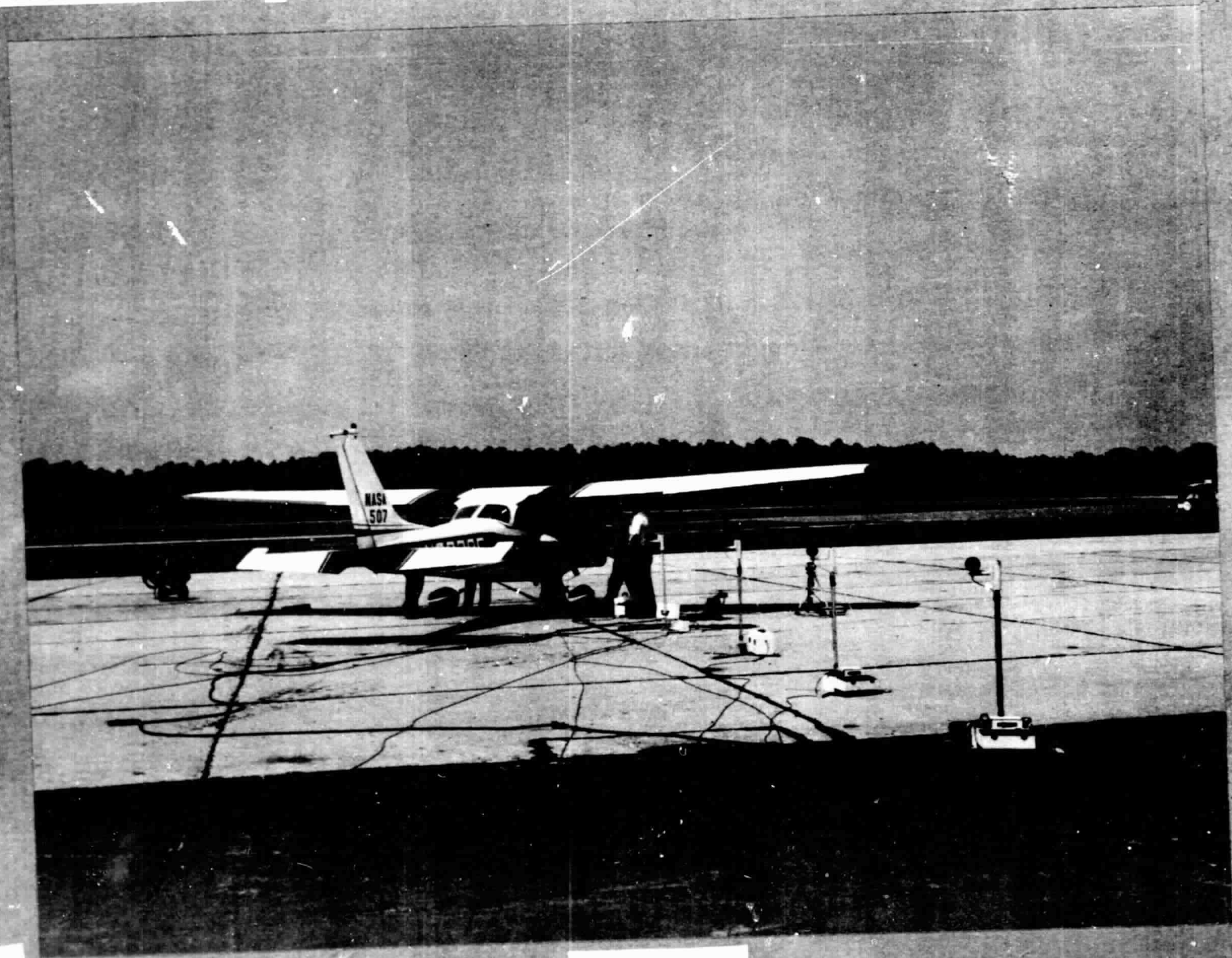


Figure 2

FAR FIELD NOISE LEVELS MEASURED AROUND LIGHT AIRCRAFT
(Figure 3)

The far field noise levels measured are shown as directivity patterns in figure 3. The polar plot shown on the left is in dBA levels, while the plot on the right is given in overall dB levels.

The overall levels are shown to increase for the 90°, 120°, 150°, and 180° positions which are in the direction or maximum propeller noise radiation (see ref. 4). The data appear somewhat unsymmetrical about the aircraft centerline with higher levels measured to the right of the aircraft, particularly noticeable in the dBA plot. This increase in level is believed to be primarily due to the engine exhaust which was located on the right side of the aircraft. Observe that within the 50 ft radius, the overall noise levels are greater than 100 dB for any position. It should be noted that the aircraft interfered with the microphones at 10 and 20 ft when the aircraft was rotated to the 180° position, and for this reason no data are presented at this location.

DIRECTIVITY OF EXTERIOR NOISE OF SINGLE ENGINE AIRCRAFT

ENGINE OPERATING AT 2300 rpm

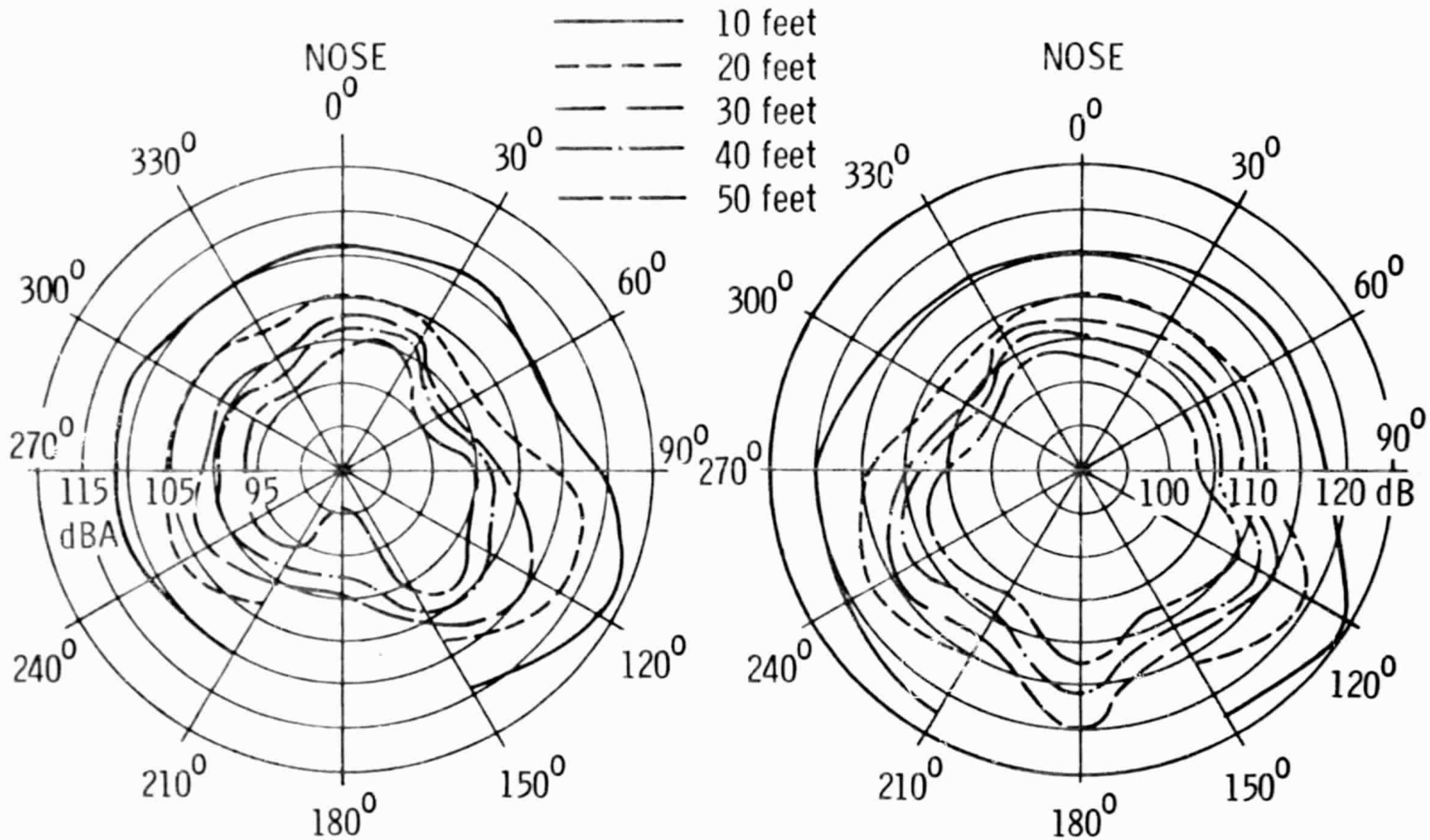


Figure 3

FAR FIELD AND NEAR FIELD NOISE SPECTRA

(Figure 4)

In the present study, measurements of both the far field and near field were obtained for comparative purposes and some sample results are shown in figure 4. The near field measurement was obtained on the left side of the aircraft, under the wing, 3 to 4 ft from the pilot's door and the far field data were measured 50 ft away in line with the propeller hub and the same azimuth angle on the near field microphone. It is seen that the near field noise differs from the far field noise in that the broadband, low-frequency data do not appear in the far field noise spectra. It is believed that the broadband, low-frequency noise results from engine related effects, such as engine exhaust (see ref. 5). The discrete frequency peaks shown in both spectra are mainly associated with the harmonics of the blade passage frequency. It can be seen that a slight frequency shift in the peaks occurs with increasing frequency which may be due to nonlinear effects and/or incremental differences in the 2,300 rpm power setting of the aircraft inasmuch as the data presented in this figure were not obtained simultaneously.

FAR FIELD AND NEAR FIELD NOISE SPECTRA

ENGINE OPERATING AT 2300 rpm

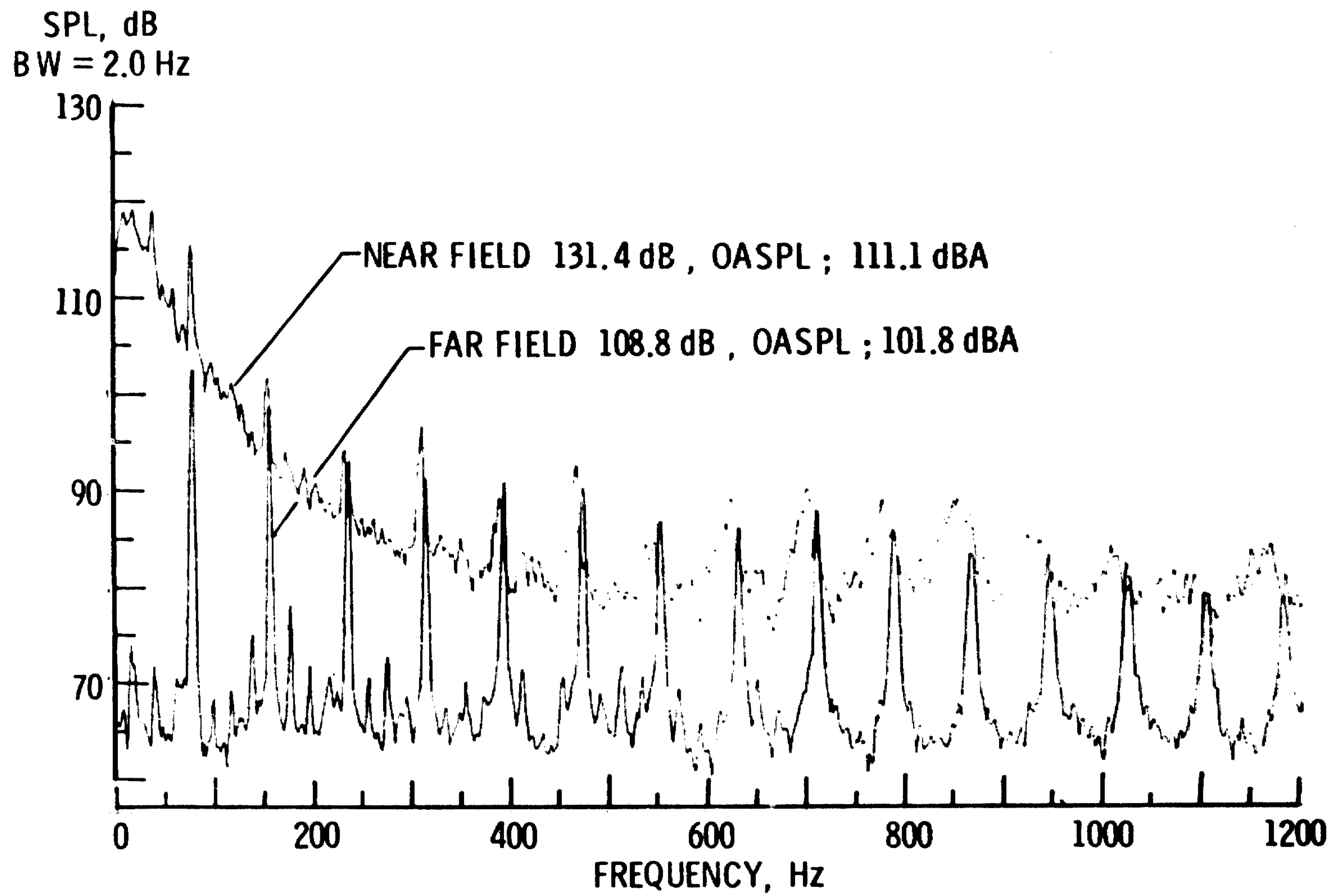


Figure 4

EXTERIOR AND INTERIOR NOISE SPECTRA
(Figure 5)

The broadband, low-frequency data are also characteristic of the interior noise spectra measured in light aircraft. An example of this observation is shown in figure 5. Also included in the figure are noise spectra measured on the right side of the aircraft near the exhaust and on the left side near the pilot's door. The broadband, low-frequency data are common to both exterior near field measurements. The levels of noise measurement on the right side of the aircraft are high due to the influence of the exhaust. The interior noise spectra show in addition to the broadband data, discrete peaks which are associated with the blade passage and engine rotational frequencies particularly below 500 Hz. Comparing the interior noise spectra with the exterior near field noise shows that the broadband, low-frequency data are common to both spectra. This result suggests that the airborne path is more dominant than the structure-borne path (i.e., vibration initiated) in the transmission of the broadband, low-frequency noise.

EXTERIOR AND INTERIOR NOISE SPECTRA

ENGINE OPERATING AT 2200 rpm

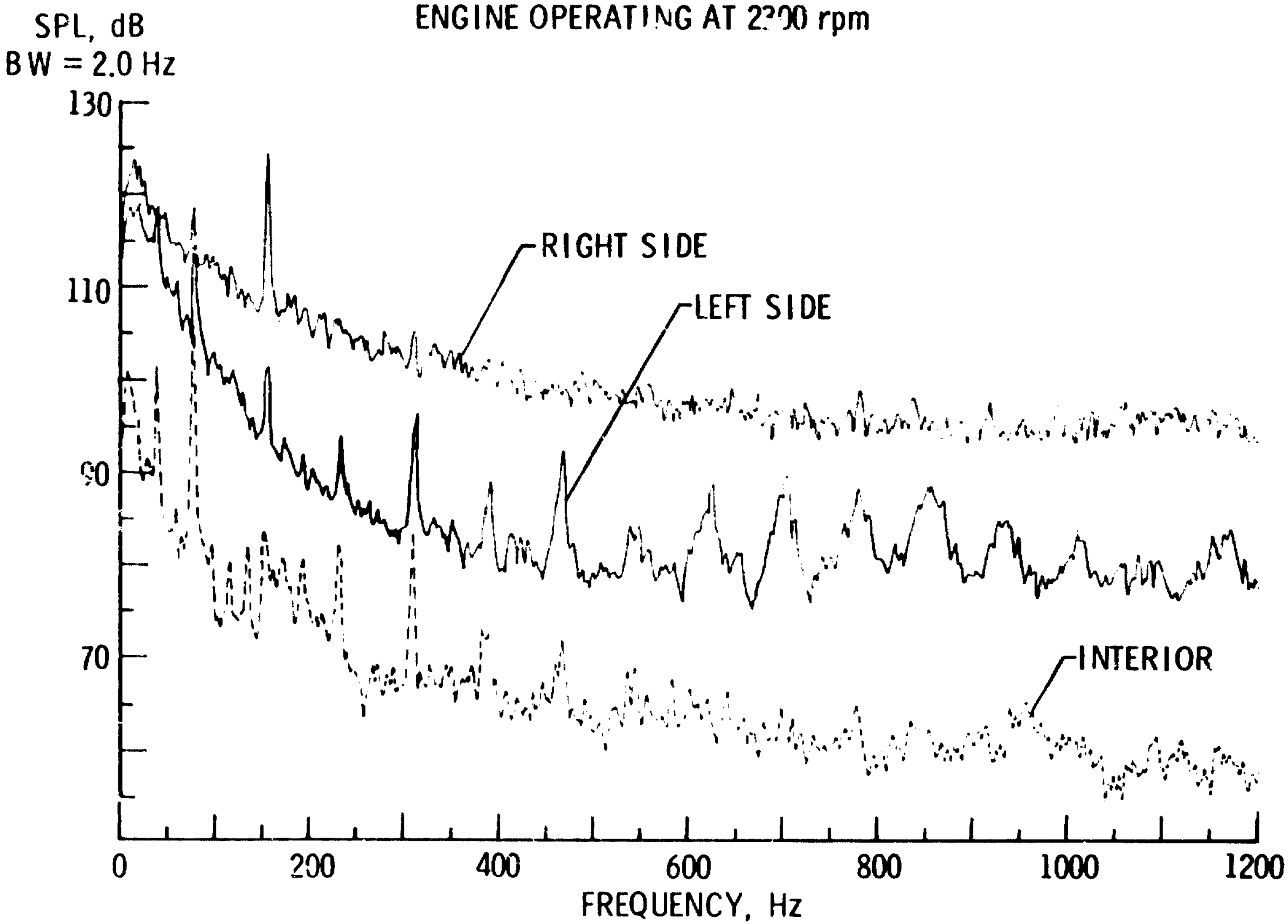


Figure 5

NOISE AND VIBRATION SPECTRA MEASURED DURING GROUND TEST

(Figure 6)

In the study of interior noise of light aircraft, data have been analyzed to evaluate the sources as well as paths of noise that may contribute to the high noise levels within the aircraft. Figure 6 shows the spectra of the interior noise and the acceleration of the aircraft's firewall which were measured simultaneously. The vibration data have been plotted to an arbitrary reference level, however, it is seen that the dominant vibration frequency peaks below 1,000 Hz, measured on the firewall, coincide with the frequency peaks in the noise spectra. These dominant frequency peaks are related to both the fundamental blade passage and engine firing frequencies (two per revolution) and their higher harmonics. The lowest dominant frequency peak shown in the interior noise spectra occurs at approximately 10 Hz, while the lowest peak shown in the vibration spectra occurs at 20 Hz which corresponds to the one-half order harmonic (one-half of rotational frequency) of the engine rotation frequency. These results show that the interior noise level of light aircraft is complex which includes a number of different sources. It can be seen that the typical broadband, low-frequency interior noise characteristics do not appear in the vibration spectra which suggests that the broadband noise is not vibration related.

NOISE AND VIBRATION SPECTRA MEASURED DURING GROUND TESTS

ENGINE OPERATING AT 2300 rpm

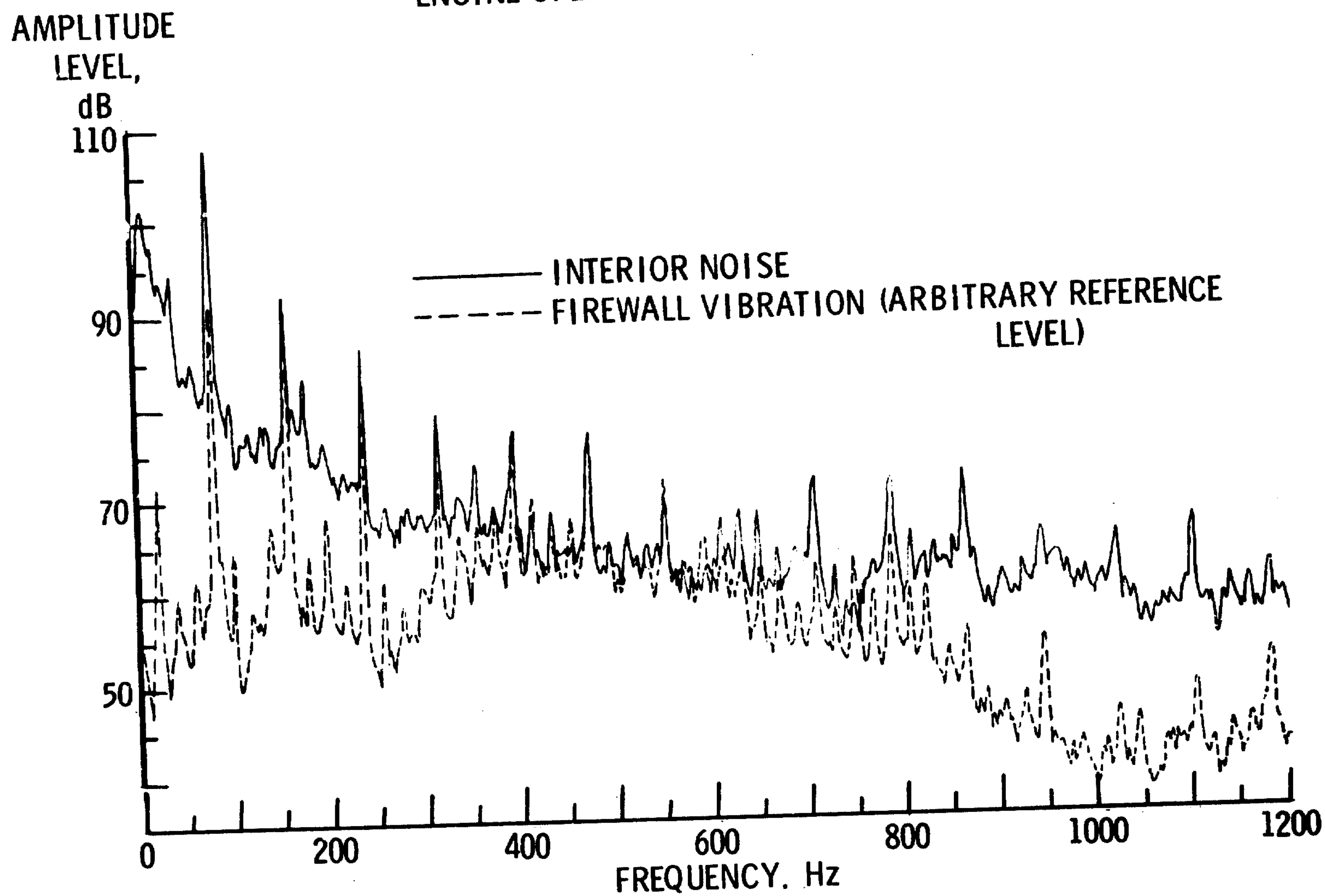


Figure 6

NOISE ATTENUATION CHARACTERISTICS OF LIGHT AIRCRAFT

(Figure 7)

This figure shows a plot of the difference between the noise levels measured outside the aircraft and those measured inside of the aircraft (3 to 4 ft from left door). The noise attenuation of the aircraft appears to be approximately 20 dB between the low-frequency range of 1 to 1,000 Hz. Sharp inverted peaks denoting less attenuation occur at the first engine rotational frequency at 38 Hz and at the combined fundamental blade passage and engine firing frequency of 76 Hz. These data tend to show that at these two frequencies, namely, 38 Hz and 76 Hz, the interior noise level measured may have been due to a vibration source and/or acoustical resonance (ref. 6). The overall attenuation of 20 dB compares well with some unpublished results obtained for a light aircraft fuselage section in laboratory studies at Langley Research Center.

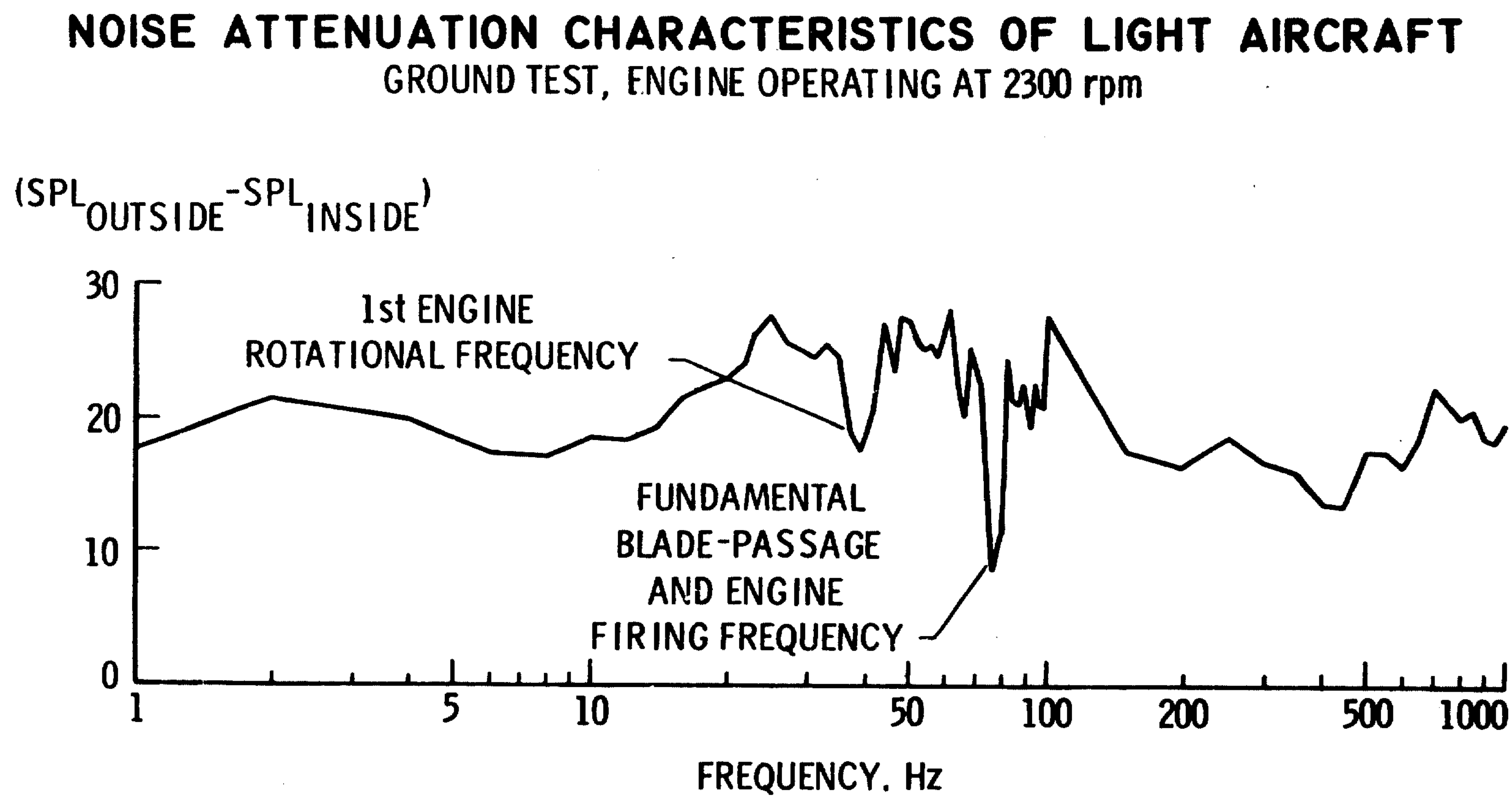
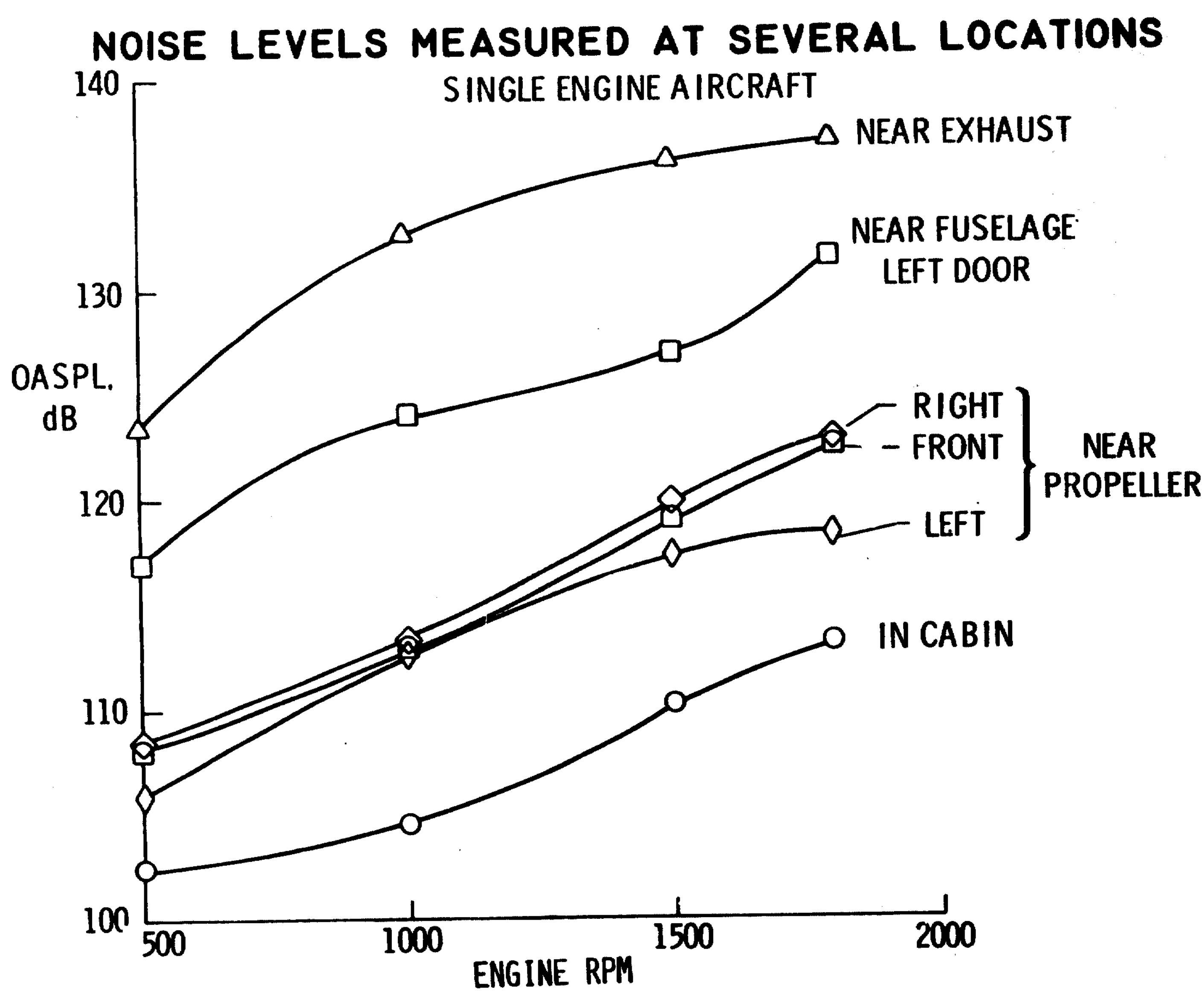

NOISE ATTENUATION CHARACTERISTICS OF LIGHT AIRCRAFT
GROUND TEST, ENGINE OPERATING AT 2300 rpm
(SPL OUTSIDE -SPL INSIDE)
30
20
10
0
1st ENGINE
ROTATIONAL FREQUENCY
FUNDAMENTAL
BLADE-PASSAGE
AND ENGINE
FIRING FREQUENCY
1
5
10
50
100
200
500
1000
FREQUENCY, Hz

Figure 7

NOISE LEVELS MEASURED AT SEVERAL LOCATIONS OF SINGLE ENGINE AIRCRAFT
(Figure 8)

The results presented thus far have been for one engine rpm condition. Data were obtained over a range of engine rpm operating conditions. Some of the results from these tests are shown in summary form in figure 8. Six microphones were employed for this investigation which were located at the following positions: (1) in the aircraft cabin, (2) left of the propeller (5 ft), (3) right of the propeller, (4) front of the propeller, (5) 3 to 4 ft from left door, and (6) near the exhaust. Some of these data have been presented previously in spectral form. The lowest overall acoustic levels were measured in the cabin which ranged from 103 dB occurring at 1,000 rpm to 113 dB at 2,300 rpm. Previous data presented showed approximately 20 dB noise attenuation between interior and exterior measurements. This degree of attenuation can be seen to occur over the entire span of rpm settings. The highest noise levels were measured near the exhaust. This was to be expected since there was no muffler on the aircraft. The propeller noise, as measured at the three locations, follows the same pattern as other locations, i.e., increasing noise with increasing rpm by approximately 10 dB/double rpm. The noise level measured to the right of the propeller is slightly higher than that measured at the left and in front of the propeller because the exhaust is located on the right of the aircraft.



NOISE LEVELS MEASURED AT SEVERAL LOCATIONS
SINGLE ENGINE AIRCRAFT
140
130
120
110
100
OASPL.
dB
NEAR EXHAUST
NEAR FUSELAGE
LEFT DOOR
RIGHT
FRONT
LEFT
NEAR
PROPELLER
IN CABIN
500
1000
1500
2000
ENGINE RPM

Figure 8

INTERIOR NOISE MEASUREMENT IN TWIN ENGINE AIRCRAFT
(Figure 9)

One of the problems encountered in identifying noise sources which contribute to the interior noise of light aircraft is the coincidence at which the fundamental of both engine firing and blade passage frequencies occur. For example, a majority of the current general aviation class aircraft have 4 cylinder-4 cycle engines and double-bladed propellers or 6 cylinder-4 cycle engines with three-bladed propellers. In either case, the fundamental firing and blade passage frequencies are the same. An exception to this case, however, was found in a twin engine aircraft having 6 cylinder-4 cycle engines with two-bladed propellers. A special ground test was performed with the use of only engine operating and a sample of the results is shown in figure 9. The spectral plot of interior noise shows the fundamental frequencies of the engine and propeller separated along with their harmonics. Also shown in the figure is a plot of the decomposition of the harmonic components of noise with respect to propeller blade and engine firing frequencies. It can be seen that the propeller contributes significantly to the interior noise of this aircraft at the fundamental blade passage frequency at 67 Hz (no. 2). The fundamental engine firing frequency occurs at 100 Hz (no. 3) and both propeller and engine firing frequency harmonics occur at 200 Hz (no. 6). It can be seen at the higher frequences (greater than 200 Hz), that the noise level is increased considerably when the frequencies of both the propeller and engine firing frequency harmonics coincide, e.g., at harmonic numbers 6, 12, 18, and 24.

It should be noted that the broadband, low-frequency data which have been shown as a characteristic of interior noise of light aircraft are not as pronounced in the data of this figure. It is believed that the reason for this difference is the fact that the engine was located to one side of the cockpit, approximately 5 ft, and the engine exhausted over the wing behind the engine and aft of the cockpit.

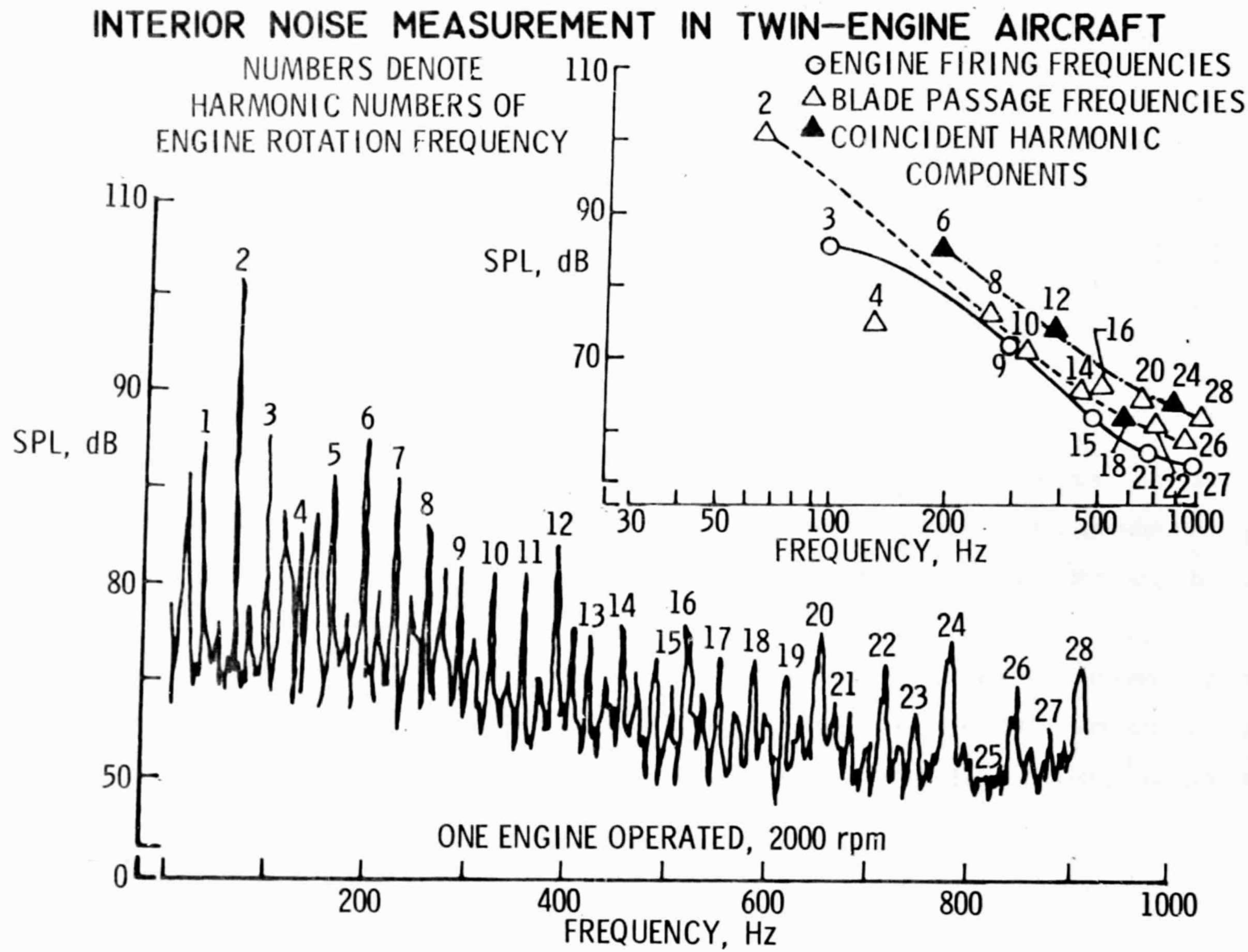

INTERIOR NOISE MEASUREMENT IN TWIN-ENGINE AIRCRAFT
NUMBERS DENOTE HARMONIC NUMBERS OF ENGINE ROTATION FREQUENCY
ENGINE FIRING FREQUENCIES
BLADE PASSAGE FREQUENCIES
COINCIDENT HARMONIC COMPONENTS
SPL, dB
FREQUENCY, Hz
ONE ENGINE OPERATED, 2000 rpm
SPL, dB
FREQUENCY, Hz

Figure 9

GENERAL OBSERVATIONS
(Figure 10)

The results from this study show that the interior noise level of light aircraft is dominated by low frequencies (below 1,000 Hz). The interior noise consists of discrete frequencies which are harmonics of engine firing frequency and blade passage frequencies and also low-frequency, broadband sounds which apparently result from the engine exhaust.

Both the propeller and the engine are dominant sources, however, the contribution from the propeller is significantly more than the engine at its fundamental blade passage frequency. The results obtained suggest that the airborne path is more dominant than the structure-borne path in the transmission of broadband, low-frequency noise.

OBSERVATIONS

- LOW FREQUENCY NOISE (BELOW 1,000 Hz IS DOMINANT
- NOISE CONSISTS OF DISCRETE FREQUENCY SOUNDS WHICH ARE HARMONICS OF ENGINE FIRING FREQUENCY AND BLADE PASSAGE FREQUENCY
- BOTH THE PROPELLER AND THE ENGINE ARE DOMINANT SOURCES. HOWEVER, THE CONTRIBUTION FROM THE PROPELLER IS SIGNIFICANTLY MORE DOMINANT AT ITS FUNDAMENTAL BLADE PASSAGE FREQUENCY
- AIRBORNE PATH IS MORE DOMINANT THAN STRUCTUREBORNE PATH IN THE TRANSMISSION OF BROADBAND, LOW FREQUENCY NOISE

Figure 10

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