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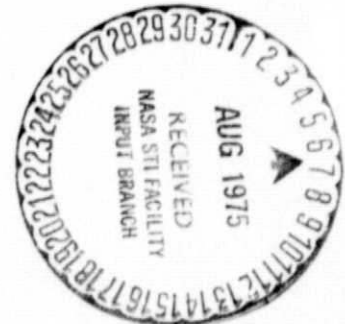
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**INTERIOR NOISE LEVELS OF TWO PROPELLER-DRIVEN
LIGHT AIRCRAFT**

By

John J. Catherines and William H. Mayes

July 1975



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ABSTRACT

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INTRODUCTION

An assessment of aircraft interior noise technology has been conducted at NASA Langley Research Center to determine whether improvements are needed to control the noise for the comfort of crew and passengers. As part of this assessment, interior noise levels of light aircraft and other current types of aircraft were examined. A sample of these interior noise levels is presented in figure 1. Interior noise levels of busses, railcars, and automobiles are included for comparison. The data shown in figure 1 were obtained from refs. 1-6. Figure 1 shows that the noise levels measured inside light aircraft were between 84 and 104 dBA. Comparison of these levels with levels found in other vehicles, and consideration of the response of people to these levels, leads to the conclusion that substantial benefits can be obtained by reduction of this noise.

Control of light aircraft interior noise requires knowledge of such factors as the noise sources and paths of entry into the interior. Some of these factors are described in figure 2. Sources of noise include propellers and reciprocating engines, as well as auxiliary equipment and flow of air over the aircraft. Noise can enter through the lightweight fuselage structure, through windows (that comprise a large percentage of the fuselage area), or through acoustic "leaks"

in the nonpressurized structure. Noise can also be transmitted directly by structural vibrations induced by the engine. It can be seen that the many factors contributing to the interior noise and the complex interactions among these factors makes it a difficult task to control the noise. The task is made more difficult by the need to maintain the performance and economy of the aircraft while reducing the interior noise. In reviewing the technology, it was found that insufficient information is available on the characteristics of the interior noise, or on methods for its control. The principal previous work is the studies by Tobias (refs. 2,3) of the effects of altitude.

As indicated in figure 3, the work described in this paper has two objectives, namely, (a) to determine the relationships between aircraft operating conditions and interior noise and (b) to determine the degree to which ground testing can be used in lieu of flight testing for performing interior noise research. The interest in ground testing arises from the thought that interior noise studies may be performed more easily and more systematically on a stationary aircraft because of the accessibility of instrumentation, added measurement capability, and a more controlled acoustic environment. However, before such studies can be performed, the important characteristics of the interior noise must be understood for both flight and ground test conditions. This paper presents results of interior noise measurements obtained for a two passenger, single engine, propeller driven aircraft for both ground operations and for a range of in-flight operating conditions. Measurements obtained in a twin engine, propeller driven type aircraft during normal flight operations are also presented.

TEST DESCRIPTION

Test Aircraft

Interior noise measurements were obtained at the passenger seat location for two types of light aircraft. The aircraft were unmodified and have specifications as presented in figure 4. The single engine, two seat aircraft (1973 model) is believed to be representative of one of the most popular currently manufactured models. The twin engine aircraft was a four seat (1957) model and had a known door seal leak.

Test Instrumentation and Procedure

Sound pressure level measurements were obtained in flight using a (type 1, precision) sound level meter. The electrical output of the sound level meter was also recorded on a portable magnetic tape recorder for subsequent detailed frequency analysis. An amplitude modulation method was used to record the data on tape, together with a 7.5 inches per second recorder tape speed allowed for a frequency analysis of up to 10,000 Hz.

The procedure for the flight tests of the single engine, propeller driven aircraft involved cruise engine rpm settings of 2,000, 2,200, and 2,500. Noise measurements were obtained for each of the rpm settings at flight altitudes of 1000, 2000, and 3000 feet and for one condition of idle descent. The flight conditions were identified on tape by the use of a three-digit, dial-set, battery operated encoder triggered by the observer. The coding device imparted a binary digital code to the tape which was used to identify the various flight events. A more complete description of coding device is given in ref. 7.

A second part of the study involved interior noise measurements on a stationary aircraft based on the objectives mentioned earlier. In order to investigate ground reflective effects, the aircraft was operated on both concrete and grassy surfaces for engine speeds of 1,200, 2,000, and 2,400 rpm. Measurements were also obtained with windows open and windows closed for the engine operating at 1200 rpm to obtain information on noise path identification.

For the twin engine aircraft, which had a known door seal leak, data were obtained on a noninterference basis during a normal passenger carrying flight.

Data Analysis

The data recorded on magnetic tape was played back to obtain an oscillograph record of the noise data, the three-digit binary code, and a NASA-36 bit time code. The time code was added to the tape in the initial data reduction process to identify the digitizing times. The data shown in this paper were reduced from 5-second segments that were selected for each aircraft condition. The data were digitized at a rate of 20,000 samples per second. Based on the Nyquist requirement of two samples per cycle, this sample rate yielded valid results up to 10,000 Hz. Before digitizing, the data were filtered with an analog low pass filter having a cutoff frequency of 10,000 Hz, in order to eliminate the problems of folding or aliasing (see ref. 8).

Lastly, the data were reduced on a CDC 6600 series computer using a Fast Fourier Transform (FFT) program (ref. 9) to obtain the desired outputs. The outputs of this program were OASPL, dBA, and sound pressure spectra in the form of constant band (20 Hz bands), 1/3 octave and octave band analysis.

RESULTS AND DISCUSSION

Effects of RPM in Flight

Sound pressure spectra obtained in the single engine aircraft are shown in figure 5 for three different engine-propeller rpm settings measured at a flight altitude of 1000 feet. In addition, the indicated airspeed, overall dB, and dBA values are given for each engine-propeller rpm condition. It can be seen that the predominant peak of the spectra, for all rpm conditions, occurs below 100 Hz. The fundamental propeller-engine firing frequencies varied from 67 to 83 Hz during the increase of engine rpm from 2000 rpm to 2500 rpm, respectively; these frequencies correspond to the dominant peaks shown below 100 Hz. For this frequency range, which controls the overall SPL, the spectral levels decrease with increasing engine rpm and airspeed. The reason for the observed decrease is not fully understood. Possible reasons are different propeller inflow conditions, effects of forward speed, and fuselage structural responses. However, at frequencies greater than 100 Hz, which controls the dBA level, the spectral levels increase with engine rpm as would be expected with the corresponding increased airspeed and engine power. The peaks in the spectra above 100 Hz are associated with propeller-engine firing frequency harmonics.

Comparison of Flight with Ground Tests

Noise spectra for both ground and flight conditions are shown in figure 6. These data were obtained for an engine-propeller setting of 2000 rpm, with the flight condition at an altitude of 1000 ft and an IAS of 72 knots. It is seen that the

dominant low frequencies (below 100 Hz) and most of the high frequency peaks measured in flight are in good agreement with those measured in the stationary aircraft. In the midfrequency range (100-2000 Hz), the noise levels are higher during ground tests by up to 6 dB and are believed to be due primarily to ground reflection. However, for frequencies above about 2000 Hz, the flight spectrum levels are higher than those measured on the ground. This result is believed to be due to aerodynamic noise associated with flight. The above results would suggest that identification of frequency components and relative amplitude effects of noise sources related to the propeller and engine may be studied on stationary aircraft.

A summary of the noise levels measured for all flight and ground test conditions are shown in figure 7. Overall and A-weighted levels are plotted as a function of propeller-engine rpm. Included in the data are results from ground tests on both concrete and grass surfaces and also flight data for each of three altitudes, including engine idle descent. The engine idle descent data are given by the two open circle data points at 1200 rpm. Curves are drawn through the data points for comparative purposes.

Several observations can be made from this figure. For all conditions tested, the dBA levels increase with increasing engine-propeller rpm. The values of dBA associated with ground runup are seen to be about 6 dBA higher than those measured during flight. It should be noted that the slopes of the curves associated with the dBA levels for both ground and flight conditions are approximately the same. This result would imply that dBA levels are independent of forward speed for this aircraft over the operating range of the study. Caution, however, should be used for this interpretation, since ground reflection and airspeed were

uncontrolled variables and may have self-compensating effects. The effects of altitude on both the overall and dBA levels are seen to be small (within 1 dB) as would be expected from the test results reported in reference 2. For higher rpm settings, the overall SPL are seen to decrease with increasing rpm particularly for all the in-flight test conditions.

Effects of Windows

As mentioned earlier, windows are considered to be an important transmission path for noise to enter the interior of light aircraft. Since to the authors' knowledge no quantitative information is available on window effects, some preliminary information was obtained on the effect of windows on the measured interior noise. The single engine aircraft was operated at a constant 1200 rpm on the ground and noise measurements were obtained with the windows open and with the windows closed. The results of these measurements are presented in figure 8. It can be seen that in general the spectra obtained for these two conditions have the same shape. Slightly higher amplitudes associated with the window open condition were measured over the frequency range of about 200 to 6000 Hz. It should be noted that the overall SPL and dBA level increased 3 and 6 dB, respectively with the windows open. This result indicates that windows do provide some noise reduction for the aircraft cabin and that the relative contribution of windows as a noise transmission path for light aircraft should be further investigated.

Effects of Door Seal Leak

Another factor that may contribute to the interior noise of light aircraft are seal leaks that may occur around openings of windows and doors of older aircraft.

Some noise data pertaining to a seal leak were obtained and are shown in figure 9. Noise spectra were measured at a passenger seat location in a twin engine, four passenger aircraft for two flight conditions, namely, lift-off and cruise. The speed of the aircraft during lift-off was approximately 87 knots compared to 161 knots measured for cruise. The spectral data has a peak at about 125 Hz which corresponds to the propeller and engine firing frequencies. Furthermore, at the higher frequencies above 1000 Hz, the noise levels are higher during cruise and, since the engine rpm is less but the speed has increased, the source of this noise is believed to be aerodynamic in nature. Further evidence of this observation is shown by the third spectrum which was measured near the door seal leak. The spectrum level at the higher frequencies is about 15 dB higher when measured near the door leak as compared to the seat location and is approximately 25 dB higher when compared to the lift-off condition.

CONCLUDING REMARKS

The results of this study show that the noise levels inside light aircraft are strongly influenced by the rotational speed of the engine and propeller. In particular, the A-weighted dB levels increase with increased engine-propeller rpm for all ground and flight operations.

Both the overall noise and low frequency spectra levels were observed to decrease with increasing high speed rpm operations during flight. This phenomenon and its significance is not presently understood.

Comparison of spectra obtained in flight with spectra obtained on the ground suggests that identification of frequency components and relative amplitude of propeller and engine noise sources may be evaluated on stationary aircraft.

Closing of the aircraft windows provided approximately 6 dBA of interior noise reduction under static conditions. Door seal leaks provided a source/path for aerodynamically generated in-flight noise.

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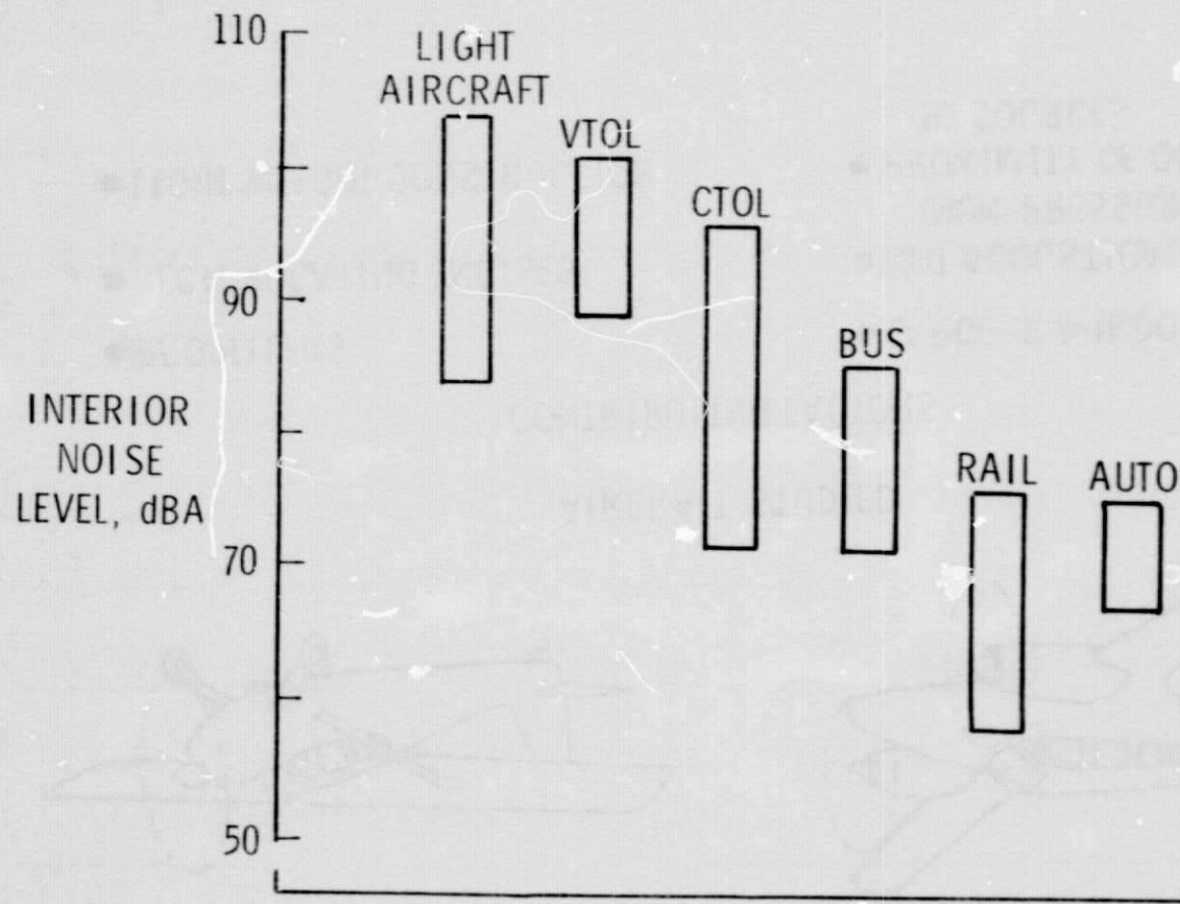
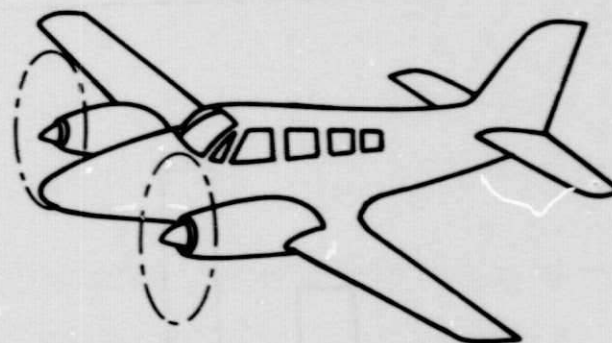
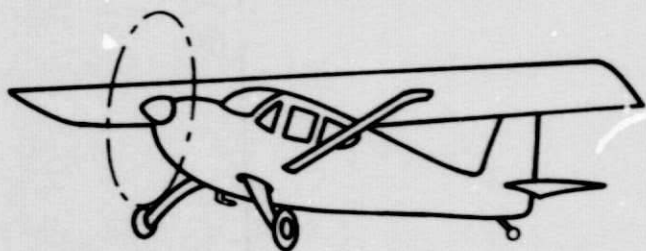


Figure 1.- Comparison of interior noise levels of current transportation systems.
(cruise conditions)



AIRCRAFT STUDIED

CONTRIBUTING FACTORS

- PROPELLERS
- RECIPROCATING ENGINES
- LIGHT WEIGHT CONSTRUCTION
- LARGE % WINDOW AREA
- NOT ACOUSTICALLY SEALED (NON-PRESSURIZED)
- PROXIMITY OF OCCUPANTS TO SOURCES

Figure 2.- Factors affecting interior noise of light aircraft.

● OBJECTIVES

TO DETERMINE INTERIOR NOISE CHARACTERISTICS WITH FLIGHT PARAMETERS
TO DETERMINE ADEQUACY OF GROUND TEST REPRESENTATION OF IN-FLIGHT
INTERIOR NOISE

● TEST PLAN

SINGLE ENGINE AIRCRAFT

FLIGHT TEST

RPM

ALTITUDE

GROUND TEST

RPM

SPECIAL TESTS

GROUND SURFACE EFFECTS

WINDOW EFFECTS

TWIN ENGINE AIRCRAFT

SPECIAL TEST

NORMAL FLIGHT CONDITIONS

WITH KNOWN DOOR SEAL

LEAK

Figure 3.- Objectives and test plan of light aircraft noise study.

| | SINGLE ENGINE | TWIN ENGINE |
|-------------------------------|-----------------------|------------------------|
| CYLINDERS | 4 | 6 |
| HORSEPOWER | 30 @ 2600 rpm | 240/ ENGINE @ 2600 rpm |
| GROSS WEIGHT, lb | 1600 (725.8 kg) | 4830 (2190.9 kg) |
| CRUISE SPEED, IAS | 104 knots (193 km/hr) | 161 knots (298 km/hr) |
| PROPELLER DIAMETER | 5 ft, 9 in. (1.75 m) | 6 ft, 9 in. (2.06 m) |
| PASSENGER CAPACITY | 2 | 4 |
| ENGINE/PROPELLER RPM RATIO | 1 | 1 |

Figure 4.- General specification of light aircraft studied.

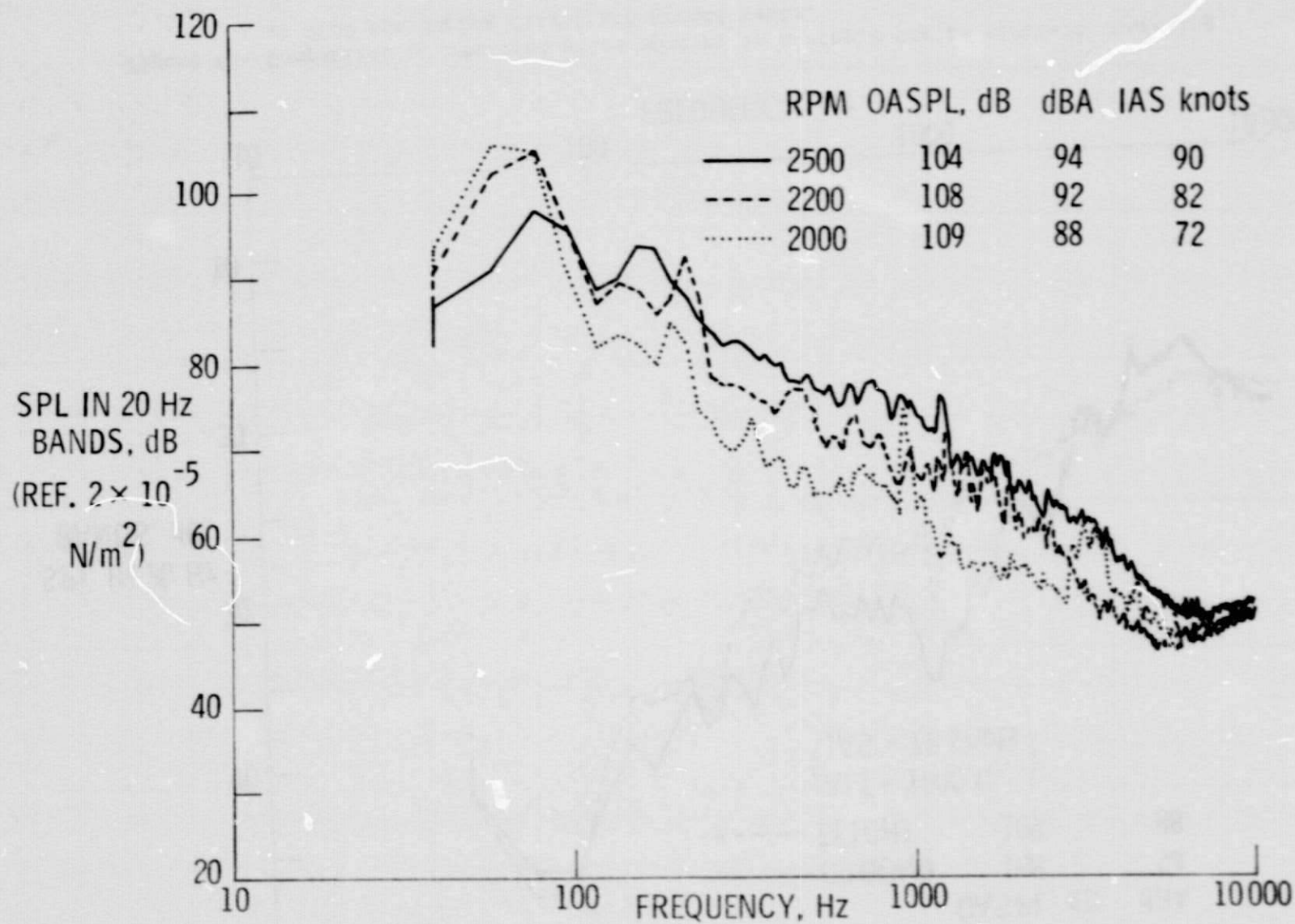


Figure 5.- Sample of noise spectra measured in a single engine aircraft for three different engine rpm settings at a flight altitude of 1000 feet.

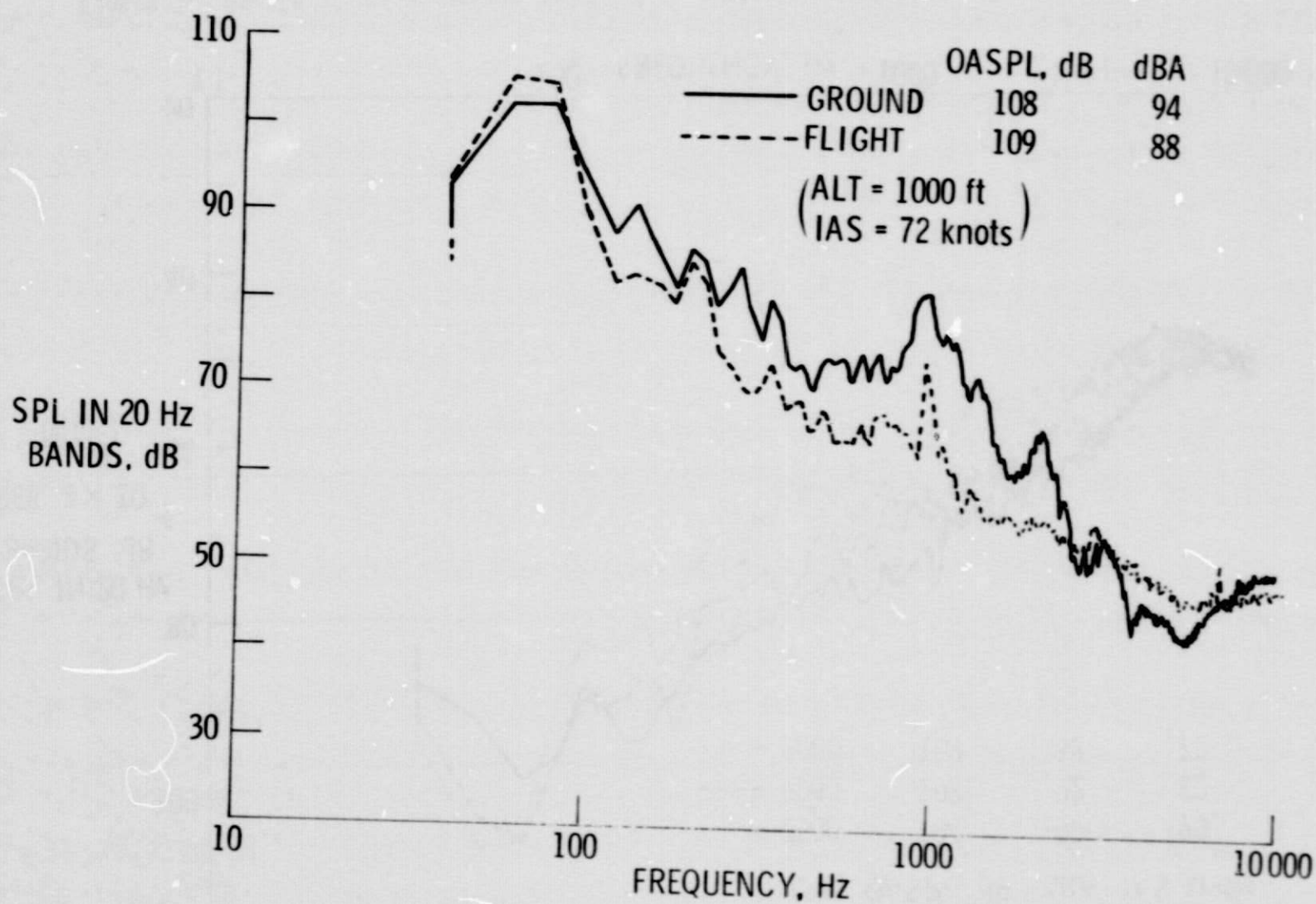


Figure 6.- Comparison of measured noise spectra in a single engine aircraft operating at 2000 rpm during flight and ground tests.

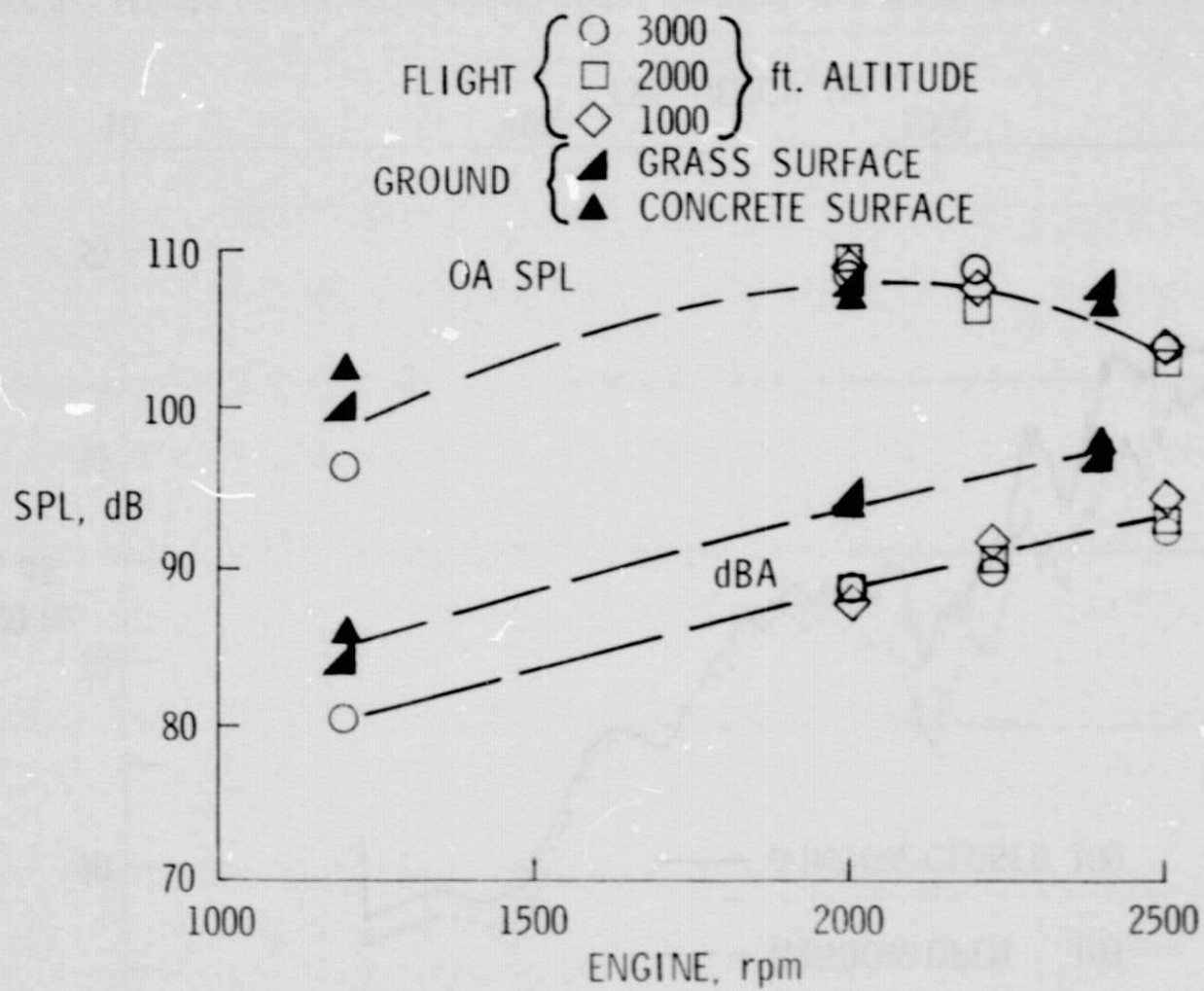


Figure 7.- Summary of interior noise levels measured during ground and flight tests in a single engine aircraft.

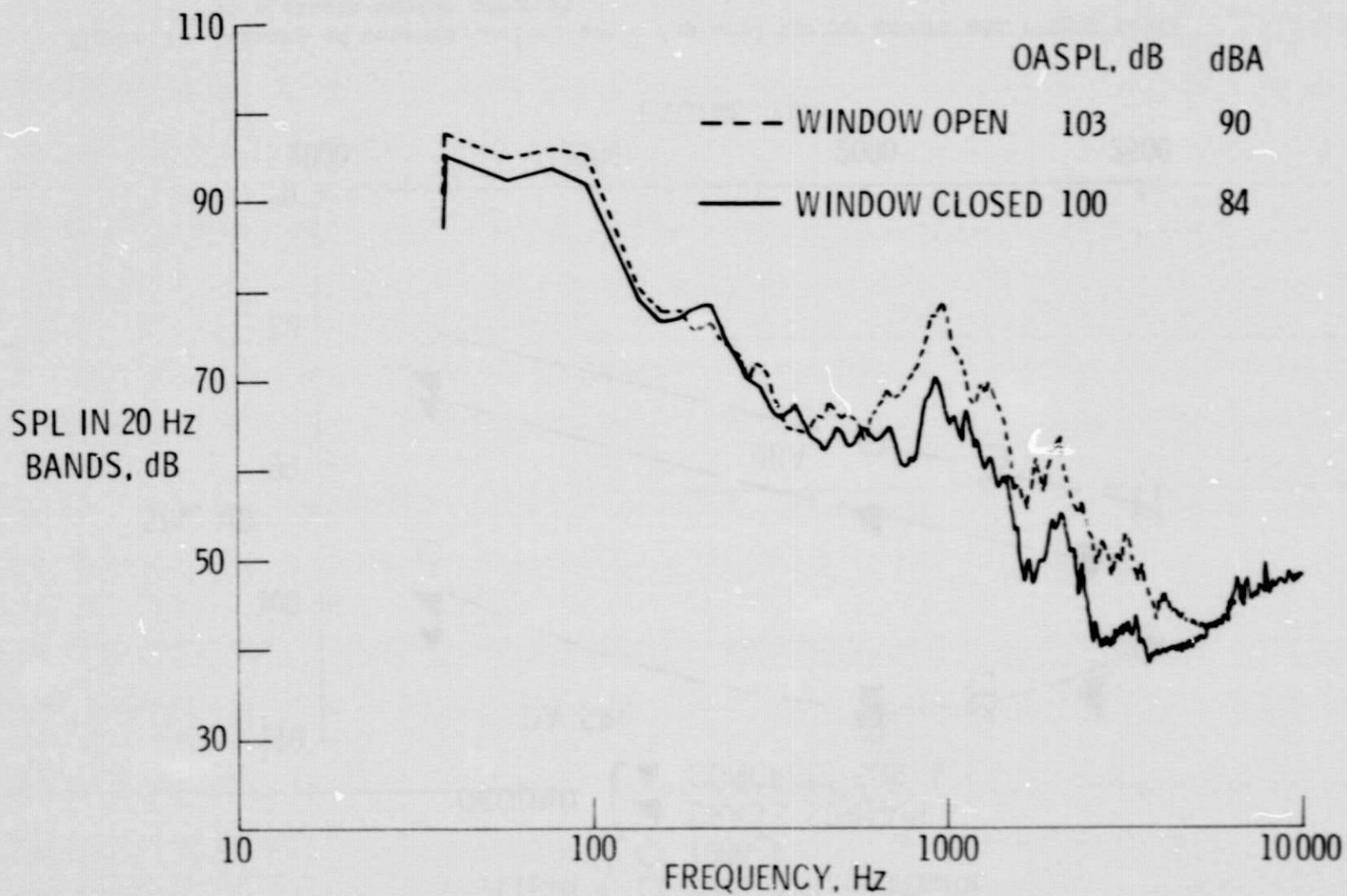


Figure 8.- Effects of windows on noise spectra measured in a stationary single engine aircraft operating at 1200 rpm.

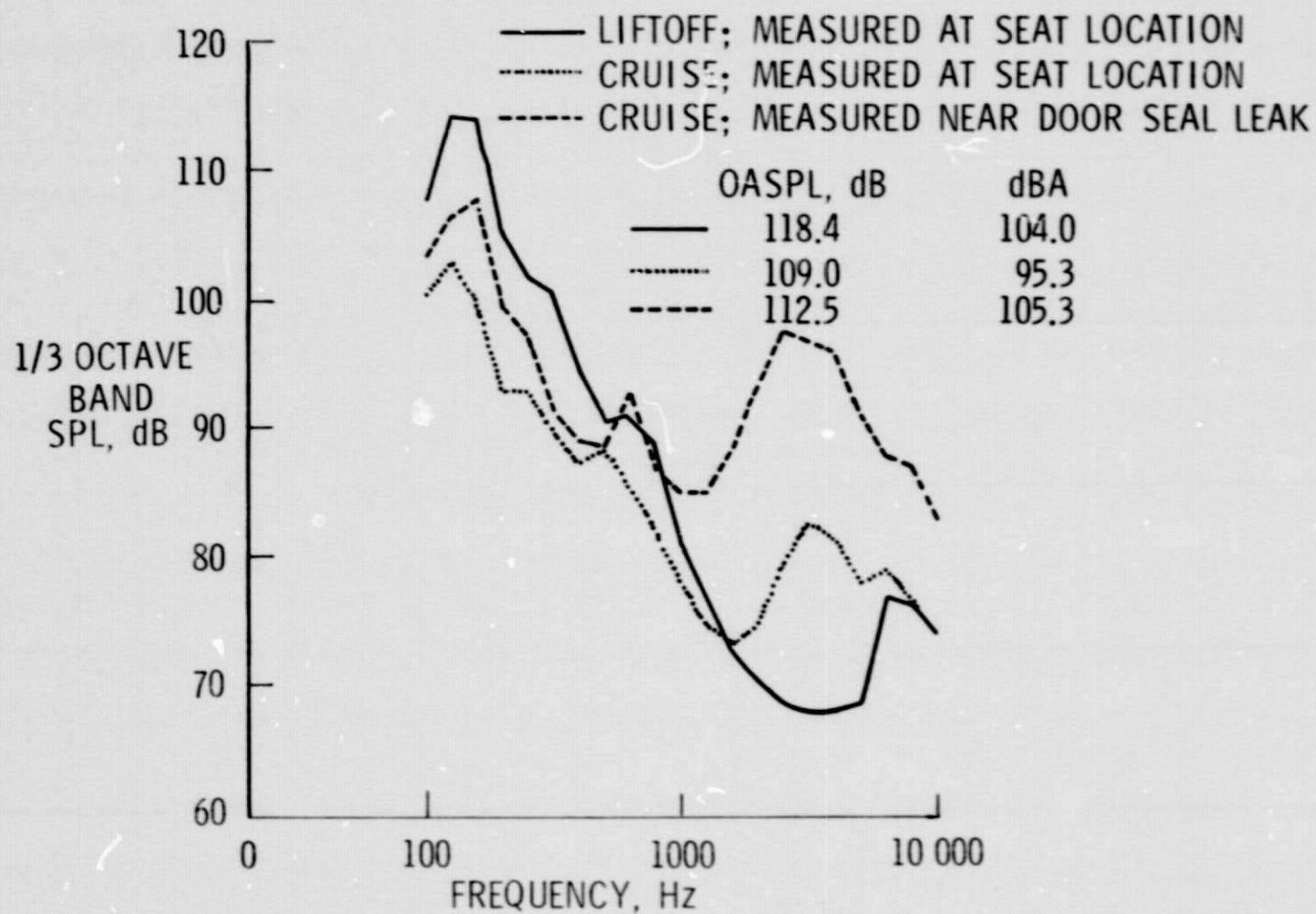


Figure 9.- Effects of door seal leak on noise spectra measured in a twin engine aircraft.