

## HELICOPTER CABIN NOISE - METHODS OF SOURCE AND PATH

## IDENTIFICATION AND CHARACTERIZATION

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## SUMMARY

The effective quieting of helicopter cabins requires that the weight and space of the treatments be minimized. The application of these treatments therefore requires that the paths by which the noise arrives at the cabin, coupled with the radiating surfaces and the sources of origin be identified as clearly as possible. The techniques described in this paper have been employed as part of comprehensive helicopter quieting programs which have achieved notable reduction of cabin noise on several existing helicopter designs.

## INTRODUCTION

The continued expansion of and competition for the helicopter market, particularly in the 8-20 seat capacity range, has led to much attention being given to the provision of quiet and comfortable passenger accommodation. The helicopter in this size range when fitted with the best "standard" interior will typically exhibit a cabin noise level of 93-95 dBA when flying at its design speed, whereas a commercial transport will have a typical noise level ranging from 75 to 82 dBA at its cruise speed. Figure 1 summarizes the typical noise levels that can be expected with various interior configurations and shows that, even with the best available treatment, the noise levels are above those for a commercial transport. Of particular note are the tone levels which control the levels in many portions of the spectrum and are of course more annoying than the same levels of random noise which tend to predominate in commercial aircraft. The selection of noise control treatments to reach the lowest helicopter level in Figure 1 requires that the noise sources and their paths to the cabin be carefully measured so that minimal additional mass is applied and that the space occupancy is not affected. In this latter regard the passenger headroom is often critical as the cabin roof may well be a major radiating area.

The mechanical design of a helicopter presents a particular challenge to noise control engineers in that it is usually a tightly coupled structure encased with light rigid panels, which radiate sound efficiently, plus relatively thin side walls and windows, which have a poor transmission loss. The presence of machinery located on the structure plus the location of the passengers within the main structure further compound the difficulty.

The magnitude of the noise control task can be appreciated by reference to Figure 1 which shows that even an engineering program which produces 20-30 dB

reduction in cabin noise levels above 500 Hz from the bare interior is insufficient to meet commercial fixed wing jet aircraft levels. This is a formidable challenge for any noise control project even without the constraint of minimum weight. This unusually high target must therefore be met with the best possible understanding of the details of the noise mechanisms and transmission paths pertaining to the particular aircraft in question.

Cabin noise reduction may be achieved by modification to the source levels, the sound path, and the receiver environment. It is not often possible to reduce the source levels in helicopters as, for example, the impact of reducing the gear noise by altering the mesh forces has wide implications in terms of reliability and load carrying capability. It is thus a matter not lightly undertaken. Accordingly the reduction of cabin noise on existing helicopters is concentrated on modification of the paths between source and receiver.

For the purposes of further discussion it is convenient to consider separately the major groups of internal noise sources in a helicopter. These may be classified as propulsion machinery comprising engine and transmission, and turbulent boundary layer effects.

The intrusion of main and tail rotor noise into the cabin we have not found to be significant. Although some tail rotor blade rate harmonics may appear in a narrow band spectrum taken in the cabin, the treatment applied to the interior to correct other source levels also leads to reduction of these harmonics. The broadband turbulent boundary layer blade noise may be considered as a series of distributed dipoles which do not radiate effectively in the direction from blade to cabin.

#### PROPULSION MACHINERY NOISE - STRUCTUREBORNE

The tight structural coupling and proximity of the main gearbox and engine(s) to the cabin usually leads to the dominance of machinery noise in the cabin. Indeed, the main reduction gear mesh tone is usually a predominant sensation in the cabin. It should be noted that work is being performed on the feasibility and techniques for mesh noise reduction at the source; however this is beyond the scope of this paper. Figure 2 is a representation of the ways in which machinery noise arrives at the cabin - other paths are possible but in our experience, the identification of the paths outlined is sufficient for all practical purposes.

In an overall sense, we attempt to measure directly the individual contribution of the machinery vibration and its case-radiated noise to the sound field in the cabin. We then analyze individually the paths for the vibrations and noise. Consider as an example the methods used in analyzing the structureborne noise from a main rotor gearbox. A very simplified diagram of the helicopter as it relates to the structureborne noise from the gearbox is shown in Figure 3. There are always more than two mounts. The flexibility and damping of each is taken as the total that exists between the transmission attachment and the structural frame attachment. Also shown is the usual honeycomb overhead panel

hich forms an integral part of the structure and, at the same time, presents a large noise radiating area into the cabin. The walls of the structural frame will also usually form part of the cabin and may be significant radiators.

The measurement program typically includes the installation of accelerometers at the points located by A in Figure 3 which are chosen to track the vibration from source to receiver (passenger). Flight tests are then performed over the required operating range to obtain the magnitude of these vibration levels which are recorded on seven or fourteen track tape machines. In this regard it is important to obtain as much coincident time history of the acceleration levels as possible to allow the use of correlation analysis later on. The actual direction and precise location of the accelerometers is a matter for the experienced judgement of the experimenter as it is simply not feasible to cover all the possibly relevant vibration locations. The locations selected are clearly influenced by his appreciation of the most likely structural paths, and will preferably involve the contribution of the structural designer.

In the flight tests, several cabin microphones will be employed to monitor the total noise as well as to locate obvious acoustic 'hot spots'.

A series of ground vibration tests are conducted with all aircraft systems shut down in which vibration is applied to the transmission case from a shaker system. The object here is to reproduce only that phenomenon which one wishes to study without any other acoustic interference. Notwithstanding the tightly coupled structure of the helicopter it is most desirable to attempt to shake the gearbox in such a way that the correct distribution of vibration levels is seen in the mounts as occurs in flight. If the noise control program is being performed on just one helicopter then it may be necessary to adjust the shaker location and direction to obtain the desired mount vibration distribution. If however, it is possible to perform the static tests on another sample then an alternative method is to provide localized excitation at each mount pad. This opportunity will also allow the measurement of mount impedance looking into the structure. This information, in conjunction with the measured vibration in flight, allows determination of the vibratory power flow into the structure.

Given that one can achieve the correct distribution of vibration on the static test at the mount pads, we then take readings of the induced noise in the cabin at the selected locations. This allows us to establish the transfer function: "Transmission Vibration-Cabin Noise". During this test measurements are made at the selected structural frame and honeycomb panel locations to arrive at the proportion of total vibration at these points to that induced by the transmission vibration alone.

The final step in the procedure is to apply the derived transfer function to the actual measured inflight vibration levels to arrive at the contribution to cabin noise levels from the transmission vibration alone.

Figure 4 represents a typical result obtained on a light helicopter and illustrates the methodology. In the example shown in Figure 4, the transfer function was based on average mount acceleration versus cabin noise and not on the actual transmission acceleration. The resultant computed cabin SPL due

to the structureborne transmission noise agrees creditably with the overall result as will be seen later. There is however some discrepancy in the high frequency range which indicates that a more searching analysis could be worthwhile depending on the methods of noise control being contemplated. There are a number of traps for the unwary in this approach of which probably the most significant is the implied assumption of linearity. As most shakers are unable to drive the mechanical elements at frequencies and levels identical to full-scale conditions, one must resort to testing at lower vibration and acoustic levels and applying linear scaling. This method is usually satisfactory for metallically mounted machinery components, but may be unsuitable for elastomeric mountings which exhibit a nonlinear load deflection curve, hence changes in isolation performance, particularly rear mount resonance may occur unless correct loading of the mounts is achieved. Depending on the particular helicopter design, it may be desirable to measure the isolation provided by the mounts during flight and compare this to the ground test runs with a view to verification of the mount performance.

Although constant bandwidth analysis is useful in determining the major contributors to the cabin noise spectrum, we find that the line density is normally so high that it is easier to analyze in 1/3 octave bands, rather than try to account for each individual discrete frequency. The use of correlation techniques has been used in some of the analyses, but in view of the highly correlated vibration signatures which appear at the mounts its success has been limited to a general overview of the contributions of transmission vibration to cabin noise. We find that the method presented here yields adequate accuracy and allows us to determine the most appropriate methods of noise control which may consist of mount modification, isolated interior panels, or a combination of these.

#### PROPULSION MACHINERY NOISE - AIRBORNE

The methods we employ to determine the contribution of case radiated noise to the cabin noise levels are similar in principle to those described above. Reference again to Figure 4 will show our assumed acoustic paths for airborne noise which may be grouped as either direct acoustic leaks through holes between the machinery and passenger compartments or as the transmission loss of the walls separating these compartments. The former case is usually easily spotted by visual inspection as well as by localizing hot spots with a roving microphone in the cabin. The latter case is investigated by measuring the acoustic levels in the machinery compartment at a number of locations during flight operations.

Static ground tests are then conducted to evaluate the transfer function between the noise in the machinery compartment and the cabin SPL. Single or multiple loudspeakers are placed in the machinery compartment to generate a acoustic field distribution similar to that observed during flight and simultaneous recordings are made of machinery and cabin noise from which the transfer function is derived.

Figure 5 demonstrates a typical result of such a test and this may be compared with the total noise in the cabin shown in a subsequent figure.

#### TURBULENT BOUNDARY LAYER NOISE

One source of broadband noise in the cabin is the turbulent boundary layer which is present over the exterior of the helicopter. At low forward velocities boundary layer noise will be negligible compared to other sources, but as helicopter speeds increase there is a likelihood that such noise will become important.

The turbulent boundary layer will excite the cabin structure and the windows. However, since the structure will be covered by insulation material and interior trim, the windows will be the important surfaces radiating boundary layer noise into the cabin. In order to estimate this contribution to cabin noise levels, it is necessary first to estimate the vibration of the window and then the acoustic radiation.

For typical helicopter speeds and window thicknesses, the acceleration power spectral density  $S_a(f)$  of a window pane can be estimated using statistical energy analysis, under the assumption that resonant response is dominant. The window vibration can be estimated using

$$S_a(f) = \frac{0.143U_c^2}{2\eta C_L K M_s^2} \frac{S_p(f)}{f}$$

where  $S_p(f)$  is the boundary layer pressure excitation at frequency  $f$ ,  $U_c$  is the pressure convection velocity,  $\eta$  the panel loss factor,  $C_L$  the longitudinal wave velocity in the panel,  $M_s$  the panel surface mass density and  $K$  the radius of gyration. Acceleration spectra have been estimated for the cabin windows assuming  $\eta = .01$  and  $U_c = 0.8 U_o$  ( $U_o$  is the forward flight speed).

The above equation has been used to estimate one-third octave band levels for windows, on a helicopter flying at its normal cruise condition. The resulting spectrum is shown in Figure 6 where it is compared with levels measured on three window panels. The agreement is quite good. The forward door windows show higher levels than predicted, which are probably due to increased turbulence, as these windows are just downstream of the most extreme bends of the fuselage contour and also may be affected by increased turbulence due to rotor downwash. The passenger door window vibration is considerably greater than predicted at frequencies below 400 Hz as this panel responds in a resonant fashion to the rotor pressure field.

The radiated sound pressure levels can be estimated using an equation of the form

$$S_i(f) = \frac{\rho_o^2 c_o^2 \sigma}{\pi^2 \alpha} \cdot \frac{A_T}{A_\alpha} \cdot \frac{S_a(f)}{r^2}$$

where  $S_i(f)$  is the power spectral density of the interior sound field,  $A_T$  is the transmitting area,  $A_\alpha$  is the absorbing area with average absorption coefficient  $\alpha$ ,  $\rho_o$  is the air density,  $c_o$  is the speed of sound, and  $\sigma$  is the acoustic radiation efficiency of the transmitting structure. As an upper limit,  $\sigma$  can be assumed to be unity.

The value of  $S_a(f)$  can be calculated, as indicated above, or obtained from measured vibration levels. An example of the latter case is shown in Figure 7, where the spectrum represents the acoustic power radiated by all windows of the helicopter cabin. In this particular case, the predicted sound levels resulting from turbulent boundary layer excitation were below those predicted for other sources. However the boundary layer contribution will become more important as helicopter speeds increase and noise control techniques are applied to other sources.

#### OVERALL RESULTS

Summation of the individual contributors calculated from the noise source diagnosis results should yield a value close to that measured in flight. Figure 8 shows the individual contributors determined for one model of helicopter and is a summary of data presented earlier with the addition of engine structureborne noise. Addition of these contributors yields the solid line shown in Figure 9 and by contrast the directly measured level in the cabin is shown dashed.

The general agreement is quite good considering certain simplifying assumptions such as averaging of the gearbox mount vibration levels. It is certainly adequate for the design of interior noise treatments although further refinements are necessary if it is desired to change the machinery mounting arrangements so as to modify the vibratory power flow or its distribution into the structure.

The estimated level above 2000 Hz in Figure 9 is about 2 dB below that measured and may indicate that an important contributor has been missed. However, given that the spectrum shapes are similar, it is more likely that there is an error in the transfer function determination. A more searching analysis is expected to resolve discrepancies of this order. A similar situation, although reversed, exists below 1200 Hz and may be caused by errors in the experiment where the same path contributes to two source mechanisms. As an example, when performing structureborne noise tests on the machinery, the casing will

radiate noise which can also arrive at the cabin via the acoustic path as well as the structural path under study. Experimental care and anticipation of this effect will ensure that nasty surprises are avoided.

#### CONCLUDING REMARKS

We have shown that by using relatively simple concepts together with careful experimental work it is possible to generate reliable data on which to base the design of high performance noise control treatments.

As an indication of the weight penalties associated with the noise control treatments derived from a thorough study of the source paths we have been able to achieve the best levels shown in Figure 1 for an added weight of some about 40 kg (100 lb) over that for the unfurnished interior. From this can be subtracted the weight of a normally furnished interior which would produce the levels shown in Figure 1. It has also been our experience that it is possible to redefine some interior furnishing arrangements, which have noise control built in, so that no weight penalty is incurred. This is achieved by removing and relocating or redesigning the noise control treatments to obtain the best efficiency.

#### REFERENCE

1. Wilby, John F. and Smullin, Joseph I.: Interior Acoustic Environment of STOL Vehicles and Helicopters. Presented at NOISE-CON 77, 17-19 October, 1977, Hampton, Virginia.

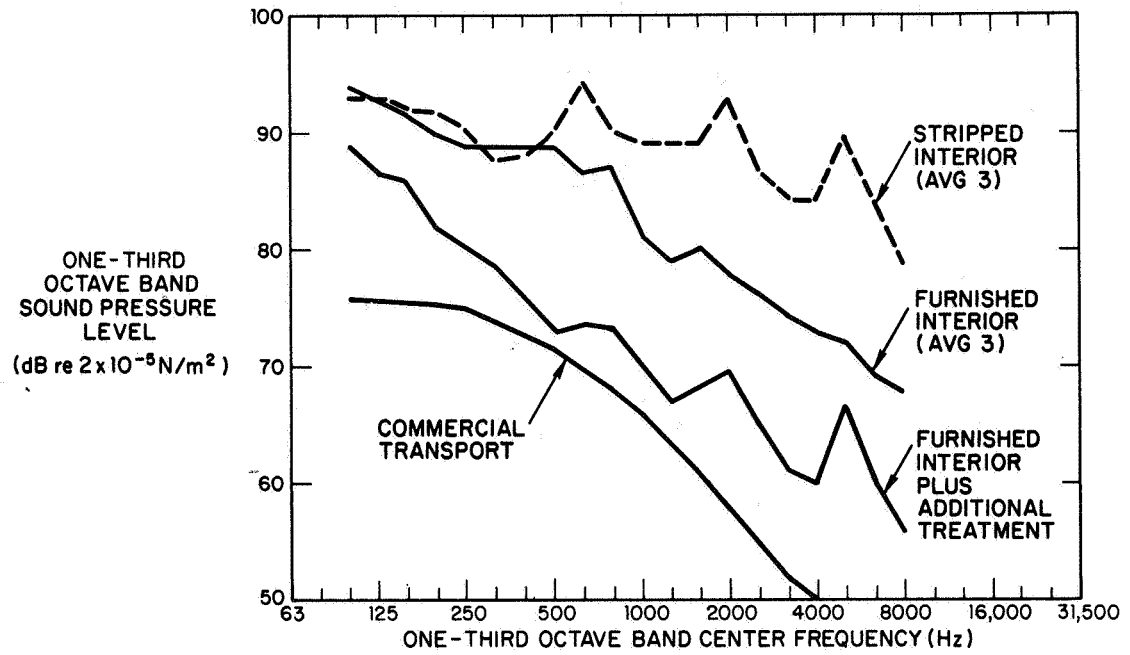


Figure 1.- Typical helicopter interior noise.

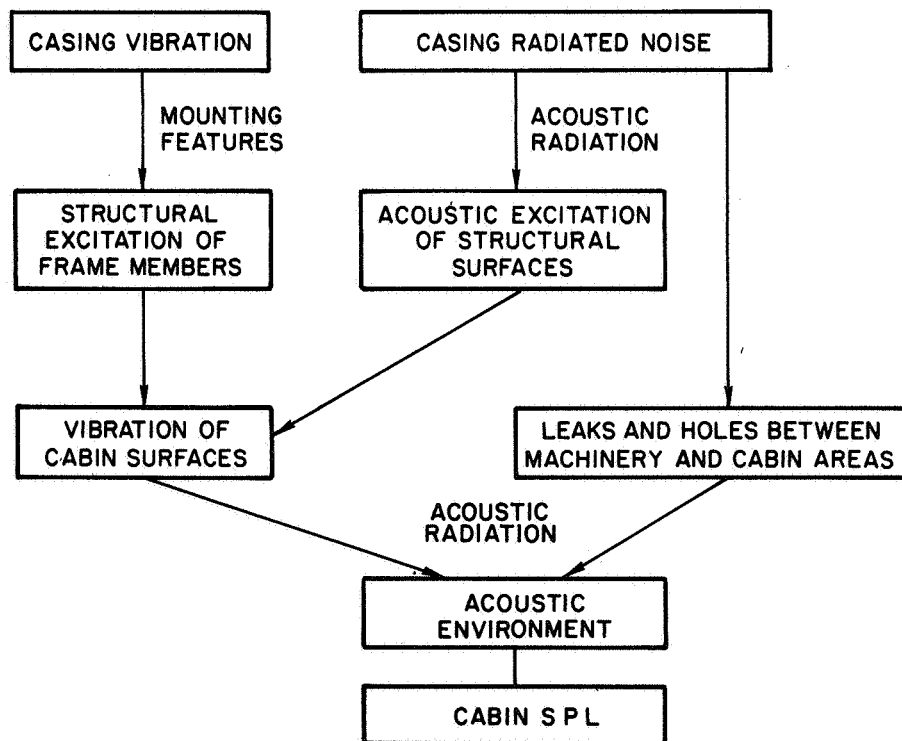
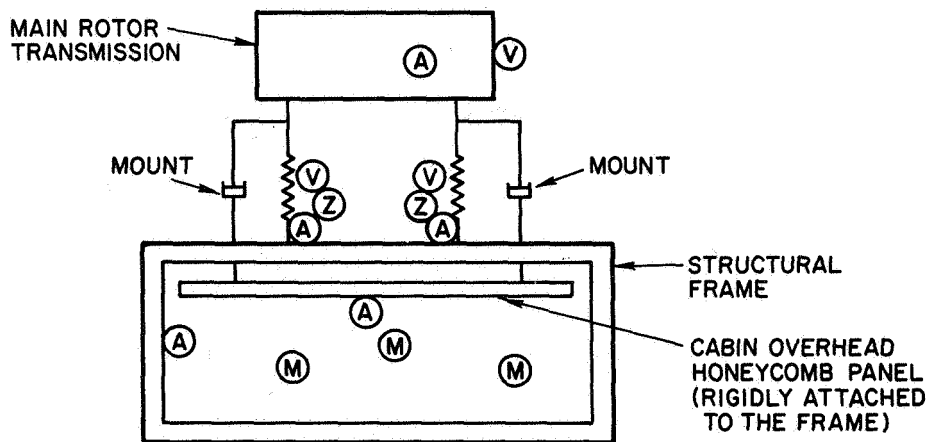


Figure 2.- Paths of engine and gearbox noise to the cabin.





- (A) DENOTES ACCELEROMETER LOCATIONS
- (M) DENOTES MICROPHONE LOCATIONS
- (V) DENOTES SHAKER LOCATIONS
- (Z) DENOTES IMPEDANCE MEASUREMENT LOCATIONS

Figure 3.- Simplified diagram for transmission noise structureborne into cabin.

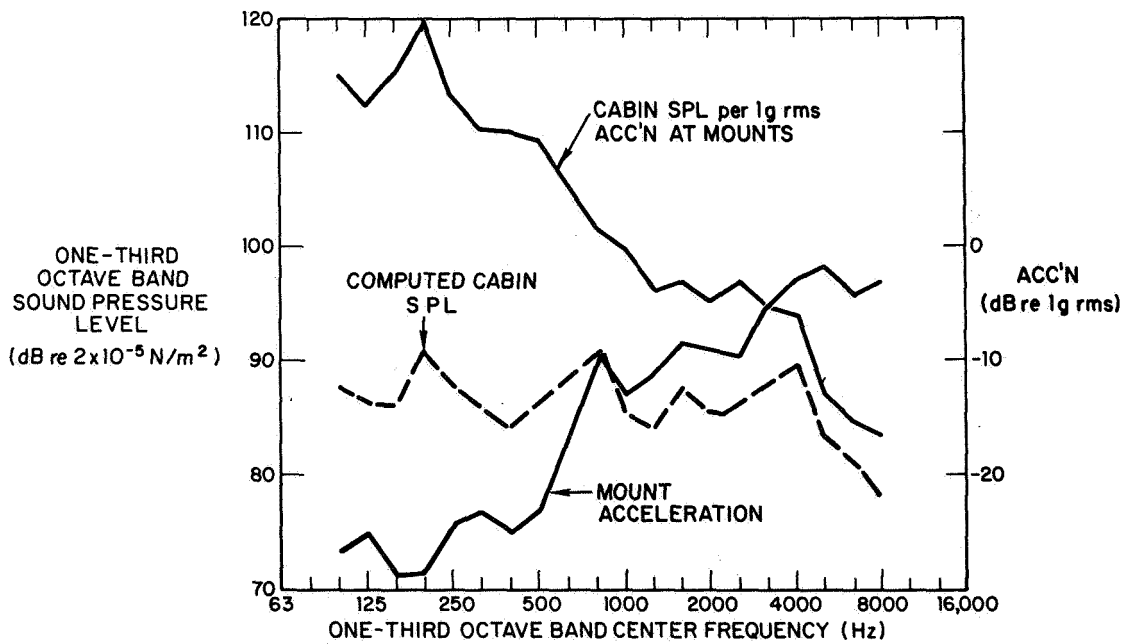


Figure 4.- Typical result of structureborne transmission noise test.

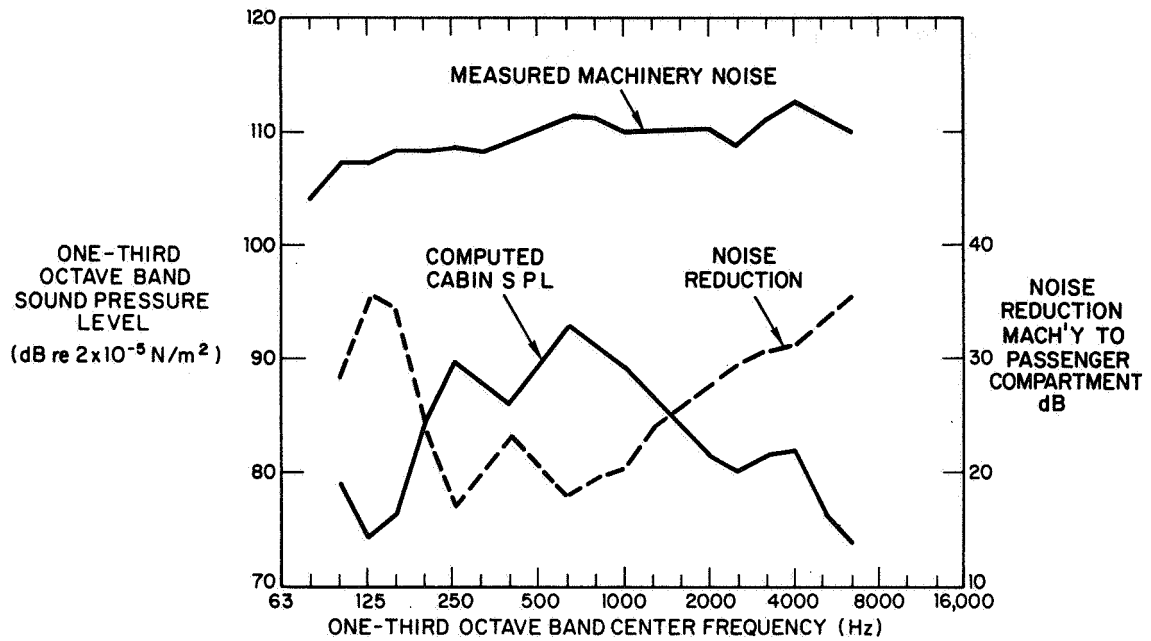


Figure 5.- Computation of cabin noise due to airborne machinery noise.

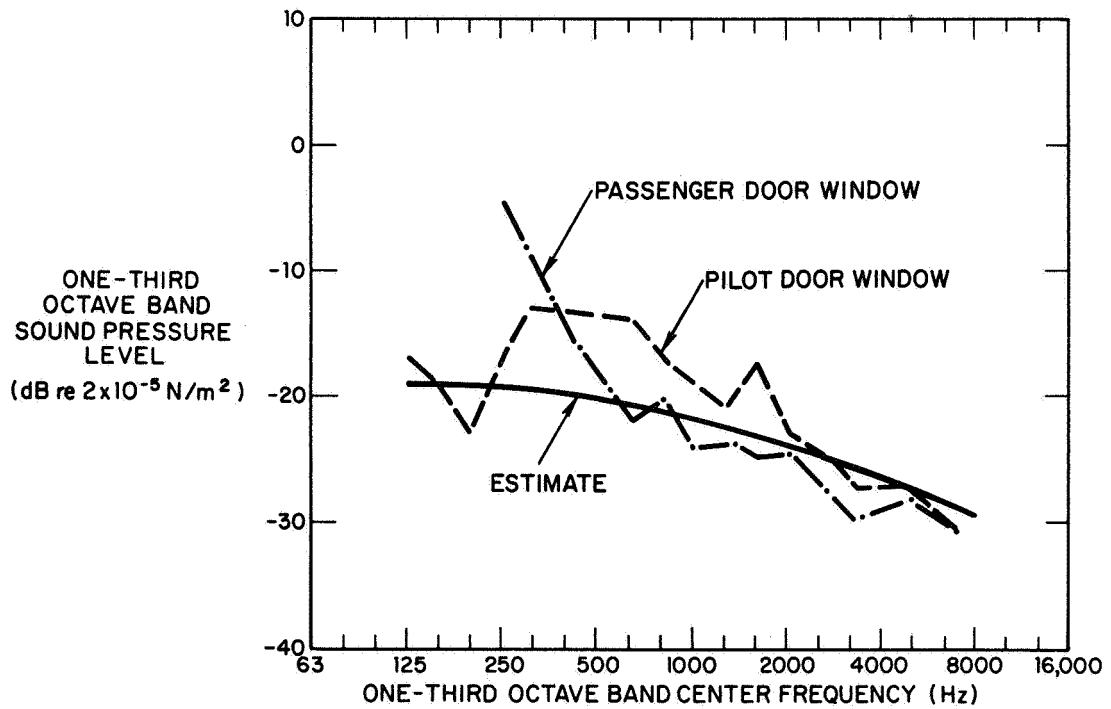


Figure 6.- Cabin window vibration levels - computed contribution of turbulent boundary layer.

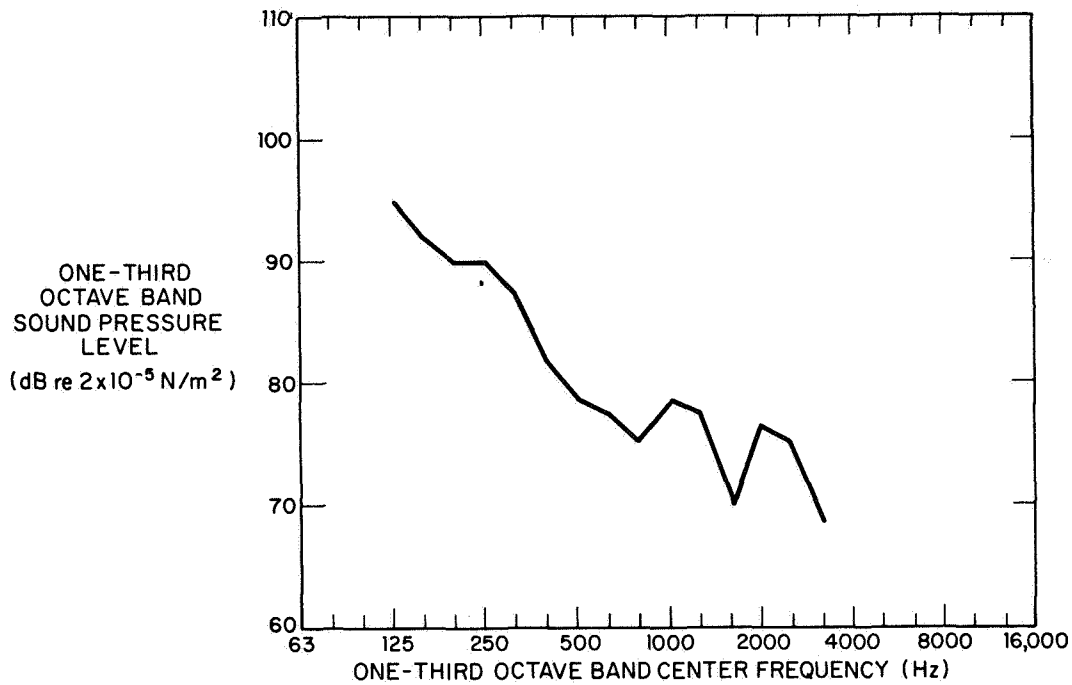


Figure 7.- Predicted cabin noise level induced by turbulent boundary excitation of cabin windows.

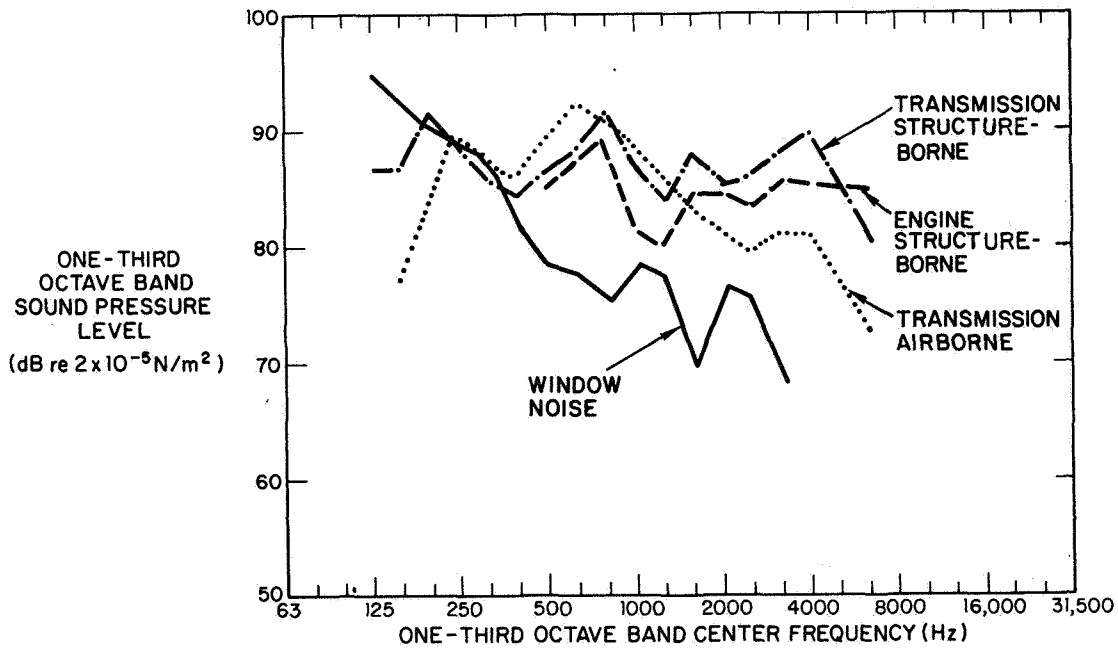


Figure 8.- Composite of noise spectra in cabin unfurnished interior.

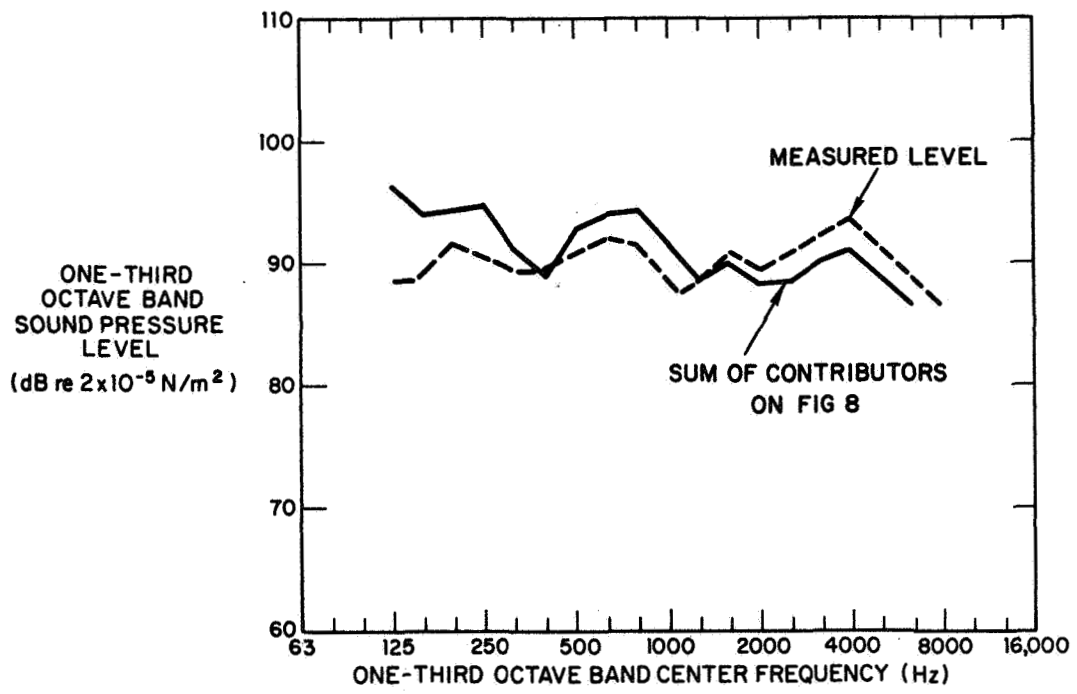


Figure 9.- Comparison of measured and computed cabin noise.