NOISE LEVEL REDUCTION INSIDE HELICOPTER CABINS

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Abstract

The paper discusses a number of measures to reduce the noise level in helicopter cabins. Laboratory test results of various panellings are presented as well as the insulation capacities of different panel mounts. Experiments in acoustic facilities - anechoic chamber and reverberation room - with the original cabin door and its frame led to an optimization of the transmission losses of door components such as window, sealing, and frame.

The reduction of the cabin noise level by adding absorption is illustrated in the case of a honeycomb bulkhead with Helmholtz resonators. These sound absorption elements were designed to damp discrete gearbox frequencies. Resonators were also used for noise attenuation of an oil cooler fan.

Cabin noise comfort can be improved by eliminating discrete frequencies. This was achieved in an experimental set-up where properly tuned resonators were placed as close as possible to the passengers' ear in the headrest of the seat.

In order to reduce structure-borne transmission system noise, ground and flight test data of gearbox strut impedance were used for the design of specially tuned vibration absorbers.

1. Introduction

Interior noise reduction research plays an important role in passengers' acceptance of modern helicopters. In light helicopters, the major noise sources are near to passengers' heads. On the other hand, the effectiveness of noise control measures such as sound absorbing materials and damping sheets, is restricted by space constraints of light helicopters, especially at the ceiling.

Presented at the Sixteenth European Rotorcraft Forum, 18-21 September 1990, Glasgow, United Kingdom

The weight penalty of conventional acoustic treatment is severe, it degrades performance and in most cases, the residual noise levels still remain relatively high. In contrast to other aircraft, for example propeller driven aircraft, the transmission system noise is dominant inside the helicopter cabin.

For several years, MBB has been engaged in the development and optimization of advanced acoustic treatment. Special interest was given to the damping of discrete tones, since these dominate many regions of the helicopter's interior noise spectrum and are more annoying than the same levels of broadband noise. Besides the optimization of conventional passive measures it is important especially for light helicopters, to apply each possibility for additional noise attenuation measures.

2. Noise Test Facilities

All tests described in this paper were performed in the MBB acoustic laboratory which is equipped with an anechoic room, a semi-anechoic chamber, and two reverberation rooms.

Anechoic Chamber:

Useable Area	=	81	m^2
Cut-off frequency	=	100	Hz

Semi-anechoic Chamber (concrete floor):

Useable Area	=	40	m^2
Cut-off frequency	=	250	Hz

Reverberation Room I:

Volume	=	200	m^3

Reverberation Room II:

Volume	=	110	m^3

Test windows between anechoic and reverberation room II as well as between both reverberation rooms are of variable size up to 2x3 m.

Complete data acquisition and analysis systems as well as structure-borne excitation facilities are available.

3. Interior Noise Treatment of Helicopter Cabins

3.1 Transmission Loss Objectives of Helicopter Interior Panelling

Former conventional helicopter fuselage designs have rarely included any noise considerations. The fuselage optimized with respect to stability and weight, was furnished subsequently with a more or less heavy sound insulation to meet the required interior noise levels. Nowadays designs take care of acoustic constraints already in the early design stages. As a first step, the desired interior noise level has to be defined regarding the following points:

- Human hearing characteristics including hearing risk criterion (Criterion: dBA or Zwicker dB)
- Speech Interference Level (dB(SIL))
- Comfort considerations (frequency analysis)

The internal noise level has to guarantee

- less noise than tolerated by the human hearing damage limitation curve for 4 hours flight time /1/,
- minimum noise in the medium and high frequency range leading to low speech interference levels and
- no significant discrete peaks in the frequency power spectrum for comfort aspects.

This approach leads to a desired spectral sound level characteristic as shown in Figure 1.

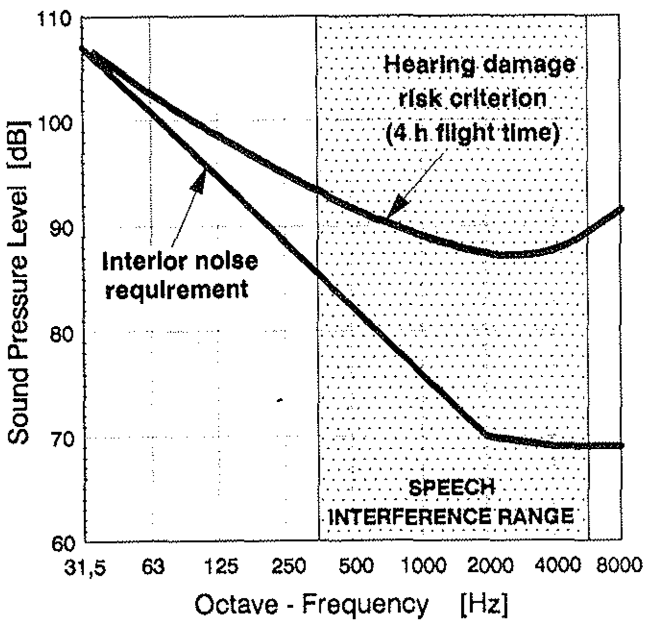


Figure 1: Definition of the Standard Interior Noise Requirement

The next step - the definition of a transmission loss specification - is an analysis of the exterior noise loading on the cabin fuselage. Figure 2 shows the noise level estimate outside the BO 108 cabin using near field helicopter noise measurements and measurements of the fluctuating surface pressure characteristic on a BO 105 cabin roof conducted by the DLR /2/. The defined interior noise requirements are also included in this Figure. The area between both curves represents the demanded transmission loss for the air-borne noise transfer to cabin.

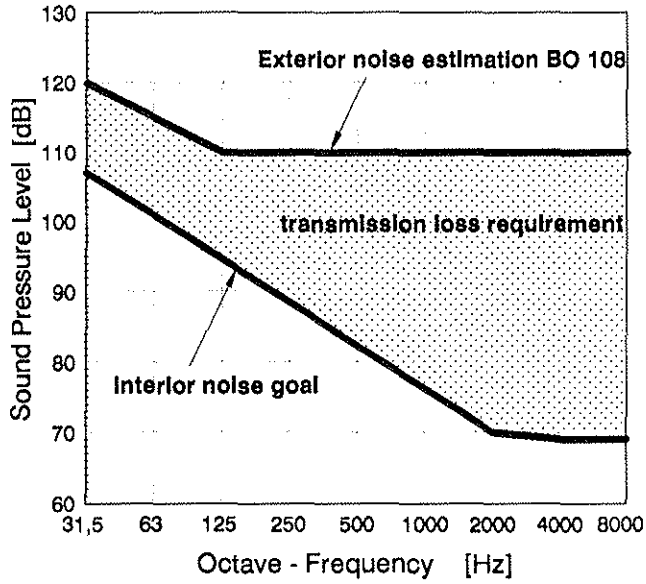


Figure 2: Standard Interior Noise Requirement and Prediction of the External Noise Loading on the BO 108 Cabin Roof

3.2 Transmission Loss of Fuselage Components

Within the scope of the BO 108 interior treatment design, several double wall systems were tested with respect to transmission loss. Interior panellings made of different materials have been measured in the laboratory regarding the influence of the space between fuselage structure and panel, and for the effect of absorptive material between both walls. Transmission loss measurements were conducted with an intensity measurement probe. The test object was a 8 mm honeycomb structure similar to the BO 108 roof section. It was arranged in a window between a reverberation room (excitation) and a anechoic room (measurement). The following panellings were tested:

- 6 mm Nomex honeycomb plate (1.25 kg/m²)
- 3 mm Polycarbonat (PC) plate (3.7 kg/m²)
- 1 mm Glass-fiber reinforced composite (GFRP) - plate (1.8 kg/m²)

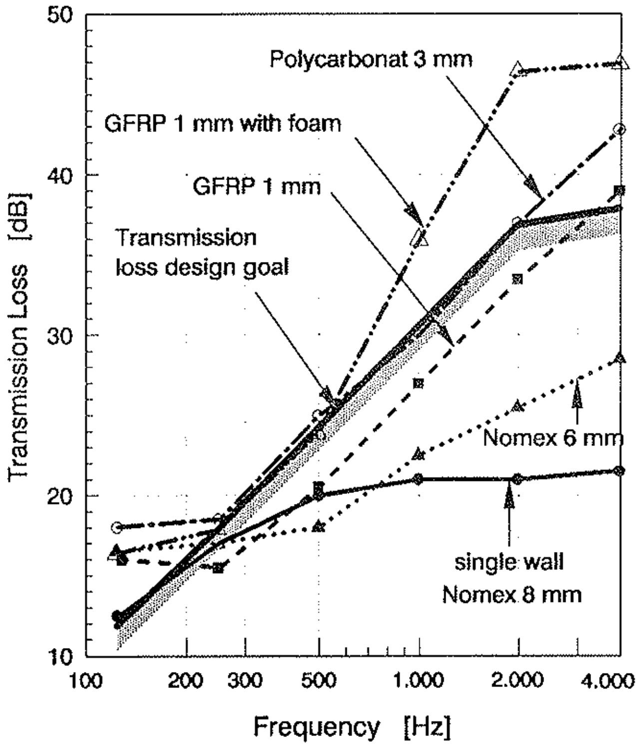


Figure 3: Transmission Loss of Different Double Wall Systems

The materials were different in weight per area and stiffness. Figure 3 shows a comparison of experimental results. The transmission loss increases with weight, as expected. Related to the same weight the PC plate and the GFRP plate show the same transmission loss values, whereas the 6 mm Nomex honeycomb has a significantly lower damping.

An increase in transmission loss was achieved by filling the 25 mm space between the fuselage structure and the panelling with foam. The transmission loss increased by 3 to 10 dB at frequencies above 250 Hz.

Besides the roof section, cabin doors are highly critical with respect to rotor and fuselage boundary layer noise. Therefore, the left cabin door with its frame was cut out of a BO 108 test structure and installed in the laboratory test window (Figure 4). Preliminary measurements with the intensity probe presented some acoustic leaks at the window frame. The transmission loss of the door components - window (2 mm thick) and honeycomb structure below window and spars - was measured at 31 points. Figure 5 summarizes the measured data and compares it with the design goal.

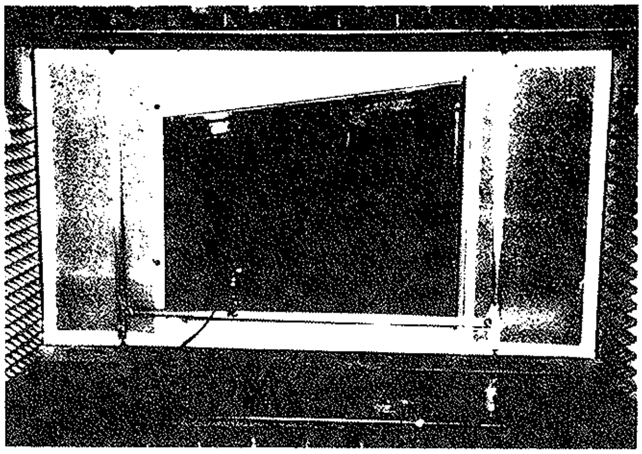


Figure 4: BO 108 Cabin Door With Frame Inside the Test Window Between Anechoic Room and Reverberation Room

In order to reach the desired transmission loss values, investigations have been conducted to optimize the damping characteristic of the various door components. The experiments resulted in the following material implementation:

- GFRP - panel and absorptive foam on the structure part of the door (below window)
- 3 mm acryl glass
- PU - foam inside the spars

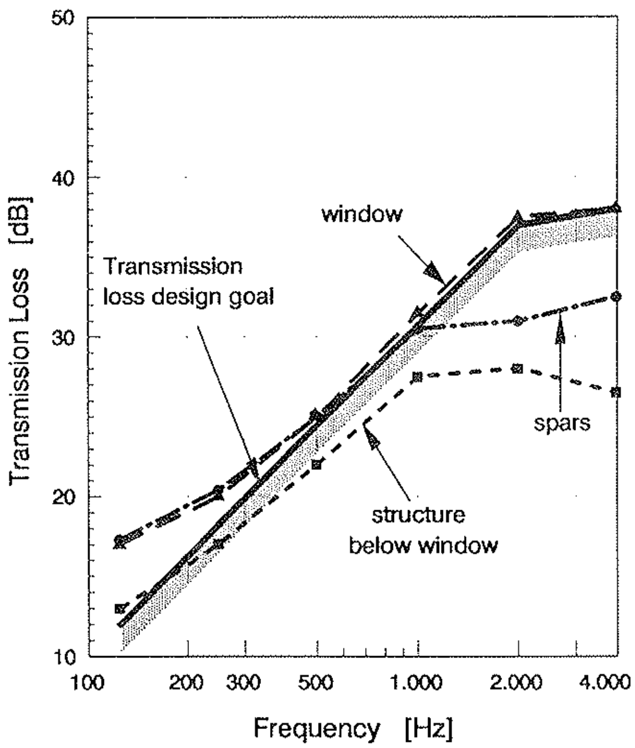


Figure 5: Transmission Loss Measurements of the BO 108 Cabin Door, Basic Design

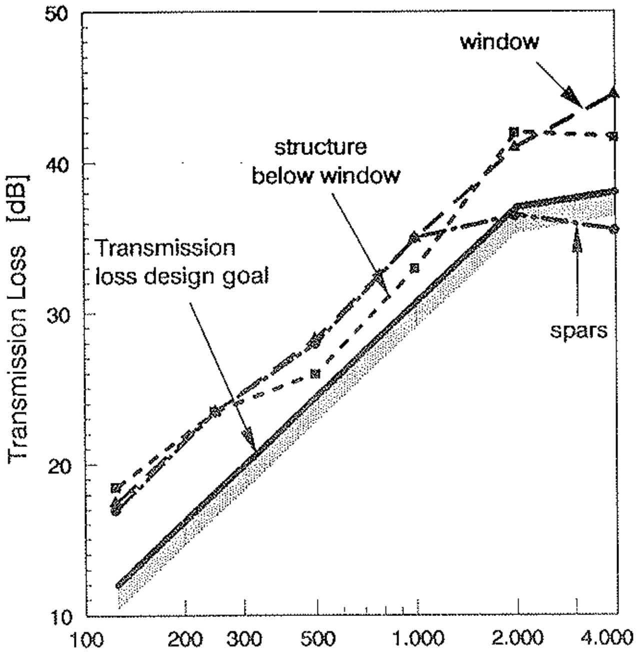
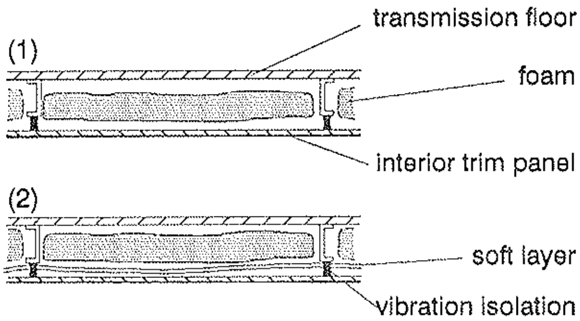


Figure 6: Transmission Loss Measurements of the BO 108 Cabin Door After Improvement



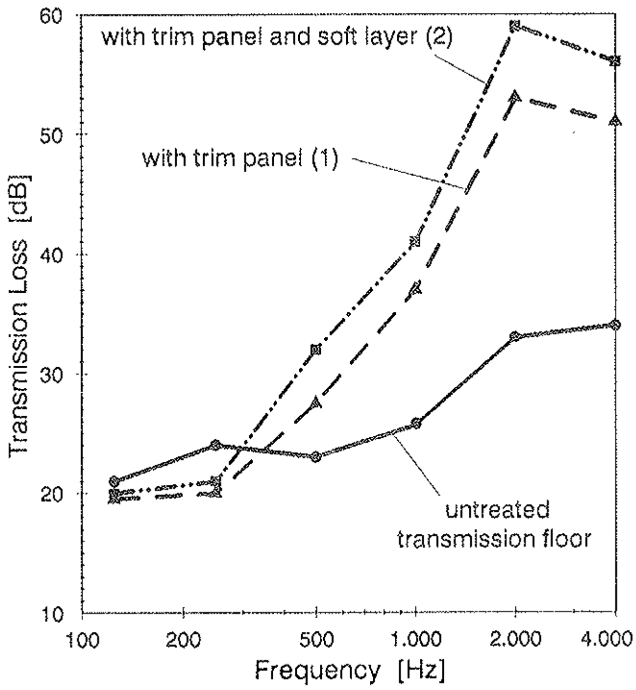


Figure 7: Sound Attenuation of a Transmission Floor

The resulting transmission loss values of the improved door are presented in Figure 6. The improvement of the part below the window resulted in 7 to 14 dB higher damping values. The foaming of the spars increased the damping only in the higher frequency range. More reduction is expected if a more flexible (soft) foam will be used.

Additionally the sealing below the gearbox was treated with respect to structure-borne and air-borne noise. A transmission floor was rebuilt and installed in the laboratory test window between reverberation and anechoic room to determine the transmission loss. Figure 7 summarizes the measurement results of the untreated structure and the best configuration with respect to noise reduction and weight requirement. The GFRP-panel increases the transmission loss by about 20 dB at 2000 Hz. An additional 5 dB reduction was reached along a wide frequency range by a soft layer between structure and trim panel (Fig. 7). Different mounts of the trim panel were investigated and optimized with respect to high vibration insulation.

4. Use of Resonators for the Damping of Cabin Noise

When a certain level of sound attenuation is reached, it is often difficult to decrease the internal noise by additional local damping measures as the noise level is influenced by reverberation inside the cabin. Therefore, it is an important flanking measure to design sound absorbing cabin surfaces in order to reduce reverberation.

In the lower frequency range, the sound energy can not be absorbed sufficiently due to the relative large wave lengths compared to the thickness of absorption materials. Here, resonance absorber systems offer additional sound reduction especially for light helicopters which normally can't provide the space required for conventional measures.

Resonance absorbers - like the Helmholtz resonator - are mass-spring systems (Figure 8). The air in the neck of the resonator can be regarded as the oscillating mass. The chamber volume located behind, is equivalent to the spring. The resonant frequency is given by the oscillating mass m and the stiffness k of the spring:

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

with $- m = m_N + m_M$

$- m_N = \rho_0 \cdot S \cdot l$

$- m_M = \rho_0 \cdot S \cdot (\Delta l_i + \Delta l_a)$

$- k = \rho_0 \cdot a^2 \cdot \frac{S^2}{V}$

So the resonant frequency results in:

$$f = \frac{a}{2\pi}\sqrt{\frac{S}{V \cdot (l + \Delta l_i + \Delta l_a)}}$$

with S - Area of the hole (orifice area)

V - Volume of the chamber

l - Orifice length

Δl - Mass correction factor

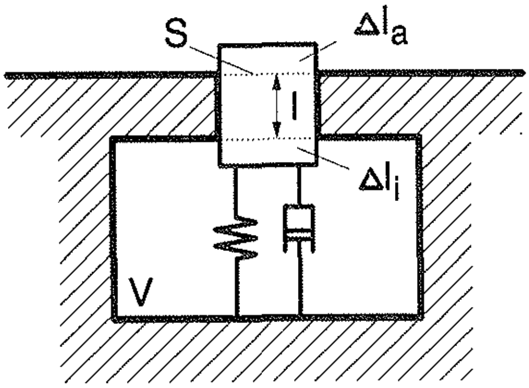


Figure 8: Helmholtz Resonator

The acoustic impedance of the resonator is complex and is the sum of the acoustic resistance r and the acoustic reactance x:

$$z = r + ix$$

These terms are determined by the geometrical and mechanical properties of the resonator which are in particular the oscillating mass in the orifice, the spring stiffness of the volume, and the resistive element due to the energy losses. The latter one can be associated with viscous dissipation in the orifice and sound radiation as an effect of the 180° phase shift at resonance. These terms can be written as:

$$r_i = \frac{4 \cdot A \cdot (\epsilon + 1/d)}{S} \sqrt{\nu \cdot \rho \cdot \pi \cdot f}$$

$$r_r = \frac{2 \cdot \pi \cdot \rho \cdot f_0^2 \cdot A}{S}$$

where ν is the dynamic viscosity, d the orifice diameter, A the area to be damped by the resonator, and ϵ the internal resistance correction factor which depends on the shape and smoothness of the orifice wall. The reactance expressed in terms of the resonator is:

$$x = \frac{\rho \cdot (l + \Delta l) \cdot A \cdot \omega_0}{S} \cdot \left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right)$$

Finally, the absorption coefficient α - defined as the power absorbed by the resonator, divided by the power arriving at the surface in form of travelling waves - is

$$\alpha = \frac{\frac{4r}{\rho c}}{\left(1 + \frac{r}{\rho c}\right)^2 + \left(\frac{x}{\rho c}\right)^2}$$

At resonance, the reactance term vanishes leading to the equation

$$\alpha_{res} = \frac{\frac{4r}{\rho c}}{\left(1 + \frac{r}{\rho c}\right)^2}$$

If $r = \rho c$ the resonator absorbs a maximum of acoustic energy.

The attenuation bandwidth of a Helmholtz resonator is relatively narrow. By selecting differently tuned resonators the bandwidth can be spread to a broader characteristic. Modern helicopter fuselage designs imply more and more honeycomb structures which can easily be converted to Helmholtz resonators. Figure 9 shows a bulkhead between cabin and cargo compartment consisting of a 19 mm thick honeycomb structure. It is situated closely behind the rear seats under the main gearbox. By perforating the cover layer of the honeycomb wall, frequentially tuned resonators are achieved.

The bulkhead was tested with 6, 12, and 25% of the honeycomb chambers used as resonators. They were tuned to the most annoying gearbox frequency of 1900 Hz. The absorption coefficient of the wall without resonators is lower than 0.12 at 1900 Hz. As can be seen in Figure 10, absorption and bandwidth increased strongly with the resonator density. An absorption degree of 0.98 has been achieved if every forth honeycomb core was converted to a resonator. An increase above 25% will reduce the absorption coefficient - the system is overdamped - but the bandwidth further increases. It should be noted, that this kind of absorption inside the cabin requires no additional weight.

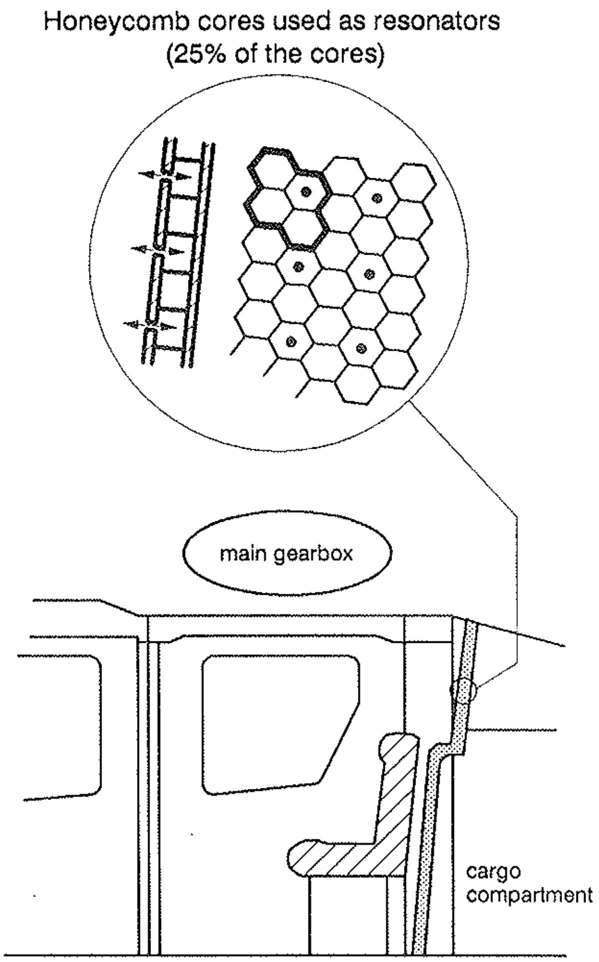


Figure 9: Resonators in a Bulkhead

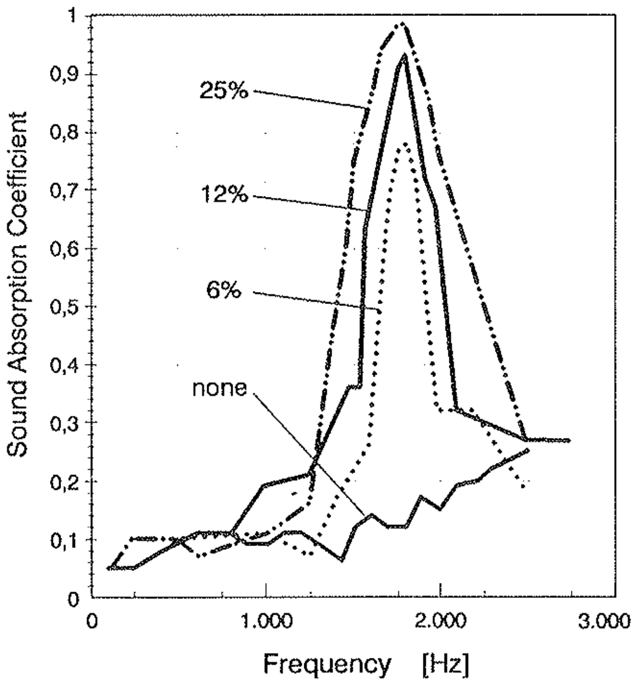


Figure 10: Absorption of the Honeycomb Separation Wall by Different Number of Honeycomb Cores Converted to Resonators (6%, 12%, 25%)

5. Cabin Seats

5.1 Seat Cover

Another important field for absorptive measures inside the helicopter cabin are the seats. The acoustic absorption of different seat pads - open cell foam with synthetic fiber cover - has been tested. The good results of the foam were considerably decreased by the covering. However, an increase of the absorption could be noticed in a narrow frequency band resulting from a resonator effect caused by the holes in the rough textile cover.

This effect was intentionally applied for the BK 117 VIP-Version. Leather seat covers reduced the capability of sound absorption to degrees below 20%. Therefore a perforated leather cover was designed to increase the absorption especially in the gearbox frequency range. Using a hole area of 5.3%, the sound energy around 2000 Hz is absorbed by 80 % (Figure 11).

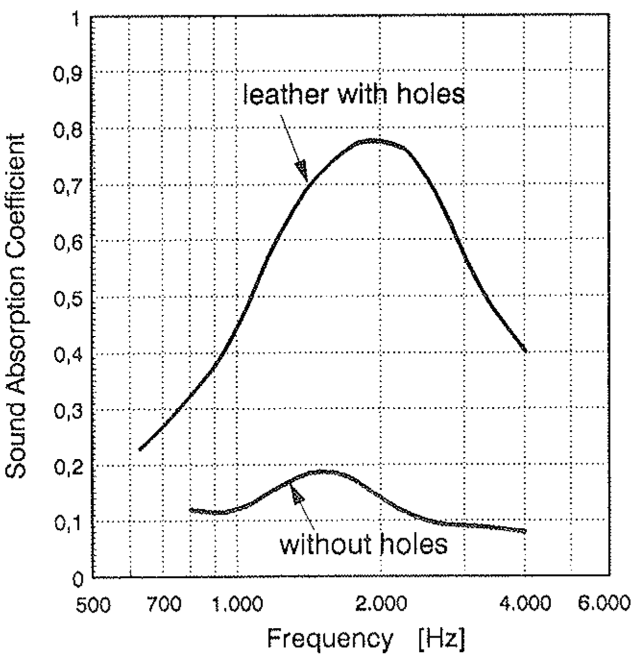


Figure 11: Sound Absorption of a Perforated Leather Cover

5.2 Integration of Resonators in the Seat

The described investigation considered the damping of sound within the transfer paths and the acoustic absorption in the cabin. All these measures improve the noise level in the cabin. In order to arrange sound damping as near as possible to passengers' ears, an experimental test was conducted by installing resonators in the headrests of the seats.

A proper layout of resonance absorbers such as $\lambda/4$ or Helmholtz resonators increases the sound absorption in a relatively broad frequency range. Due to the effect described in Chapter 4, a sound cancellation takes place at a restricted area around the resonator. Figure 12 shows test results of the distance efficiency of four $\lambda/4$ resonators tuned to a frequency of 350 Hz. In front of the resonators up to a distance of 100 mm as well as at the sides, a considerable sound reduction was measured.

In a second experimental program, adjustable Helmholtz resonators were arranged at the location of the headrest of a seat and tested in the laboratory. One center plate and two turnable side plates contain 114 resonators to reduce discrete gearbox frequencies at 600 and 1900 Hz.

The sound was first measured by a single microphone and later by an artificial head with a microphone at the ear position (Figure 13).

For a more realistic design, the test model has been covered with a sheet of foam (20 mm thick). The thickness of the resonator plate was only 27 mm which can be easily integrated in a helicopter seat headrest. All resonators were tuned slightly different for a broader damping characteristic. To minimize the influence of the cover foam, holes were pierced into it at the locations of the resonators' orifices. The achieved sound level reduction has been measured in flight test to 7 dB around 600 Hz and 5 dB around 1900 Hz (Figure 14). The bandwidth was above 100 Hz.

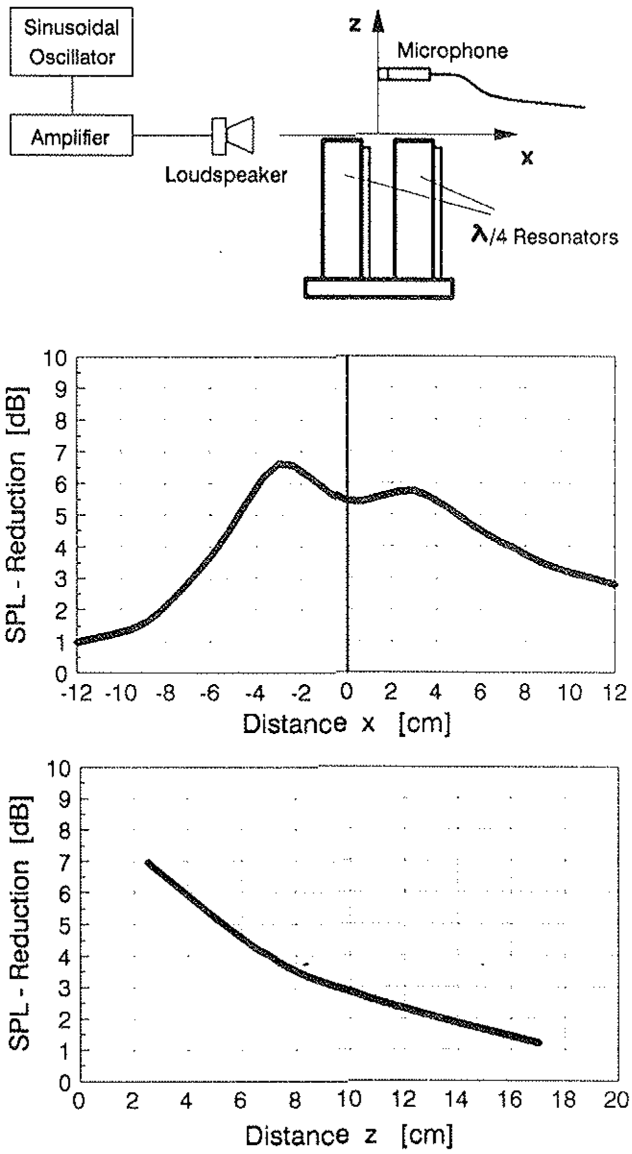


Figure 12: Preliminary Investigation of the Distance Efficiency of Resonators

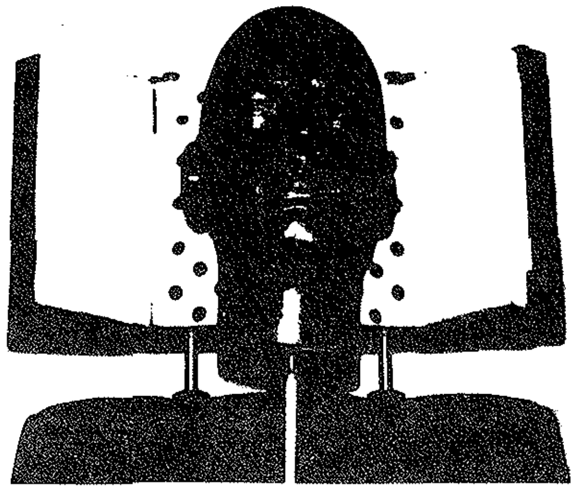


Figure 13: Model Headrest with Helmholtz - Resonators

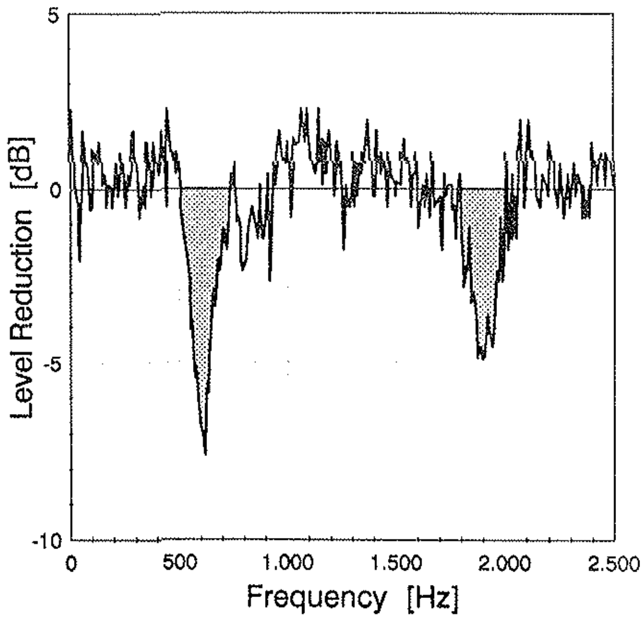


Figure 14: Noise Level Reduction of the Headrest Resonator System in Flight Test

7. Noise Supression of Fans

Oil cooling fans of helicopters are often situated on the cabin roof close to passengers' heads. Fan noise may be divided into a rotational component and a vortex component. The rotational part is associated to an impulse transferred to the air each time a blade passes. It is a series of discrete tones at the fundamental blade passage frequency and its harmonics. Because of the constant rotation provided by the main gearbox, resonators are an appropriate mean of reducing the rotational noise component.

For preliminary investigations with a 8-bladed radial test fan, a ring was fixed to the air inlet which contains three layers of Helmholtz resonators (Fig. 15). Each layer was tuned to a different frequency range. The chamber volumes could be changed by finely threaded screws to adjust the resonant frequency.

In a first step, the resonance was measured and tuned by adjusting the resonator volumes. White broadband noise supplied by a loudspeaker at the position of the fan was used for this procedure. A schematic diagram of the test set-up is shown in Figure 16. The resonators were tuned to damp the frequency range from 500 to 2000 Hz. After adjustment of all resonators, the damping capability of the system was measured with the fan operating. The frequency response in the direction of the air inlet with open and closed resonators are shown in Figure 17. This design of an inlet silencer provides a broadband and not only a dicrete frequency damping characteristic with sound pressure level reductions up to 17 dB. The overall noise level was decreased by 7 dB.

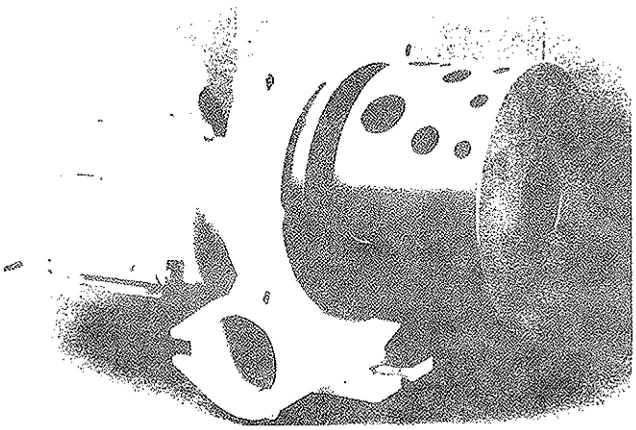


Figure 15: Test Fan with Resonator Ring

As the volume flow of the fan changed only by 1%, the efficiency of the fan will not be influenced. By a closer arrangement of the resonator layers and volumes without adjustment screws it is possible to integrate the resonator ring in the air inlet structure. The damping characteristic was estimated theoretically based on the equations in Chapter 4. A comparison of the theoretical design data and the experimental results is illustrated in Figure 18.

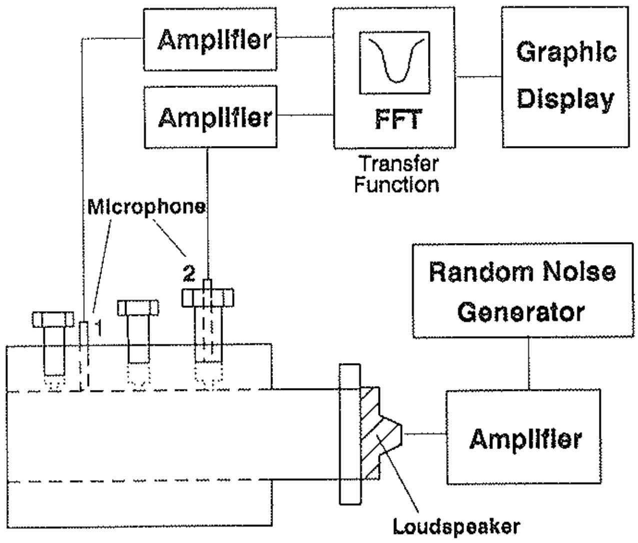


Figure 16: Schematic Diagram of the Test Set-up

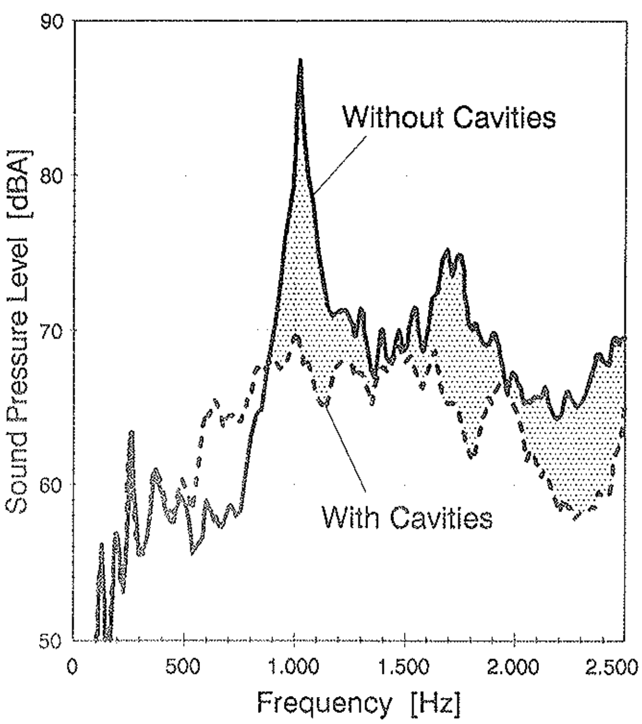


Figure 17: Noise Level Measurements With and Without Resonator Ring

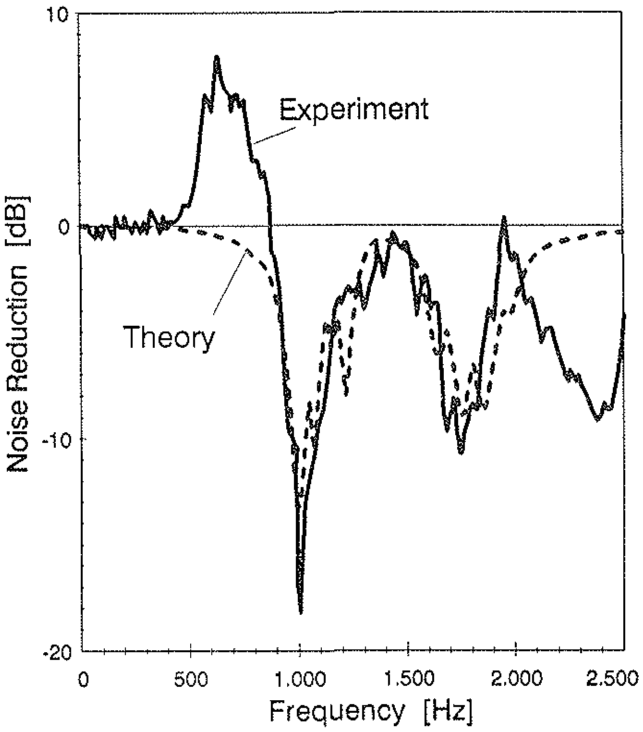


Figure 18: Estimation of the Expected Noise Reduction by the Resonator Ring Compared with Measurement Results

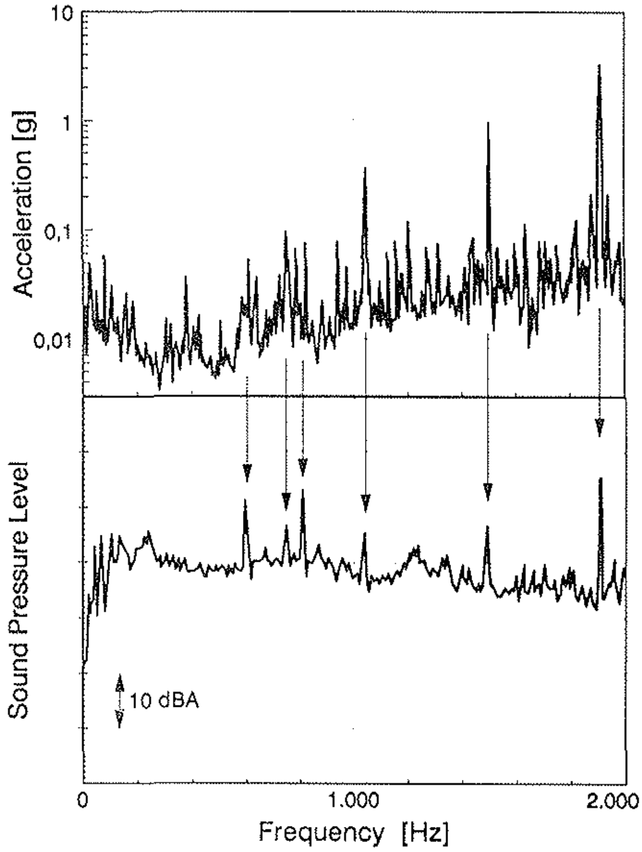


Figure 19: Gearbox Mount (Z1) Acceleration and Cabin Sound Levels of the BK 117

8. Impedance Measurements of Gearbox Mounts

The transmission system of a helicopter generates a high frequency noise which is mainly transmitted into the cabin by gearbox struts. In general, there is very little structure-borne noise attenuation through any path between gearbox and cabin because there are no impedance changes to cause a loss. Often design changes - e.g. a soft mounted gearbox - are no more possible, therefore it is convenient to change the transmission characteristic of the gearbox struts.

As an example, in Figure 19, gearbox vibrations and cabin sound pressure levels are shown for the BK 117 helicopter. The transfer of the acceleration levels to the fuselage is nearly 100%, this means that there is no damping between gearbox and fuselage. Since modifications of gearbox mounts are not possible, it was suggested to arrange resonance vibration absorbers on the mounts adjusted to the frequency which causes the highest interior noise level.

Point impedance measurements on all gearbox struts have been conducted with and without absorbers (Figure 20). All four Z-struts showed an individual frequency response with values up to 20000 kg/s. At frequencies above 2000 Hz, the impedance was with 4000 kg/s rather constant.

With absorbers, the impedance increased up to 60000 kg/s. The weight of one absorber was about 0.8 kg. The point where the absorber is fixed to the helicopter, is essential for the design of the absorbers. Inside the test programme, it was proposed to fix the absorbers rigidly to the Z-struts on the fuselage side. The schematic diagram of the test set-up is shown in Figure 21. In Figure 22 the transmission of the gearbox lever with and without absorber is shown during ground tests. The excitation was on the gearbox while the acceleration was measured at the attachment point of the gearbox strut to the cabin structure. The vibration transmission could be decreased by factor 1000 at 1930 Hz.

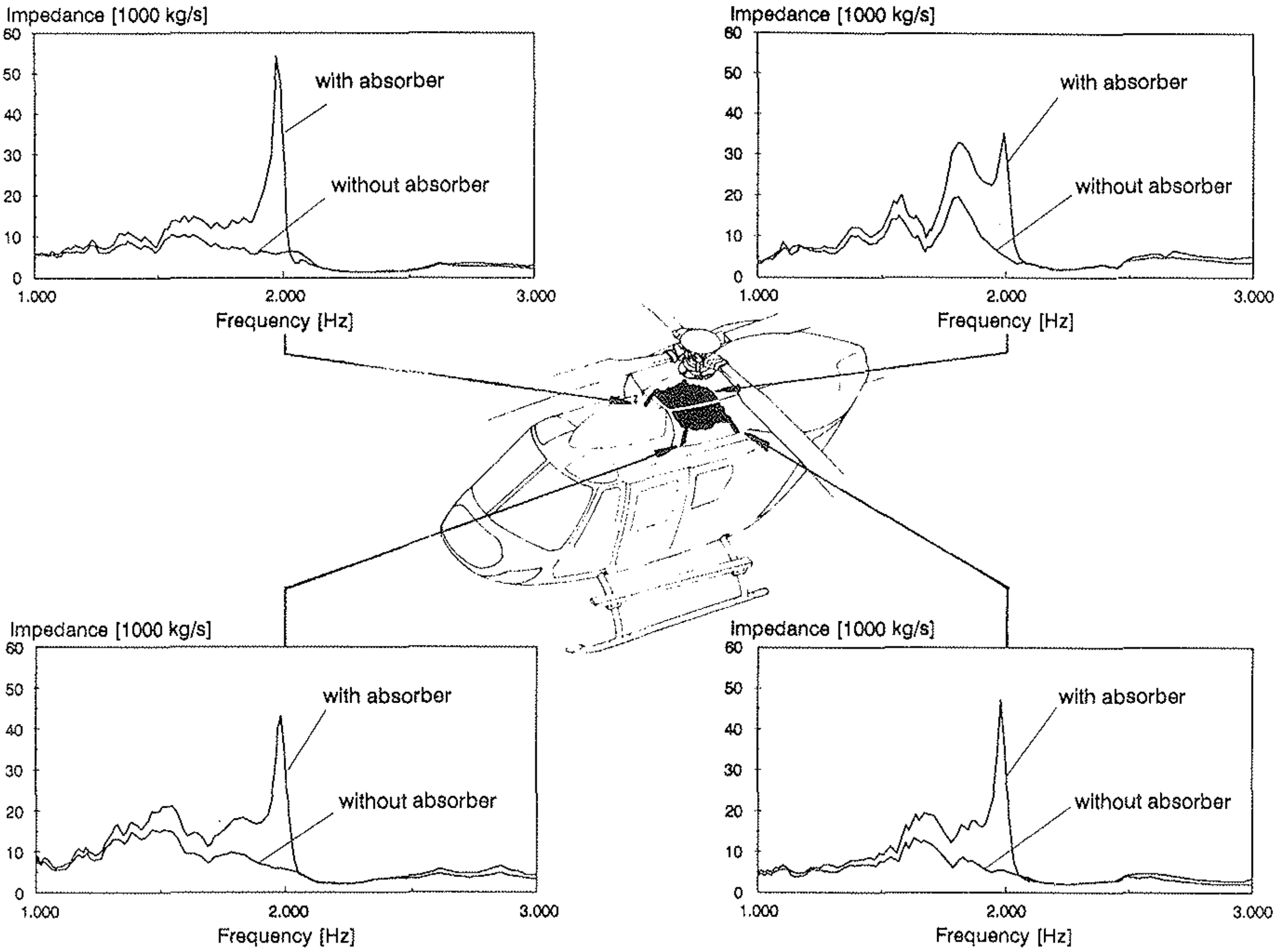


Figure 20: Impedance Measurements of the Four Vertical Gearbox Levers With and Without Absorbers

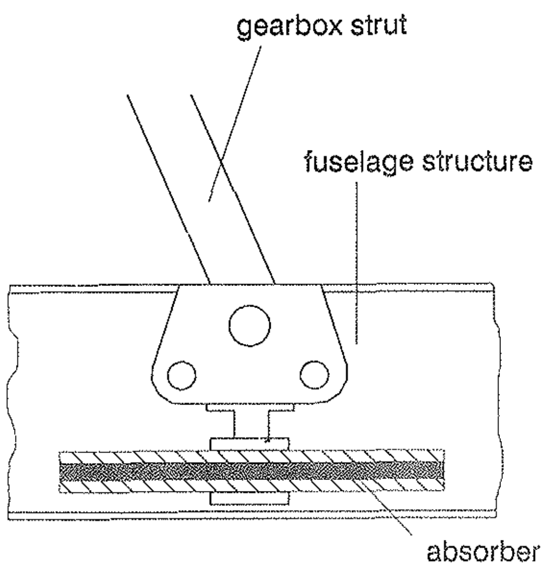


Figure 21: Schematic Diagram of the Test Arrangement Inside the Helicopter

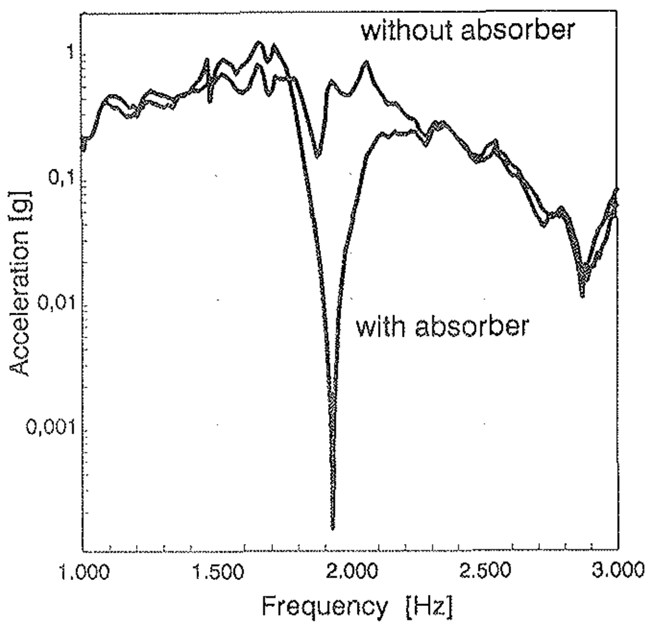


Figure 22: Vibration Transmission Frequency Response of Gearbox Strut Z1 With and Without Absorber

9. Noise Level Reduction

A BK 117 has been equipped with some of the examined damping and absorptive measures. Compared with the original equipment which also represents a noise treated interior standard, the noise level could be considerably decreased (Figure 23). At a flight speed of 110 kts, the noise level reduction was 5 dBA. During take-off, a noise reduction was measured by 7 dBA whereas during approach only 3 dBA could be reached. At a higher flight speed, the internal noise level is dominated more and more by boundary layer noise especially in the cabin door region which limited the noise reduction to 4 dBA at 130 kts. As the most applied measures result only in reduction of small frequency ranges, an improvement in comfort was achieved which is not sufficiently expressed in dBA-values. For example, the 2000 Hz 1/3 octave band which contains very annoying tones, has been decreased by 12 dB at 110 kts and 7 dB at 130 kts.

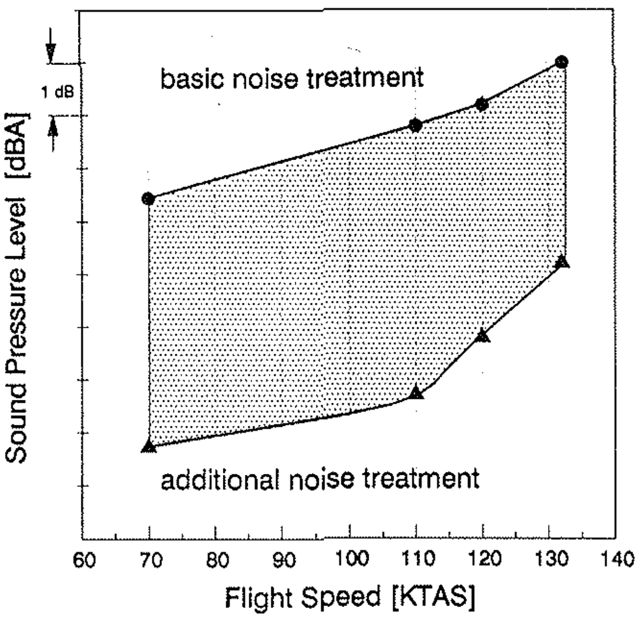


Figure 23: BK 117 Measurement Results Before and After Additional Noise Treatment

Conclusion

The investigations have shown that a reduction of cabin noise demands a large effort. Most noise reducing measures lead to weight constraints or design changes. But there are numerous cases where noise reduction is possible with a minimum of additional weight, for example, by use of existing volumina as resonators

The results of the described experimental research effort are summarized as follows:

- The best results of double wall systems for helicopter honeycomb fuselage structures were reached by a 8 mm honeycomb structure with a 1mm GFRP-panel filled with foam.
- The transmission loss of a BO 108 cabin door was optimized to reach the defined design goal.
- The sound absorption coefficient of a honeycomb bulkhead was increased to 0.98 at 1900 Hz by use of 25% of the cores as resonators.
- An integration of resonators in the headrest of a seat reduced the noise levels of discrete tones by about 5 dB.
- The vibration transmission was considerably decreased by mounting specially tuned vibration absorbers to the gearbox struts.
- The effectiveness of resonators arranged at the air inlet of fans, could be proved in laboratory tests. The specially tuned resonators reduced the overall sound pressure level by 7 dBA. Discrete frequencies could be decreased by up to 17 dBA.

The described experimental work allows to improve the comfort inside existing and newly designed helicopters. Some of the research has been associated with the development of the BO 108 /3/. In connection with the low noise design applied to the BO 108 helicopter, this will lead to an excellent interior noise standard for the production version.

References:

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