29. évfolyam (2019) 1. szám 95–104. • DOI: 10.32562/mkk.2019.1.8.

MŰSZAKI KATONAI KÖZLÖNY

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# Reduction of Noise Loads in Rotorcraft Interior Using Poroelastic Materials

## Zajterhelés csökkentése helikopterekben akusztikus zajcsillapító anyagok alkalmazásával

*Operators of military vehicles are subject to harsh noise loads. In some cases this is severe enough to warrant long-term health impacts; in order to avoid this, restricted operating hours for various noise levels are prescribed. In case of rotorcraft vehicles, both the rotor and its driving engine are serious sources of noise, therefore the crew can only spend their operating hours using (active or passive) hearing protection headphones or helmets. Since sound pressure level peaks from the primary noise sources are in the low-frequency range, the application of poroelastic and solid damping materials for interior noise reduction will be investigated using the finite element method. In order to do so, a helicopter interior model is simulated without acoustic damping materials and with the use of solid damping materials as well. Sound pressure level reduction shown in the results increases service time in the vehicle and reduces noise-induced fatigue of occupants.*

***Keywords:*** *helicopter, noise level, noise load, poroelastic materials, finite element method*

*Katonai járművek operátorai erős zajterhelésnek vannak kitéve. Esetenként ez olyan komoly mértéket ölt, hogy a tartós egészségkárosodás megelőzése érdekében zajszintenként korlátozott munkavégzési időt kell bevezetni egyes járművek esetén. Jelen munka a helikopterek esetét vizsgálja kiemelten. A helikopterek esetén mind a rotor, mind az azt meghajtó motor komoly zajforrás, emiatt a bent ülők csak (aktív vagy passzív) zajvédelemmel ellátott fejhallgatóban, illetve sisakban tudnak megfelelő ideig a kabinban tartózkodni. Mivel az elsődleges zajforrás által keltett gerjesztések zajnyomásszint-csúcsai az alacsony frekvenciatartományban vannak, a végeselem-módszer használatával szimulációs úton vizsgáljuk a poroelasztikus és szilárd csillapítási anyagok alkalmazását a belső zajszint csökkentésére. Ennek érdekében egy modell helikopterbelső kerül szimulációra,*

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*akusztikus bevonat nélkül és szilárd csillapító anyagok használatával együtt is. Az eredményekből kimutatható zajszintcsökkenés növeli a kabinban tölthető időt, illetve csökkenti a bent ülők zajszint miatti fáradását.*

***Kulcsszavak:*** *helikopter, zajszint, zajterhelés, poroelasztikus anyagok, végeselem-módszer*

## Introduction

Helicopters are instrumental machines in aerial transport nowadays. Their vertical takeoff and landing capabilities make them more versatile than fixed-wing aircraft, yet with development, their load carrying capacity has increased as well. However, due to their working principle, the interior noise loading on the operator personnel is high. Without protective headgear, noise levels would be harmful for human health inside the cabin.

In this article, noise levels will be highlighted in rotorcraft machinery through literature review of measurements conducted on helicopters. Porous materials and acoustic damping layers will be introduced thereafter, which could alleviate the health hazard by providing an efficient means for reducing interior noise. To demonstrate their effect, simulations on an approximated helicopter interior model will be performed with and without acoustic treatment.

## Helicopter Noise Sources

To understand the frequency range and the noise problem in helicopters, we need to first look at how they operate, as their operating principle directly results in the noise problems inside the cabin.

Rotorcraft generate lift force to elevate their cargo and the vehicle body into the air using rotating horizontal propellers. Propellers consist of a shaft and rotor blades, whose cross-section corresponds to an airfoil profile. By means of rotating these airfoils, their relative air speed is high therefore the airfoils themselves produce lift. However, as it is expected with moving airfoils, these rotor blades generate vortices, which pose significant acoustic issues.

Figure 1. Simulated rotor vortices [1]

Figure 1 shows a simulation conducted by Gennaretti et al., where the goal was to calculate rotor tip vortices and the motion of the rotor itself through these vortices. This is a critical scenario in certain flight maneuvers from an acoustic point of view. In such cases, the rotor blades actually pass through the vortices generated by themselves due to the combined relative motion of the rotorcraft and the rotor itself. With high rotor angular velocities, combined with the high air velocities in the vortices, transonic flow can occur at the rotor tips, resulting in shockwaves. These directly translate to loud noise peaks into the cabin, which give the helicopter its signature sound.

Such interactions are strong and so pronounced in helicopters, that they have been identified as blade-vortex interactions (BVI). Amiraux notes that BVI is characteristic for helicopters and it is the predominant noise source of the craft. It requires certain conditions to occur, namely that the inflow towards the rotor reduces and approaches zero, which allows the trailing vortex system to remain in the plane of the rotor itself. Such conditions occur in low speed descent, for example, but certain other flight maneuvers can induce BVI as well.

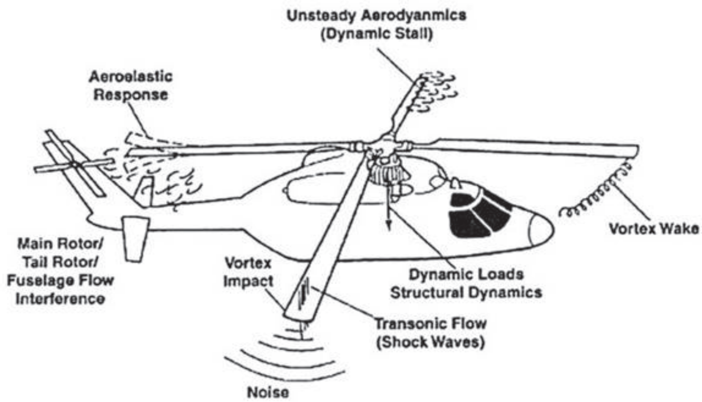


Figure 2. Rotorcraft noise sources [2]

In addition to the predominant PVI-induced noise, multiple other noise sources burden the cabin crew of helicopters. Brentner et al. identify thickness noise and loading noise (together as rotational noise), as well as high speed impulsive noise, turbulence ingestion noise, blade-wake interaction noise and blade self-noise. Evidently, various noise components are responsible for the high levels within the aircraft, as shown on Figure 2, which gives a more illustrative description of noise sources. Their classification according to Brentner et al. was done by their mathematical description, while Amiraux's figure gives a more pragmatic and tangible representation, focusing especially on vortex-induced noises.

It has been well established that a variety of noise sources exist in helicopters which contribute to significant sound levels. However, in order to accurately assess the severity of the situation, actual measurement data needs to be reviewed to identify sound pressure levels within the cabin and their impact on crew.

## Helicopter Interior Noise Review

As rotorcraft interior noise levels from earliest experience onwards have been very high, a number of measurements have been carried out to assess noise levels. The following paragraphs will review some of the more important and accessible measurement data for various helicopters in different configurations.

In order to assess the significance of noise levels inside the cabin, Table 1 below summarizes the allowed exposure times for noise levels exceeding 85 dB(A). 85 dB(A) is considered to be the limit from where precautions are necessary to ensure safe working conditions to operators exposed to higher noise levels.

An exponential decline of the exposure duration is obvious, which relates to the logarithmic nature of the decibel scale used to measure sound pressure levels. Table 1 therefore provides a striking description of how much difference in acoustic power is between each decibel level.

Table 1. Exposure limit duration for specified sound pressure levels [3]

| SPL dB(A) | Exp. Limit (hours) | SPL dB(A) | Exp. Limit (hours) | SPL dB(A) | Exp. Limit (hours) | SPL dB(A) | Exp. Limit (hours) |
|---|---|---|---|---|---|---|---|
| 84 | 16.0 | 93 | 2.0 | 102 | 0.25 | 111 | 0.032 |
| 85 | 13.0 | 94 | 1.6 | 103 | 0.20 | 112 | 0.025 |
| 86 | 10.0 | 95 | 1.3 | 104 | 0.16 | 113 | 0.020 |
| 87 | 8.0 | 96 | 1.0 | 105 | 0.13 | 114 | 0.016 |
| 88 | 6.4 | 97 | 0.80 | 106 | 0.10 | 115 | 0.013 |
| 89 | 5.0 | 98 | 0.64 | 107 | 0.080 | 116 | 0.010 |
| 90 | 4.0 | 99 | 0.50 | 108 | 0.064 | 117 | 0.008 |
| 91 | 3.2 | 100 | 0.40 | 109 | 0.050 | 118 | 0.006 |
| 92 | 2.5 | 101 | 0.32 | 110 | 0.040 | 119 | 0.005 |

In the first test reviewed, Novak et al. measured and compared interior noise levels in two helicopter models: a piston-engined Robinson R44 Clipper, as well as a turbine engined Bell 206B. To record noise levels, a Bruel&Kjaer 2231 Sound Level Meter was used, positioned centered in the cabin at the pilot's ear level.

Three operating modes were selected, idle, hovering and corrected full power flight modes. Full power results are chosen for examination in this paper, as this operating condition is the most common and, therefore, most critical. Figure 3 shows the results. Particularly interesting is the peak noise levels under 500 Hz, which – depending on the octave band – reach or even exceed 100 dB. Such noise levels exceed the recommended 8-hour exposure limit, causing excessive fatigue and preventing direct communication between occupants.

Price`s thesis describes a data acquisition system's design for helicopter noise measurement. Although the focus is not on the measurements themselves, the system was still tested in real flight and significant measurement data was recorded. The helicopter in question was a Bell 412, equipped with 3 microphone locations within the cabin. These locations represented a pilot's ear level position, as well as a representative standing and a seating position. Standardised standing position could not be recorded, as the interior height of the helicopter did not permit the installation of the microphone in the required height.

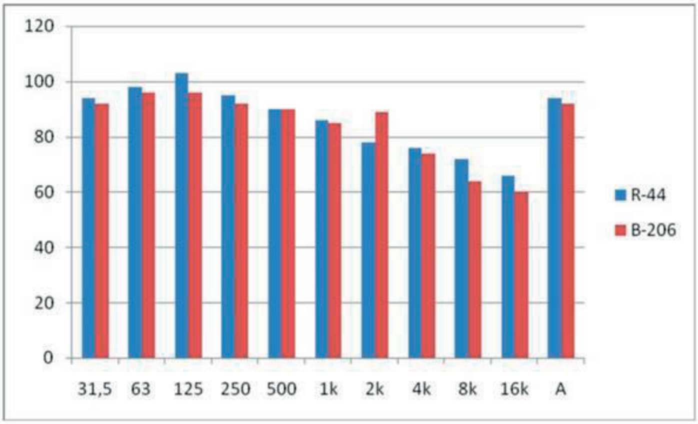


Figure 3. Interior noise measurements in dB(A) for two helicopter models [4]

Similarly to the previously described test, this measurement also resulted in findings that concluded that interior noise levels in helicopters are beyond tolerable for long exposure times for operators. Interior noise levels were recorded both during climb and descent flight stages, and repeated multiple times for open and closed door configurations. As only a closed door case will be simulated, in this investigation open door measurements will not be examined. Table 2 below summarizes the closed door segments.

Table 2. Bell 412 helicopter interior noise in selected positions for two climb and descent flight maneuvres [5]

| Position | Climb A | Climb B | Descent A | Descent B |
|---|---|---|---|---|
| Seated Position | 107.00 dB | 108.36 dB | 114.40 dB | 113.34 dB |
| Standing Position | 104.92 dB | 105.02 dB | 113.74 dB | 112.61 dB |
| Pilot Position | 104.38 dB | 103.92 dB | 112.08 dB | 111.77 dB |

Values in the table clearly show the issue: noise levels are all above 100 dB, significantly more than that during descent. According to the Aviation Occupational Health and Safety Regulations summarized in Table 1, maximum continuous exposure time to a noise level of 103 dB is 12 minutes, which is significantly detrimental to the efficient operation of the machinery.

The exponential decrease of exposure time limit means that occupants and pilots require hearing protection – however, such noise levels may cause other detrimental health effects as well.

As helicopters have been in service for decades, these issues have been realized throughout the operation of rotorcraft. Therefore, effects of noise reduction measures have also been studied experimentally. As procurement of a helicopter solely for measurement purposes is very costly, mainly larger research institutions dealt with such a topic. One of the most prominent tests was conducted by NASA on a modified CH-53 large passenger helicopter. The choice of craft plays a very important role in the research: with its large interior space, the CH-53 was suitable for a wealth of modifications, including a completely encapsulated passenger cabin with various sound-absorbing insulation material layers, which not only required a relatively large amount space but also reduced the payload capacity of the helicopter.

Considering that the helicopter's weight was 20,000 kg, even with the addition of the sound-deadening material the craft retained a useful amount of payload. Figure 4 below shows the obtained A-weighted decibel readings for each seat in the insulated passenger compartment.

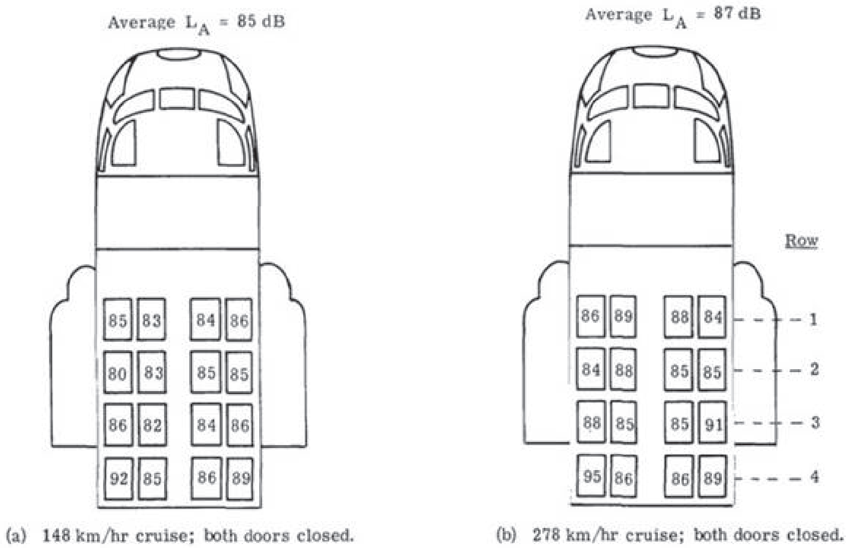


Figure 4. Interior noise measurements for an acoustically treated CH-53 helicopter in dB(A) for two flight conditions at different cruising speeds [6]

In comparison, cabin noise levels between 70 and 85 dB(A) speeds [7] can be measured in today's airliners, which shows how difficult the task of noise reduction in helicopters is – even with extensive modifications and sound deadening applied, the NASA experimental rotorcraft's interior noise levels were still significantly higher than those of even contemporary airliners.

Furthermore, the noise treatment applied to this particular case is not applicable to most helicopters, as it requires large cabin volume and has a high total weight.

The following chapter will explore in a virtual environment the application of a low-volume, higher-density damping material's noise reduction capabilities.

## Representative Numerical Simulations

Numerical acoustic simulations require a high amount of computational power, as the calculation of eigenmodes for a modal analysis can be quite complex. The finite element method provides a useful discretization scheme to solve the necessary equations, which results in the frequency response functions or sound pressure levels that are of interest. An acoustical finite element simulation first solves the structural equations, then – using their results – solves the acoustic response as well. As with all discretized simulation methods, it is essential to create a mesh for the model, so the equations can be solved for each element.

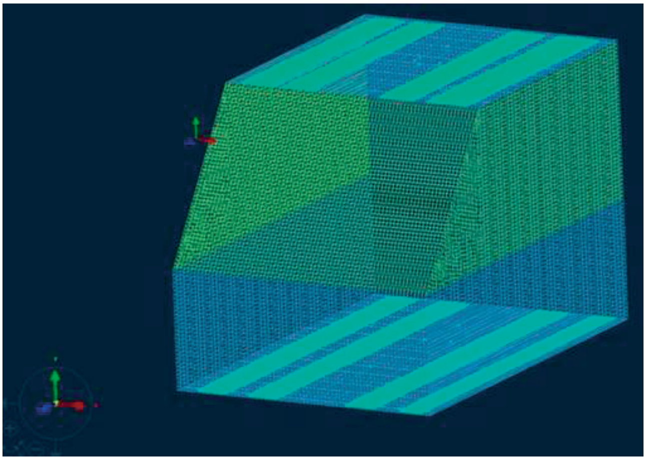

Figure 5. Representative interior cavity model with glass windshield and side windows (yellow) and added acoustic damping layer (turqoise). Measurements: 1600 mm (height) x 1000 mm (length) x 700 mm (width)

As the computational requirement for a real helicopter model would be excessive for the current possibilities of this investigation, a simplified mockup interior model will be used. Figure 5 shows the mockup model. Divisions are created to represent different materials: aluminium as the structural material of walls, and glass for the windshield and side window panels.

Unit excitation is applied to the centre of the representative roof – as only the modal response is investigated, such an excitation is sufficient. The frequency range is between 20 and 250 Hz. With more computational capacity, a broader frequency range could be studied. Microphone data recording points are located at the driver and passenger's ear positions in the cabin. One simulation was performed without sound deadening, while the other included 8 sound deadening strips, 4 on the floor and 4 on the roof of the model. The material properties for the sound deadening foam were the following: E = 400 MPa, ρ = 3 $g/cm^{3,}$ GE = 0.2 (structural damping coefficient). As the density of this foam is only less than 10% heavier than that of the aluminium structural material's, it is ideally light for such an application. However, its structural damping coefficient is significantly higher than that of either the aluminium or glass panels (GE for aluminium: 0.01, GE for glass: 0.1), so it helps to obtain a lower sound pressure level within the cabin itself. Table 3 summarizes the properties used for each material in the model for ease of understanding. Four strips of 3 mm thick and 200 mm wide applications of the foam were simulated on the floor and the roof sections of the model, which comparatively add negligible weight and take up negligible space from the cabin.

Table 3. Material properties used in the simulation

| Material | Young`s Modulus (GPa) | Density (g/cm$^3$) | Poisson`s ratio (-) | | Structural damping coefficient (-) |
|---|---|---|---|---|---|
| Aluminium | 70 | 2.7 | 0.334 | | 0.01 |
| Glass | 70 | 2.5 | 0.22 | | 0.1 |
| Damping layer | 0.4 | 3 | 0.35 | | 0.2 |

Simulation preprocessing was performed within ANSA, including meshing and load application, as well as material property inputs, while the solver used to obtain results was the ESI Group's VPS software. Postprocessing and evaluation was carried out in META.

Figure 6 shows the resulting sound pressure levels in Pa for the pilot's ear level microphone. Red represents the untreated, blue represents the treated cabin. It is evident that especially in the sub-50 Hz region, the damping material effectively reduces the pressure levels by 50%. This material is especially suitable for sound pressure reduction in the very low frequency range, so it is suitable to reduce the effect of noise sources such as the main rotor's excitation.

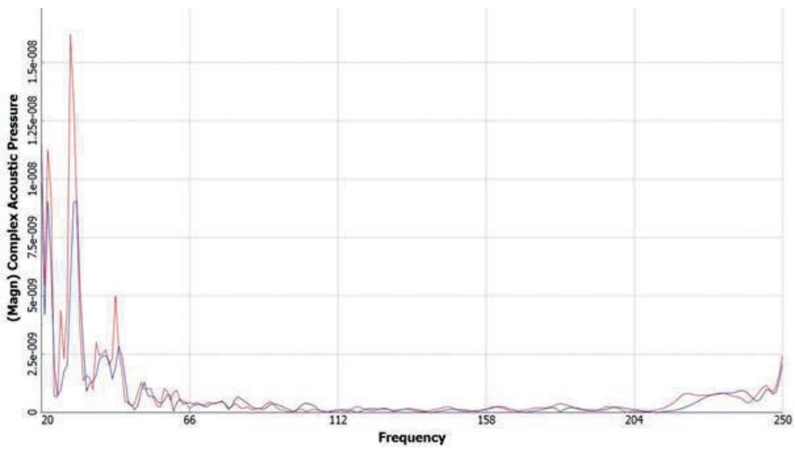


Figure 6. Acoustic sound pressure in the pilot's ear position microphone in Pascals. The red line shows untreated, the blue line shows acoustically treated results. Reduction in noise peaks reaches almost 50% in certain locations.

It must be noted that a more complex simulation analysis would reveal more accurate results for such a configuration. This investigation primarily showed the effect of the application of such a damping layer to a representative cavity model. The main hindrance in designing a more complex simulation is the available computational power. With a more complex model, the number of cells would drastically increase, especially if higher frequencies are required. Maximum frequency of the investigated frequency band has a significant effect on the element size, as elements have to be large enough to fit at least 3–6 wavelengths of the shortest possible stationary wave inside. This would reduce element size and increase the number of elements drastically, lengthening the simulation process even more.

## Conclusions

Helicopter interior noise was reviewed in international papers describing tests and measurements with various helicopter types. It has been identified that interior noise in helicopters exceeds exposure limits and hearing protection must be worn by occupants. Effectively reducing the interior sound pressure levels reduces interior space and payload. An approximate representative study of a cavity model with a low-density acoustic damping foam has been carried out. It has been shown that especially in the very low frequency range, such a damping foam can effectively reduce sound pressure levels without reducing space. However, to accurately assess noise reduction capabilities of this setup, a longer investigation has to be carried out with a much higher computational power, which would allow for more detailed modelling and for the examination of a broader frequency range. It also has to be added that the application of a single type of damping material will most likely not cover the requirements for the entire excitation spectrum, however, the damping foam has proven effective in one of the most critical excitation ranges.

*The present work was supported by EFOP 3.6.1-16-2016-00017 project.*

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