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EFFICIENCY OF AN ACOUSTIC BLACK HOLE EMBEDDED INTO A HONEYCOMB SANDWICH PANEL

Alex Besse[1*] **Omar Aklouche**[2] **Frédéric Ablitzer**[1]
Adrien Pelat[1] **François Gautier**[1]
[1] Acoustic Laboratory of Le Mans University (LAUM), Le Mans University, France
[2] National Engineering school of Le Mans (ENSIM), Le Mans, France

ABSTRACT

The Acoustic Black Hole (ABH) is a passive vibration control technique that enhances damping without increasing structural mass. This effect is achieved by reducing stiffness locally, such as tapering plate thickness following a power-law profile, and adding a viscoelastic coating for increased damping. In lightweight honeycomb sandwich panels, the shear effect significantly influences wave propagation, introducing unique ABH characteristics. This study investigates the behavior of an ABH embedded in a honeycomb sandwich panel (with glass fiber skins and a honeycomb core) in the vicinity of a point excitation force. Using models and experiments, the aim is to evaluate the ABH's ability to absorb vibrations generated by the source. Vibration fields of several samples panels (without ABH, with one and multiple) are measured using a scanning laser vibrometer. The absorption effect (reduction in the average mobility of the panel mobility) is compared with models predictions. Results reveal that the distance between the excitation point and the ABH is critical for good performance. This finding raises the possibility of seeing an ABH not only as a passive vibration absorber but also as a vibrations isolator to decouple the force entry point and the rest of the structure.

Keywords: *acoustic black hole, numerical model, experimental results, vibration isolation*

*__Corresponding author__: *alex.besse@univ-lemans.fr.*

1. INTRODUCTION

The Acoustic Black Hole (ABH) is a passive vibration control technique that enhances damping without adding mass. This technique consists of locally reducing the thickness, through a tapered profile, and increasing local loss, with an added viscoelastic layer. Originally proposed by Mironov [1] and Krylov [2], the concept has been extensively studied in uniform panels [3, 4] and more recently in complex structures such as honeycomb sandwich panels [5]. These panels, commonly used in aerospace and automotive applications due to their low weight and relative stiffness, introduce additional challenges due to frequency-dependent bending stiffness induced by shear effects [6, 7].

Experimental studies have demonstrated the effectiveness of ABHs for reducing structural vibrations across various configurations. O'Boy et al. [8] and Georgiev et al. [9] validated the ABH effect through measurements on beams and plates. Recent work [10, 11] extended these findings to composite materials, highlighting the industrial relevance of ABH. In order to further develop the industrial applications of ABH, this study investigates the performance of an ABH embedded in a honeycomb sandwich panel under point excitation. Using experimental measurements and numerical models, the relevance of ABH positioning for performance is studied by comparing configurations with single and multiple ABHs. In highly damped structure, such as honeycomb sandwich panels, the proximity between the vibration source and the ABH is found to be crucial for effective vibration reduction. This finding suggest that ABHs can function not only as vibration absorbers but also as isolators, offering new possibilities for decoupling vibration sources from surrounding structures. These insights contribute to the ongoing development of ABH-based solutions for lightweight and high-performance engineering applications.

2. EXPERIMENTAL PROOF OF MOBILITY REDUCTION INDUCED BY ABHS

In order to evaluate the performance of an ABH placed inside a honeycomb sandwich panel, the spatially averaged squared mobility is evaluated outside of the ABH. Such quantity is proportional to the panel's kinematic energy and corresponds to the panel's overall vibratory level. This quantity is experimentally obtained on free boundary panels, using a scanning laser vibrometer (Polytec PSV500 Xtra), an impedance head (PCB 288D01) and an an electrodynamic shaker (Modal Shop 2075E). The excitation is placed close to one corner. A periodic chirp signal is used as excitation. Using this setup, three panel configurations are tested: a uniform reference panel (Figure 1 (a)), a panel with a central circular ABH (Figure 1 (b)), and a panel with four ABHs placed at each corner (Figure 1 (c)). The results of these measurements are shown in (Figure 1 (d)) in one third octave band representation. The single ABH panel shows a reduced mobility of 4dB up to 3500 Hz, demonstrating the effect of the ABH. Above this frequency, the reduction diminishes to less than 1dB . This is due to the highly damped nature of the reference panel. At low frequencies, the displacement field corresponds to a modal field while at higher frequencies, only the propagative field exists in the panel. The propagative field leads to sub-optimal interaction with the ABH leading to a limited mobility reduction effect. To counteract this issue, the ABH is placed closer to the excitation point, aiming to absorb the vibratory energy upon entry and decouple the rest of the panel before it can propagate. Based on this approach, a panel equipped with four ABHs is designed. This configuration offers enhanced low-frequency performance due to the simultaneous operation of all four ABHs, (7dB instead of 4 dB). However, at higher frequencies, 3 out of the 4 ABH are not interacting with the propagative displacement field, rendering them ineffective. This transition phase is observed from 2000 Hz onward leading to an improvement in mobility reduction from 2 dB, for the singular ABH, to 4 dB, for the 4 ABH. The proximity of an ABH to the excitation point ensures sustained efficiency over the entire frequency range for highly damped structures.

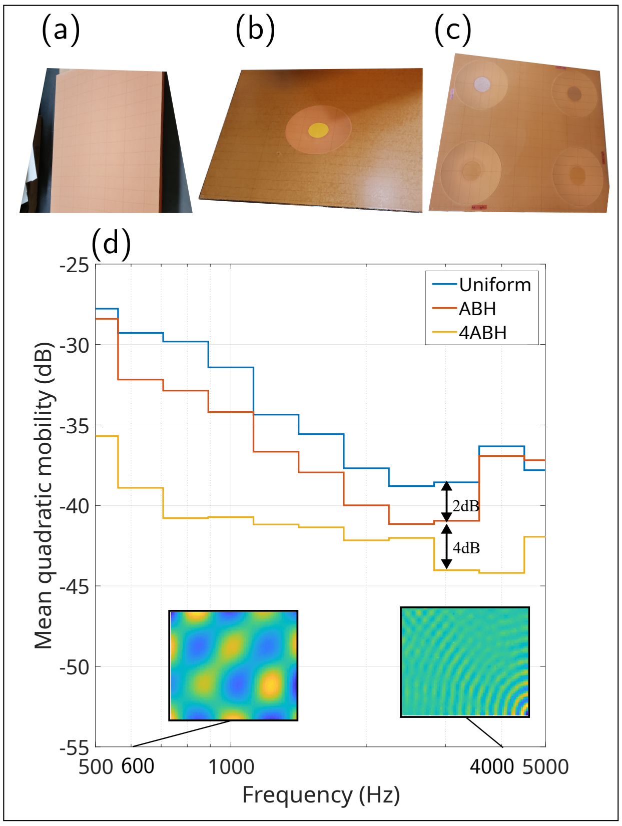

Figure 1. (a) Uniform honeycomb sandwich panel. (b) ABH embedded at the centre of a honeycomb sandwich panel. (c) 4 ABHs embedded at each corner of a honeycomb sandwich panel. (d) Comparison between the spatially averaged quadratic mobility outside of the ABHs for the three panels.

3. NUMERICAL INVESTIGATION OF THE EFFECT OF THE PROXIMITY OF AN ABH TO AN EXCITATION POINT

As stated previously, placing an ABH close to the excitation point of the structure is beneficial to ensure good performance of the device, in both low and high frequency. This is demonstrated by experimental results, under the assumption that ABHs placed too far from the excitation point are not active. In order to verify this assumption, finite element models are created, using the commercial software Comsol Multiphysics, to represent a sandwich panel, based on material properties from [5] with one or multiple ABHs embedded. These models are used to evaluate the spatially averaged quadratic mobility, outside of the ABHs, for different configurations. In total, five panel are tested with the first three being identical to the three experimental configuration (no ABH, centred ABH and 4 ABH) of Figure 1. The last two configurations correspond, respectively, to a single ABH placed next to the excitation point (corner ABH) and 3 ABH placed at the opposite corners of the excitation, (3 ABH) as represented in Figure 2 (a) and (b). The results, shown in one third octave band, are visible in Figure 1 (c). These curves highlight the importance of ABH positioning. The lowest mobility is observed in configurations where an ABH is close to the excitation point (e.g., 4 ABH or Corner ABH), highlighting the importance of proximity. However, the 3 ABH provide similar performance than the centred ABH due to the ABHs being further away from the excitation and them not being active. The models of ABH embedded in sandwich panel are still under development and are not yet giving results that can directly be compared to the experimental results. However, they still demonstrate the importance of ABH proximity and can be used to generate the hypothesis that an ABH can be used not just as a vibration absorber, but also as a vibration isolator, by decoupling an entire structure from a vibration source. This new application of the ABH is especially beneficial in specific scenarios, such as highly damped panels.

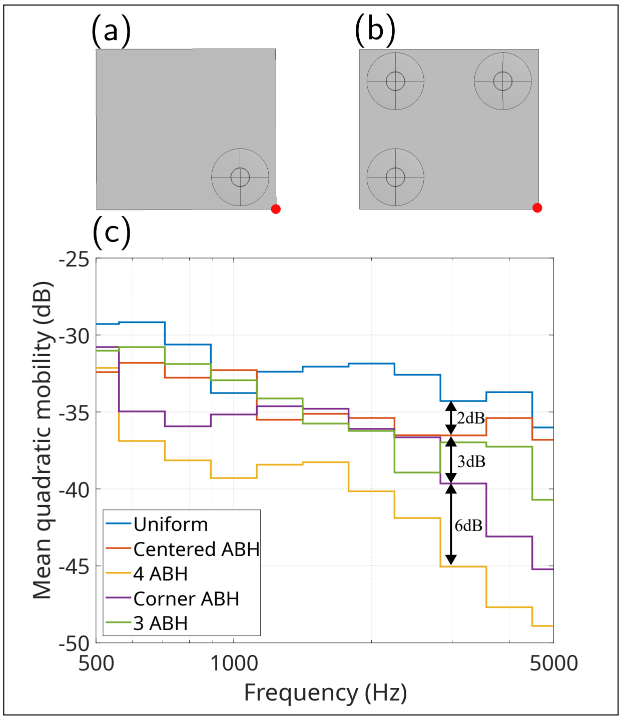

Figure 2. (a) Honeycomb sandwich panel equipped with an ABH placed in the corner next to the excitation. (b) 3 ABHs embedded at the opposites corners of the excitation of a honeycomb sandwich panel. (c) Comparison between the spatially averaged quadratic mobility outside of the ABHs for the five configurations.

4. CONCLUSION

This study explored the performance of an Acoustic Black Hole (ABH) embedded in a highly damped honeycomb sandwich panel using experimental samples and numerical models. The spatially averaged quadratic mobility of a uniform sandwich panel was compared to that of a panel equipped with a centrally located ABH and another with four ABHs positioned at the corners. Results revealed a 4 dB reduction in mobility at low frequencies, with diminished performance at higher frequencies. This decline is attributed to the transition of the displacement field from modal to propagative, which weakens the interaction with the scatterer. The findings highlight the importance of ABH placement, as demonstrated by the four-ABH panel, which achieves improved performance across both low and high frequencies. This insight suggests a novel application of ABHs as vibration isolators, capable of decoupling an entire structure from its excitation source. Ongoing Numerical simulations further confirm that strategic placement of a single ABH can outperform multiple poorly positioned ABHs, reinforcing the potential of this approach for advanced vibration control strategies.

5. ACKNOWLEDGMENTS

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