INVESTIGATION OF THE ACOUSTIC PERFORMANCE OF PERFORATED STEEL INSULATION PANEL USING EXPERIMENTAL AND NUMERICAL METHODS

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Abstract: *Engineering acoustics is a multidisciplinary field that involves the use of mathematical and physical principles to model, analyze, design, develop, and test engineering systems, with the goal of ensuring that these systems exhibit desirable acoustical behavior. This study aimed to investigate the acoustic performance of a steel insulation panel using experimental and numerical methods. The experimental investigation involved measuring the sound pressure level at different distances and frequencies. The numerical investigation involved creating finite element models of the acoustic panel and analyzing the pressure distribution field for different frequencies and sound pressure levels. The results showed a good correlation between the numerical and experimental data.*

The study provides valuable insights into the acoustic behavior of steel insulation panels and demonstrates the effectiveness of combining experimental and numerical methods in acoustic research. The findings can be used to optimize the design of steel insulation panels for better sound insulation performance in various applications, such as building construction and industrial noise control.

Keywords: *acoustic wave, acoustic pressure, finite element method, acoustic protection, perforated steel panel, panel insulation*

1. INTRODUCTION

Engineering acoustics is a multidisciplinary field that involves the use of mathematical and physical principles to model, analyze, design, develop, and test engineering systems, with the goal of ensuring that these systems exhibit desirable acoustical behavior [1]. It encompasses a wide range of applications, including the design of noise control systems for buildings, vehicles, and industrial machinery, the optimization of sound quality in concert halls and other performance spaces, and the development of hearing aids and other assistive listening devices. The ultimate aim of engineering acoustics is to improve our understanding of sound and its effects on people and the environment, and to use this knowledge to create more efficient, effective, and sustainable acoustic systems. [2]

W. Wu [3] has conducted significant research in this field, where he modeled a domain similar to the propagation domain analyzed in this study, using finite element analysis. Wu’s research provided valuable insights into the behavior of acoustic waves in such domains and helped to further develop the field of engineering acoustics.

Kirby presented finite element models for bulk reacting absorbent materials acoustics in order to consider perforated dissipative mufflers with homogeneous properties [4, 5].

A more detailed study regarding the transmission loss of a lined expansion muffler assuming locally reacting effect of the absorbent material is presented in the works of Graggs [6] and Antebras [7]. These studies provide a valuable insight into the behavior of acoustic materials and can help in the design and development of effective noise control systems.

Carl Howard and Ben Cazzolato [8] present a very good guide for achieving high performance in acoustic and vibro-acoustic simulations using Ansys Mechanical. This book is ideal for engineers with limited background in acoustics, as it explains numerous examples and numerical methods to help them discover the fundamentals of acoustics. The book covers a wide range of topics, from basic acoustic theory to more advanced topics such as modal analysis, coupled field analysis, and nonlinear acoustics.

This paper presents a combined experimental-numerical investigation aimed at analyzing the propagation of sound waves in a particular context. The study employs both experimental measurements and computational simulations to comprehensively examine the behavior of sound waves in the target medium, with a focus on factors such as frequency, intensity, and wave speed. Through the integration of experimental and numerical techniques, this research seeks to enhance our understanding of the mechanisms underlying sound wave propagation and to identify strategies for optimizing acoustic performance.

The authors have undertaken a comprehensive investigation into small to medium thickness acoustic insulation panels made of metallic materials. The focus of their research centers on developing a better understanding of the acoustic properties of these panels under varying conditions, such as changes in the material density and thickness, to achieve optimal sound insulation performance. This study is crucial for enhancing the design and manufacture of such acoustic panels for use in a wide range of applications, including but not limited to building construction, transportation, and industrial noise control.

The constructive solution of these small or medium thickness acoustic insulation panels made of metal materials consists of a flat plate that features perforations with a specific density on the surface. This innovative design allows sound waves to pass through the perforations and into the cavity behind the panel.

2. EXPERIMENTAL INVESTIGATION

Within the framework of the Erasmus program, an experiment was conducted at the University of the Basque Country in Spain to study the propagation of acoustic waves through a steel panel with perforations, as depicted in Fig.1. The purpose of this experiment was to investigate the effect of the perforations on the acoustic properties of the panel and to determine how it affects the transmission of sound waves through the panel. This type of research is critical for applications in fields such as aerospace, automotive and building acoustics, where the design and optimization of structures for noise reduction and sound insulation are essential.

The perforated sound-absorbing plates (Fig. 2) studied and analyzed are steel plates with dimensions of 1.5 m x 1 m and a thickness of 0.0015 m and the diameter of the holes is 0.03 m. The holes in the plates are strategically placed and sized to maximize their sound absorption efficiency while maintaining the structural integrity of the plates.

The perforated plates analyzed were placed at distances of 0.5 m, 0.7 m, 0.8 m, and 1 m from the measurement point (sound level meter) and at a distance of 50 m from the sound source.

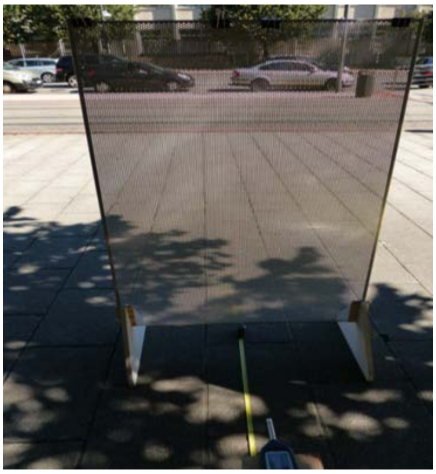

FIG.1 Perforated steel plate with hole diameter of 0.03 m

The measurement and calculation of the equivalent sound pressure level and maximum sound level were carried out using a SOLO 11605 sound level meter, which was calibrated both before and after the measurements were taken. This ensured that the readings obtained were accurate and reliable. The measurement process was conducted with care and attention to detail to ensure that the results obtained were as accurate as possible. The measured data was then analyzed and processed to determine the effectiveness of the perforated steel plates as sound absorbers.

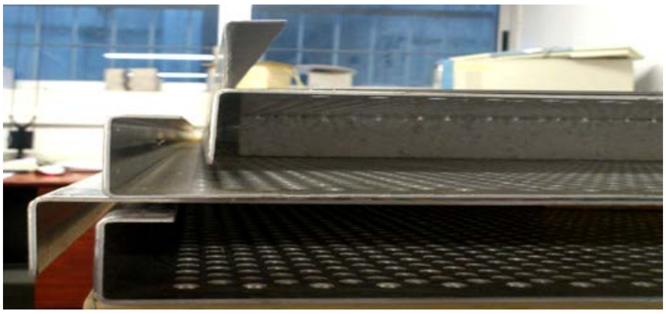

FIG. 2 Definition of areas on the field of analysis

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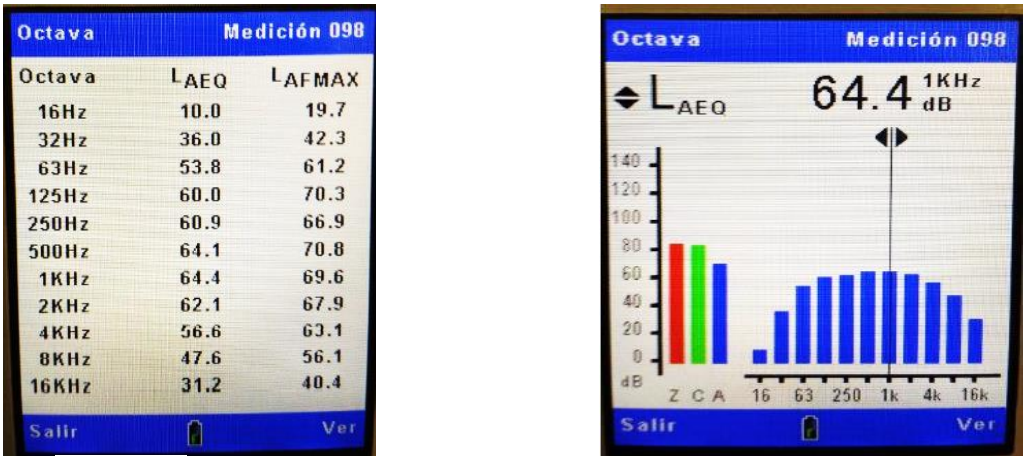
2.1 Experimental measurements and results

Figure 3 shows screenshots of the sound level meter, representing the equivalent sound pressure level and maximum sound level at a distance of 0.5 m.

The equivalent sound pressure level is the constant sound level that, if it were maintained over a certain time, would result in the same sound energy as the fluctuating sound level that is actually present. The maximum sound level, on the other hand, represents the highest instantaneous sound level reached during a certain time interval. Both of these parameters are important in evaluating the effectiveness of the perforated plates in reducing the overall sound level in the measured area.



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16Hz	10.0	19.7
32Hz	36.0	42.3
63Hz	53.8	61.2
125Hz	60.0	70.3
250Hz	60.9	66.9
500Hz	64.1	70.8
1KHz	64.4	69.6
2KHz	62.1	67.9
4KHz	56.6	63.1
8KHz	47.6	56.1
16KHz	31.2	40.4

Salir Ver

(a) (b)

FIG.3 Definition of areas on the field of analysis

Table 1 presents the measured values of the constant noise level and the maximum sound level obtained during the measurement period at distances of 1 m, 0.8 m, 0.7 m, and 0.5 m.

Table 1. The measured values of the constant noise level and the maximum sound level

F [H_Z]	Constant noise level, L_{AEQ} dB				Maximum sound level, L_{AFmax} dB			
	d=1m	d=0.8m	d=0.7m	d=0.5m	d=1m	d=0.8m	d=0.7m	d=0.5m
16	10.5	9.4	8.1	10.0	20.9	16.9	16.2	19.7
32	33.6	31.7	31.9	36.0	38.5	35.16	36.6	42.3
63	47.3	45.2	48.5	53.8	55.3	51.6	53.7	61.2
125	52.7	58.7	53.9	60.0	62.1	66.1	63.3	70.3
250	55.7	57.8	58.5	60.9	63.8	63.6	64.9	66.9
500	57.1	61.1	63.1	64.1	63.1	68.0	72.0	70.8
1000	57.4	62.6	64.5	64.4	62.1	68.8	70.8	69.6
2 000	56.0	57.2	61.8	62.1	61.0	64.8	70.3	67.9
4 000	49.8	53.9	55.4	56.6	55.5	62.5	62.9	63.1
8 000	40.4	46.2	47.0	47.6	53.9	64.4	58.6	56.1
16 000	24.7	30.5	36.2	31.2	57.5	56.7	55.8	40.4

This results indicates that the perforated steel plates have a more significant impact on reducing noise levels when placed closer to the source of the sound. These findings demonstrate thes effectiveness of perforated steel plates in attenuating noise levels and highlight the importance of considering the placement distance when designing noise control solutions in various settings.

3. NUMERICAL INVESTIGATION

Based on the experimental setup presented above, numerical simulations have been carried out to faithfully replicate the experimental investigation. These simulations use acoustic models that incorporate the physical properties of the materials and geometries involved in the experiment. They allow for a more detailed and comprehensive analysis of the acoustic behavior of the system under investigation. Additionally, numerical simulations can provide insights into acoustic phenomena that may be difficult or impossible to measure experimentally, such as sound pressure distribution within complex geometries or the effect of small variations in material properties [9].

3.1 Materials

The perforated acoustic panel studied, as depicted in Figure 4, has dimensions of 0.6 m x 0.6 m x 0.015 m with a hole diameter of 0.03 m. The air behind the panel has a thickness of 0.5 m. These dimensions are essential in determining the panel's sound absorption coefficient and transmission loss, which are crucial parameters in evaluating the panel's effectiveness in reducing noise levels. The panel's thickness and hole diameter also impact its acoustic impedance and sound transmission properties. These factors are taken into account in the numerical and experimental analysis to assess the panel's performance and potential for acoustic insulation applications.

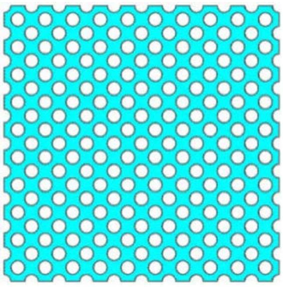


FIG. 4 Acoustic insulation panel with holes

For the proposed numerical analysis, steel was chosen as the material for the panel, as it was in the experiment. The material's physical and mechanical properties, such as density, Young's modulus, Poisson's ratio and shear modulus are precisely defined and can be accurately simulated in numerical models.

A comprehensive evaluation of the physical and mechanical properties of the chosen material is presented in Table 2. This data is vital in assessing the suitability of the material for use in acoustic insulation applications and provides a benchmark for future studies in this field. The table outlines essential characteristics, which are crucial factors in determining the effectiveness of the material as a sound insulator.

Table 2. Properties of steel acoustic insulation panel with holes

Speed of sound (c)	5000 m/s
Density (ρ)	7850 kg/m^3
Young's modulus (E)	$2 \cdot 10^{11}$ Pa
Shear modulus (G)	$1.75 \cdot 10^{11}$ Pa
Poisson's ratio (μ)	0.30
Impedance (Z)	$39.25 \cdot 10^6$ Pa·s/m

By utilizing these material properties, can be obtained concrete values of acoustic pressure and displacements, as well as deformations occurring on the perforated plate used. This will allow for a more accurate analysis of the sound insulation capabilities of the panel, and provide insight into potential areas for improvement in future designs. Additionally, this data can aid in the development of more effective and efficient acoustic protection solutions for a variety of applications, from industrial noise reduction to architectural soundproofing.

3.2 Numerical analysis

In the acoustic analysis, a domain of interest is cut out from the real domain, consisting of a perforated steel plate and air.

The analysis domain has dimensions of 0.6 m x 0.6 m x 0.5 m. The steel plate was modeled using SOLID 185 finite element and for air FLUID 30 finite element was used.

The FLUID 30 finite element was utilized with its "structure present" option, which considers fluid-structure coupling, for discretizing the domain representing the air in the holes and the first layer after the steel panel. he remaining wave propagation domain, represented only by air, was discretized using the same element but with the "structure absent" option.

The boundary conditions applied to the analysis domain were as follows: at the end of the propagation direction, impedance was applied to prevent wave reflection; on all lateral faces, the boundary conditions consisted of imposing a zero normal velocity, which is necessary given the planar nature of the wave propagation and the adoption of a planar model.

The part of the domain represented by the presence of the perforated plate represents the location where the acoustic pressure was applied. This was applied over the entire surface representing both the air holes and the steel. The presence of the structure, the panel, also required the imposition of specific boundary conditions for mechanical structures, which in the considered case consisted of clamped at the base of the panel.

The applied boundary conditions reproduce both the real conditions of the experiment and the characteristics of the planar model of acoustic wave propagation.

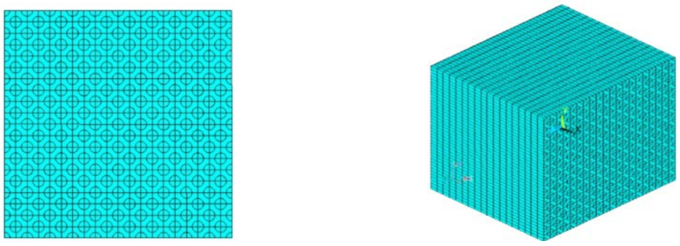
The combination of the SOLID 185 and FLUID 30 finite elements, along with these boundary conditions, allows for an accurate numerical analysis of the acoustic and structural behavior of the panel.

When discretizing with linear elements, a minimum of six finite elements per wavelength is used, which determines the size of the finite elements (element size) to be $\lambda/6$. This ensures that the numerical solution captures the behavior of the wave at a sufficiently high resolution [8].

The panel is subjected to a sound pressure level of 80 decibels at three different frequencies: 500 Hz, 1000 Hz and 2000 Hz. The pressure level corresponds to the root-mean-square sound pressure level, which is a measure of the average sound pressure level over a period of time. The three frequencies were chosen based on their relevance to the application and the expected performance of the panel in attenuating sound at these frequencies.

In a 3D acoustic wave propagation model in open space with a distant acoustic source, the acoustic pressure loading on the analyzed domain can be considered uniform.

Figure 7, (a) shows the finite element model for the acoustic panel used in the analysis, while (b) presents the acoustic domain of analysis.



(a) (b)

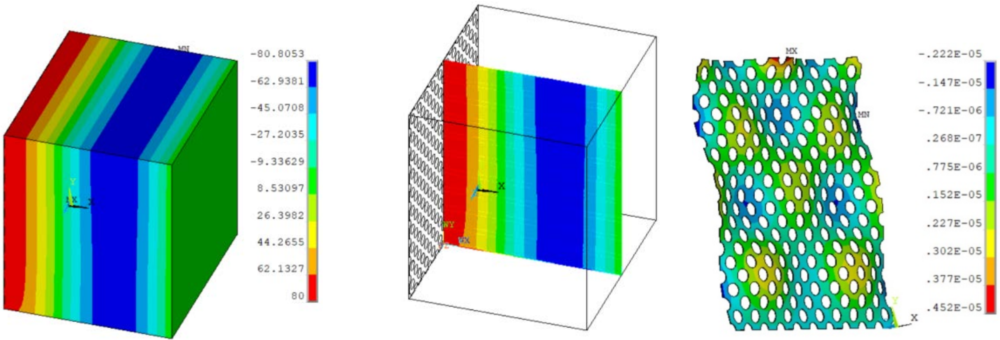
FIG. 7 Finite element models for acoustic panel (a) and acoustic domain of analysis (b)

3.3 Numerical results

Numerical results obtained from finite element analysis are presented in Fig. 8-10 for those three cases.

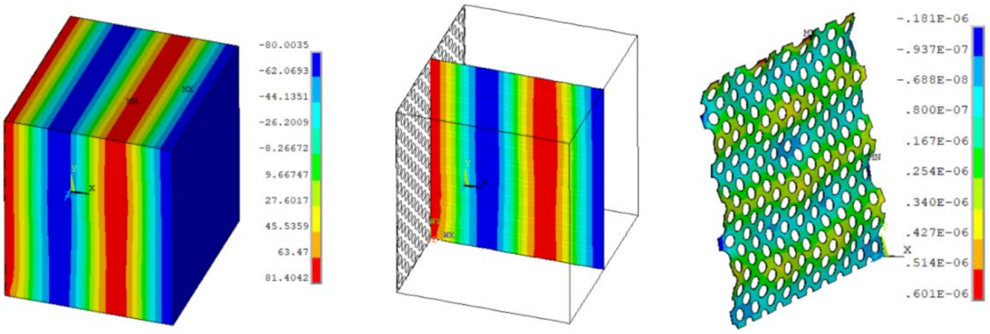
Figure 8 shows the pressure distribution field for P=80 dB and f=500 Hz, where (a) represents the pressure field of the entire domain of analysis, (b) acoustic pressure field in the central plan and (c) shows the Ux displacement field on the deformed panel.

The pressure is applied uniformly to the entire surface of the panel and is assumed to be a plane wave.



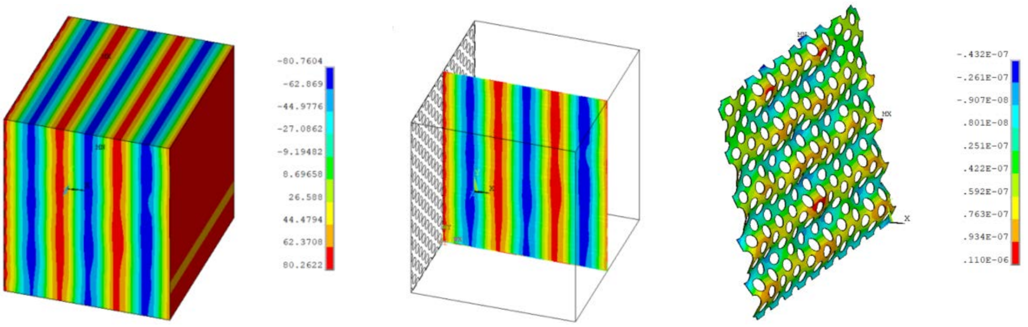
(a) (b) (c)

FIG. 8 Pressure distribution field for P=80 dB and f=500 Hz



(a) (b) (c)

FIG. 9 Pressure distribution field for P=80 dB and f=1000 Hz



(a) (b) (c)

FIG. 10 Pressure distribution field for P=80 dB, f=2000 Hz

Also, Fig. 9 and Fig. 10 show the pressure distribution fields for P=80 dB and f=1000 Hz, respectively P=80 dB and f=2000 Hz.

These numerical results can be used to analyze the acoustic behavior of the panel, providing valuable information on how the panel responds to different sound pressures and frequencies. By analyzing the pressure distribution fields, researchers can identify areas of high and low pressure, and understand how the panel vibrates and deforms under different conditions. This information can be used to optimize the design of acoustic panels for specific applications and improve their overall performance.

In Fig. 11, the acoustic pressure variations depending on propagation distance for P=80 dB and F=500 Hz, 1000 Hz, 2000 Hz are presented. The graph shows how the acoustic pressure varies as the distance from the source increases at different frequencies.

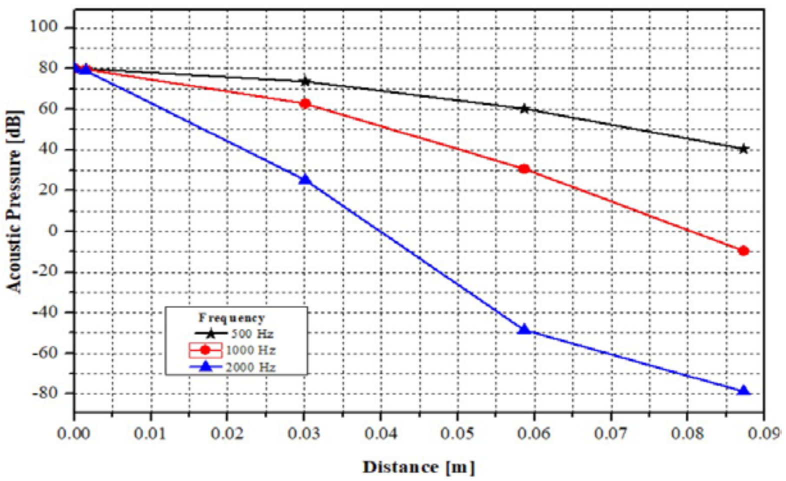


FIG. 11 Acoustic pressure variations depending on propagation distance

The graphical representations in Fig. 8-10 highlight a uniformity of the acoustic pressure in the yz planes and a variation of its values in the propagation direction. As for the acoustic panel, it is mechanically stressed extremely little (displacements smaller than $1x10^{-5}$ m), and these very small deformations result in very low mechanical stresses that were not of interest for the research conducted. However, the effect of the presence of the panel, that of reducing the level of acoustic pressure behind it or in the propagation direction, should be noted.

4, CONCLUSIONS

This paper presents an experimental and numerical investigation of the sound absorption properties of an acoustic panel. The experimental investigation consisted of measuring the sound pressure level and sound absorption coefficient of the panel for various frequencies. The numerical investigation involved creating finite element models of the acoustic panel and analyzing the pressure distribution field for various frequencies and sound pressure levels. The experimental investigation is an essential part of acoustic engineering as it provides crucial data to validate the numerical models and simulations.

The results of the experimental investigation showed that the acoustic panel had good sound absorption properties for frequencies ranging from 500 Hz to 2000 Hz, with the sound absorption coefficient increasing with frequency. The numerical investigation confirmed these results and showed a very good correlation between the experimental and numerical results.

The article also highlighted the importance of numerical investigation in acoustic research, as it allows for a more detailed analysis of the acoustic properties of materials and structures. The combination of experimental and numerical investigation proved to be an effective approach for characterizing the acoustic properties of materials and structures.

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