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ATTENUATION OF NOISE IN THE CABIN OF A REGIONAL AIRCRAFT BY METAMATERIAL TRIM PANELS

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Abstract

Interior noise has always been an issue for aircraft manufacturers, even if only recently has it received equal importance to other design requirements. Passengers are increasingly concerned about cabin comfort, which they consider high priority for medium and long flights. In order to reach the challenging interior noise target set for the new generation small aircraft 80 OASPL dB, 70 dBA, 56 dBSIL3, a noise reduction plan must address and accurately identify noise sources. The main goal of this work is to evaluate acoustic comfort, by analysing sound pressure levels, in the cabin of a regional turboprop subjected to multiple broadband noise components, that simulates the noise generated inside the aircraft with monopolar sources. Sandwiches with metamaterial core are employed as trim panels of the cabin for improving sound absorption through the fuselage and the averaged interior noise level at seated person ear height is numerically evaluated with the Finite Element commercial software, Actran®. In particular, this work aims to show the higher acoustic performances of innovative passive Noise & Vibration technologies, such as acoustic metamaterials, with respect to classical soundproofing solutions.

Keywords: metamaterial; finite element method; vibroacoustic analysis; noise reduction; cabin comfort

1. Introduction

Interior noise is in important issue in aircraft design since the born of the aviation [1, 2, 3, 4]. Although, only in the last thirty years, the demand of new design factors [5], as cabin comfort, leads to seek new acoustic solutions in order to reduce the interior noise. In fact, the exposure to loud noises could undermine the physical health [6] of the passenger and decrease their comfort. Therefore, the aim of this work is to achieve an important reduction in the perceived noise inside the passenger cabin of a turboprop commercial aircraft.

Noise levels inside the passenger cabin in a commercial aircraft change depending upon the different operations of aircraft, and they can be defined as the total noise during takeoff and landing and level flight (cruise). The main sources of aircraft interior noise are the power plant (propeller and engine-reciprocating or turbine) and the turbulent boundary layer as described in [7, 8, 9, 10]. High speed turbulent flow over an aircraft fuselage is responsible for a substantial component of the interior noise, and is probably the most important source of cabin noise in steady cruise. The ground operations of aircraft include aircraft engine tests, takeoff preparation and braking after landing. If noise effect is related to its duration, then it can be seen that cruise flight of the aircraft is the most important noise type, affecting health and comfort of passengers and flight crew. Minor, but not negligible, noise sources are air conditioner humming and air friction. There are also noise sources that are not aircraft-related. These are non-special noises, such as conversations and noises during placing of hand-luggage into overhead compartments. Noise sources due to flight crew are flight attendant conversations, loudspeaker announcements by pilots and attendants, mechanical noises during food and beverage service and flight safety demonstrations, and announcements. Different works defined and estimated some of these sources through numerical analysis and field tests [11, 12]. Although,

due to the complexity of the field and the high number of variables not all sources are completely defined and understood with numerical and analytical models. In this work we concentrate on internal sources, their importance in cruise flight is described by the field tests in [13]. At authors knowledge there are not any completely accessible references and data in literature, that describe or model these internal sources, as the air conditioning system, in a commercial aircraft. Therefore, we decide to model the internal sources with a theoretical spherical source: a constant amplitude monopole.
In order to reduce the noise and increase the comfort, several solutions are exploited on commercial aircraft [14], both active and passive. Acoustic treatments are all the mean technical solutions that are installed on board either to reduce the noise transmitted through the fuselage wall or to control the internal noise sources. These treatments need to be optimized taking into account different parameters, particularly the weight, the cost and the mechanical resistance. For these reasons, it is necessary to establish a methodology for the vibroacoustic design going through the characterization of basic material, small sub-components (stiffened panels in transmission loss test) and large sub-components (full scale fuselage barrel for testing different solutions) that will support the aircraft design development. Acoustic metamaterials (AMM) can satisfy both the weight requirements and high transmission loss in a desired frequency range [15].
The characteristic wavelength of noise sources in aeronautics is usually very high, so latest research focused on the possibility to control low frequencies by the use of acoustic metamaterials. In particular, heterogeneous metamaterials are considered in this work. These can be defined as a composite system consisting of multiple small masses embedded within a passive poro-elastic matrix material. The embedded masses create an array of resonant mass-spring-damper systems within the material that operate at low frequencies where the passive poro-elastic material is no longer effective. By employing the poro-elastic material to provide the stiffness for the embedded masses, the metamaterial utilizes two passive control schemes: damping at high frequencies, and dynamic absorption at low frequencies, into a single device for broadband noise reduction. The displacement of the masses against the foam stiffness at their low frequency resonance leads to an increase in mechanical damping losses and absorption. Acoustic metamaterials can be used for controlling low frequency sound radiation, improving low frequency transmission loss and sound absorption when attached to vibrating structures, and is a lighter and thinner replacement to conventional materials. Several studies design and test metamaterials for low frequency applications [16, 17, 18, 19]. In this paper we continue to develop and validate the AMM designed by [20]. The transmission loss capacity was already estimate and previously studied for an external real acoustic source by [21] and with a Statistical Energy Analysis (SEA) for high frequencies in [22]. The aim of this work is to understand the vibro-acoustic behaviour of this acoustic solution with respect to an internal source in order to quantify the variation in the sound pressure level (and in the noise) inside the passenger cabin, so the absorbtion features of the material.
Actually, there is a lack of reliable and useful numerical models, valid for innovative materials, able to predict the structural response and the radiated acoustic power. The availability of a numerical tool, especially for regional aircraft, which are subject to very different customer requests, is a fundamental need together with the confidence of the users of such tools which should have the ability for a correct, realistic interpretation of the results produced numerically. In parallel, the possibility of studying innovative materials is a driving factor for approaching the problem of the aircraft interior noise. Since internal noise is a low-frequency problem, Finite Element Method (FEM) can be adopted in this case. In this framework, Actran®is a powerful FEM tool of MSC Software for the acoustic and vibro-acoustic simulation of complex structures, accounting for various geometries, load conditions and innovative materials, among these metamaterials, which can present negative, complex and frequency-dependent mechanical and mass properties. Moreover, this software allows different types of analyses, already validated through many applications.

2. The vibro-acoustic problem

The vibro-acoustic problem is simplified applying the following hypotheses on the fluid and on the structure:

- the fluid-structure system has a linear behaviour;

- small deformations for the structure;
- the fluid, in contact with the structure, is homogeneous, inviscid and irrotational compressible;
- body forces are neglected.

Then, from a numerical point of view, we discretize our problem defining the continue unknowns $\mathscr{U}$ as a function of the vectorial unknowns $\boldsymbol{U}$ of the numerical problem (so the nodal value):

$$\mathscr{U} = \boldsymbol{N}_i^s \boldsymbol{U} \tag{1}$$

in which $\boldsymbol{N}_I^s$ is a generic row matrix function of the space coordinates x_i, which interpolate the continuous unknown variables.
From the structural system and the acoustic or wave equations we obtain the following matricial discretized equation to describe our problem:

$$\begin{bmatrix} \boldsymbol{M}_{ss} & 0 \\ -\rho_f \boldsymbol{S}_{sp}^T & \boldsymbol{Q} \end{bmatrix} \cdot \begin{Bmatrix} \ddot{\boldsymbol{U}} \\ \ddot{\boldsymbol{P}} \end{Bmatrix} + \begin{bmatrix} \boldsymbol{D}_{ss} & 0 \\ 0 & 0 \end{bmatrix} \cdot \begin{Bmatrix} \dot{\boldsymbol{U}} \\ \dot{\boldsymbol{P}} \end{Bmatrix} + \begin{bmatrix} \boldsymbol{K}_{ss} & \boldsymbol{S}_{sp} \\ 0 & \boldsymbol{H} \end{bmatrix} \cdot \begin{Bmatrix} \boldsymbol{U} \\ \boldsymbol{P} \end{Bmatrix} = \begin{Bmatrix} \boldsymbol{F}_s \\ \boldsymbol{F}_p \end{Bmatrix} \tag{2}$$

in which the mass ($\boldsymbol{M}$ and $\boldsymbol{Q}$) and the stiffness matrices ($\boldsymbol{K}$ and $\boldsymbol{H}$) appear both for the fluid and for the structure. The structural damping matrix $\boldsymbol{D}_{ss}$ become important for a visco-elastic material. Moreover, the coupling of the system is represented by the coupling matrix $\boldsymbol{S}_{sp}$. Finally, the load vector contains the external loads $\boldsymbol{F}_s$ and acoustic sources $\boldsymbol{F}_p$, as a spherical one, applied on the structure and on fluid respectively. The unknowns for the structure are the displacements $\boldsymbol{U}$ (in the three directions) and for the fluid the pressure $\boldsymbol{P}$. Both are nodal values. Moreover several boundary conditions could be applied on the displacements or on the pressure (Dirichlet boundary condition), on the forces, as an imposed normal velocity (Von Neumann boundary condition) and an imposed impedance (Robin boundary condition).
The equation can be transformed from the time to the frequency domain thanks to the Fourier transform:

$$\begin{bmatrix} -\omega^2 \boldsymbol{M}_{ss} + i\,\omega \boldsymbol{D}_{ss} + \boldsymbol{K}_{ss} & \boldsymbol{S}_{sp} \\ -\rho_f \omega^2 \boldsymbol{S}_{sp}^T & -\omega^2 \boldsymbol{Q} + \boldsymbol{H} \end{bmatrix} \cdot \begin{Bmatrix} \boldsymbol{U} \\ \boldsymbol{P} \end{Bmatrix} = \begin{Bmatrix} \boldsymbol{F}_s \\ \boldsymbol{F}_p \end{Bmatrix} \tag{3}$$

where the unknown vectors $\boldsymbol{U}$ and $\boldsymbol{P}$, and the structural, acoustic, coupling matrices and the force vector, depend on the pulsation $\omega = 2\pi f$.
The multifrontal massively parallel solver (MUMPS), implemented in Actran®, has to find the solution of the vibro-acoustic problem described by equation 3. This solver is based on the LU decomposition.

3. FEM model

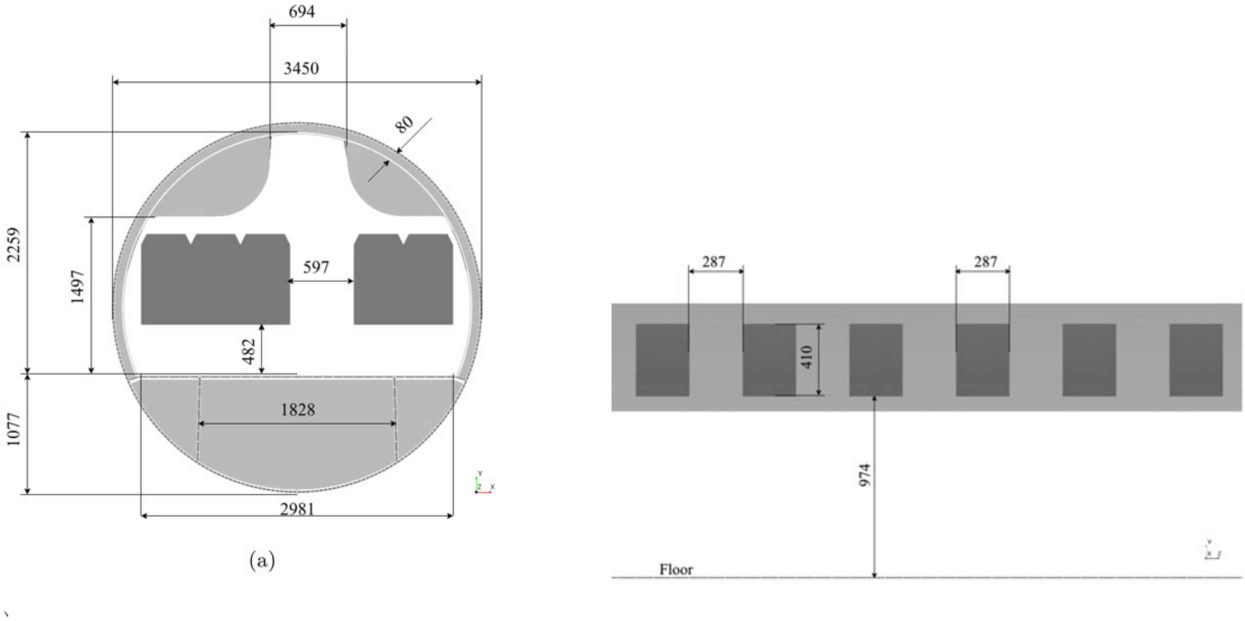
3.1 Geometry and material

The aircraft reference model is a turboprop passenger aircraft, where we consider only the central barrel of the fuselage (without the nose and the tail) [21, 22]. The sizes are reported in figure 1. The passenger cabin is designed with windows, overheads and seats. The cabin is surrounded by the trim panel (or lining panel) and by the floor.
The fuselage structure (planes and beams) are made of a composite material, homogenized as an orthotropic material. The trim panel core is be made of Nomex or metamaterial (melamine foam with cylindrical inclusions in aluminium, see section 3.3). The trim panel shells are made by two layers each of a composite material: two fiberglass epoxy layers with orientation 0° and 90°. Moreover, we define the windows and overheads materials: tempered glass and PMMA for the former and PVC for the latter. The fluid is composed by air (density $\rho = 1.21\, kg/m^3$ and speed of sound $c = 340 + 1.7i\, m/s$). Seats are defined as impedance boundary condition (see section 3.2).

3.2 Boundary conditions

The following boundary conditions are applied:

- the clamped edges at the two sides of the fuselage in order to block the model;



(a) (b)

Figure 1 – The fuselage dimensions [mm]. (a) The frontal view and the cabin interior. (b) The side view with the windows.

- the imposed impedance on the seats (18 rows with five seats each), we model the seats as a solid with a frequency dependant impedance, so we do not have to model the seats porous material. The not-normalized impedance imaginary values are reported in figure 2. The seats concur to the sound absorption;
- the monopole (spherical source) inside the passenger cabin in order to simulate an internal acoustic source of noise. The monopole sources is modeled as a pulsing sphere. A point source of complex amplitude A, located at point P, generates an incident sound field p_i defined by:

$$p_i = A\frac{e^{-ikr}}{r} \tag{4}$$

where r is the distance between P and the point where the incident pressure is computed, and k is the wave number defined by the ratio of the frequency f and the speed of sound: $k = 2\pi f/c$. In order to define the spherical source we must choose the amplitude A and the position P, so its coordinates. The monopole is almost at the centre of the cabin (see figure 3) with a complex amplitude equal to $A = 1+i$ specifies in the equation 4.

3.3 Acoustic solution

The trim panel is made of a sandwich material with a core made of Nomex and the faces of epoxy carbon (two layers each). The trim panel has to absorb noise and vibrations from the external and the internal sources, to thermally insulate the cabin and, in case of emergency, to support the pressure loads caused by the cabin pressurization. Moreover, it must be fireproof and have a low weight.

The new trim panel core made of the AMM, studied and developed by [20], is designed to be placed in the core of the sandwich. The new AMM exploits a better sound insulation, without loosing key properties as the fireproof and the thermal insulation. The volume fraction, the ratio between the volume of foam and of the inclusions, is chosen in order to obtain a similar density compare to that of the Nomex. The AMM is composed by melamine foam (open-cell foam made material consisting of formaldehyde-melamine-sodium bi-sulfite copolymer melamine) with cylindrical inclusions of aluminium (chosen for its relatively high Young modulus-specific weight ratio) with volume fraction equal

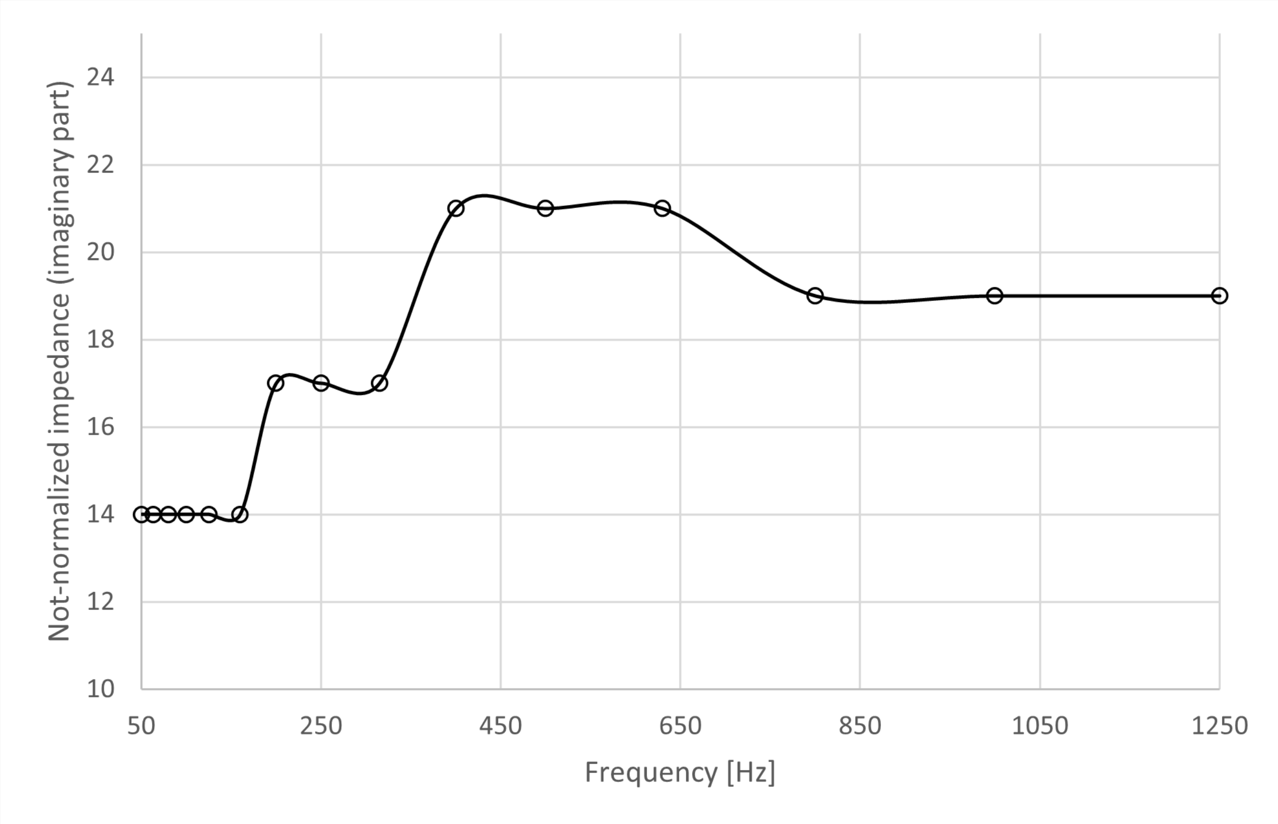


Figure 2 – The imaginary part of the not-normalized impedance of the seats as a function of the frequency.

to 0.015, figure 4. Its frequency dependant mechanical properties were previously homogenized by [20] and reported for the Young module in 11 direction in figure 5 (with respect to the reference system in 4) and in [20] (the curve is similar for the other Young and shear modulus, while the Poisson's ratio has a constant value, $\nu_{12} = 0.22 + 0.01i$, $\nu_{23} = 0.43$ and $\nu_{13} = -0.5$). The homogenization is necessary for computational reason: it would be impossible to model the meta-atoms size (in the order of millimeters) in a macro-structure, as an aircraft fuselage. The overall density of this AMM is very similar to the density of Nomex: 48.38 kg/m^3 for the former instead of 48.00 kg/m^3 for the latter. The two fiberglass plates and the thickness of the core are not changed.

3.4 FEM model overview

The FEM model of the fuselage is composed by four different domains:

- the structure, defined by 2D and 1D elements with linear interpolation;
- the trim panel core, in order to describe the complex kinematic behaviour of this material, it is modeled by 3D elements with quadratic interpolation. A 2D model for the trim panel core will lead to a loss of information due to the Equivalent Single Layer (ESL) approach exploited by Actran® or by other commercial software;
- the fluid inside the passenger cabin, the cargo hold and the the air gap between the trim panel and fuselage skin. This domain is defined by 3D elements with a linear interpolation;
- the interfaces between the structure and the fluid, is modeled by 2D elements. The role of the interface is to convert displacements from the structure in pressures to the fluid and vice-versa.

The whole model was already validated in our previous work for an external source with the same maximum frequency equal to 300 Hz [21].

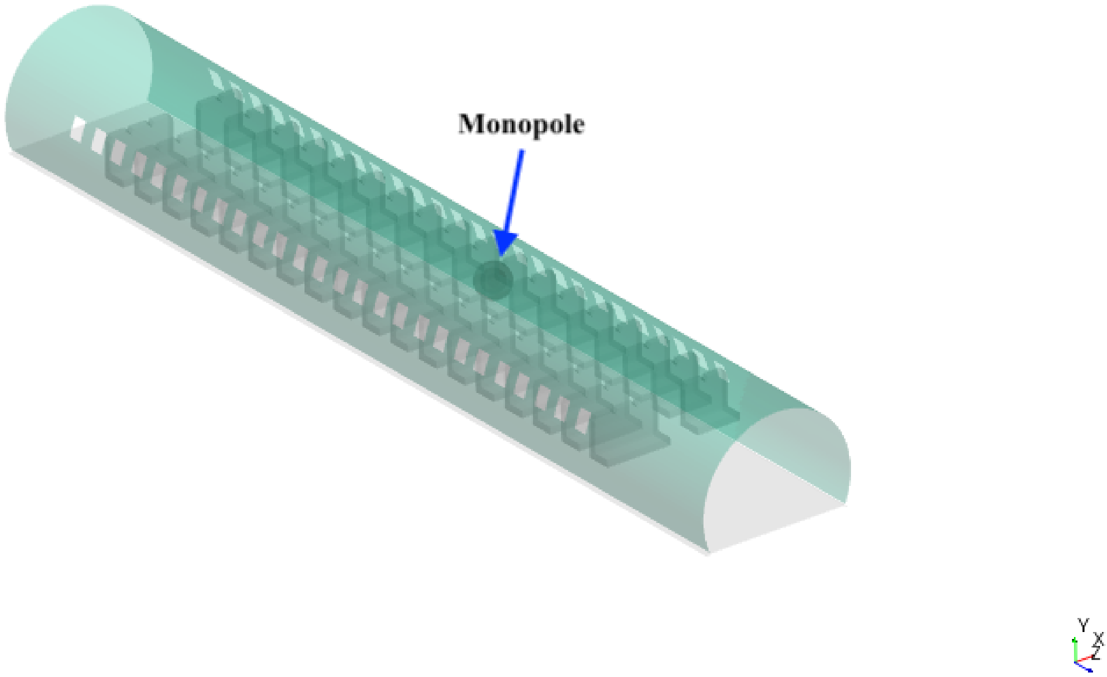


Figure 3 – The passenger cabin in the FEM model with seats and windows. The monopole is visible as the sphere at centre of the cabin.

3.5 Analyses

We perform two direct frequency analyses from 0 Hz to 300 Hz and a step of 5 Hz. In the first analysis we study the plain configuration, so the core of the trim panel is made of Nomex. In the second analysis the possible advantages of a trim panel made of AMM are verified and quantified.

4. Results

The results are reported in terms of sound pressure level SPL in dBA, so we apply the A filter in order to include the human ear sensitivity for low frequency noise. In fact, the human ear strongly attenuates sound below 1000 Hz. The weights for the A filter are referred to the work of [23]. So in dB (or in dBA) we can define the SPL as a normalized pressure in the logarithmic scale:

$$SPL = 10 \cdot \log_{10} \left(\frac{p}{p_{ref}} \right)^2 dB \tag{5}$$

where the reference pressure is equal to $p_{ref} = 20\ \mu Pa$ for air and p is the pressure in Pascal that depends on frequency besides the space coordinates. Another useful parameter is the total energy contained in the spectrum, so the weighted mean of the pressure in the frequency range. The overall sound pressure level $OASPL$ can be expressed with the following definition (in dB or dBA):

$$OASPL = 20 \cdot \log_{10} \frac{\sqrt{\int_{f_{min}}^{f_{max}} p^2 dp}}{p_{ref}} dB \tag{6}$$

in which f_{min} and f_{max} are minimum and maximum frequency on which the pressure p is calculated. The SPL is calculated as the average of the six sets of FRF points (microphones), one for each row of seats, so as a mean of the sound pressure perceived by seated passenger (1.20 m from the floor).

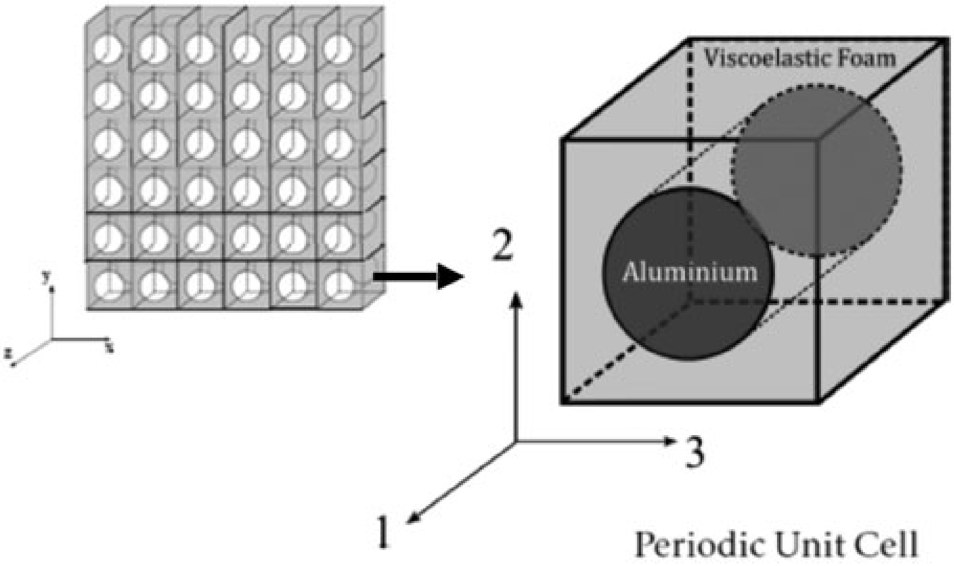
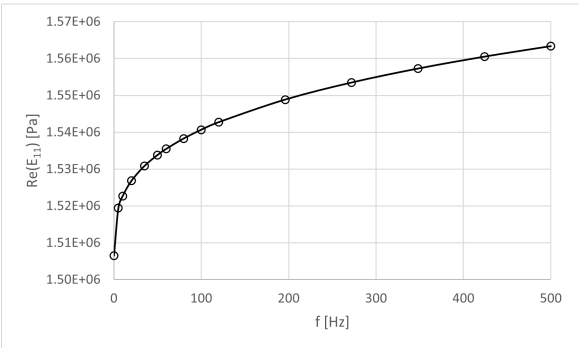
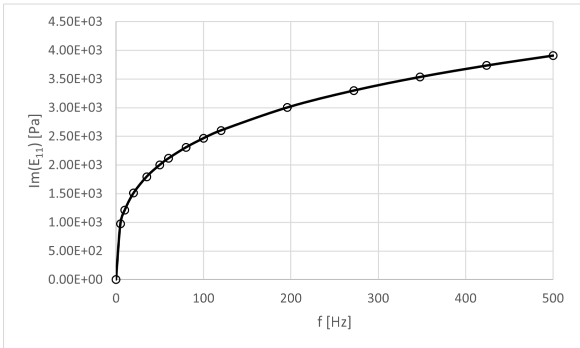


Figure 4 – The AMM structure, both the meta-atom (the periodic unit cell) and the AMM plate.



(a)



(b)

Figure 5 – The Young module [Pa] for direction 11 of the AMM as function of the frequency [Hz]. (a) The real part. (b) The imaginary part.

Another set of microphones is placed in the central corridor at the height of 1.70 m from the floor, to simulate a standing passenger. The results in terms of OASPL for the seated passenger perceived noise are equal to 89.1 dBA for the plain configuration and to 83.8 dBA for a configuration with a metamaterial made trim panel. So the exploitation of the chosen metamaterial in the trim panel leads to a reduction of 5.3 dBA. The OASPL is reduced by the 6.32%. The reduction is in accordance to that previously obtained in [21].
Moreover, the OASPL map are shown in figure 6. As expected there is an increase of the value near the monopole position and a reduction in OASPL with the trim panel core made of the AMM. Finally, we report in figure 7 the pressure in dB as mean value on the last FRF point set validating the previous results for the corridor position too.

5. Conclusions

The reduction in the interior noise is a challenge for the future of the aviation, in order to increase the passenger comfort. In particular for short route, as those performed by turboprop aircraft, where the aviation sector suffers the concurrency of other transports [24].
Low frequency noise is always a difficult issue and its insulation is traditionally obtained with an increase in the weight of the system. In fact, for a traditional material the transmission loss (TL) and the absorption directly depend on the frequency, on the material density and on the plate thickness. An high insulation for low frequencies requires either an high material density or an increase in the plate thickness. Both the cases have as a consequence an increase in the system weight. In order to

decrease the noise inside the passenger cabin and not increase the system weight, in this work we choose an high innovative acoustic solution, an acoustic metamaterial, and we validate it in a FEM model inside real-like environment: the central barrel of the fuselage containing the passenger cabin. The selected AMM was already modeled and studied, both in order to estimate its homogenized properties and in the fuselage model with an external acoustic source. In this work the absorption capacity of the proposed acoustic solution is tested for an internal acoustic source.
The results show an important reduction in the SPL inside the passenger cabin: 6.32%. This decrease is similar to those obtained in the previous work by [21] with an external source (7.01%). Therefore, the following remarks from the numerical results are obtained:

- the trim panel material leads to a reduction of the noise. This reduction strongly depends on the metamaterial properties and on the panel thickness;
- there is not an increase in the aircraft weight because the new AMM has a similar density compared to the Nomex;
- as expected there is an increase in the SPL near the source position (the monopole).

Moreover, several future developments and studies could be developed:

- a structural analysis on the AMM is required in order to satisfy safety regulations;
- a vibro-acoustic analyses must be performed with a real internal acoustic source as the air conditioning system noise;
- the computational model could be used to optimize the metamaterial itself.

Finally, this work validates and shows the advantages of the exploitation of an acoustic metamaterial, as an acoustic solution inside a commercial aircraft for low frequency noise.

6. Copyright Statement

References

[1] Bassett, PR, and Zand, SJ. Noise Reduction in Cabin Airplanes. *Transactions of the A.S.M.E.*, pp 49-56, reprint, February 1934.
[2] Nichols Jr. RH, Sleeper Jr. HP, Wallace Jr. RL and Ericson HL. Acoustical Materials and Acoustical Treatments for Aircraft. *The Journal of the Acoustical Society of America*, Vol. 19, pp 428-443, 1947.
[3] Beranek LL. The noisy dawn of the jet age. *Sound & Vibration Magazine*, 40th Anniversary issue, pp 94–99, 2007.
[4] Dobrzynski W. Almost 40 Years of Airframe Noise Research: What did we Achieve?. *Journal of Aircraft*, Vol. 47 (2), pp 353-367, 2010.
[5] Hall A, Mayer T, Wuggetzer I and Childs PRN. Future aircraft cabins and design thinking: optimisation vs. win-win scenarios. *Propulsion and Power Research*, Vol. 2, Issue 2, pp 85-95, 2013.
[6] Basner M, Babisch W, Davis A, Brink M, Clark C, Janssen S and Stansfeld S. Auditory and non-auditory effects of noise on health. *Lancet*, Vol. 383(9925), pp 1325-13323, 2014.
[7] Wilby JF. Aircraft interior noise. *Journal of Sound and Vibration*, Vol. 190, Issue 3, pp 545-564, 1996.
[8] Mixson JS and Powell CA. Review of recent research on interior noise of propeller aircraft. *Journal of Aircraft* Vol. 22, Issue 11, pp 931-949, 1985.
[9] Hayden RE, Murray BS and Theobald MA. A study of interior noise levels, noise sources and transmission paths in light aircraft. *Final Report Bolt*, 1983.
[10] Bertsch L, Simons DG. and Snellen M. Aircraft Noise: The major sources, modelling capabilities, and reduction possibilities. *DLR-Interner Bericht*, DLR-IB 224, 2015.

[11] Bhat WV and Wilby JF. Interior noise radiated by an airplane fuselage subjected to turbulent boundary layer excitation and evaluation of noise reduction treatments. *Journal of Sound and Vibration*, Vol. 18, Issue 4, pp 449-464, 1971.

[12] Orrenius U, Cotoni V, and Wareing A. Analysis of sound transmission through aircraft fuselages excited by turbulent boundary layer or diffuse acoustic pressure fields. *38th International Congress and Exposition on Noise Control Engineering*, Ottawa, Canada, pp 2637-2645, 2009.

[13] Hu N, Buchholz H, Herr M, Spehr C and Haxter S. Contributions of Different Aeroacoustic Sources to Aircraft Cabin Noise. *AIAA 2013-2030. 19th AIAA/CEAS Aeroacoustics Conference*, Berlin, 2013.

[14] Leylekian L, Lebrun M and Lempereur P. An overview of aircraft noise reduction technologies.. *AerospaceLab*, Issue 7, pp 1-15, 2014.

[15] Chen S, Fan Y, Fu Q, Wu H, Jin Y, Zheng J and Zhang F. A Review of Tunable Acoustic Metamaterials. *Applied Sciences*. Vol 8(9):1480, 2018.

[16] Yang Z, Mei J, Yang M, Chan NH and Sheng P. Membrane-type acoustic metamaterial with negative dynamic mass. *Physical review letters*, 101(20), 204301, 2008.

[17] Hyeon Lee S, Mahn Park C, Seo YA, Wang Z and Kim C. Composite Acoustic Medium with Simultaneously Negative Density and Modulus. $Physicalreviewletters$, 104. 054301. 2010.

[18] Brooke DC, Umnova O, Leclaire P and Dupont T. Acoustic metamaterial for low frequency sound absorption in linear and nonlinear regimes. *Journal of Sound and Vibration*, Vol. 485, 2020.

[19] De Miguel AG, Cinefra M, Filippi M, Pagani A and E. Carrera. Validation of FEM models based on Carrera Unified Formulation for the parametric characterization of composite metamaterials. *Journal of Sound and Vibration*, Vol. 498, 2021.

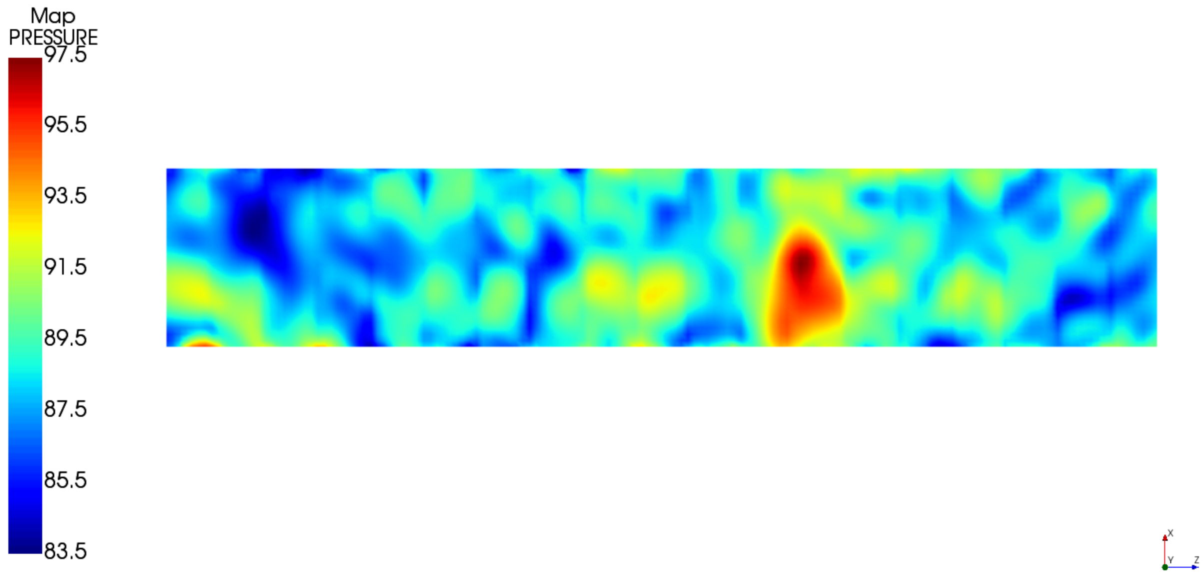
[20] Cinefra M, D'Amico G, De Miguel AG, Filippi M, Pagani A, Carrera E. Efficient numerical evaluation of transmission loss in homogenized acoustic metamaterials for aeronautical application. *Applied Acoustics*, Vol. 164, 2020.

[21] Moruzzi MC, Cinefra M and Bagassi S. Vibroacoustic analysis of an innovative windowless cabin with metamaterial trim panels in regional turboprops, Mechanics of Advanced Materials and Structures, Published online, 2019.

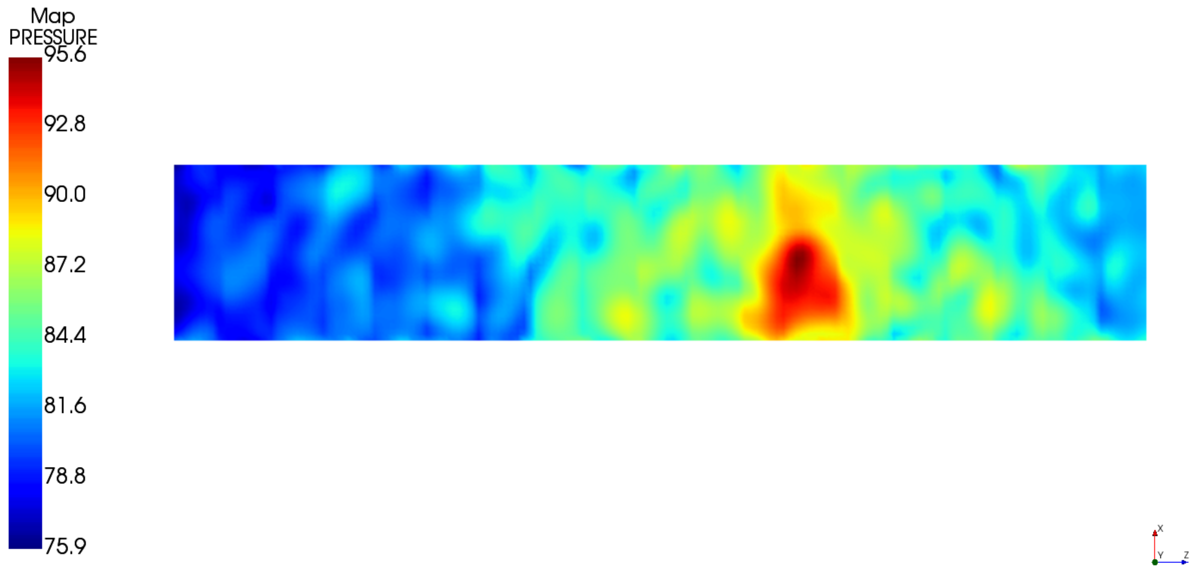
[22] Cinefra M and Petrone G. SEA analysis in the cabin of a regional turboprop with metamaterial lining panels. *AIAA Scitech Forum*, 2019.

[23] Robinson D, and Dadson R. A re-determination of equal-loudness relations for pure tones. *British Journal of Applied Physics*, Vol. 7 166, 2002.

[24] Albalate D, Bel G and Fageda X. Competition and cooperation between high-speed rail and air transportation services in Europe. *Journal of Transport Geography*, Vol. 42, pp 166-174, 2015.



(a)



(b)

Figure 6 – The OASPL maps in dBA of the passenger cabin at the height of 1.20 m from the floor, so the position of the seated passenger heads. (a) Trim panel core made of Nomex. (b) Trim panel core made of AMM.

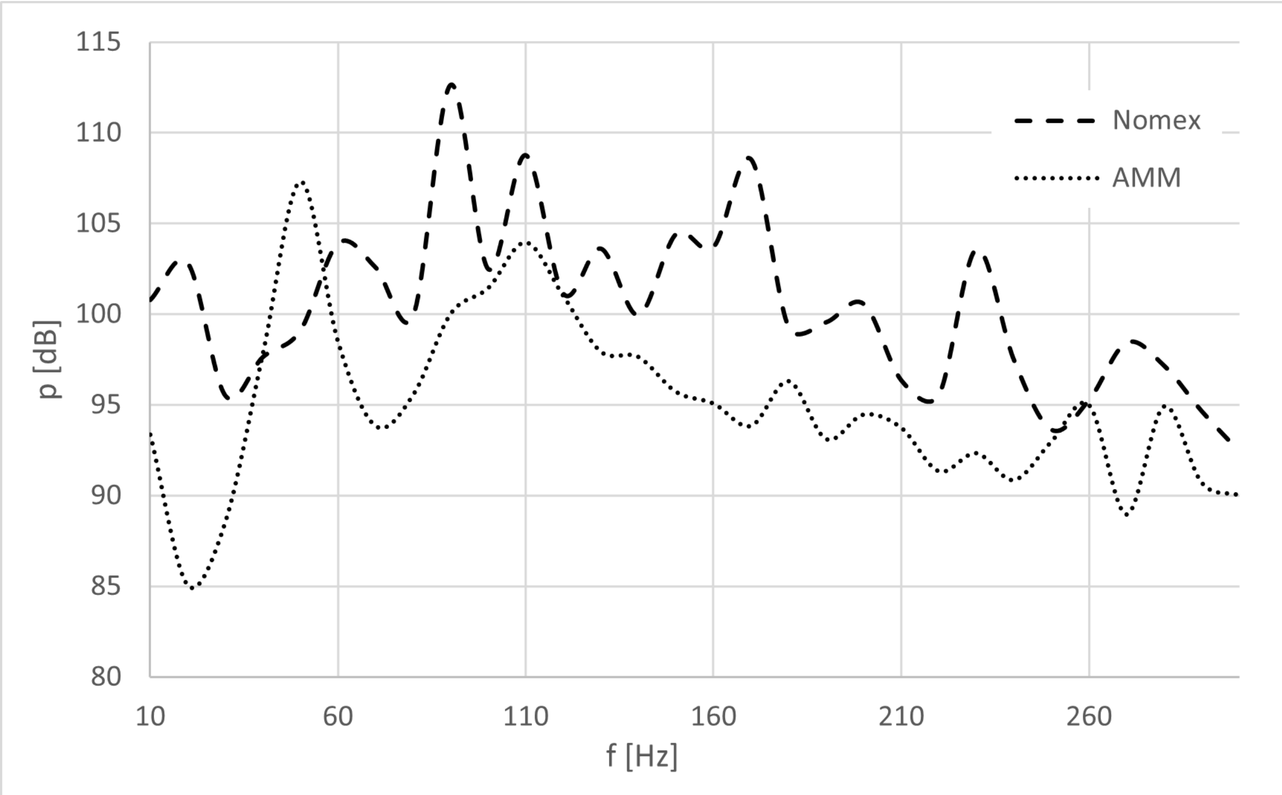


Figure 7 – The SPL mean value in dB in the cabin corridor at an height of 1.70 m from the floor as a function of the frequency. The dashed line refers to the trim panel made of Nomex and the dotted one to the trim panel made of AMM.