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NUMERICAL AND ANALYTICAL ANALYSIS OF TRANSMISSION LOSS OF PANELS WITH INSERTION OF HELMHOLTZ RESONATORS AND POROUS MATERIAL

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Abstract. *Reducing noise in the cabin of an aircraft has been a difficult task, because there is the need to use materials that increase transmission loss without increasing the weight of the structure. Currently, a way to increase the transmission loss of the joint without the weight is increased too, is to add porous material between the outer and inner panels of the cabin of an aircraft. However this technique does not solve all the problems, because there are lower frequencies that have a considerable share in the sound transmission. To try to solve this problem this work have studied the transmission loss of panels with insertion of resonators in porous materials.In this paper a numerical model has been developed with the goal of determining the transmission loss of the assembly: panels, porous material and resonators. The results obtained were compared with an analytical model of transfer matrices order to evaluate if the same is the physical behavior of the analyzed system.*

Keywords: *Transmission loss. Resonators. Porous materials. Painels. Numerical simulation. Analytical model*

1. INTRODUCTION

For some time already there is a great concern in the control of noise and vibrations in equipment, structures, automobiles and aircraft. ue to this problem many studies have been developed, and one of the techniques that is being used is the addition of porous materials internally to the panels, in a "sandwich" configuration.

This work intends to use this technique, which proved very efficient when the goal is to have an increase in the transmission loss in medium and high frequencies, as can be seen in [1], however there are still lower frequencies that have a significant share in the transmission of noise to the cabin. Studies show that by adding Helmholtz resonators to the panels and/or porous materials an increase in transmission loss and, consequently, a decrease in cabin noise [3,6,7] occurs. The addition of the porous material and resonators internally to the panels generates an irregular geometry as well as a complex velocity and wave number, hence the importance of creating an equivalent fluid model that will make possible the use of the transfer matrix method In the analytical implementation and in the numerical model.

1.1 Objectives

This work has as general objective to present a comparison of the results obtained analytically and numerically for the whole panels, resonators with and without porous material. How Specific objectives include:

- Implementation of the analytical of transfer matrices model (TMM);
- Implementation of the numerical model using software COMSOL;
- Comparison between methods used;

2. ANALYTICAL MODEL

In this topic of the work will be presented the formulation used to obtain the panels curves of transmission loss. The method used was that of the transfer matrices.

2.1 Transfer matrices method (TMM)

According to presented in the authors [7] work, the general transfer matrix can be determined by relating the pressure p_1 (outside the panel) and the panel velocity v_1 with the pressure Inside the panel p_t and the speed v_2. This transfer matrix can be seen in Equation 1:

$$\begin{Bmatrix} p_t \\ v_2 \end{Bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \begin{Bmatrix} p_1 \\ v_1 \end{Bmatrix} \tag{1}$$

Where a_{11}, a_{12}, a_{21} e a_{22} are the coefficients of the overall transfer matrix to be determined.

As previously seen to determine the transmission loss of the panels it is necessary to first determine the transmission coefficient of the set. For this method the calculation of this coefficient can be given by Eq. 2:

$$\tau = \frac{\rho c}{\rho_i c_i} \left| \frac{p_t}{p_{inc}} \right|^2 . \tag{2}$$

Where p_{inc} is the incident pressure on the left side of the panel. The relation $\frac{p_{inc}}{p_t}$ can be calculated, by Eq, 3, in terms of the coefficients of the global transfer matrix.

$$\frac{p_{inc}}{p_t} = \frac{1}{2} \left[(a_{22} - \rho_0 c_0 a_{21}) - \left(\frac{1}{\rho_i c_i} \right) (a_{12} - \rho_0 c_0 a_{11}) \right] . \tag{3}$$

The overall matrix is formed by three matrices: the first one being a matrix representing the resonators and the support panel, the second is a matrix that encloses the cavity and/or insulators and the latter represents the outer panel. This configuration can be seen in Eq. 4:

$$\begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} = \begin{bmatrix} A_{11}^{TP} & A_{12}^{TP} \\ A_{21}^{TP} & A_{22}^{TP} \end{bmatrix} \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix} \begin{bmatrix} 1 & \mathrm{i}\omega m_1 \\ 0 & 1 \end{bmatrix} \tag{4}$$

For the case that includes the tuning of multiple resonators, the terms of the matrix representing the resonators and the sustaining panel can be seen in Eq. 5a a 5d:

$$A_{11}^{TP} = 1 + \mathrm{i}\omega \left\langle \frac{L_j \sigma_j}{Z_j} \right\rangle ; \tag{5a}$$

$$A_{12}^{TP} = \mathrm{i}\omega \left[m_2 + \left\langle L_j \sigma_j A_t^j \left(\frac{1 + i\omega L_j}{L_j} \right) \right\rangle \right] ; \tag{5b}$$

$$A_{21}^{TP} = 0 ; \tag{5c}$$

$$A_{22}^{TP} = 1 . \tag{5d}$$

Where:
L_j is the inertia and is given by Eq. 6:

$$L_j = \frac{\rho_i (l_j + B_j \left(\frac{\pi}{2} \right) r_j)}{\pi r_j^2} \tag{6}$$

ρ_i is the density of the fluid;
L_j is the resonant length of the resonator;
R_j is the radius of the throat of the resonator;
B_j is an empirical correction;
Z_j is the input impedance of the resonator and is given by Eq. 7:

$$Z_j = R_j - \mathrm{i} \left(\omega L_j - \frac{1}{\omega G_j} \right) \tag{7}$$

G_j is the completeness and is given by Eq. 8:

$$G_j = \frac{V_j}{\rho_i c_i^2} \tag{8}$$

c_i is the velocity of sound in the fluid;
V_j is the volume of the resonator;
R_j is the resistance of the resonator nozzle;

For the space formed by the cavity and/or insulating materials, the terms of its transfer matrix are given by the terms of Eq. 9a to Eq.9d:

$$A_{11} = \bar{a}_{11}\,; \tag{9a}$$

$$A_{12} = \bar{a}_{12}\,; \tag{9b}$$

$$A_{21} = \frac{\bar{a}_{21} - \frac{\bar{a}_{11}}{z}}{A_{11}^{\text{TP}}}\,; \tag{9c}$$

$$A_{22} = \frac{\bar{a}_{22} - \frac{\bar{a}_{12}}{z}}{A_{11}^{\text{TP}}}\,. \tag{9d}$$

Where$\bar{a}_{11}$, $\bar{a}_{12}$, $\bar{a}_{21}$ e $\bar{a}_{22}$are the elements of the cavity matrix with the insulation material. This transfer matrix is given by Eq. 10:

$$\begin{bmatrix} \bar{a}_{11} & \bar{a}_{12} \\ \bar{a}_{21} & \bar{a}_{22} \end{bmatrix} = \begin{bmatrix} \bar{C} & i\rho_i c_i \bar{S} \\ \frac{i\bar{S}}{\rho_i c_i} & \bar{C} \end{bmatrix} \begin{bmatrix} C & -WS \\ \frac{-S}{W} & C \end{bmatrix} \tag{10}$$

Where:
$C = \cos(\gamma d_1)$;

$S = \sin(\gamma d_1)$;

d_1 Is the thickness of the insulating material;

W Is the insulation impedance wave (complex);

γ Is the complex propagation constant of the insulation material and is given by Eq. 11:

$$\gamma = \alpha - \frac{\text{i}2\pi}{\lambda_m} \tag{11}$$

α Is the material attenuation constant;

λ_m Is the wavelength in the material;
$\bar{C}$=cos $\left[\omega \frac{(d-d_1)}{c_i}\right]$;
$\bar{S}$=sin $\left[\omega \frac{(d-d_1)}{c_i}\right]$.

Since there is a need to use porous material, one can also use the formulation seen in [2,4]. These formulations can be seen in Eq. 12.

$$T^{\text{camada},i} = \begin{bmatrix} T_{11}^i & T_{12}^i \\ T_{21}^i & T_{22}^i \end{bmatrix} = \begin{bmatrix} \cos(k_{\text{eq},i} l_i) & \text{i}Z_{\text{eq},i}\sin(k_{\text{eq},i} l_i) \\ \text{i}\frac{\sin(k_{\text{eq},i} l_i)}{Z_{\text{eq},i}} & \cos(k_{\text{eq},i} l_i) \end{bmatrix} \tag{12}$$

The properties of the equivalent wave numbers and characteristic impedances, seen in [1,5], can be determined by Eq. 13 and 14 respectively:

$$Z_{\text{eq},i} = \frac{(\rho_i \kappa_i)^{\frac{1}{2}}}{\phi} \tag{13}$$

$$k_{\text{eq},i} = \omega \left(\frac{\rho_i}{\kappa_i}\right)^{\frac{1}{2}} \tag{14}$$

where κ_i Is the bulk modulus of the medium and ϕ is the porosity of the medium.

3. NUMERICAL MODEL

The numerical model of this work was done in software COMSOL, where the panels and resonators were created.To create the panels were used shell-type elements, already to create the resonators were created elements of the solid type. three types of discretizations were made in this model. The first one for the plates, considering the velocity of flexion of the sound (c_f),as can be seen in Eq 15 for a maximum frequency of 500 Hz, the second one for the acoustic domain, using the same reasoning and finally one for the region of the neck of the resonator, where it was necessary to do a much more refined mesh because of the size of the element.

The model seen in the Fig.1 was developed using the finite element method (FEM), having a frequency spectrum of 100 to 500 Hz, as the tuning frequency of resonators is found around 240 Hz.

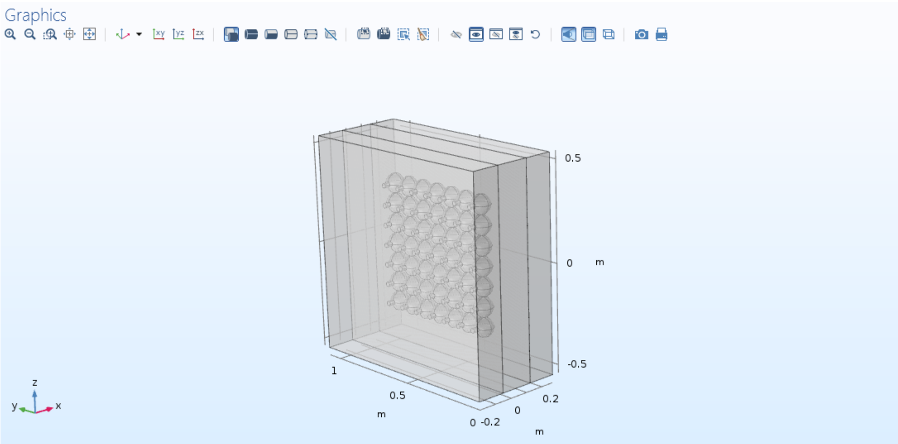

Figure 1. Model of panel with resonators .

Source: Prepared by the author

$$c_f = \sqrt{\omega}\left(\frac{EI_z}{\rho_{al}h}\right)^{\frac{1}{4}} \qquad (15)$$

Where:

E = Modulus of elasticity of aluminum;

$I_z = \frac{h^3}{12(1-\nu^2)}$.

h = Tickness of panel;

ν = Poisson's modulus;

ρ_{al} = Density of aluminium;

4. ANALYSIS AND RESULTS

In this topic the analytical and numerical results will be presented. A comparison of these results will be made, as well as an analysis of the results.

4.1 Analytical Results

In the implementation of the analytical model, we obtained as a result the Fig. 2. In this figure it is possible to observe that there is an increase in TL for the frequency at which the resonator was tuned (240 Hz).

With the use of resonators, there was an increase in the TL to which they were tuned, however at high frequencies there are still the effects of the resonances of the cavity. To solve this problem a layer of porous material is used together with the resonators. The results of this implementation can be seen in the Fig. 3.

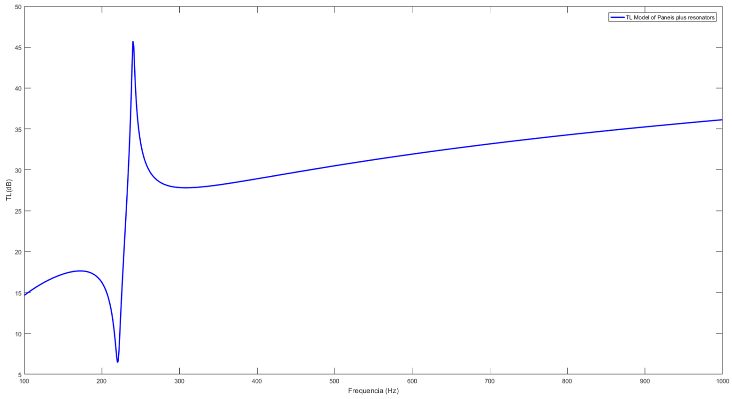

Figure 2. TL of panels with the insertion of the resonators and without porous material.

Source: Prepared by the author

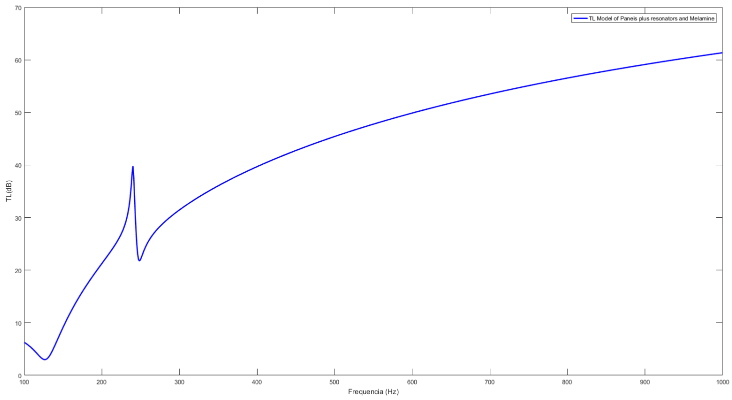

Figure 3. TL of panels with the insertion of the resonators and porous material.

Source: Prepared by the author

4.2 Numerical Results

In figure 4 it is possible to see the result for the sound pressure level of the set, obtained by the numerical model. Already in Fig. 5, we have the TL result for the resonators between the panels. In the last figure it is possible to see that tuned frequency of resonators (around 240 Hz).

This work did not simulate the behavior of panels with porous material between them, due to the large number of works that cite this theme and due computational cost . However in the work of (8), Fig. 6, we can see the result of an SEA model for double panels with porous material between it, and it is possible to see that it improves the performance of the system only in the medium and high frequencies.

4.3 Analysis of Results

In the Fig.2, it was possible to observe that even when using the 49 resonators tuned to the frequency of 240 Hz, although there is an increase in TL for this frequency, a new frequency arises where there is a decrease in TL, Way to minimize this effect would be to tune in some of the resonators for this second frequency. When we observed the Fig. 3 it was noticed that when using the porous materials an increase of the TL occurred in medium and high frequencies, besides minimizing the effects of the resonances due to the cavity. In Fig. 5 it is possible to observe that there are several anti-resonances, which are not observed in the analytical model (Fig, 2). It is believed that this occurs because the analytical model considered the panels as lumped masses, so the panel flexion was not considered, while the numerical model makes all these considerations.

Finally we have the Fig. 7, which shows the numerical results for the complete arrangement. The results are very similar,when we compare the tuned frequency of resonators, but we can see many differency in low frequency, this problems can be due to the analytical model considering the panels lumped mass only.

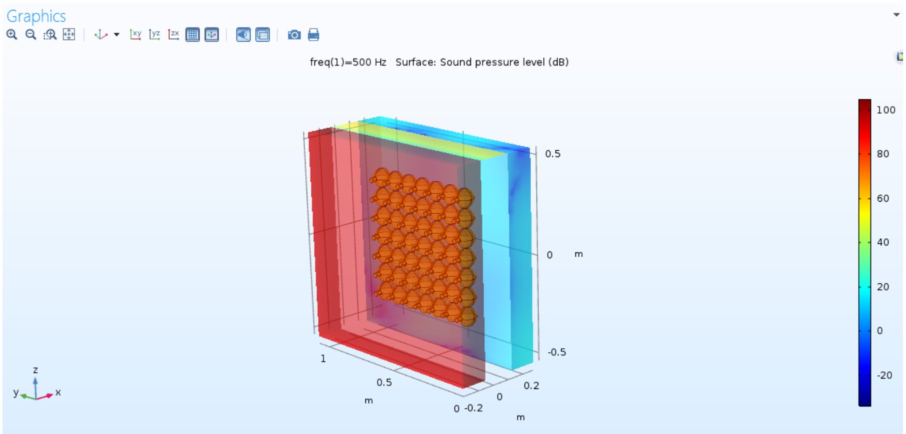

Figure 4. Model of panel with resonators .

Source: Prepared by the author

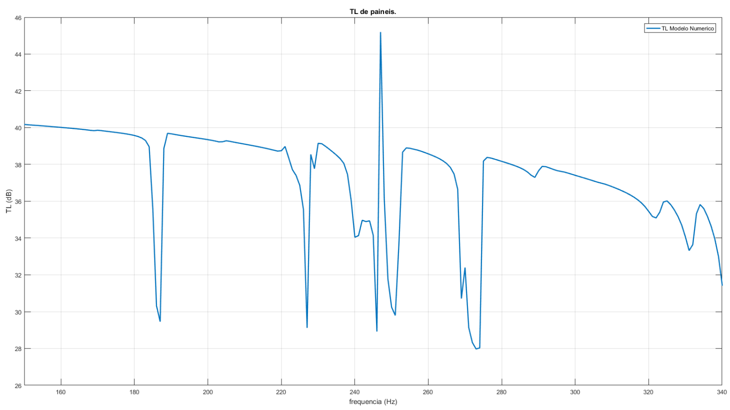

Figure 5. Numerical model of panel with resonators .

Source: Prepared by the author

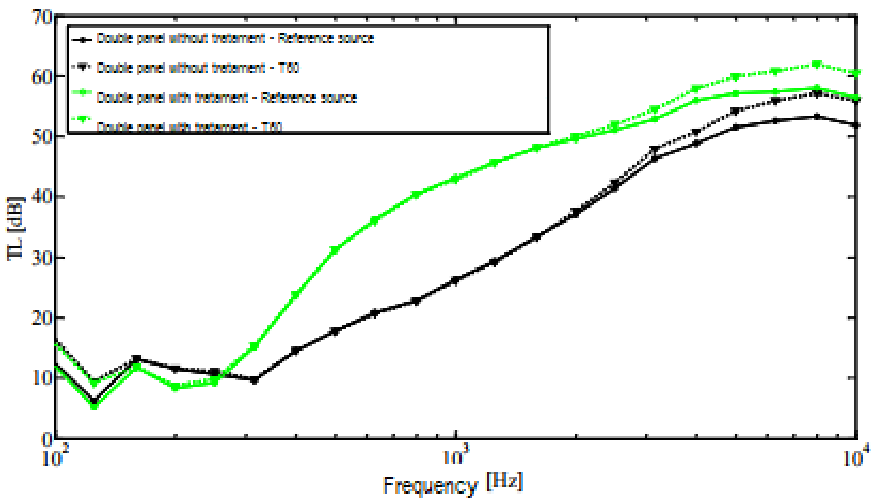

Figure 6. TL of pouros material modeling in SEA .

Source: (8)

5. CONCLUSIONS

With this work it was possible to verify that the use of the Helmholtz resonators is a viable alternative when it is desired to increase the TL to a specific tuning frequency. When it is desired to obtain an increase in the TL for medium and high

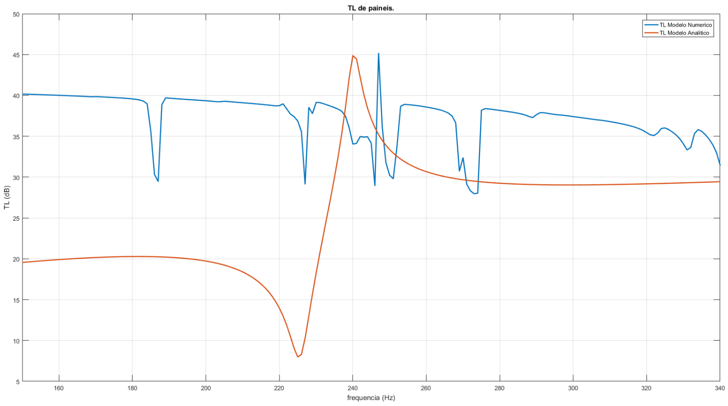

Figure 7. Numerical model of panel with resonators .
Source: Prepared by the author

frequencies, it is possible to use insulating materials, porous for example, if there is a need to increase TL over the entire frequency range, an alternative is the use in Set of resonators and porous materials. This study did not evaluate the best positioning of the resonators and nor what this would influence the TL, this study may be a next step to complement this work.

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