EXPERIMENTAL AND NUMERICAL ANALYSES OF AIR CAVITIES FOR ENHANCING THE SOUND TRANSMISSION LOSS OF MASS-SPRING-MASS LIKE SYSTEMS FOR AUTOMOTIVE APPLICATIONS

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1 - Introduction

This paper discusses an innovative solution to improve the sound insulation performance of a mass-spring-mass like systems, reducing at the same time the overall weight

The idea is based on the creation of air cavities within the poro-elastic foam, so as to reduce the contact areas between foam and sheet, and then to reduce the structural transmission towards the same foam taking advantage of the higher elasticity of the air present in the cavities

2 – Experimental survey

Experimental investigation have been carried out on a steel plate (0.7 mm thick) with different noise treatments. In particular two poro-elastic foams, named **PU** (30mm thick and density of 59 kg/m^3) and **Puler** (30mm thick and density of 104 kg/m^3) and a heavy rubber layer , named EPDM (1.6 mm and 2.9 thick and density of 1800 kg/m^3) have been used for enhancing the sound transmission loss of the multilayer systems.

In the present research air cavities have been obtained removing blocks of foam with a square base of **50 mm x 50 mm** and depth **10 mm**. The distance between cavities is equal to 10 mm, therefore the contact surface between the foam sheet and is reduced to 17% compared to the initial one. An example of air cavities is shown in figure 1 for PU foam.

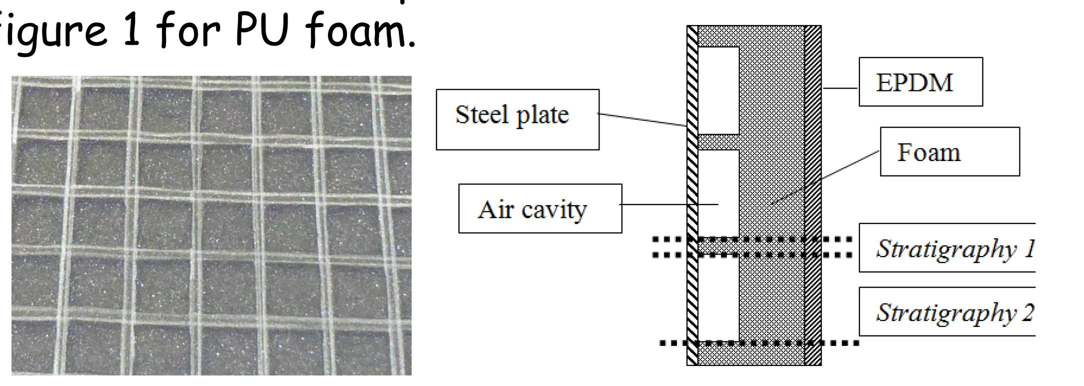


Figure 1: Air cavities for PU foam

Finally the diffuse field sound transmission loss has been measured according to ISO 15186-1:2003 Standard in a laboratory for automotive applications.

Figure 2 depicts experimental results for:

(a) Steel plate + Puler (with and without air cavities) + EPDM 2.9 kg/m^2

(b) Steel plate + PU (with and without air cavities) + EPDM 2.9 kg/m^2

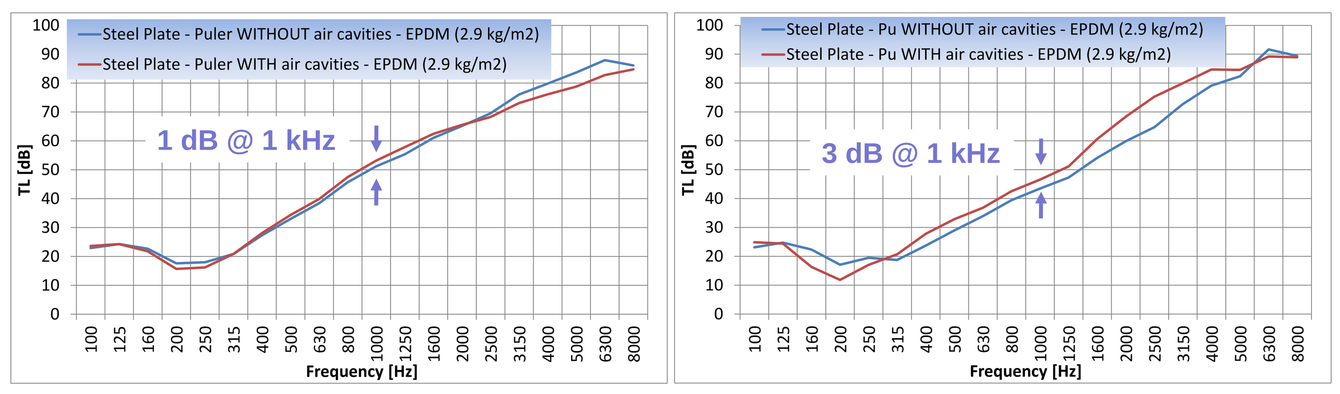


Figure 2: Air cavities effect on Transmission Loss for PU and Puler foams

As can be noted, in the case of polyurethane the creation of the air cavity leads to an improvement of the insulation performance of the system, equal to 3 dB at 1000 Hz and 12 dB at 2500 Hz; the increase tends to vanish at frequencies above 5000 Hz.

In the case of the Puler improvements are equal to 2 dB at 1000 Hz, and limited to frequencies up to 2000 Hz; over such frequencies the creation of air cavities determines a worsening of the isolation curve.

In order to get input parameters for numerical models, materials have been characterized and physical and mechanical properties are summarized in Table 1.

	Steel	EPDM	PU	Puler
E[N/m^2]	2.00E+11	2.24E+06	Fig. 3	Fig. 3
ν[-]	0.33	0.48	0.25	0.21
η [-]	0.05	0.1	0.28	0.54
σ[Ns/m^4]	-	-	126565	13014
ϕ [-]			0.93	0.86
α [-]			2.5	1.78
Λ[μm]		-	8	48
Λ'[μm]	-	-	120	231

Young's modulus for PU and Puler has been determined using a transmissibility based technique which minimizes difference between dynamic tests and analytical model for linear viscoelastic materials

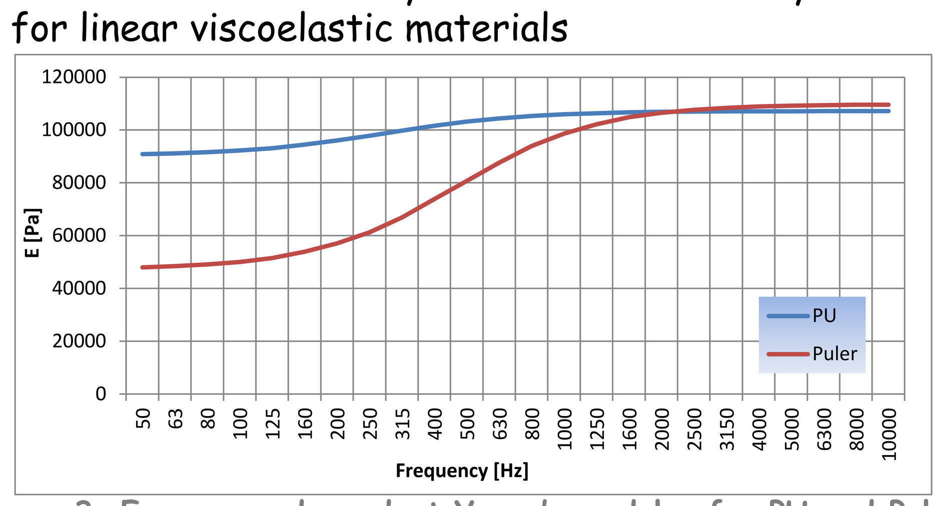


Figure 3: Frequency dependent Young's modulus for PU and Puler

3 – Numerical simulations

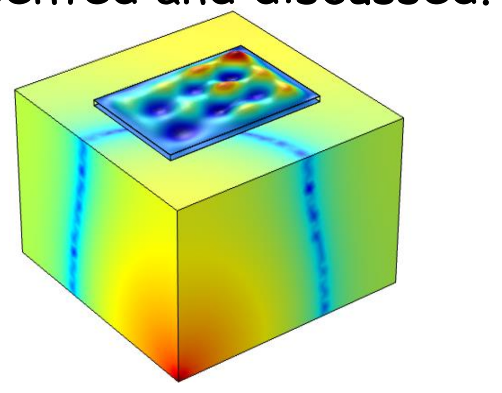
For the sake of simplicity only results on Steel plate + PU (with and without air cavities) + EPDM 2.9 kg/m^2 system will be presented and discussed.

3.1 – Finite element modelling

A finite element model of the real geometry of air cavities has been investigated using commercial software Comsol Multiphysics 4.3a. In order to reduce the computational cost of the model the emitted sound has been calculated using an analytical model based on the surface velocity of the outer layer (EPDM). Thus the Transmission Loss is calculated as follows:

$$TL = Lp_{cavity} + 10\log 10\left(\frac{W_{emitted}}{10^{-12}}\right) - 10\log 10(S) - 6 \quad [\text{dB}]$$

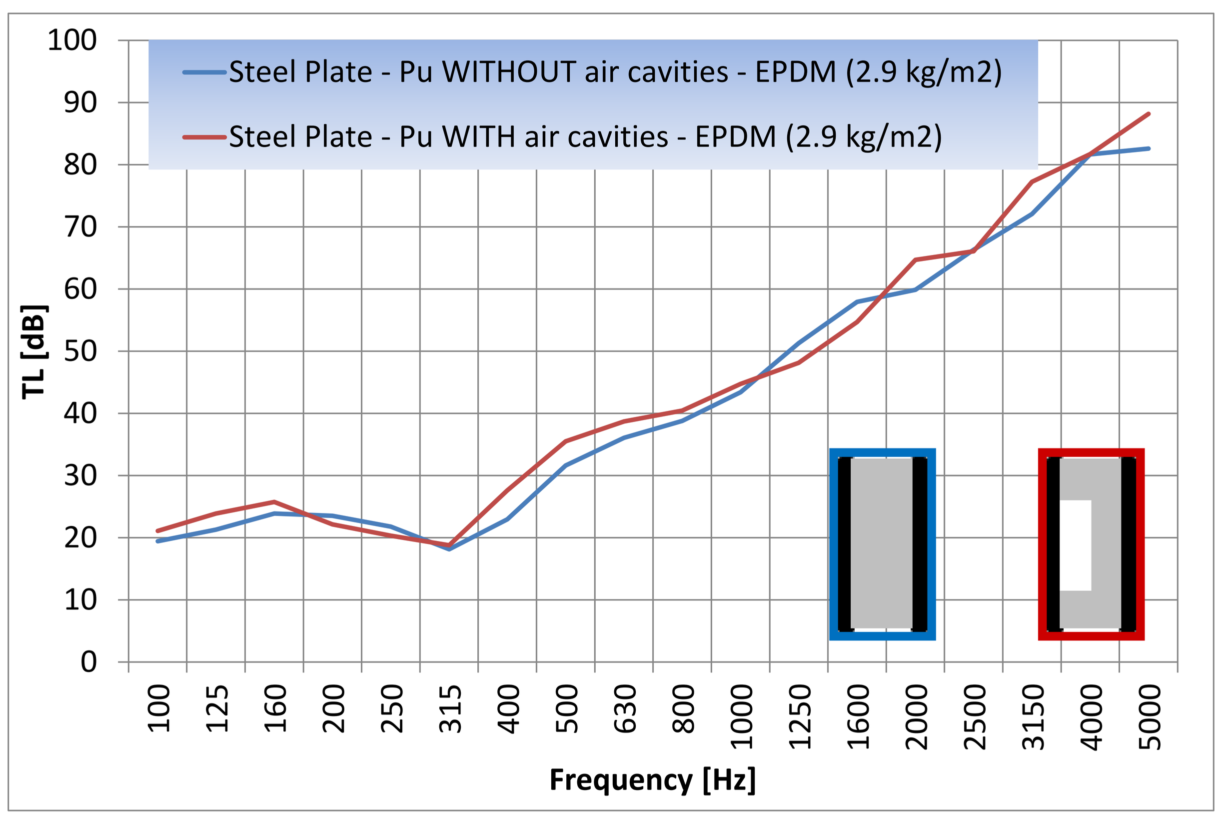
$$W_{emitted} = \frac{\rho c}{2}\int_S |v_n|^2 \, dS$$



being Lp_{cavity}, the average sound pressure level within the emitting domain, S the area of the samples, v_n [m/s] the normal velocity of the external layer, ρ [kg/m^3] the air density and c [m/s] the sound speed.

3.2 – Numerical results and comparison with tests

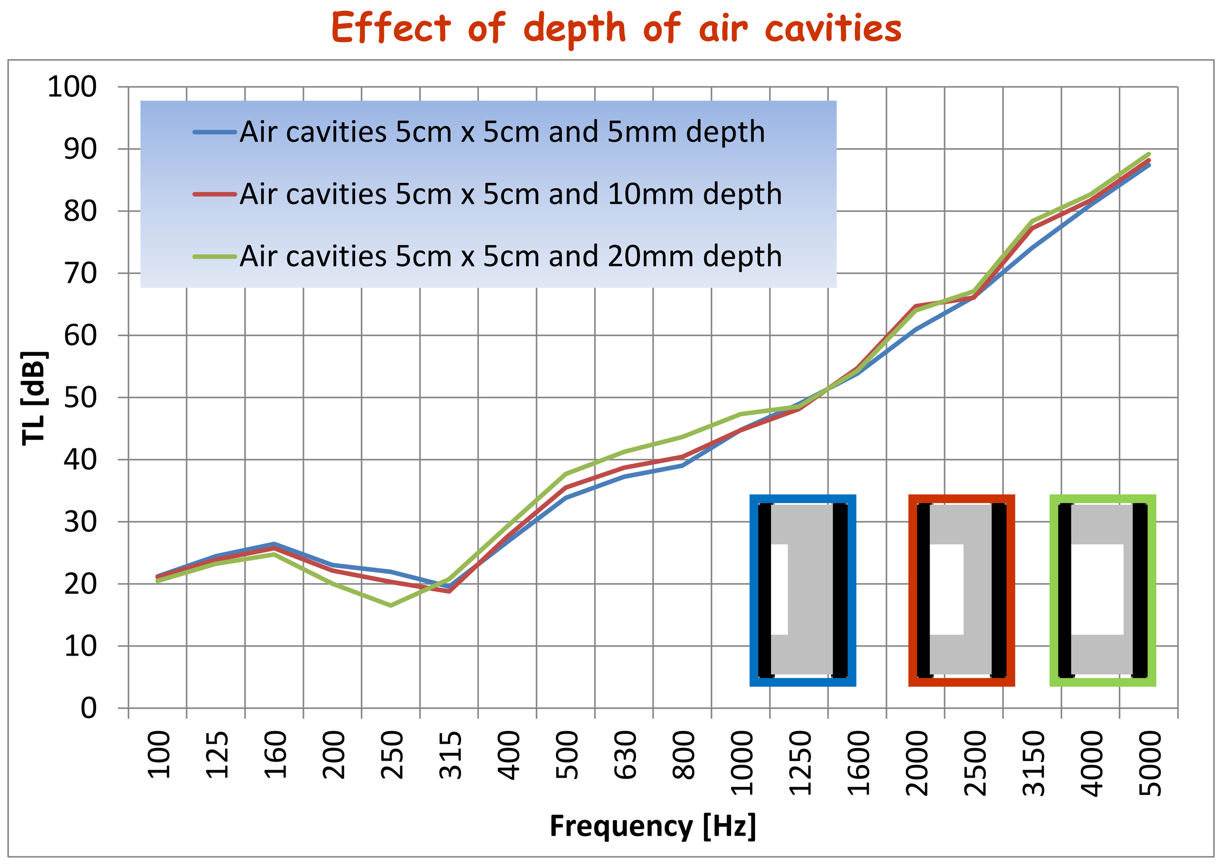
Effect of air cavities



Numerical models permits to highlight the benefit in using air cavities. Comparison with experimental tests is satisfactory up to 1 kHz while at higher frequencies FEM model underestimates the increase in sound transmission loss.

A shift towards lower frequencies is observed in the mass-spring mass resonance due to the decrease of the rigidity of the entire system.

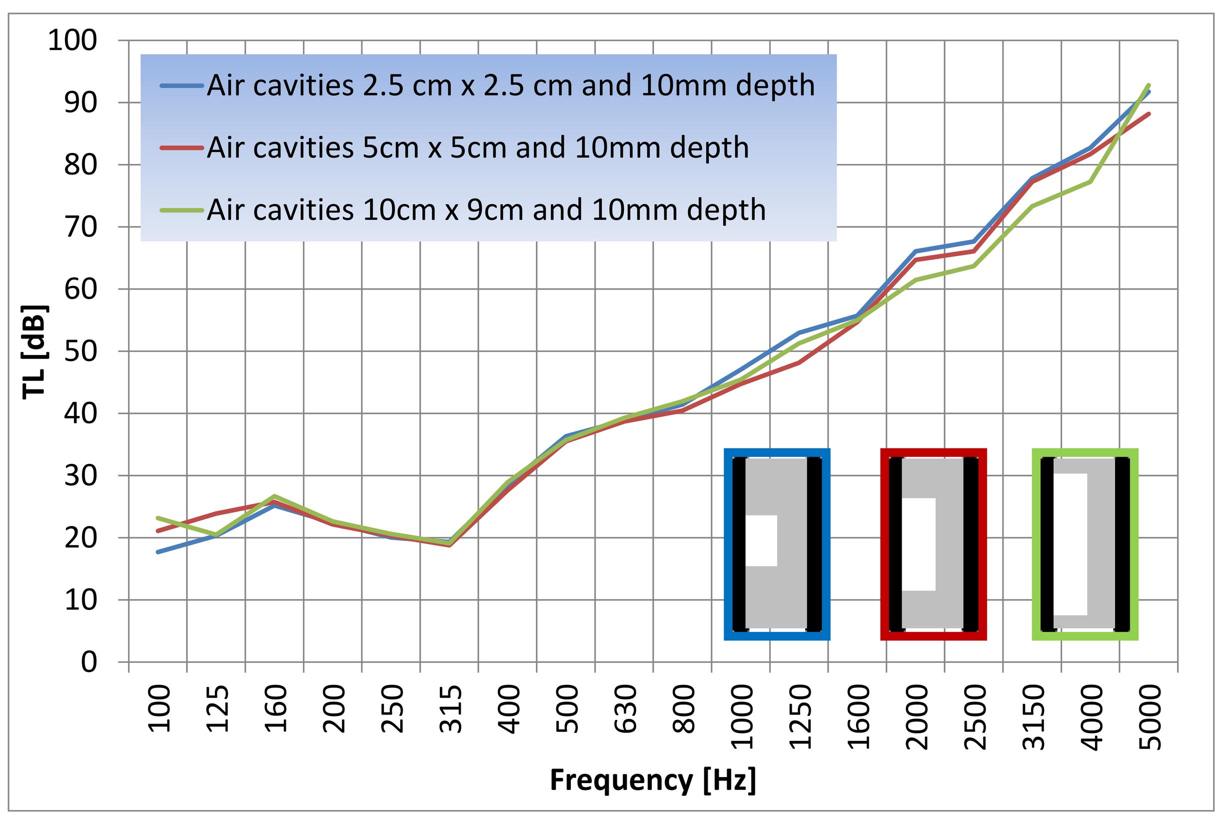
Effect of depth of air cavities



A series of numerical simulations with the same percentage of air cavities (44%) with different depths show that higher is the depth higher will be the increase in terms of sound transmission loss at frequencies up to 1 kHz.

Moreover a shift towards lower frequencies is observed in the mass-spring mass resonance due to the decrease of the rigidity of the entire system.

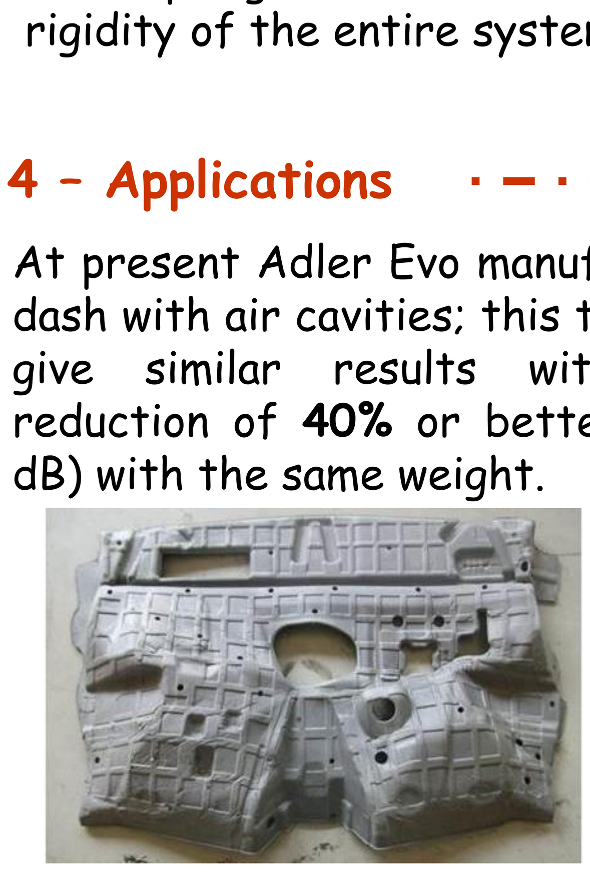
Effect of size of air cavities

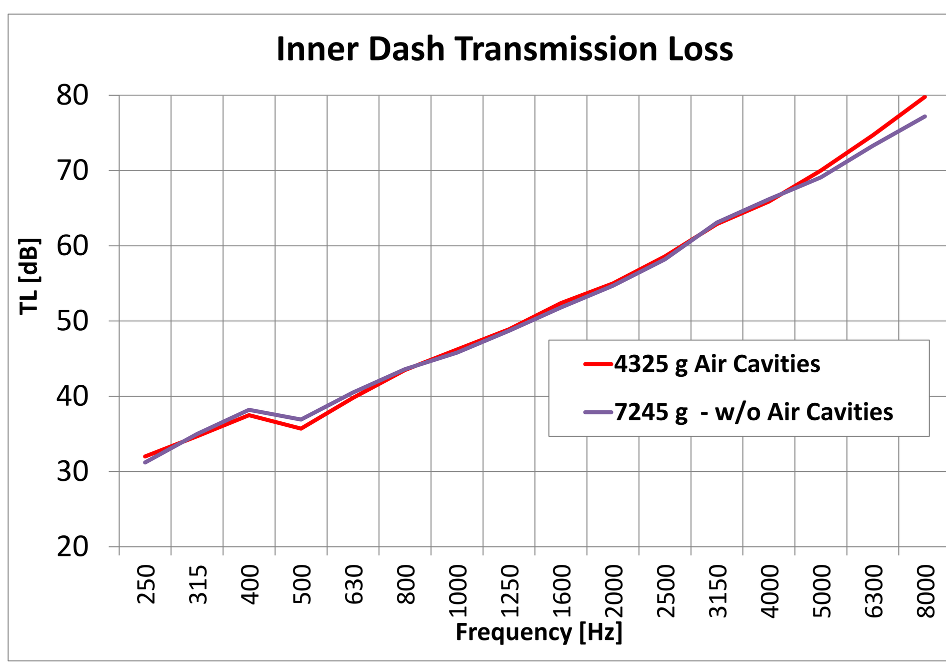


A series of numerical simulations with the same percentage of air cavities (44%) with different lateral size and same depth show that no effect is observed up to 800 Hz while at higher frequencies the increase in terms of sound transmission Loss is observed for the smallest air cavities (2.5 cm x 2.5 cm).

4 – Applications

At present Adler Evo manufactures inner dash with air cavities; this technology can give similar results with a weight reduction of **40%** or better results (+3 dB) with the same weight.





5 – Conclusions

- In order to increase acoustical performance and reduce the weight of soundproofing treatments it is possible to use air cavities within the main foams;
- Air cavities result in a reduction of the overall stiffness of the foam, a reduction of the resonance frequency of the system and a greater sound reduction at frequencies higher than the resonance;
- The increase in performance is significant to the middle frequencies and tends to vanish in the higher ones, as a function of the mechanical properties of the foam;
- This technology can be extended to all fields of noise control.7
- Numerical finite element modeling has been demonstrated to be a useful tool for designing the most appropriate geometry of air cavities