



PREDICTION MODELS OF AIRBORNE SOUND INSULATION

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ABSTRACT

The growing introduction of new insulation materials in building acoustics has caused an increase of the importance of the prediction tools. Indeed, the simulation allows selecting the strictly necessary laboratory measurements, and this way, costs are reduced. On the other hand, the necessity to fulfil the demands of the legislation has caused the appearance of different software's that facilitate the technician's work. As it is known, different prediction models exist, each one based on different hypothesis: adaptation of impedances, spatial behaviour of spectral components, energy statistical distribution, Finite Elements Method (FEM), etc. Each one of these models and methods present advantages and inconveniences, as well as certain limitations related with the starting hypotheses. In this work, different prediction models are analysed, especially the one based on adaptation of impedances, and the results are compared with those obtained when applying FEM and with experimental results. Some adjustments are also proposed to the models to improve the prediction in certain frequency ranges.

INTRODUCTION

Nowadays, prediction software's are tools to be considered in testing laboratories of airborne sound insulation. In the last past years, a multitude of multilayer panels is appearing to give a commitment solution between good sound insulation and acoustical conditioning. Moreover, there are appearing some new materials or recycled materials focused on acoustics, some of them still not characterized, which might form part of different constructive solutions in order to increase their airborne sound insulation.

Some theories describe the multilayer behaviour from the point of view of the acoustic insulation [1], and finally, a clear evolution from the mass law theory can be observed in different works about this topic. Some of the most important are Ookura & Saito model [2], based on the adaptation of impedances between different layers, Trochidis & Kalaroutis [3] or Bruneau [4] method, which uses the special Fourier Transform, or other models developed by Lauriks, based on Biot's theory [5], or Panneton & Atalla [6], based on Finite Element Method (FEM). Actually, the increase of computational capacity is giving more and more importance to these numerical methods.

In this study, two methods are compared: Ookura & Saito model [2] and Finite Elements Methods, and the results are further confronted with experimental measurements.

MATHEMATICAL MODEL: TRANSMISSION LOSS OF MULTIPLE PANELS IN A RANDOM INCIDENCE BY OOKURA & SAITO [2]

In this work, an impedance transfer method is developed, similar to the technique proposed by Beranek & Work [7], for the case of oblique incidence waves in a random field, which is easy to realize. Transmission Loss Index expressions are obtained for multilayer solutions with several combinations of solid materials, air cavities and sound absorbing materials. Bruneau [4] describes a similar method, with some corrections.

The model considers a general structure of infinite multilayer walls, as it is represented in Figure 1. This structure is constructed with N elements and each of these elements can be an impermeable layer, an air cavity or sound absorbing material, where p_i is the incident pressure wave. This incident plane wave acts on the left side of element N with the incidence angle θ . This incident wave continues propagating through the structure and radiates in free field, in the right side of this first element, according to a plane pressure wave p_t and a transmission angle θ_t . In this analysis, each one of the physic parameters of the element i is numbered with the subindex $l = 1, 2, \dots, n$, and a second subindex is used to indicate the right side (1) or the left side (2) of the element.

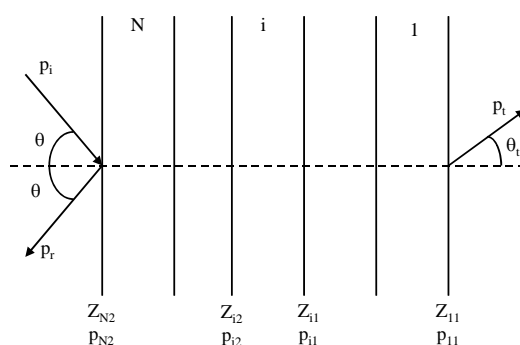


Figure 1.- Multilayer model

The relation between the pressure p_{N2} in the incidence surface and the incidence pressure p_i is the following:

$$\frac{p_{N2}}{p_i} = \frac{p_i + p_r}{p_i} = \frac{2Z_{N2}}{Z_{N2} + \frac{\rho c}{\cos \theta}},$$

where Z_{N2} is the normal acoustic impedance on the left side of the element N and $\frac{\rho c}{\cos \theta}$ is the normal acoustic impedance in free field of a surface with oblique incidence. Using the pressure conditions in each surface, the transmission coefficient can be written, and obtained, by means of the suitable integration. Finally, the transmission loss in a random incidence field is:

$$\tau(\theta) = \left| \frac{p_t}{p_i} \right|^2 = \left| \frac{p_{11}}{p_i} \right|^2 = \left| \frac{p_{N2}}{p_i} \right|^2 \left| \frac{p_{N1}}{p_{N2}} \dots \frac{p_{i1}}{p_{i2}} \dots \frac{p_{11}}{p_{12}} \right|^2.$$

The pressure relations can be obtained from impedance characteristics of each element which are classified in impermeable layer, sound absorbing material and air cavity. The impedance expressions can be consulted in the original work.

FINITE ELEMENTS METHOD

For Finite Elements simulations, COMET Acoustics software has been used [8]. Figure 2 presents an example of a FE Model, where the acoustical solution is collocated between two air layers. This can be described by the following equation:

$$L_s w = p^e + p^r + p^t,$$

where L_s is the differential operator acting on the structural displacement w , p^e the excitation pressure, p^r the reflected pressure in the source side and p^t the transmitted pressure in the receiving side.

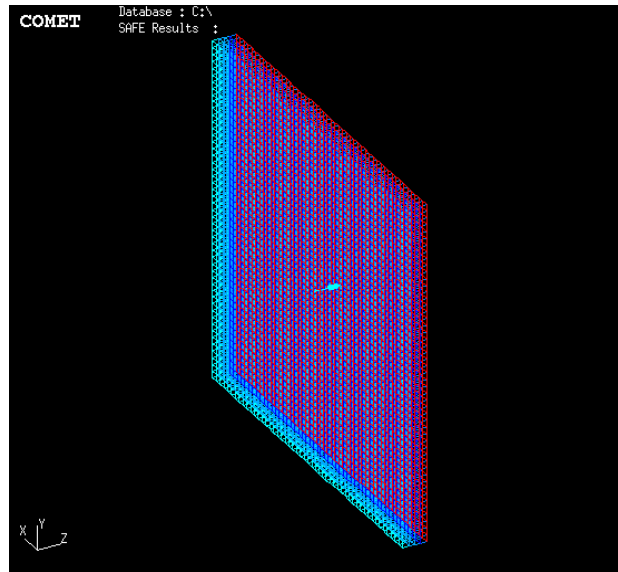


Figura 2.- Finite Element Model

The pressures and displacements are assumed to be in the linear range, and the time dependency is assumed and thus, omitted. This formulation results in a system of motion equations with n degrees of freedom, depending on mass and stiffness matrices, as described in [9,10]. A diffuse field excitation is considered in the source side, as well as an adequate coupling between internal material and surrounding air layers [11]. Then, the structural displacement is related to the FE nodal displacements, and the pressures are transformed to force vectors.

In order to reduce computation time, the displacements are expressed in a finite number of frequencies, and the integration is performed on each side of the structure. Finally, the sound transmission loss, or sound reduction index, of the structure is calculated as the quotient of real power radiated from the structure to the receiving side over real incident power.

NUMERICAL RESULTS

In Table 1 the characteristics and global results of simulations of different heavy laminated materials are showed, with Ookura & Saito and with FEM. Frequency results are presented in Figure 3 for Ookura & and in Figure 4 for Finite Elements Method.

Step	Young (Gpa)	Poisson	Density (kg/m ³)	Loss factor	Thickness (mm)	Dw (dB) EL	Dw (dB) OOK
01	2,9	0,37	825	0,06	1,1	22	22
02	2,9	0,61	825	0,06	1,9	26	26
03	2,9	0,37	825	0,10	1,9	26	27
04	2,9	0,61	825	0,10	1,1	22	22
05	1,7	0,61	1375	0,06	1,9	30	31
06	2,9	0,61	1375	0,06	1,1	26	26
07	2,9	0,37	1375	0,10	1,1	26	26
08	2,9	0,37	1375	0,06	1,9	31	31
09	1,7	0,37	1375	0,10	1,9	31	31
10	1,7	0,61	825	0,06	1,1	22	22
11	1,7	0,37	1375	0,06	1,1	26	27

12	1,7	0,37	825	0,06	1,9	26	26
13	1,7	0,61	1375	0,10	1,1	26	27
14	2,9	0,61	1375	0,10	1,9	31	31
15	1,7	0,37	825	0,10	1,1	22	22
16	1,7	0,61	825	0,10	1,9	26	27

Table 1.- Heavy laminated materials

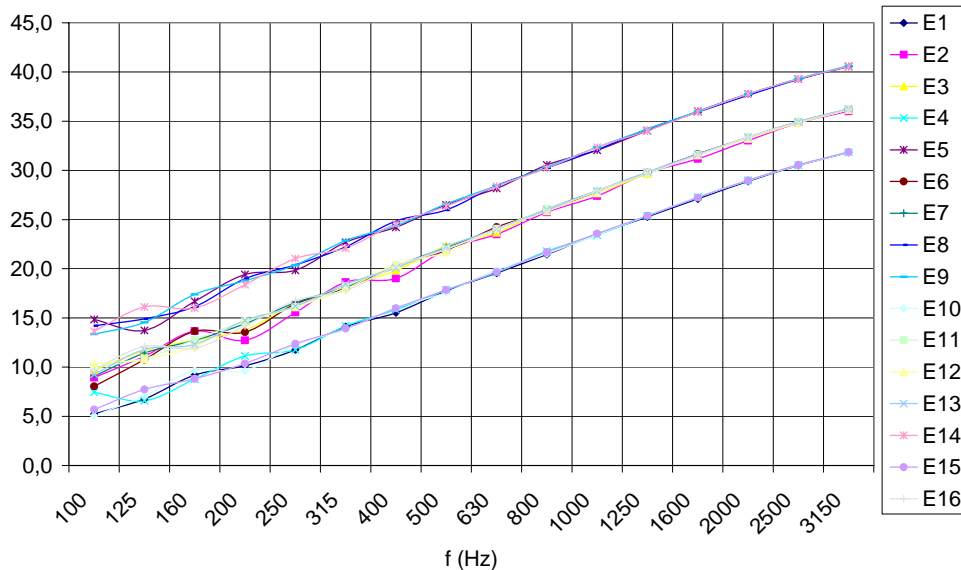


Figure 3.- Heavy laminated materials. Ookura & Saito

In Table 2 the characteristics and global results of simulations of different 2-layer materials (heavy laminated + sound absorbing material) are showed, with Ookura & Saito and with finite elements methods. Frequency results are presented in Figure 5 for Ookura & and in Figure 6 for Finite Elements Method.

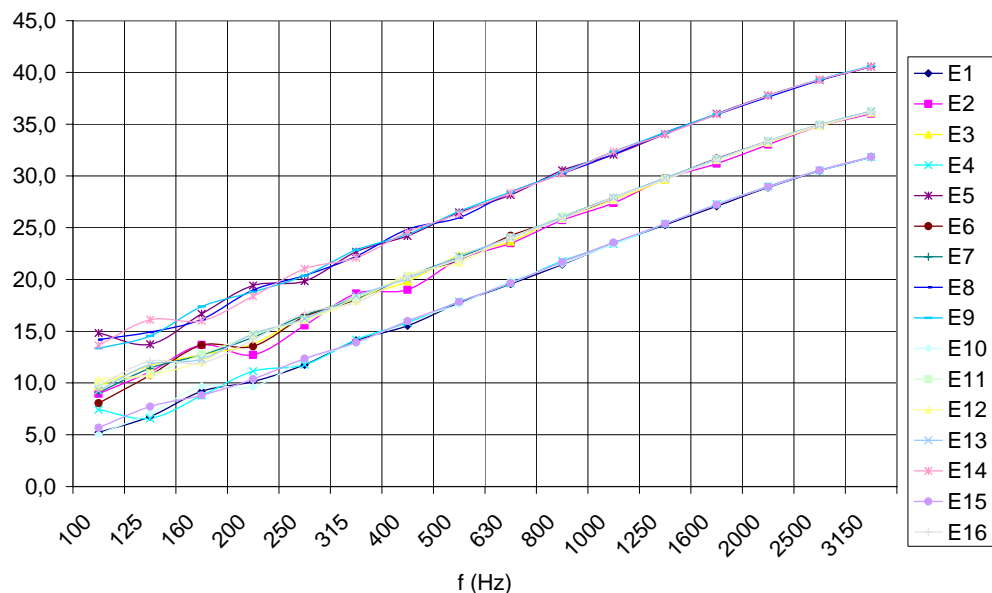


Figure 4.- Heavy laminated materials. Finite Elements.

Ejecución	Densidad Lam (kg/m ³)	Espesor Fiel (mm)	Dw EL (dB)	Dw OOK(dB)
01	825	15	25	27
02	1375	25	29	31
03	825	15	25	26
04	1375	25	30	31
05	825	25	25	27
06	825	25	25	29
07	1375	15	29	31
08	1375	15	29	30

Table 2.- 2-layer materials (heavy laminated + sound absorbing material)

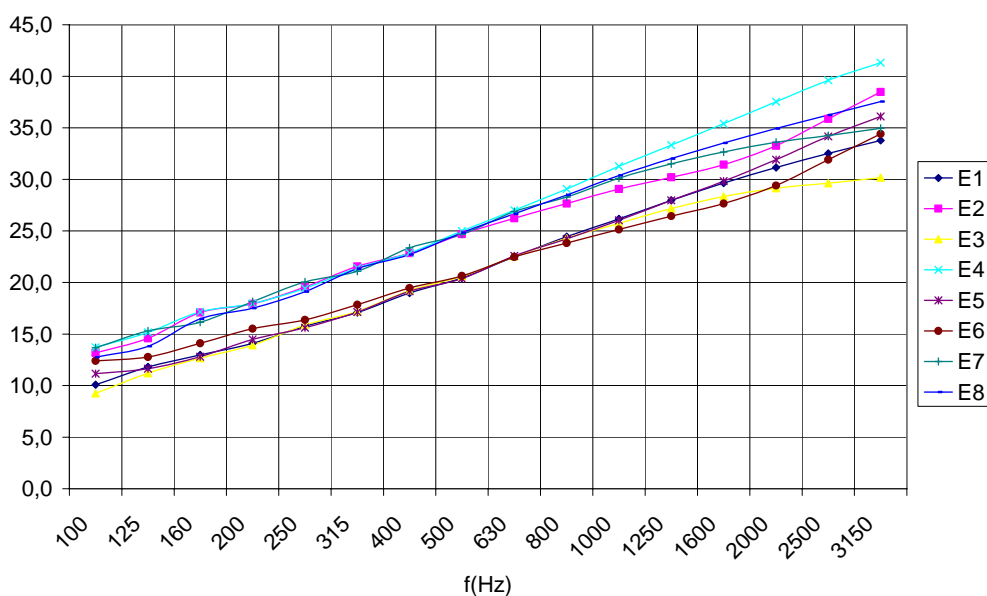


Figure 5: 2-layer materials (heavy laminated + sound absorbing material). Ookura & Saito

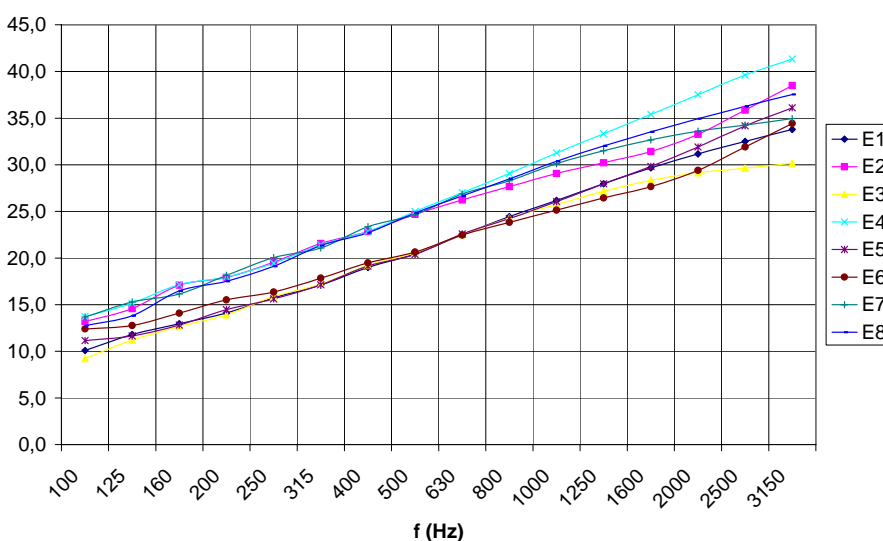


Figure 6: 2-layer materials (heavy laminated + sound absorbing material). Finite Elements

EXPERIMENTAL RESULTS

In Figure 7 both models results are showed with experimental values of a 2-layer materials (heavy laminated + sound absorbing material).

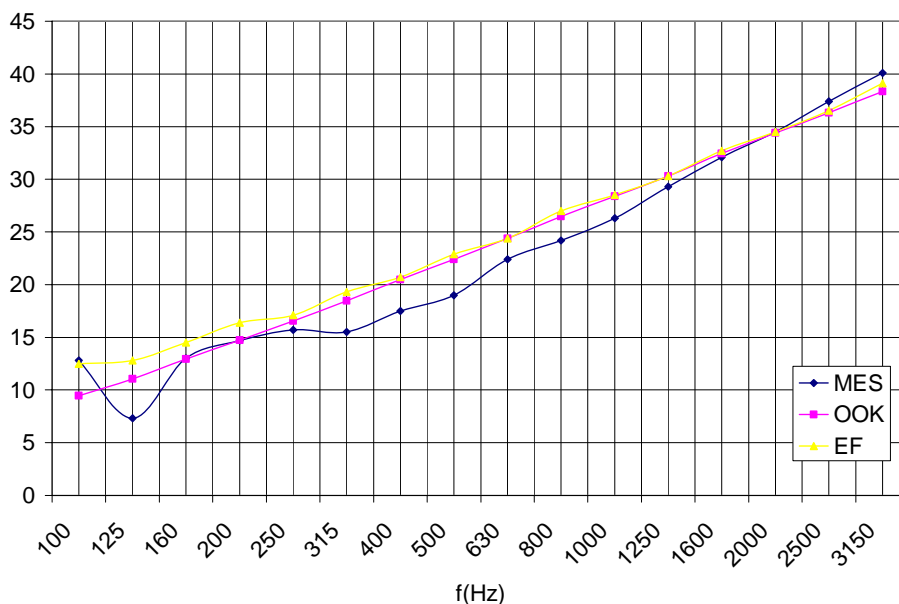


Figure 7.- Comparisons with experimental results.

CONCLUSIONS

Se han comparado dos métodos matemáticos totalmente diferentes, obteniendo resultados aceptables. Los resultados son bastante parecidos al resultado experimental. El análisis de diferentes configuraciones de láminas nos indica que hay una dependencia clara con la densidad y el factor de pérdidas, pero es poco sensible a los parámetros elásticos.

In this work, two methods totally different are compared, the results are acceptable. The results are enough similar to the experimental results. Different lamina's configurations laminas are analyzed, we can see an evident dependency with the loss factor and the density, but it is little sensible to the elastic parameters.

The results show that it's possible to obtain results with high degree of precision, although it's necessary to improve the behaviour of both models, above all for acoustic field assumptions.

References:

- [1] Alba Fernández, Jesús, "Algoritmos De Modelado De Particiones Multicapa Para La Predicción De Su Aislamiento Acústico A Ruido Aéreo", Tesis Doctoral (2000)
- [2] Ookura K., Saito Y., "Transmission Loss Of Multiple Panels Containing Sound Absorbing Materials In A Random Incidence Field", *Internoise 78*, 637-642
- [3] Trochidis A., Kalaroutis A., "Sound Transmission Through Double Partitions With Cavity Absorption", *Journal Of Sound And Vibration* 107 (2), (1986) 321-327
- [4] Bruneau M., "Manuel D'acoustique Fondamentale", Editions Hermès (1998)
- [5] Panneton R., Atalla N., "Numerical Prediction Of Sound Transmission Through Finite Multilayer Systems With Poroelastic Materials", *J. Acoust. Soc. Am.* 100 (1), (1996) 346-354
- [6] W. Lauriks, P. Mees & J. F. Allard, "The Acoustic Transmission Through Layered Systems", *Journal Of Sound And Vibration* (1992) 155 (1), 125-132
- [7] Beranek L. L., Work G. A., "Sound Transmission Through Multiple Structures Containing Flexible Blankets", *J. Acoust. Soc. Am.* 21, (1949) 419
- [8] "COMET Acoustics User Document", V5.2, Collins & Aikman, Plymouth, Michigan
- [9] Brunsog J., Davidsson P. "Sound transmission of structures. A finite element approach with simplified room description", *Acta Acustica* Vol. 90(2004)
- [10] Bathe K.J., "Finite elements procedure", Prentice Hall, Upper Saddle River, New Jersey (1996)
- [11] Marant V., Aguilera J.L., "Método global de diseño de soluciones optimizadas de aislamiento acústico", *Tecnicacústica* 2006