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FINITE ELEMENT METHOD (FEM) MODEL FOR THE HEARING PROTECTOR NOISE ATTENUATION FOR IMPULSIVE NOISE

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ABSTRACT

The effectiveness of plug type hearing protectors in situations of high amplitude impulse noise levels remains the subject of research with objective testing and/or modelling techniques offering the only realistic method of providing rapid performance data for design and qualification of the protector. Based on a simple 2-D finite element model (FEM) of the auditory canal, the work presented in this paper examines some of the basic parameters, which influence the performance of the plug (density, position and length). Some results of experimental tests on a typical moldable foam plug, using an acoustic test fixture and source impulse of 159.7 dB peak and 1.38 ms duration of the principal pulse, are also presented.

1 - INTRODUCTION

Plug type hearing protectors offer a quick and cheap method of protecting hearing and, under certain circumstances such as for example military use, they offer the only practical method of providing protection. The evaluation hearing protectors for the attenuation of high amplitude impulsive noise cannot be carried out using the conventional subjective REAT (Real Ear Attenuation at Threshold) technique. Other problems such as resolution, cost and turn-around-time are inherent problems in the REAT method which often leads to a design synthesis based on the manufacture and test of several prototypes. Clearly, quicker and less costly techniques for the development of auditory protectors are desirable. FEM has become a common method of modelling and is available using affordable desk top computing hardware. Software packages, such as Sysnoise, offer relatively easily to provide solutions prior to final prototyping, accreditation and manufacture. The noise impulse is a transient pressure pulse of short duration, normally considered to be less than 1 second, that contains peaks of acoustic energy produced either in isolation or as a series of pulses occurring at regular or irregular time intervals at peak levels of sound pressure in excess of 110 dB [1]. The peak level, rise time and duration of the pulse are dependent on the source parameters such as size, geometric characteristics [2]. Essentially, two pulse types are classified as either non-reverberant (Duration A) or reverberant (Duration B). The external ear comprises the pinna, auditory canal and tympanum. A canal length between 27−37 mm and diameter of 7.5 mm at the tympanum are normal dimensions for the average adult. The walls of the auditory canal have a dilation impedance approximately four orders greater than the air in canal itself and can be treated as a rigid surface [3]. Impulsive noise is particularly dangerous to hearing as it is the inability of the human auditory system to sense the peak level accurately in relation to the levels of steady state noise.

2 - NUMERIC SIMULATION

A series of experiments were carried out to provide data in order to provide some validation for the FEM model. This was done using an acoustic test fixture shown in Fig. 1. The acoustic impedance of the human tympanum has a similar value to that of the acoustic impedance of the microphone [4]. The noise impulse was generated using an exploding pressure vessel. Fig. 2 shows and example of the attenuation of a 159.7 dB peak pulse by a foam plug placed level with the entrance of the auditory canal simulator tube.

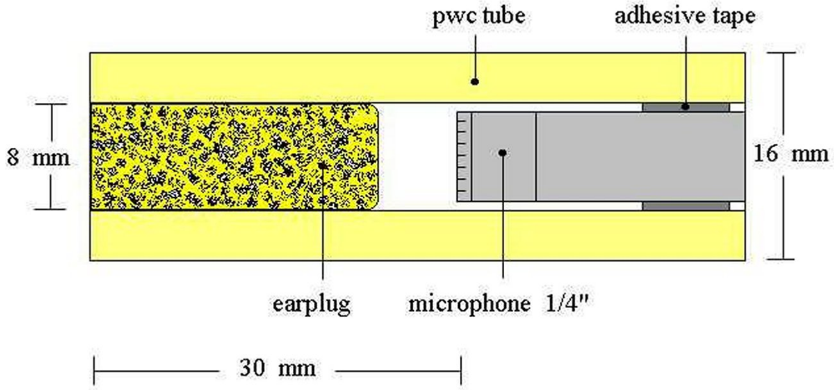

Figure 1: Auditory canal simulator.

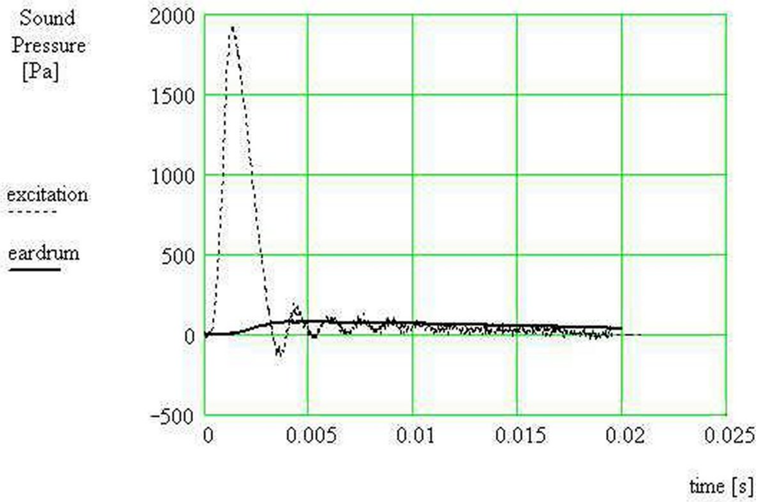

Figure 2: Experimental measurement at the tympanum, with and without plug.

FEM modelling was carried out using the Sysnoise 5.4 software package which has the capability of solving problems of wave propagation in the time domain. The external auditory canal was modelled simply as a two dimensional straight uniform tube. Boundary conditions for the ear model were imposed at the surfaces and at the ends of the canal using impedances for the tympanum and foam plug protector as shown in Fig. 3. The external excitement was imposed using the impulsive sound field measured during the experimental study. Fig. 4 shows an example Sysnoise simulation of the pressure at the tympanum with auditory plug inserted and using the experimentally measured excitation pulse from Fig. 2 . This reference simulation represents the basic condition of materials (properties used in the reference simulation; for air at ambient pressure and temperature: speed of the sound = 344 m/s, density = 1.21 kg/m^3; for the foam plug material: speed of the sound = 320 m/s, density = 98 kg/m^3, structural factor = 7.9, porosity = 0.9, resistivity = 25000 Ns/m^3), boundary and excitation level. An interesting case of sound pressure distribution inside the auditory canal (without plug) is shown in Fig. 5, where it can be seen that the maximum sound pressure at the typanum position, at 1.42 ms is increased to 1.99 kPa (160 dB peak).

The initial conditions at t=0 were imposed as 0 pressure and 0 derivative pressure. The impulsive pressure loading was distributed over the mesh at position x=30 mm (see Fig. 3). An impedance value of 10^8 Ns/m^5 was imposed at the position x=0 representing the tympanum, while a value of 10^4 Ns/m^5 was used to represent the impedance of the walls of the auditory canal. The parameters that controlled

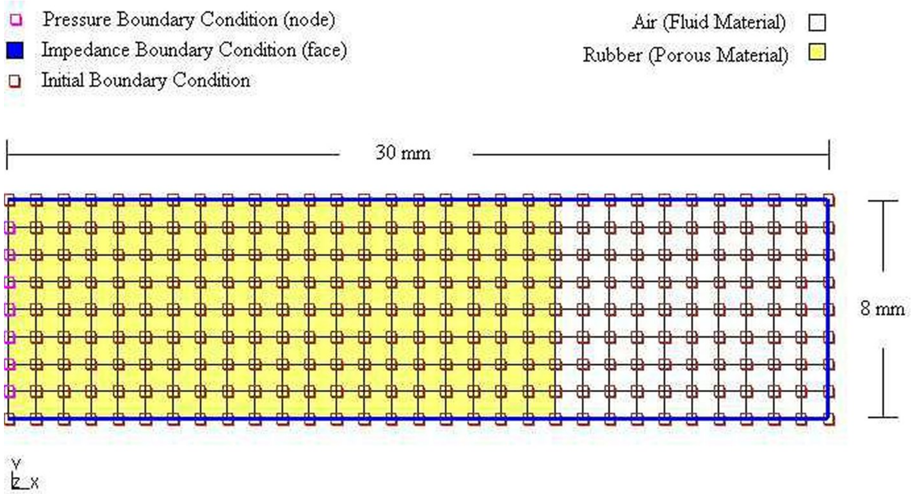

Figure 3: Numerical model of auditory canal and boundary conditions applied.

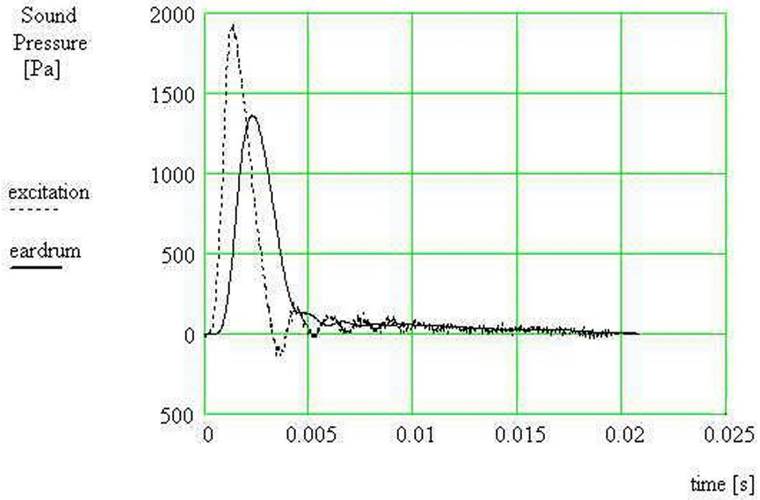

Figure 4: Simulation test at the tympanum with plug, using the reference condition.

the numeric integration in the time domain obeyed the outline of integration of Newmark that considers α=0.25, δ=0.5. With these values of α and δ the solution transient does not exhibit an amplitude error. To avoid oscillation or overshoot effects a mesh refinement and step selection was used such that the product of the speed of the sound for the step in the time, would be equal to the size of the element [5]. In this way a stable solution was obtained using the conditions listed in Table 1.

Condition	Plug Parameter		
	Density [kg/m^3]	Length [mm]	Position [mm]
1	275	5	5-25
2	550	15	10-30
3	1100	25	—
reference	98	20	0-20

Table 1: Conditions of the parametric study.

3 - DISCUSSION AND CONCLUSIONS

When considering the different simulations presented in this paper (see Figs. 6, 7, 8, 9 and 10), it can be observed that the attenuation of sound pressure is increased when the plug is located very close to the tympanum (see Fig. 6). When increasing the length of the plug, this attenuation (at the tympanum) is significantly higher than in the case of simply altering the location of the plug inside the auditory canal.

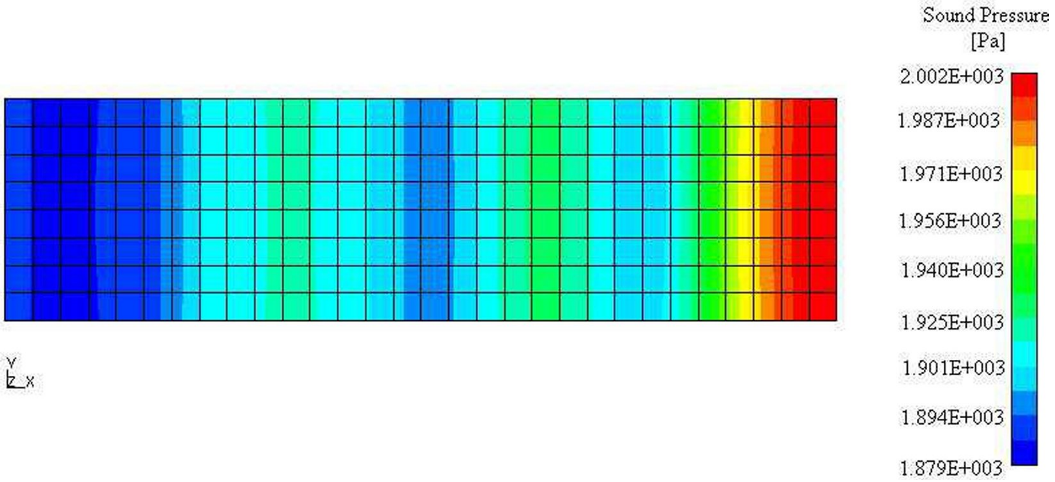

Figure 5: Sound pressure inside the simulated auditory canal (without plug).

The numerical simulations indicate that the attenuation of a plug is strongly linked to the density of the plug material used and, for the largest value of density considered here (1100 kg/m^3) the model predicts an attenuation of 20 dB while keeping the porosity, resistivity and structural factor constant. Clearly, this result from the FEM model has to be considered with respect to the experimental test results where a sound attenuation of over 30 dB was measured with an apparent lower plug density of 98 kg/m^3 (uncompressed). However, the form of the experimental and FEM curves are similar in the rise time to peak pressure and overall duration of the principal pulse (see Fig. 10). In reality, the plug is held inside the auditory canal in a compressed state and, therefore, has is higher value of density, lower porosity and higher resistivity. An example of the distribution of sound pressure inside the auditory canal, with plug inserted, is shown in Fig. 11 where the effect of attenuation of the plug and the maximum sound pressure of 227.98 (141 dB peak) occurs at t=5.16 ms.

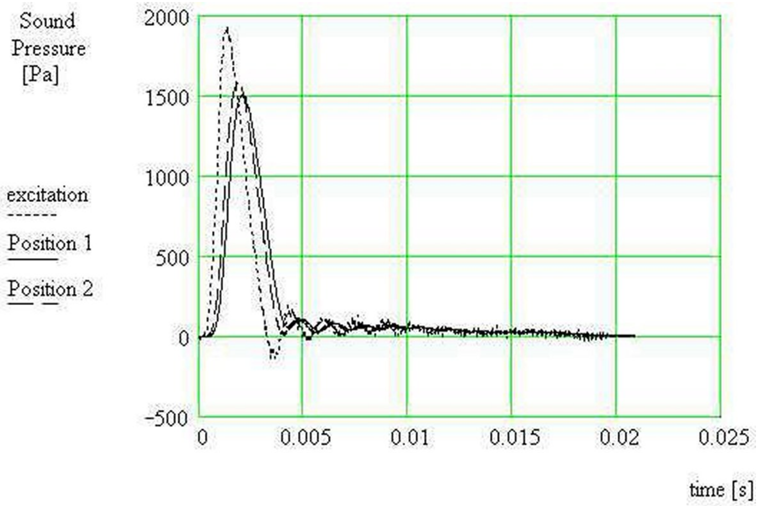

Figure 6: Simulation with position parameter.

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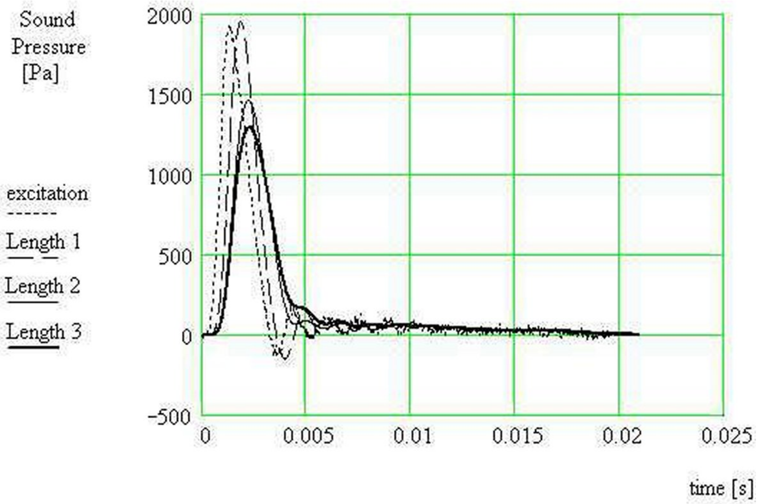

Figure 7: Simulation with length parameter.

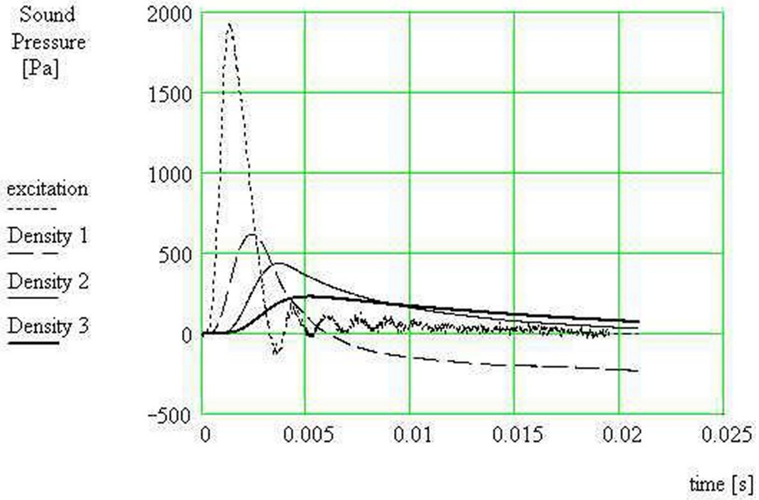

Figure 8: Simulation with density parameter.

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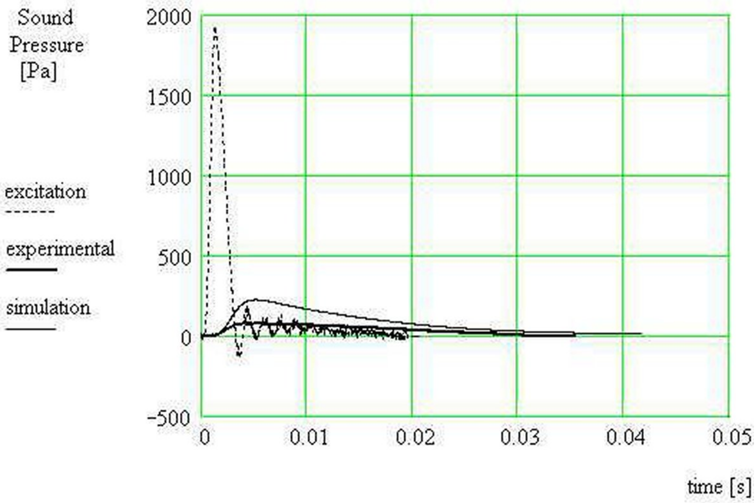

Figure 9: Excitation, experimental and simulation (density 3).

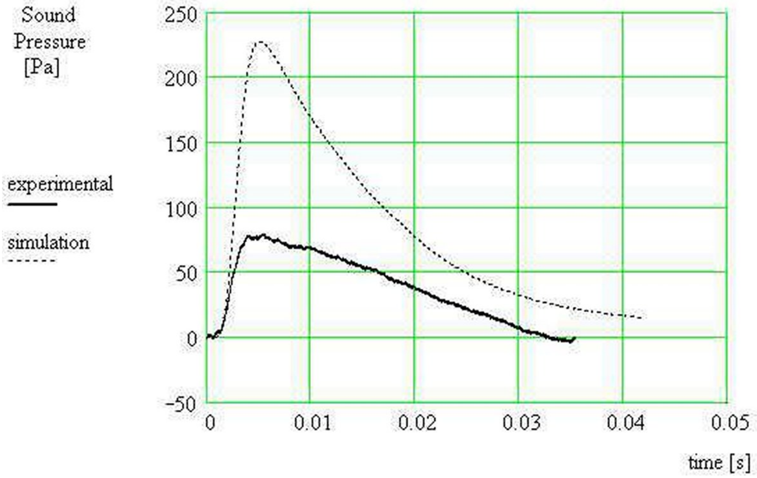

Figure 10: Experimental and simulation (density 3).

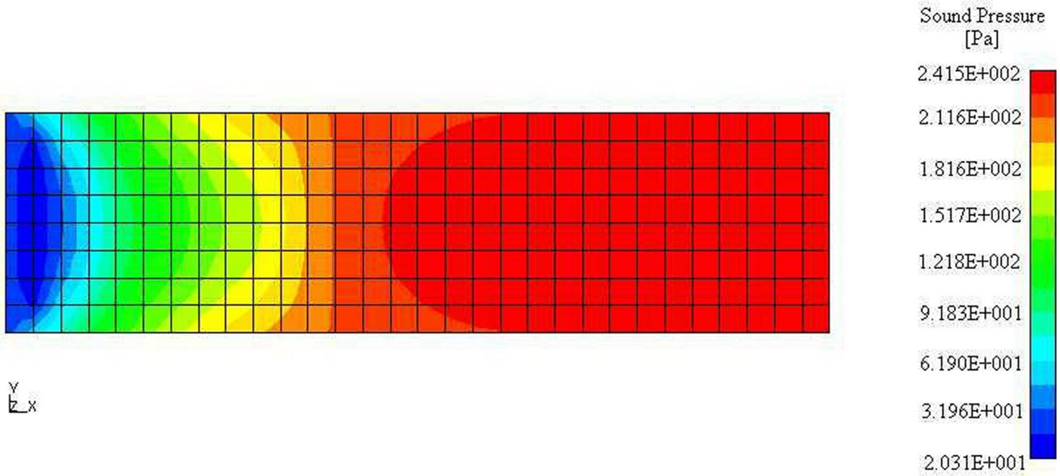

Figure 11: Sound pressure inside the simulated auditory canal (with plug).