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DESIGN OF AN OBJECT ORIENTED FINITE ELEMENT SOFTWARE FOR VIBRO-ACOUSTIC PROBLEMS - APPLICATION TO POROELASTIC MULTILAYER INSULATING SYSTEMS OF AEROPLANES

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ABSTRACT
In contrast to many other works dealing with Object Oriented Finite Element Method (OO-FEM), which used class inheritance in order to specialise finite elements to acoustics and to structure, we have developed an OO-FEM which solve Differential Equations in a formal manner. It is thus the user who creates the type of the finite element which best suited to the problem. If the first vibro-acoustic computations considered only problems of pure acoustics coupled to structural dynamics, we intend today to take into account absorbing materials. Thus, we illustrate our work with the study of poroelastic materials as glass wool, for which variational formulation is non obvious and was, in any way, out of reach of the first software generation.

1 - INTRODUCTION
In this paper will be presented the most interesting points that we have experienced during the realisation of a specific vibro-acoustic software developed by using object oriented (OO) concepts. The code which name is CAVOK (Computations on Acoustics and Vibro-acoustics OK) is to be applied in the field of vibro-acoustics of transport (car, train, aeroplane). At first, we will explain our motivation for this project and the general architecture of the code. The second part of the paper is devoted to actual works for predicting the transmission loss of multi-layered insulating panels.
Actually, this program allows to:

- study various variational formulations
- model poroelastic multi-layers
- teach the FEM

The original aspect of this work comes from the proposed implementation of the FEM. The common approach is to use OO class heritage to specialise Finite Elements (FE) to acoustics or structure. In this work, we have privileged an approach based on the formal solution of partial differential equations.
It is thus up to a user to define the finite elements corresponding to the variational formulation which is to be solved. We will also show that such an approach is attractive from the point of view of design and programming for the problematic conception of too complex inheritances is avoided and the resulting code is smaller.

2 - SOFTWARE ENGINEERING
The whole of the software is implemented in C++ and runs as a stand-alone application under Windows. It has a form of an interactive CAD software. More detailed explanations of quality gains (time of development, maintenance, modularity, code readability) that can be achieved by adopting OO languages instead of classical non-object languages (Fortran 77, C) can be found in the reference [1,2,3].

Nevertheless, the choice of an OO language to develop the whole of this application can be discussed nowadays. The OO approach demands an advanced conception of the software which is not easy to put in place. It seems today, that more than the use of a specific language (C++, C, Fortran, Java,...), the help of software engineering tools (which are now available) is of major importance for fast and coherent developments. According to our experience, the conception is to be divided in 2 levels:

- The general CAD environment
- FEM programming

As much as the first point is concerned, it is the broadness of CAD concepts which makes the conception difficult within the OO approach. Thus, higher level languages such as script ones represent a way to develop the main program. The other way round is to use design patterns. We have used the pattern called MVC (Model-View-Controller) for the general organisation of this software. The Model contains a list of pertinent entities of CAD and FEM domains, Views allow to manipulate data and the Controller deals for the communication between the Model database and Views.
Concerning the second point which is relative to FEM programming, C++ is particularly well suited given that high-level abstractions (as finite elements) can co-exist with low-level programming (C-like code) needed to improve the efficiency of calculation steps. Details explanation of our implementation can be found in [4]. The formal side of our approach comes from the fact that neither Degrees of Freedom nor Finite Elements have predefined physical nature. The input is the variational formula to solve. Each new type of Finite Elements is built, using a *Reference Finite Element Class* which acts as a FE Generator.

3 - APPLICATION TO ACOUSTIC INSULATING SYSTEM

The leading industrial problems which sustains our development is linked to aeroplanes insulating systems. The system to study is a multi-layer made of: the skin of the aeroplane, a visco-elastic damping layer, glass-wool poroelastic layers, an acoustic cavity and the composite interior revetment of the cabin. For this problem, we have used our software to create FE based on the Love-Kirchhoff and Reissner-Mindin theories of plate bending, poroelastic elements according to the (u,W) formulation detailed in [5] and pressure acoustic elements. Validation of each of these fields is now acquired and we make tests to validate the overall coupling system. At present, 2D and 3D computations show bad convergence when all domains (structural, poroelastic, acoustic) are involved. Further works must be done to improve numerical solutions. These problems do not occurred in 1D simulations and our tool is now currently used to analyse 1D experiments as presented hereafter.
The poroelastic finite element created by CAVOK, have been firstly validated from [5] and [6]. Complete examples of single and multi-layered poroelastic computations can be found in these references. Next, the code was applied to the simulation of a series of experimental tests undergone by Dassault Aviation at "Le Mans" University. The example presented is extracted from this study.

Glass wool measured characteristics :

Length : 25.4 (mm)
Porosity: 0.98
Tortuosity: 1
Resistivity: 35 E+3 (N s m-4)
Viscous dimension: 60 E-6 (m)
Thermal dimension: 150 E-6 (m)
Frame density: 9.6 (kg m-3)
Frame Young Modulus (estimated) : Ys=10 E+3 (Pa)
Frame damping Ns = 0.05 so that Y =Ys(1+jNs)
Poisson coefficient: 0.0

Figure 1: Material characteristics.

A sample of glass-wool for which poroelastic material characteristics has been determined before (fig. 1) is placed in an impedance tube. The absorption coefficient is compared to FE calculations (fig. 2). For this mono-dimensional problem the FE model is composed of 10 nodes linked with 1D linear poroelastic element. At the end of the tube the frame is clamped (u = 10) and the fluid is impermeable (w = 0). On the other end, where a plane wave arises, the material is free. The comparison of figure 2 shows a good agreement between tests and FE calculus.

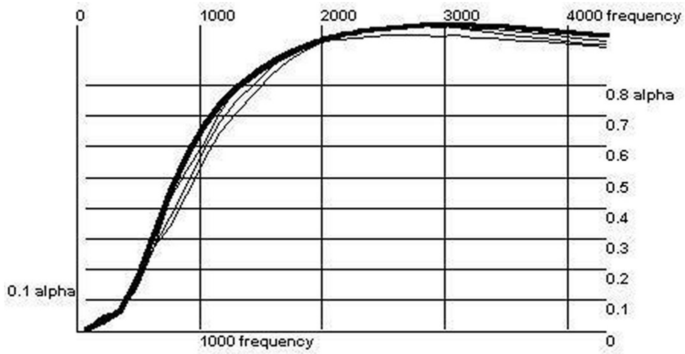

Figure 2: Absorption coefficient (alpha) from three tests (light curves) and FE calculation (bold curve).

4 - CONCLUSION

This work shows that within an OO approach, a formal implementation of the FEM is more attractive compared to the static FE class inheritance commonly used in others OO approaches. The implementation is more natural and the method is more flexible for it allows to solve a wide range of Differential Equations. In particular, coupled vibro-acoustic studies including poroelastic medium are made possible. For this very problem and at present, 1D simulations are operatives but 2D and 3D computations are numerically difficult when poroelastic medium are coupled with structures and air cavities. Further works will consist in improving numerical schemes and modelling rules.

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