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CALCULATION OF THE ACOUSTIC RADIATION OF STRUCTURES WITH OPENINGS

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ABSTRACT
This article presents a method applied to the acoustic radiation of a parallelepiped structure with an opening. The interior/exterior problems are solved separately and coupled using continuity conditions at the opening surface between the two domains. The current approach is illustrated using both directivity diagrams and color scaled pressure representation.

1 - INTRODUCTION

Although acting directly on the source is preferable for machine noise reduction, partial or full encasing are often used. Encasing design optimization needs the understanding and the modeling of its vibro-acoustic behavior. Most of scientific researches conducted on this particular scope are concerned with full encasing. But many machines require feeding and supplying (fuel, ventilation, and raw material) and modeling shall therefore include functional apertures to fit with industry application. A possible approach to solve such problems is presented here. First we describe the problem mathematical formulation, then the numerical method used to obtain a solution. On these bases, a scientific software, BEMOL, has been developed which allows calculating the acoustic radiation of a structure with openings vibrating with a given velocity. A comparison is done with results obtained on a closed structure.

2 - FORMULATION

The structure surface is moving with a velocity V_n. One of the structure faces comprises an opening. The radiated acoustic pressure p is expressed using Helmholtz equation. Acoustic field boundary conditions on the structure surface are of non-homogeneous Neumann type − e.g. proportional to parietal velocity − exterior boundary conditions are expressed using Sommerfeld infinite space conditions.

$$\begin{cases} \left(\Delta p + k^2 p\right) = 0 & \text{in } R^3/\Gamma \\ \partial_n p = -j\omega\rho V_n & \text{on } \Gamma_{\text{int}} \\ \partial_n p = -j\omega\rho V_n & \text{on } \Gamma_{\text{ext}} \\ \lim\limits_{r\to\infty} r\left(\dfrac{\partial}{\partial r} + ik\right) p = 0 & \text{on } \Gamma_{\text{inf}} \end{cases}$$

In our approach, the problem is divided into an interior problem and an exterior problem (1). This implies the introduction of a new variable g representing the acoustic velocity on the opening surface. Interior and exterior problems are coupled using continuity conditions on velocities and on pressures at the opening. Therefore, the system to solve can be expressed as:

2.1 - Interior problem

Find p_i (acoustic interior pressure) in Ω_i and g on Γ_0 such that

$$\begin{cases} \left(\Delta p_i + k^2 p_i\right) = 0 & \text{in } \Omega_i \\ \partial_n p_i = -j\omega\rho V_n & \text{on } \Gamma_{\text{int}} \\ \partial_n p_i = -g & \text{on } \Gamma_0 \end{cases}$$

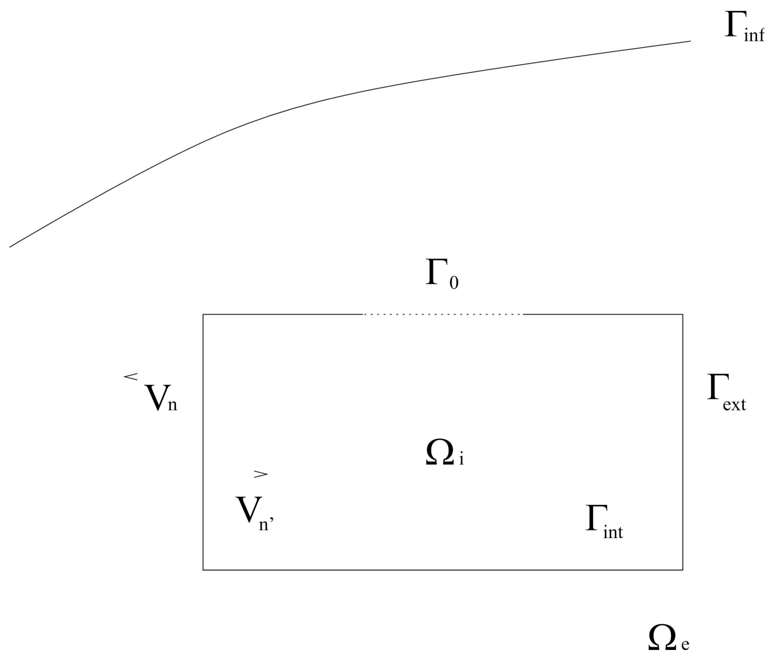

Figure 1: Box horizontal section.

2.2 - Structure external surface problem

The pressure $\overline{p_e}$ on the structure external surface is a solution of the problem:
Find $\overline{p_e}$ on Γ_{ext} and g on Γ_0 such that

$$\frac{1}{2}\overline{p_e}\,(y) - \int_{\Gamma} \overline{p_e}\,(x)\,\partial_n G\,(x,y)\,d\Gamma + \int_{\Gamma_0} g\,(x)\,G\,(x,y)\,d\Gamma_0 = j\omega\rho \int_{\Gamma_{\text{ext}}} V_n G\,(x,y)\,d\Gamma_{\text{ext}},\ \forall y \in \Gamma$$

where G is the free field Green function,

$$G\,(x,y) = \frac{e^{-jk|y-x|}}{4\pi\,|y-x|}$$

2.3 - Pressure continuity at the opening

Two linear applications R_1 and R_2, used as restriction operators, are introduced. They are defined as:

$$R_1 : \begin{array}{c} \overline{\Omega_i} \longrightarrow \Gamma_0 \\ p_i \longrightarrow p_{i|\Gamma_0} \end{array} \qquad R_2 : \begin{array}{c} \Gamma \longrightarrow \Gamma_0 \\ \overline{p_e} \longrightarrow \overline{p_{e|\Gamma_0}} \end{array}$$

and the pressure continuity at the opening is therefore expressed as:

$$R_1 p_i - R_2 \overline{p_e} = 0$$

3 - NUMERICAL IMPLEMENTATION

A numerical solution to the previous equations can be achieved by discretizating the interior volume into elements and nodes. The structure under study is a parallelepiped. A finite difference method (2) is used. The exterior problem is discretized by collocation.
At least, the pressure continuity can be included using rectangular matrix whose coefficients are given by:

$$\left(R^T\right)_{ml} = \begin{cases} 1 & \text{if } m \text{ if the global number in } \overline{\Omega_i}\ (\text{or } \Gamma)\ \text{of the 1th degree of freedom of } \Gamma_0 \\ 0 & \text{otherwise} \end{cases}$$

Then the global matrix problem can written as:

$$\begin{pmatrix} A & 0 & B \\ 0 & C & D \\ R_1 & -R_2 & 0 \end{pmatrix} \begin{pmatrix} p_i \\ \overline{p_e} \\ g \end{pmatrix} = \begin{pmatrix} f_1 \\ f_2 \\ 0 \end{pmatrix}$$

The global matrix is a non-symmetric sparse square matrix of high dimensions. Such matrices are usually inverted by means of iterative methods. The biconjugate gradient method (3) has been applied here, which is a derivative of the conjugate gradient method used for symmetric matrix.

When $\overline{p_e}$ and g have been identified, the acoustic radiation can be calculated for every point in the exterior domain applying Helmholtz integral formulation:

$$p_e(y) = \int_\Gamma \overline{p_e}(x)_n \, \partial_n G(x,y)\, d\Gamma - \int_{\Gamma_0} g(x)\, G(x,y)\, d\Gamma_0 + j\omega\rho \int_{\Gamma_{\text{ext}}} V_n G(x,y)\, d\Gamma_{\text{ext}}, \ \forall y \in \Omega_e$$

4 - NUMERICAL RESULTS

Acoustic radiation obtained by numerical calculations is presented using directivity diagrams. Calculations have been performed on a cubic box of height L, with a negligible thickness and a volume of 1 cubic meter. One of the faces presents a central opening. A velocity field equivalent to an acceleration of 1m/s^2 is applied on the cube faces. The opening is located at the right of the diagram. Dotted circles are 10 dB apart.

On the directivity diagrams, both responses obtained with and without an opening have been plotted, in order to highlight the opening influence.

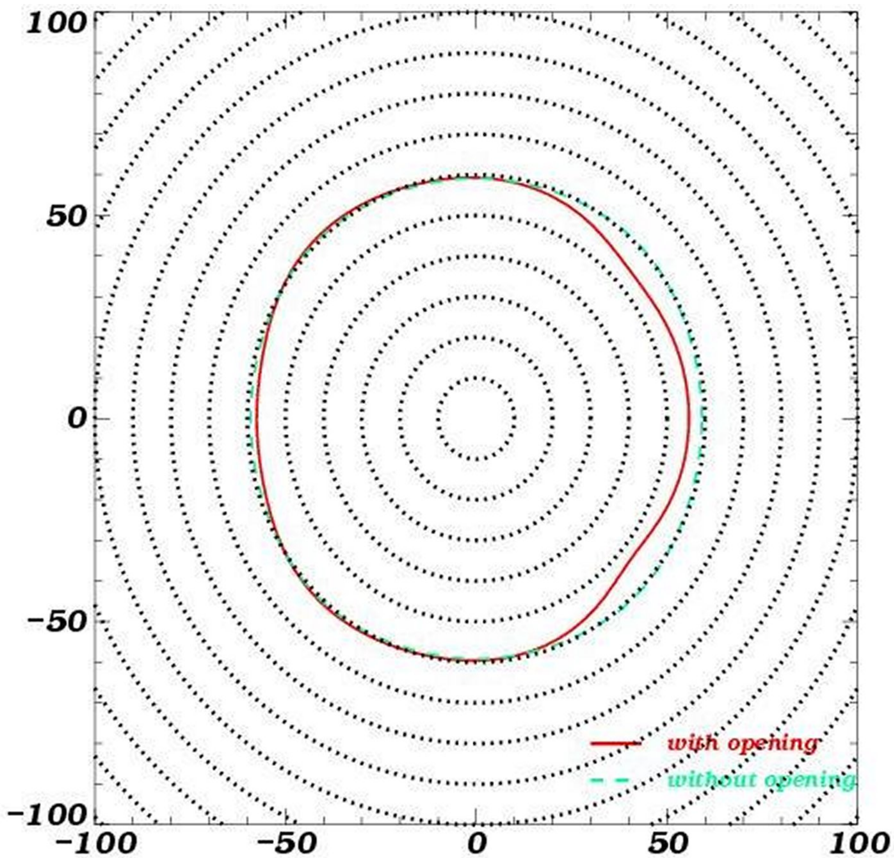

Figure 2: Sound pressure level (dB), 10 m distant from the center of the opening (14% of the surface), kL=5.

We also represent the sound-pressure level directly on the faces:

5 - CONCLUSION

With BEMOL, we intend to obtain dedicated software for a particular class of machines. An original methodology has been developed for structures with openings whose vibration is computed by the Finite element method. The originality lies in the fact that this method allows to separately processing the interior problem and the exterior problem. This is of a main interest when one of these two problems shall be treated in a particular way. The application of such a method has been motivated here by the use of an internal absorbent in the open cavity. Indeed, in this case, the method use to solve the internal problem strongly depends on the absorbent type and shall be adapted in function of the material choice.

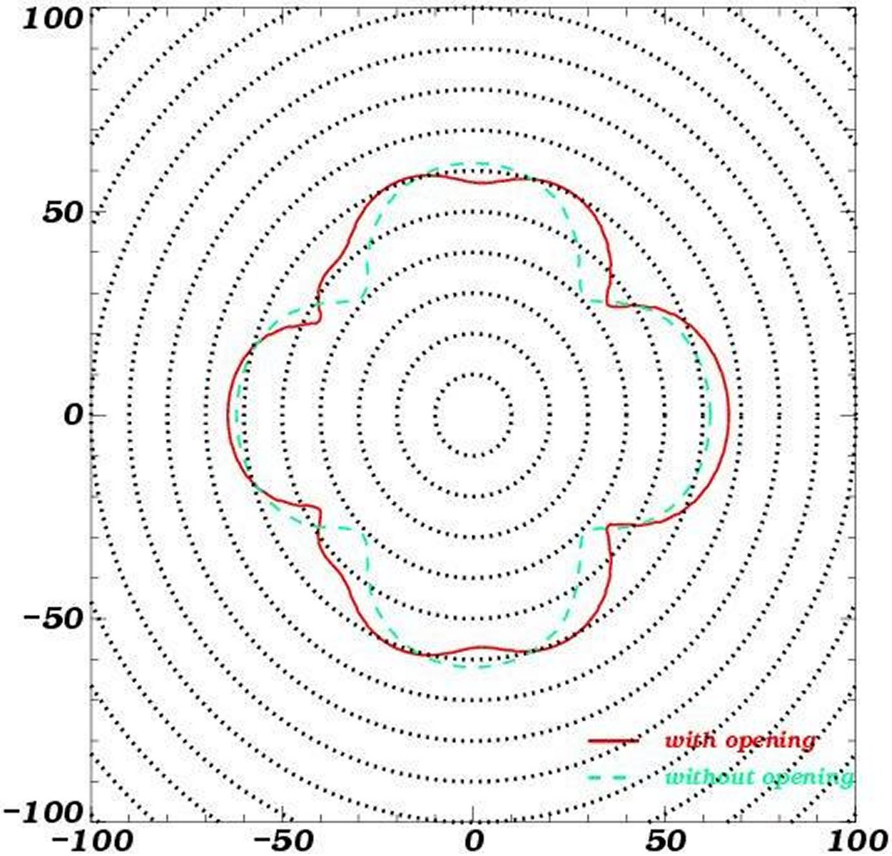

Figure 3: Sound pressure level (dB), 10 m distant from the center of the opening (14% of the surface), kL=8.

Validations will be done both by comparison with other software − i.e. ASTRYD.

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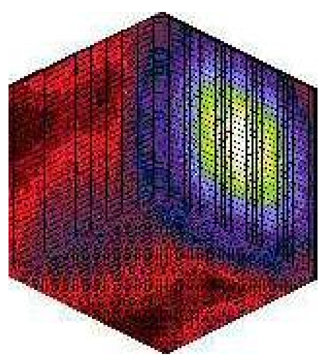

Figure 4: Sound pressure level on the faces of the box with an opening (14% of the surface), kL=5.