A SIMPLE DECOUPLED MODAL CALCULATION OF SOUND TRANSMISSION BETWEEN VOLUMES

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ABSTRACT

Uncoupled sound transmission between two volumes. Various boundary conditions for the plate are considered. A computer program –named GAIA- has been derived which enables the study of various situations. This program can be interfaced with other models for complex multilayered structures provided that they can be described by equivalent data for simple panels. Validation against FEM is very satisfactory. Interfacing GAIA with a modal computation of double partitions (plate-volume-plate system) enables a faster computation of the sound transmission between two volumes than a fully coupled computation. Finally, various applications of GAIA are presented.

1. A DECOUPLED APPROACH

The problem of sound transmission through panels is a cornerstone not only of building acoustics but also of transport industries, such as car, train or aircraft, only to name a few. It involves several sub-problems and consequently several approaches can be used independently or best with a unified strategy. Simple canonical problems can be solved by using analytical approaches, such as the modal method for coupled rectangular geometries [1]. Volume acoustics can be dealt with, up to high frequencies, by using geometrical models [2].

Introducing vibrating panels into such models has been shown possible if a Rayleigh like integral is employed, using what has been named the GRIM approach (Green Ray Integral Method) [3-4]. For a volume having mixed boundary conditions, either defined by a vibrating surface S_V of velocity V or by acoustic boundaries, the computation of a full domain Green function G_V, between receiver and a blocked S_V, leads to a simple expression of the pressure at any point R as

$$P(R) = jwr \int_{S_V} G_V(M,R)V(M)dS_2(M) \qquad (1)$$

This is an exact expression where V and P are coupled. It could be used in a classical FEM/BEM scheme with the main advantage of reducing the surface of integration to S_V, leading to a matrix expression to solve. Fortunately in most air-like situations the assumption that the velocity can be estimated a priori is possible so that one simply ends up with a simple integration of two known quantities. G_V can be estimated by any means such as modal or geometrical approaches. V can be measured [5] or estimated by separate calculations such as modal computations either through analytical of finite element calculations. In [6], it has been shown that sound transmission can be simply expressed as a double integral over both sides S_1 and S_2 of a partition of the product of the Green functions on both sides and of the cross mobilities Y between pairs of points on S_1 and S_2.

$$P(R) = jwr \int_{S_2} G_2(M,R)\left[\int_{S_1} G_1(Q,R)Y(Q,M)dS_1(Q)\right]dS_2(M) \qquad (2)$$

Using a finite element calculation of Y has proved very satisfactory both for 2D and 3D situations. An alternative, evoked in [6], consists [7], in using a modal approach for the partition. In order to validate this procedure, the case of a simple rectangular plate is considered analytically.

The modal response of the plate is simply described as

$$V(x,y) = \sum_{l,m} \frac{4F_{lm}}{M.L_x.L_y} \frac{H_{lm}(x,y)}{\left(w_{lm}^2 - w^2 + 2jh_{lm}.w_{lm}.w\right)}, \quad F_{lm} = \int_{S_1} G_1(M).H_{lm}(M).dS \qquad (3)$$

where F_{lm} is the generalised force expressed as the integral of the trace of the incident field G_1 times the modal response of mode lm with eigenfrequency w_{lm}. The evaluation of F_{lm} assumes as previously a decoupling of incident pressure and velocity fields. So that the assumptions are the same than in (2). In the case of a simply supported plate, H_{lm} is simply the product of sin functions. Using the Warburton's approach [7], one can write in the same manner, expressions of H_{lm} as products of beam functions corresponding to the sides of the plate. Expressions for any combination of Free, Clamped or simply Supported conditions have been given by Warburton. Rather than using these functions directly to evaluate the associate eigenfrequencies –which would imply the solution of a matrix system- the approximate expressions suggested by Warburton (which result from a Rayleigh-Ritz calculation) are employed. Contrary to other solutions [7] based on either a polynomial of trigonometric basis, one has here the advantage of dealing with physical functions very close to the actual modes; and will be showed to be very precise. One should also note that an extension of this approach has been made [8] for orthotropic plates.

2. NUMERICAL ASPECTS

A computer program, named GAIA has been developed. It is a simple program aiming to interface several different approaches. Green functions can either be imported from other models, such as ICARE, a general purpose beam-like geometric approach [5], based on the propagation of beams made of 3 rays, which can deal with curved surfaces and multiple diffraction. GAIA can compute Green functions for simple cases, such as baffled plates, eventually with a reflecting ground (window pane in a semi-infinite facade) or a diffracting edge using GTD, rectangular geometries using an analytic modal computation. The response of the structure is based on a modal description either based on Warburton's simple approach or as a result of finite element calculations. The computation of sound radiation makes use of equation (1) and several means of evaluating the radiated power W_r have been programmed. For instance, the GRIM approach uses a meshing of S_V which is employed to evaluate W_r as

$$W_r = Re \int_{S_R} V^*(Q)\left[\int_{S_V} V(M)G(M,Q)dS\right]dS$$

where S_R can be an hemisphere or equal to S_V using a classical BEM integration technique. In the case of sound transmission between two rooms, very good results [9] have been obtained simply assuming a diffuse receiving field and estimating the radiated power as $P^2.A/4r.c$, where A is the total surface of absorption and where the mean square pressure P^2 is evaluated using a limited number of pressure points at which (1) is applied.

3. APPLICATIONS

First, the validity of Warburton's approximation is checked in the case of a 3x2.5 m^2 5 cm-thick clamped baffled plaster plate excited by a unit mechanic force at (0.9,0.75). *Figure 1* shows a comparison of the plate velocity level obtained by FEM and GAIA, showing a very good comparison up to rather high frequencies considering the size of the plate.

Next, *Figure 2* shows the plate's velocity when excited by a plane wave with angle of incidence of (30 deg, 30 deg) with respect to both sides, either computed by GAIA, AMOTRA, FEM; in this case the plate is damped along two sides and simply supported along the two other parallel sides (noted SCSC according to [7]) . AMOTRA is a program developed at CSTB by Ivan BOSMANS [10] using a mixed simply supported plate solution and a Lévy-type solution on the clamped sides. Very good agreement can be seen. Computations made for an orthotropic Kevlar plate [8] have showed results of the same order of quality.

Figure 3 compares the corresponding radiated loss factor obtained by the 3 approaches. FEM results differ slightly above 600 Hz.

Figure 4 shows the pressure level (rms value over 4 positions) in the receiving room when the same CCCC plaster plate is placed between two 22.5 and 30 m^3 volumes, either computed using equation (2), with an FEM evaluation of Y or using GAIA. Note that GAIA also includes equation (2) with a modal evaluation of Y but that it leads to significantly longer computation times. Good agreement can be observed; one should be conscious of the large size of the problem considered and of the large modal density of the partition. *Figure 5* shows the plate velocity level. The agreement is even better.

A last application of GAIA concerns the effect of angle of incident of incoming waves upon a 10 mm-thick window pane, first baffled and second placed against a room either reverberant of with a T_R of 0.16 sec. *Figure 6* show the directivity patterns (referenced to maximum pressure values) at a given point behind the pane. Two remarks can be made. First, strong directivity effects can be noticed, the higher the frequency the more pronounced this effect. Even at 1/3 octave 100 Hz, several dB's angular dependence can be seen. Above the pane's critical frequency the pattern does not depend upon the acoustic field behind the window. The first result suggests that in order to estimate the efficiency of facade elements against outdoor noise sources, one should avoid dealing with data obtained from classical diffuse field measurements and that dedicated indices and measurement facilities should be proposed. This is the object of undergoing research at CSTB. The second result is also of interest since it suggests that at high frequencies the use of baffled plates may suffice to study sound transmission, but that it will not be adequate below the critical frequency.

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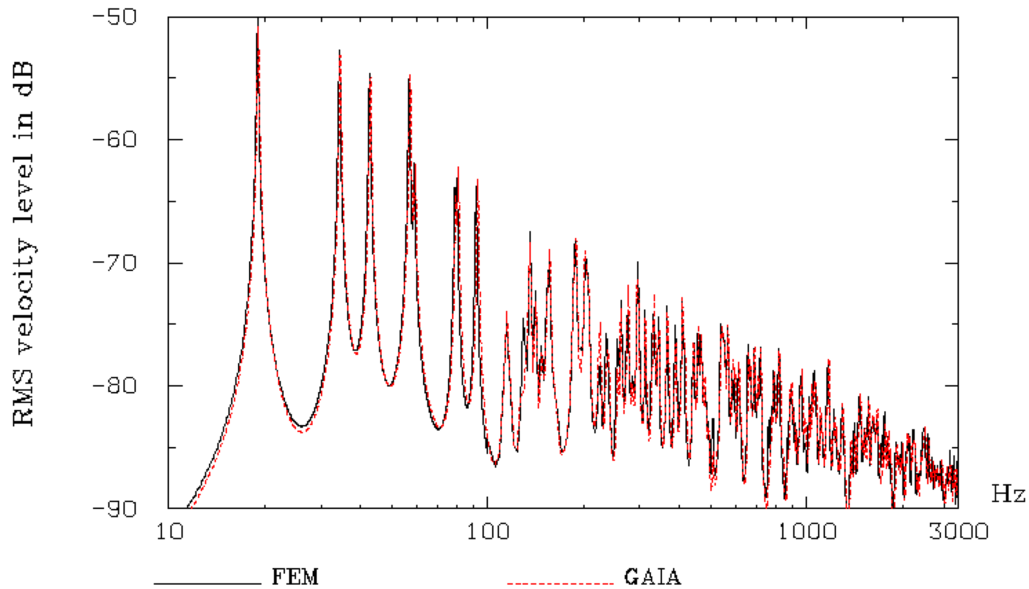

Figure 1. Plaster 3x2.5 M2, 5 cm-thick clamped plate. Unit force at (0.9,0.75).

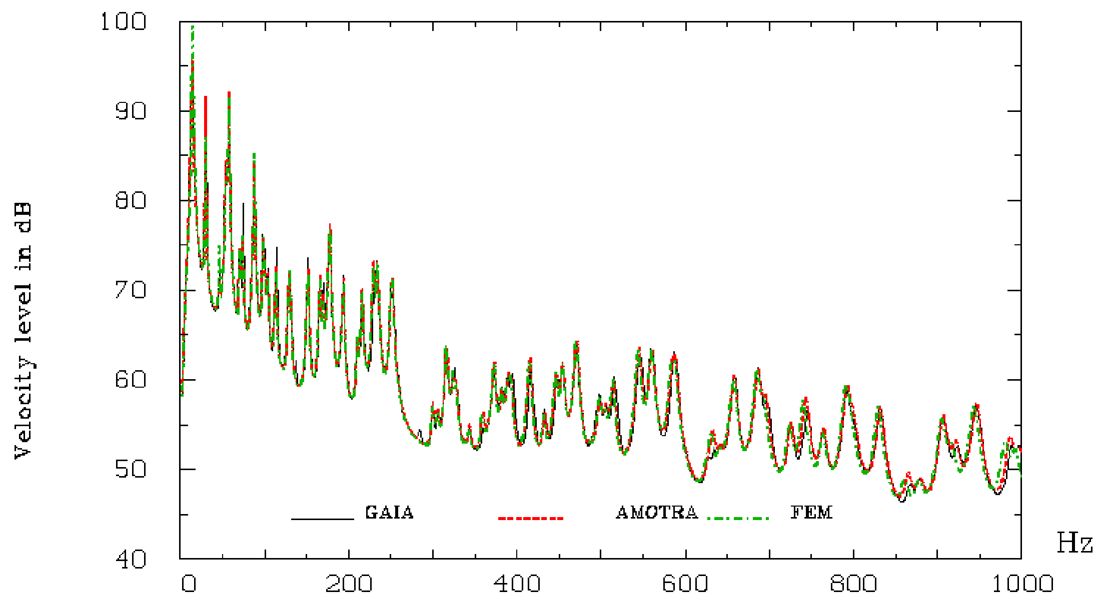

Figure 2. Velocity level of a SCSC 5-cm plaster plate excited by a (30,30) deg plane wave.

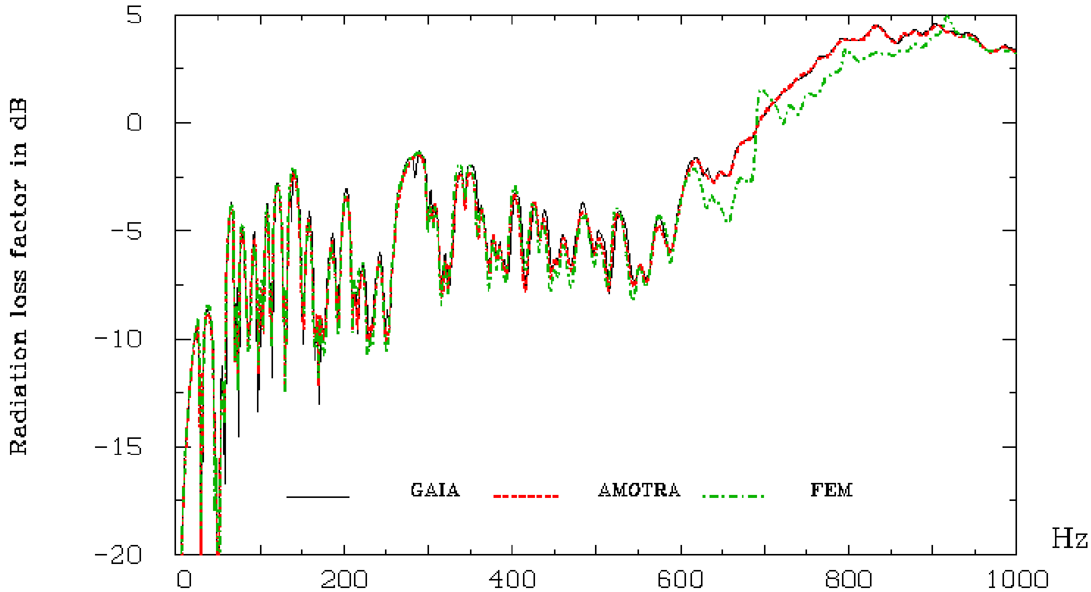

Figure 3. Radiation loss factor. SCSC 5 cm-thick plaster plate.

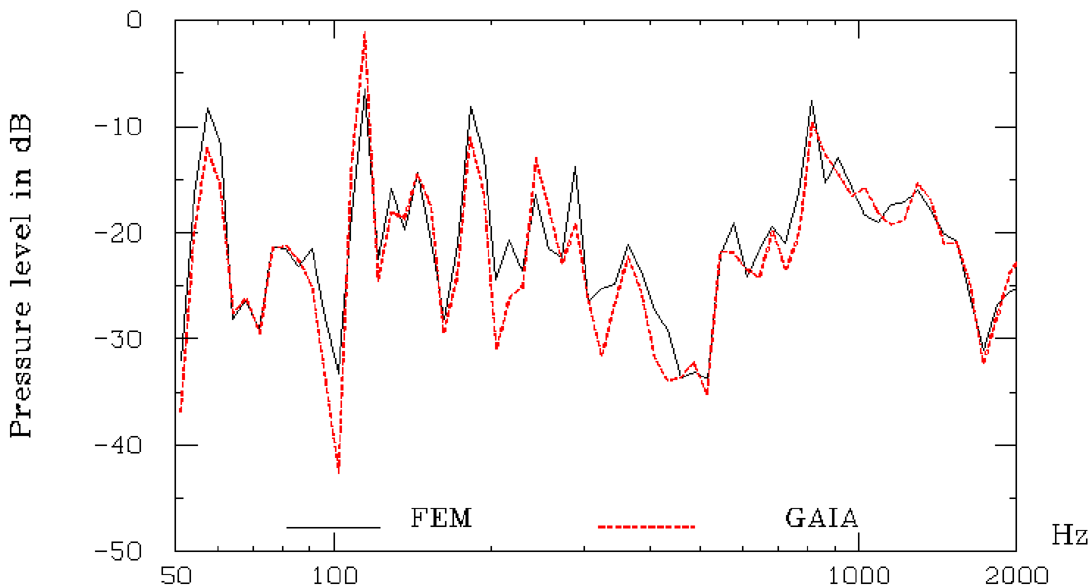

Figure 4. Transmitted SPL through a 5 cm clamped plaster wall between 2 volumes.

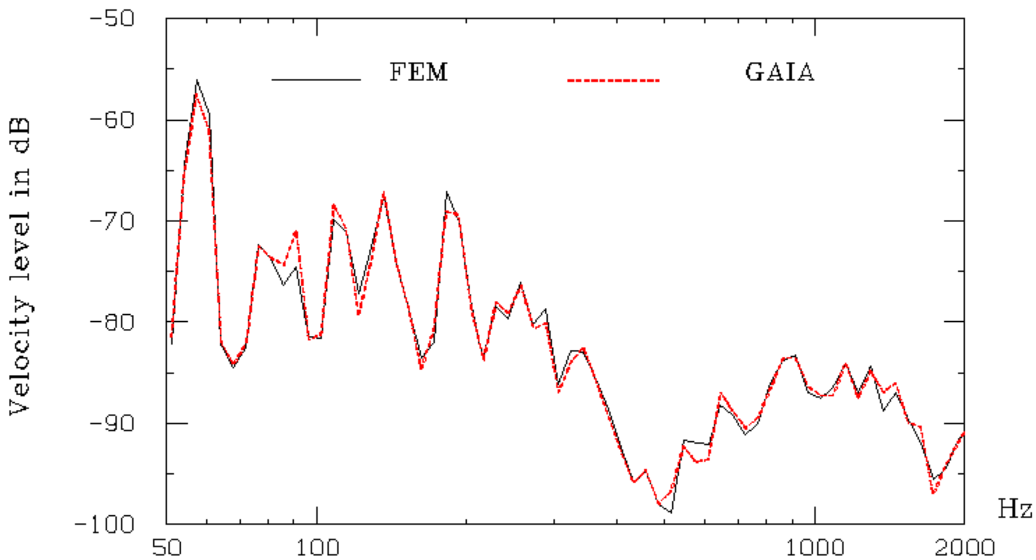

Figure 5. Velocity level on the clamped partition.

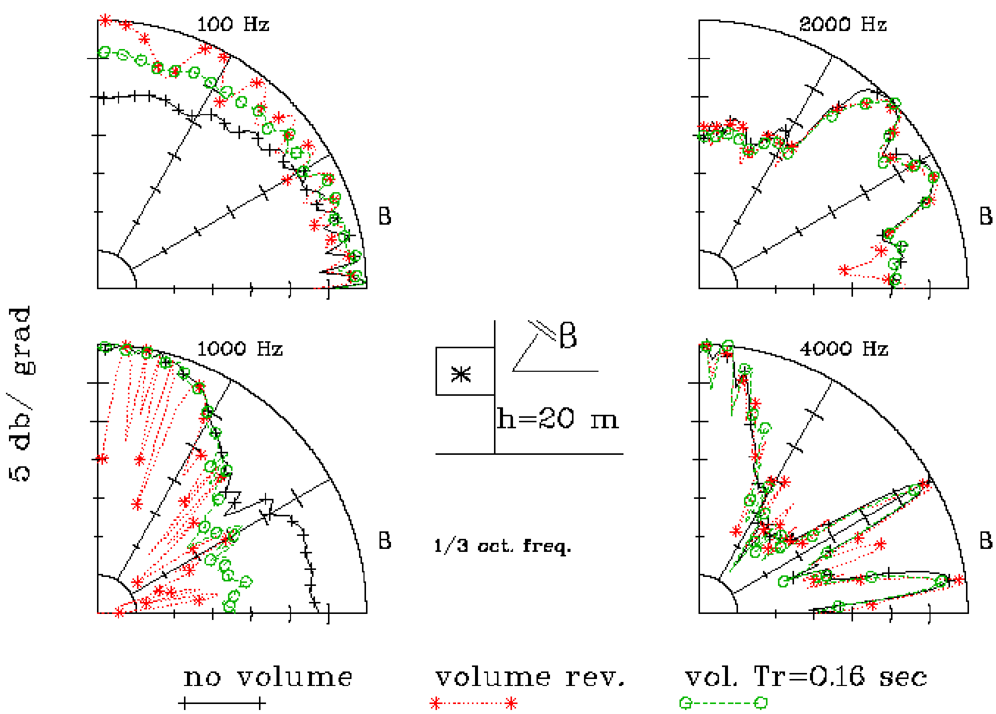

Figure 6. Influence of angle of incidence of incoming wave on transmitted SPL.