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COMPARISON BETWEEN ROOM TRANSMISSION FUNCTIONS CALCULATED WITH A BOUNDARY ELEMENT METHOD AND A RAY TRACING METHOD INCLUDING PHASE

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INTRODUCTION

No single analytical or numerical tool can model the wide audible frequency range between 16Hz and 15kHz. Ray tracing techniques are established as the appropriate numerical tools to model high-frequency sound in closed and/or open enclosures. The wavelengths are small enough for geometric acoustics to apply. Specular reflections and ray driven propagation predominate, while wave related effects such as diffraction, interference, ... are usually neglected. More exact solutions can be obtained using energetic (Finite Element Methods) or integral (Boundary Element Methods) formulations of the Helmholtz equations. They allow simulation of acoustic fields as function of space, frequency and time, but are primarily efficient in the low frequency range, i.e. frequencies for which the wavelengths are comparable with the dimensions of the room. Its upper boundary can be approximated by the well-known Schroeder Cutoff Frequency f_c [2]. This is the frequency for which the separation of two adjacent frequency curve maxima is comparable with the average bandwidth of the room resonances, in other words the frequency at which modal overlap becomes important. Between the low frequency domain and the high frequency domain there is a transition region, where wave acoustics become inefficient, but where wavelengths are too long for ray acoustics. It is bounded on the low-frequency end approximately by the Schroeder Cutoff frequency f_c and on the high end approximately by $4f_c$. [1]. Example, for a small recording studio : 3x5x7m and RT60=0.5s : 138Hz to 552Hz; for a car compartment :V=2.5m^3 and RT60=0.05s : 282Hz to 1131Hz. This paper examines to what extent it is feasible to adapt ray techniques to model Room Transmission Functions, especially for these "medium" frequencies.

MODELING WAVE ACOUSTICS WITH RAYS ?

Although the ray approach is said to collapse when dealing with low frequencies, it is very well possible to model eigenmodes by means of rays. Firstly, a hybrid MISM/RTM method is used to compute echograms at receiver positions inside an enclosure (MISM=Mirror Image Source Method; RTM=Ray Tracing Method). A hybrid method searches the image sources in an efficient way by using a ray tracing method [3]. Currently, two different alternatives have been implemented : CBM (Conical Beam Method) and TBM (Triangular Beam Method), both yielding similar results.
In order to obtain steady-state transfer functions, we assume sound from the image sources to be coherent. Therefore, when calculating the contributions of the various reflections, phase is included. The steady state sound pressure at one receiver in a room can be considered as the superposition of numerous components (= reflections) of the same frequency, but with different amplitudes and phase angles. The SPL is derived from

$$p = \sum_i A_i \exp(j\phi_i)\exp(-jkd_i),$$

where p is the pressure; d_i distance between receiver and image source i; A_i the amplitude of reflection i, including the distance attenuation and the absorption at wall reflections; ϕ_i includes the phase change at wall reflections and the initial phase of the source; k the acoustic wavenumber. Sound components of which the phase information is poorly known, such as non-specular or diffuse reflections, contributions due to diffraction, background noise levels, statistical tail energies ... can be accounted for by considering them as incoherent, and hence :

$$p = \frac{\sqrt{(|\sum_i p_i|^2 + p_s^2)}}{|\sum_i p_i|}\sum_i p_i\,,$$

where p_s is the incoherent pressure.

COMPARISON BETWEEN PHASE RTM AND BEM

A parallelepiped sized 2.5x1.5x1.2m is modeled by a geometry model of 3200 QUAD4 elements. One spherical source is defined at position S1(0.5,0.3,0.2). A receiver is defined at location R1(1.8,0.7,0.8). The applied material lining is homogeneously distributed across floor, ceiling and walls. Its impedance is 7657 rayl, equivalent with a Sabine absorption coefficient of 0.3. The resulting Schroeder Cutoff Frequency is 340Hz. The dependency of the absorption coefficient with the angle of incidence is derived from the impedance description of locally reacting materials. Fig. 1 shows the Room Transmission Function in R1 obtained with 1) the BEM Variational approach, 2) Phase RTM. [4,5]

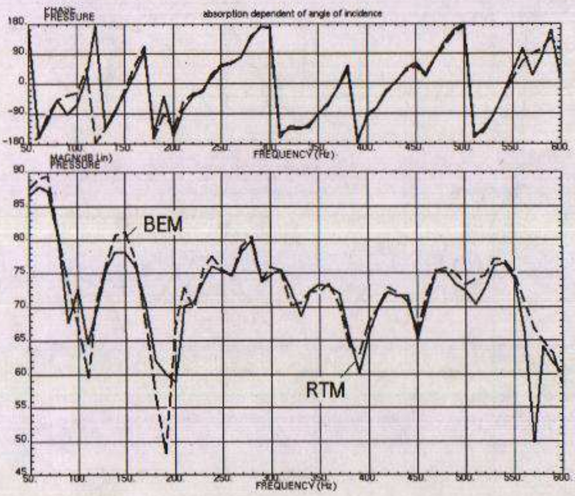

Fig. 1. Comparison between BEM Variational and phase Ray Tracing at receiver position R1, with absorption dependent of angle of incidence.

A more irregularly shaped cavity is chosen (see Fig. 2), modeled by 2168 QUAD4 elements. One spherical source is defined inside the enclosure. The material lining is the same as before : 7657 rayl. The Schroeder Cutoff Frequency is 222Hz. Figure 3 displays the Room Transmission Functions in a receiver point inside the cavity, calculated by BEM and phase RTM. The match is not so good as for the previous case. This is due to diffraction. Unlike in the previous case, not all image sources are visible. Therefore, diffracted energy propagating from "visible" zones to "shadow"-zones becomes important, especially at lower frequencies.

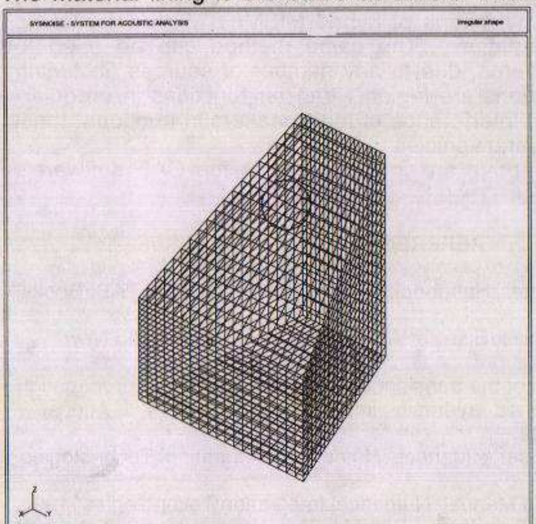

Fig. 2 - Isometric view of surface mesh

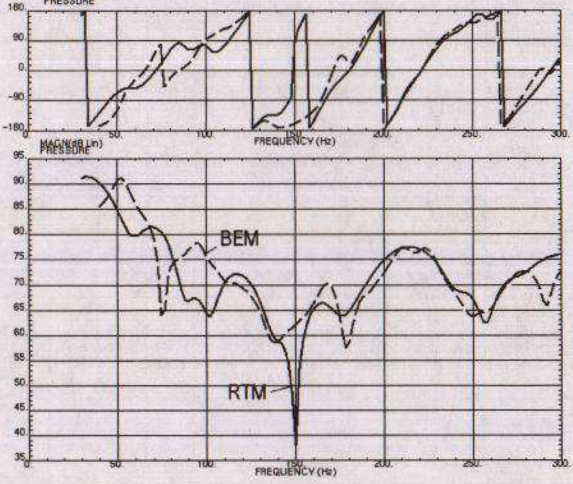

Fig. 3. Comparison between BEM Variational and phase Ray Tracing at receiver position R1 for an irregularly shaped cavity

CONCLUSION

Complex Room Transmission Functions in arbitrarily shaped enclosures can be easily calculated by means of hybrid MISM/RTM models, taking into account phase information. The same method can be used to calculate interference patterns, due to any number of sources (including image sources). Applications are legion : transfer functions in irregular-shaped recording studios, interference of loudspeakers in auditoria, tonal coloration in concert halls and vehicles.

The methods described above are implemented in the CAE software's SYSNOISE™ [4] and MOSART™ [5].

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