Wave versus Ray-Based Room Noise Models

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INTRODUCTION

Traditionally, room acoustics prediction models have been ray-based (geometrical) and thus ignore phase. Wave-based models on the other hand, make use of phase information to properly determine interference phenomena. This paper outlines some preliminary studies performed on two-dimensional geometries to compare these two classes of methods.

PROCEDURE

In order to compare predictions garnered from wave-based methods with those from geometrical techniques, a procedure was devised to compare harmonic signals with sources that emit energies within a limited frequency band. The reason for this is that mono-frequency responses are highly dominated by modal effects. These effects cannot be predicted by geometrical approaches due to its inherent assumption of a diffuse sound field. Nevertheless, comparisons can still be made if banded signals are used. By selecting a sufficiently wide frequency spectrum, modal effects caused by any single frequency are damped out when all the responses within the bandwidth are superimposed. This can be done by assuming that a banded source behaves like a combination of N of elemental point sources, each of which radiates at different frequencies. With this in mind, the total bandwidth can be subdivided into small intervals, within which each sound power remain relatively constant. The total power, W, radiated by the banded source then equals the summation of all the elemental powers, W_i, at discrete frequency intervals. The total pressure response can then be found by treating these elemental sources as un-correlated noise signals and adding their mean square values. Thus,

$$P_t^2 = \sum_{i=1}^{N} P_i^2$$

from which the sound pressure level (SPL) can be found. The sound pressure level is one of the most fundamental quantities easily produced by either class of methods and is directly measurable by standard acoustical equipment.

This study will make use of a two-dimensional empty rectangular cavity with a single point source. A 7m x 4m room is modelled with a point source located at (1.0m, 1.0m). Uniform damping on all four walls will be used for the subsequent analysis of the room. Air absorption is assumed small and therefore will be neglected.

In a wave-oriented approach, most boundary interactions are described by a complex quantity known as the acoustic impedance, **Z**, or admittance, β, of the surface. A locally reacting surface is assumed. The specific admittance is defined by

$$\beta = \frac{\rho c}{Z} = \xi - i\sigma$$

where ρc is the characteristic impedance of air. In geometrical acoustics, phase relationships between acoustic waves and the boundary are neglected. Instead, only the rate of sound energy being absorbed by the boundary surface is modelled. The rate of absorption is usually given in terms of a constant known as the Sabine absorption coefficient, α. This absorption coefficient can be related to the acoustic admittance as follows [1],

$$\alpha = 8\xi\left[1 + \frac{\xi^2 - \sigma^2}{\sigma}\tan^{-1}\left(\frac{\sigma}{\sigma^2 + \xi^2 + \xi}\right) - \xi\ln\left(\frac{(\xi+1)^2 + \sigma^2}{\xi^2 + \sigma^2}\right)\right]$$

Iterative calculations using an absorption coefficient, α, equal to 0.1 yields a specific admittance β of 0.0141. It should be noted that this is not a unique solution to the equation.

RESULTS

Using the defined room, source and wall properties, the acoustic response over the area of this room was evaluated by the finite element method (FEM) [2]. The results at 50 Hz and 1000 Hz are shown in Figures 1 and 2 respectively.

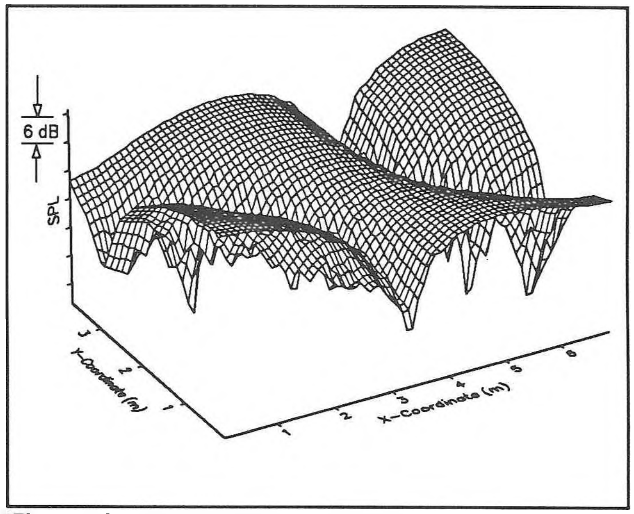

Figure 2- SPL at 50 Hz - 10% Absorption

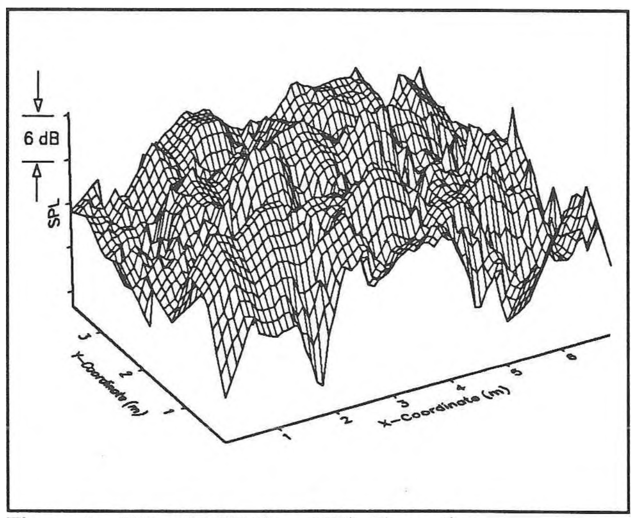

Figure 2 - SPL at 1000 Hz - 10% Absorption

From these figures, it is seen that a low frequency response is very modal dominated while the higher frequency test exhibits a more uniform and almost *random* response. This can be explained by knowing something about the *modal density* in the room. At low frequencies, where there are few room modes governing the pressure distribution in the enclosed space, the sound energy propagation is dominated by the mode nearest the excitation frequency. However, as the modal density increases, the effects of each individual room resonance are summed up so that the effects of any single room mode are averaged and reduced. Eventually, there are enough modes present so that the sound energy propagation are nearly uniform in all directions. This is called a diffuse sound field and is the fundamental assumption used by geometrical approaches.

At a low frequency, the SPL fluctuates dramatically with frequency. As the frequency is increased, the SPL remain relatively constant, indicating a more uniform energy level.

Banded signals can be used to further reduce the effect of any single room mode so that direct comparisons can be made with geometrical techniques. The advantage of using banded signals is that individual frequency response are summed and averaged so that the effects of any single room resonance are reduced.

To determine a suitable bandwidth for use in comparison, a frequency response was plotted for a point located at (6.0m, 1.5m) as shown in Figure 3.

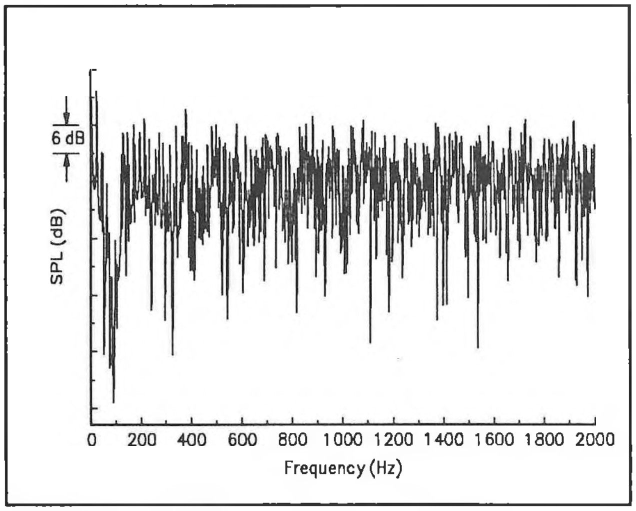

Figure 3 - Frequency Response at a Single Point

A statistical analysis was performed on this curve using the statistical sampling equation,

$$N = \left(\frac{z_{\alpha/2}\,\sigma}{E}\right)^2$$

where N is the number of sampling points required to calculate the sample mean with a 90% chance (α) that the error (E) will not exceed 1.5 dB. By assuming a normal distribution, the minimum number of calculation points required is 85. Using a 56 x 32 finite element mesh and using the 5 node per wavelength requirement, this limits the maximum frequency for accurate modelling to about 700 Hz. Using these parameters, a frequency spectrum from 500 Hz to 680 Hz discretized at a 2 Hz interval, was selected for simulation of the limited band signal.

A comparison between the banded signal generated by the FEM and the ray-tracing method is shown in Figure 4. This plot shows the SPL predictions along Y = 1.0m at ten, thirty and fifty percent boundary absorptions. The overall sound propagation predicted by the FEM shows good agreement with those predicted by the ray-tracing technique. Figure 5 shows the SPL distribution with a 3m high barrier located at x = 3.5m. Again, good agreement is achieved between the two approaches. However, the banded signal simulated by the FEM still obviously contains wave characteristics.

One particular area of interest in comparison is at the boundary surface. In Figures 4 and 5, the FEM consistently predicts a higher SPL than that using the ray-tracing technique. This can be explained by the fact that individual standing waves of a rectangular enclosure can only be excited to its fullest extent by a sound source located in regions where the particular standing wave pattern has a pressure antinode. In order to excite every mode to its fullest extent, the source must be located at the corner of a room. Similarly, a point on the boundary surface will excite more modes to its fullest than any points not on the boundary. This modal effect cannot be accounted for using geometrical methods.

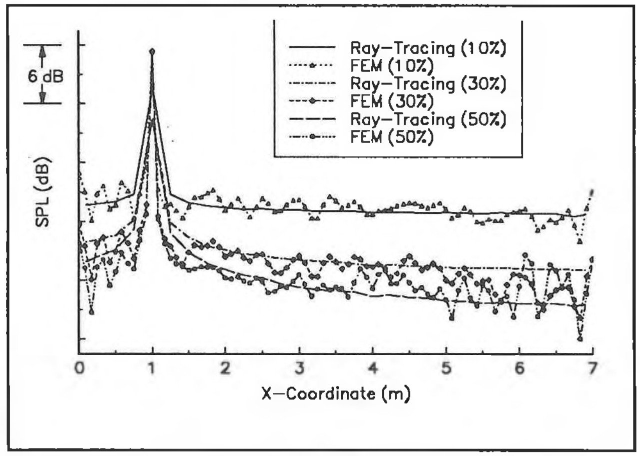

Figure 4 - Response in Room at Different Absorption Levels

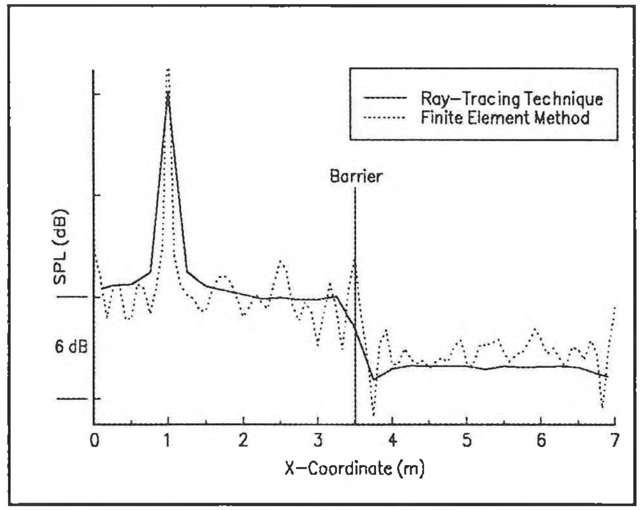

Figure 5 - Sound Levels due to Presence of Barrier

CONCLUSIONS

In general, good agreement between the two methods is observed except at the boundaries. There are a several factors that contribute to deviations between the two approaches. First, the bandwidth of the signal may not be wide enough to eliminate biasing the room resonance within the frequency band chosen. Secondly, the number of calculation points used is insufficient to statistically average out the modal effects of the signal. Finally, the frequency of the banded signal may be too low to exhibit geometrical behaviour.

ACKNOWLEDGEMENTS

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[1] Morse, P.M. and Ingard, K.U., **Theoretical Acoustics**, McGraw-Hill, 1968

[2] SYSNOISE User's Manual, NIT, Leuven, Belgium, 1994