Analysis of Acoustic Response of Rooms

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Abstract: This paper demonstrates the use of COMSOL Multiphysics to predict the acoustic response of a room. The baseline response of the room contained a series of unwanted resonances below 500Hz. The baseline response was modified by positioning specially designed acoustic distribution panels throughout the room. The use COMSOL Multiphysics to perform the acoustic analyses allowed the design, location and materials of the panels to be optimized to provide a room in which an even energy response occurs over the full audio spectrum.

Keywords: Acoustics, Room design.

1. Introduction

Recording studios, auditoriums and conference halls all possess inherent unwanted acoustic resonances. The acoustic response is sharply boosted for a narrow frequency band near resonance, and then is depressed between resonances. This response is most strongly observed at frequencies below ~500Hz; above 500Hz resonances are still present but are traditionally considered less of a problem because they contain less spatial variability. Ideally, all resonances should be reduced and an even acoustic response obtained across the whole frequency spectrum.

Conventional approaches to control the resonant acoustic response of rooms use treatments that combine simple absorbing surfaces placed around the room with recommendations for standardized reverberation times. Placement of the absorbing surfaces is generally operator specific with little consideration given to predictive approaches to decide on placement. The reverberation time is a function of the room volume and standardized reverberation times are recommended for different applications. For example, reverberation times for concert halls are recommended to be between 1.5 and 2s, whereas recording studios have a recommended reverberation time of less than 1s.

Most attempts to analyze the acoustic response of a room make use of simple ray tracing methodologies and fail to consider interactions between waves in determining the spatial and temporal distribution that arises across the entire frequency domain.

This work used COMSOL Multiphysics 3.5a to predict the acoustic response of rooms containing acoustic distribution panels made from hard materials with complex surface structures and sound absorbing materials. This allowed the positions and designs of acoustic panels to be optimized, and the preferred materials for room construction to be identified without the need for subjective iteration and experimental evaluations.

2. Analysis

The acoustic panels applied in this work (Figure 1) have a complex surface geometry, with each panel containing hundreds of individual surfaces.

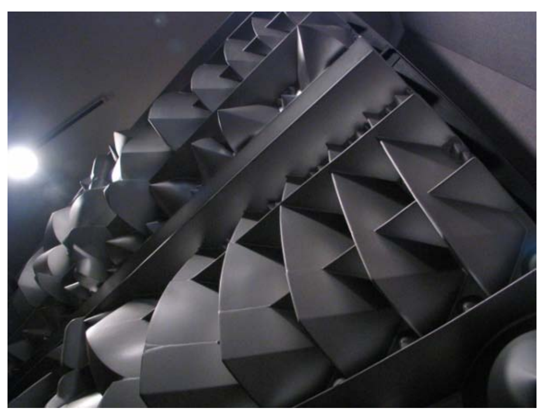

Figure 1. Example of the surface structure of acoustic panels.

Consequently, building and meshing of the acoustic panel geometry were complicated. The panel geometries were originally specified as surfaces. Initially these were defeatured in SolidWorks and changed into solid bodies before importing them into COMSOL Multiphysics. As a part of this process, features that were much smaller than the shortest wavelength of interest, for this study generally less than 1kHz, were entirely removed. This limited the complexity of the geometry and reduced the computational resources required for subsequent analysis. After importing into COMSOL Multiphysics, further defeaturing was done to remove the remaining short edges. Successful meshing was performed by creating separate domains surrounding each of the acoustic panels. These domains were then meshed individually before meshing the remaining portion of the panel geometry.

Although the creation and meshing of room geometries with a variety of acoustic panels was complex, the physics of the acoustic modeling of the room was relatively straightforward. The air in the room was assumed to be a lossless medium, in which case the time-harmonic acoustic field is described by the following equation:

$$\nabla \cdot \left(-\frac{1}{\rho_0} \nabla p \right) - \frac{\omega^2}{\rho_0 c_s^{\ 2}} p = 0$$

where ρ_0 is the density, p is the time-harmonic acoustic pressure, ω is the frequency, and c_s is the speed of sound. The surfaces of the acoustic panels were represented as sound-hard boundaries with a normal acceleration equal to zero at the wall:

$$\frac{\partial p}{\partial n} = 0$$

The sound absorbing material on the walls of the room was modeled using an impedance boundary condition:

$$\mathbf{n} \cdot \left(\frac{1}{\rho_0} \nabla p \right) + \frac{i\omega}{Z} p = 0$$

where Z is the acoustic impedence, which corresponds to the ratio between the acoustic pressure and the normal velocity. The acoustic source was a small loudspeaker with the diaphragm represented by a normal acceleration boundary condition:

$$\mathbf{n} \cdot \left(\frac{1}{\rho_0} \nabla p \right) = a_n$$

where a_n designates the amplitude of the normal acceleration.

3. Results

The preferred acoustic response of recording studios, auditoriums and conference halls is to have an even energy response over the entire room and throughout the full audio spectrum. Analysis of a small recording room, approximately a cube of 9’ 6” edge, was used to define the room’s acoustic signature over the range of frequencies of interest. For the current study the results of the baseline acoustic signature at frequencies of 200Hz and 500Hz are shown in Figures 2 and 3.

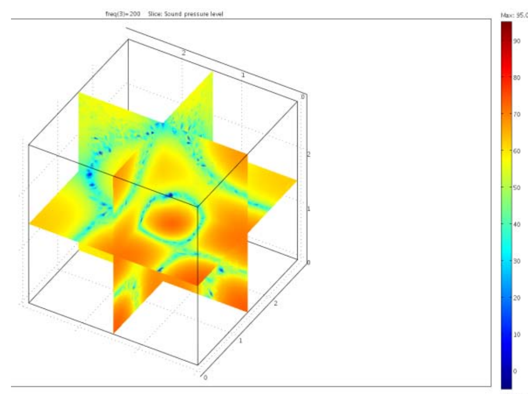

Figure 2. Resonant acoustic signature of room described using sound pressure level at 200Hz.

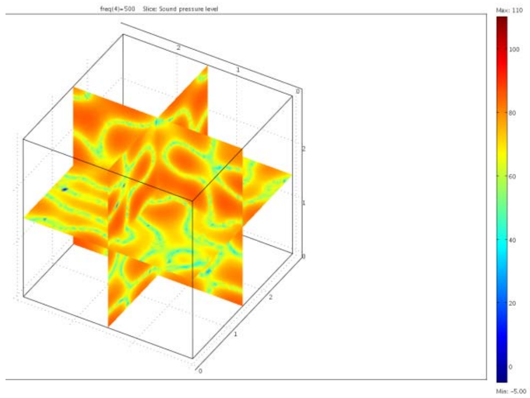

Figure 3. Resonant acoustic signature of room described using sound pressure level at 500Hz.

The room response shows significant variability of the sound pressure levels (SPLs) at resonance. Considerable variation occurs in the SPLs over short distances thus providing different acoustic response as a function of position in the room; this response translates into an unwanted acoustic performance of the room.

Changes to the acoustic response of the room can be accomplished by combining the use of acoustic distribution panels that have complex surface structures and sound absorbing materials. The acoustic distribution panels scatter acoustic waves and diffuse sound level variability over the room volume, the sound absorbing materials that prevent reflections from hard surfaces.

The acoustic distribution panels are designed for use in multiple sizes and surface formats to fit various locations in a room. The combination of the location and surface geometry of the panel is important in changing the acoustic signature of the room. However, defining the precise location and orientation of these panels to optimize the distribution of acoustic energy currently relies upon experience and intuition. Using the analytical procedures developed during this work, the acoustic distribution panel selection, location, orientation and surface format were systematically varied to develop room layouts that provide an even energy response over the entire room and throughout the full audio spectrum. An example of the variation of SPL at 200Hz in a room with multiple acoustic distribution panels is shown in Figure 4.

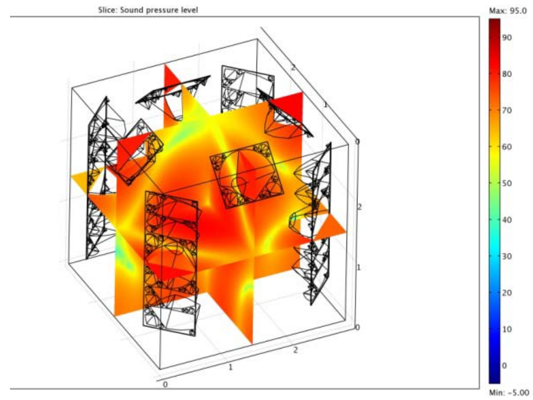

Figure 4. Resonant acoustic signature of room containing multiple acoustic distribution panels described using sound pressure level at 200Hz.

The effect of the acoustic panels on providing an even distribution of SPL through the room can be more clearly seen by examining the variability in SPL in the horizontal mid-plane of the room without (Figure 5) and without (Figure 6) acoustic distribution panels.

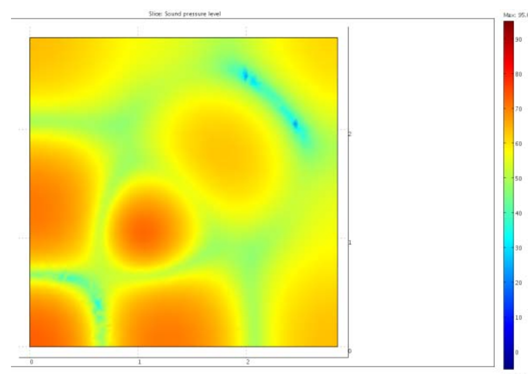

Figure 5. Variability in SPL in the horizontal mid-plane of the room without acoustic distribution panels.

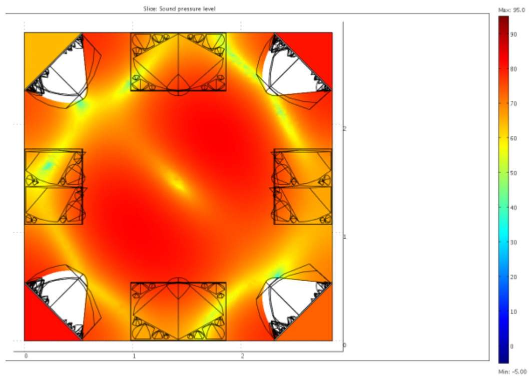

Figure 6. Variability in SPL in the horizontal mid-plane of the room with acoustic distribution panels.

4. Conclusions

This work demonstrates the capabilities of COMSOL Multiphysics to solve the complex problem of acoustic performance of rooms. Acoustic panels having a complex surface structure can be developed in COMSOL and their effect on the distribution of sound energy within a room predicted. By incorporating multiple panels of differing designs at strategic locations, rooms with an even energy response over the entire volume and throughout the full audio spectrum can be produced.