Acoustical Analysis of a Home Recording Studio

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Abstract: This paper presents the results of an acoustic analysis of a home recording studio. Previous works using COMSOL to model room acoustics include the study of [1]. When designing a recording studio it is imperative to take the resonances into account. For the home recording studio owner, the most relevant question is where should the speakers be put for best sound? To illustrate theses effects this paper uses COMSOL Acoustics to compute the eigenmodes of a home recording studio. The analysis herein computes every eigenfrequencies lower than 150 Hz, together with their corresponding eigenmodes. The eigenmode shows the sound intensity pattern for its associated eigenfrequency. From the characteristics of the eigenmodes we can draw some conclusions as to where the speakers should be placed. For the purposes of this study, higher frequencies will be omitted, to focus our efforts on lower frequencies (50-150 Hz). Lower frequencies are of interest because they are typically where the fundamental resonance exists for a given dimension of the room [2]. To this end, herein COMSOL is used to help locate the optimized position of speakers in the recording studio.

Keywords: Acoustics, Audio, Room Modes, Studio, Sound Pressure

1. Introduction

In the field of acoustics, the study of room modes (eigenfrequencies) is of significance because they are the frequencies where the room will resonate, which can adversely affect a desired state. It is challenging to obtain modes and their corresponding pressure plots of rooms with complex geometries, which exemplifies the usefulness of COMSOLS's acoustic pressure module.

The study presented in this paper will carry out the acoustic pressure analysis of a home recording studio. This includes the evaluation of a room for its properties in its natural state (eigenfrequencies/natural frequencies), as well as how speakers driven at these frequencies influence the room. the speakers were also loaded at a 1000 Hz to demonstrate how the pressure waves at a higher frequency are shorter and denser.

2. Objective

The principle of this study is to calculate the Eigenfrequencies of a room, and to evaluate their corresponding pressure plots. The Eigenfrequencies of a room are important to study because they can force a room into resonance, which can be potentially destructive to a desired sound as well as to structures. Because sound waves are measured as pressure waves, obtaining pressure plots from COMSOL is highly valuable. For the purposes of this study, higher frequencies will be omitted, to focus our efforts on lower frequencies (50-150 Hz). Lower frequencies are of interest because they are typically where the fundamental resonance exists for a given dimension of the room. Figure 7, which is the isosurface pressure plot corresponding to an Eigenfrequency of 75 Hz, depicts how the pressure waves blanket the entire room, where as Figure 8 (1000Hz) depicts how tightly and clustered the individual waves are.

3. Assumptions and Approach

In order to set up the model, the negative space of the following room was modeled as a solid with the properties of air as the working fluid. The spatial model was constructed in SolidWorks, exported as a parasolid, and imported into COMSOL under geometry.

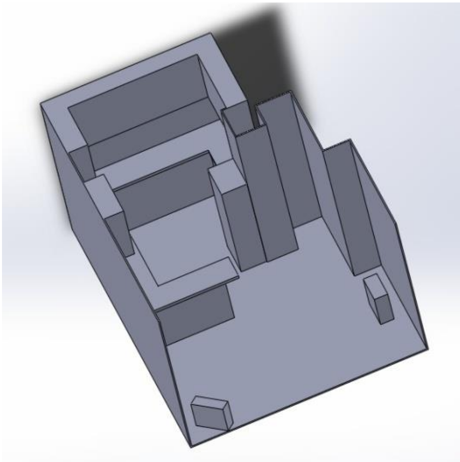


Figure 1- Model of Room

The figure below depicts the tetrahedral mesh, consisting of 31,289 elements, associated with the geometry of the modeled room. The only boundary condition implemented in this study was a sound hard boundary.

The air in the room was taken to be a lossless medium, wherein the time-harmonic acoustic field is governed by the following Helmholtz equation [2,3]:

$$\nabla \cdot \left(\frac{1}{\rho} \nabla p \right) = -\frac{k^2 p}{\rho}$$

$$k = \frac{2\pi f}{c}$$

where ρ is the density, p the time-harmonic acoustic pressure, k is the wavenumber, f is the frequency, and c is the speed of sound. The surfaces comprising the room walls were modeled as sound-hard boundaries with a normal acceleration equal to zero at the wall, such that

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

This boundary condition essentially turns the perimeter of the model into walls which do not exchange information with the model, effectively turning off damping. Furthermore, since the fluid that was modeled was air, a density of ρ=1.25 kg/m^3 and a speed of sound of c=343 m/s were used accordingly.

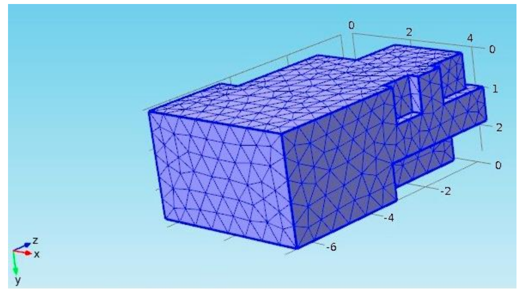


Figure 2 – Tetrahedral Mesh

4. Results

To begin this study, the natural frequency of the room is desired to know what to drive the speakers at. To obtain the lower frequencies, which are critical to driving the room to resonance, the following study was directed to solve for twelve Eigen frequencies around 90 Hz.

Figure 3 was obtained after successfully running the solver, which reports the pressure plot of the Eigenfrequency at 75.459997 Hz. Since sound waves are modeled as pressure waves, this plot depicts the effects of acoustic pressure throughout the room. Pressure is also related to sound pressure level (loudness), which is critical to achieve an even and uniform sound in a given room. As expected areas of high pressure are located in corners due to the sharp geometry, and areas of low pressure occur in the open areas of the room.

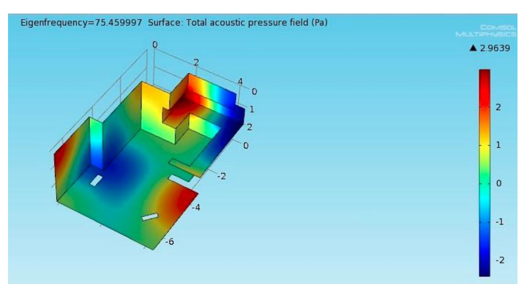


Figure 3 – Pressure Plot at 75 Hz

The results were further processed to render the isosurfaces of the various pressures in the room. This plot provides a clear visual of how the pressure waves are layered in the room at a given frequency in three dimensions. This is an extremely useful feature of COMSOL, due to the fact that isosurfaces are extremely challenging to obtain otherwise.

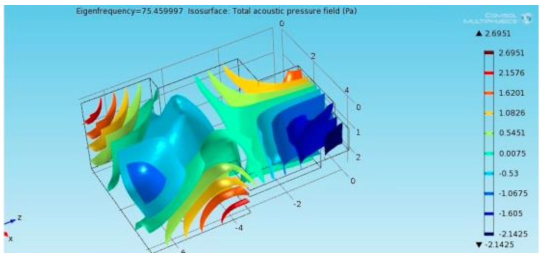


Figure 4 – Isosurfaces at 75 Hz

With the desired eigenfrequency, speakers, modeled as point loads, were simulated as shown in **Figure 5**. A COMSOL Flow Point Boundary condition was used to simulate the effects of a speaker driving a given load.

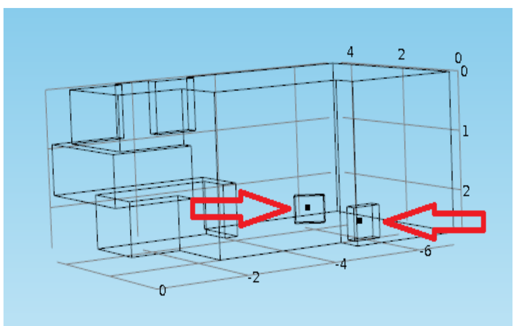


Figure 5 - Point Loads in the Room

The following pressure field on the walls was presented after the simulation was executed at 75 Hz. As expected, this pressure field is extremely similar to those obtained from the modal analysis.

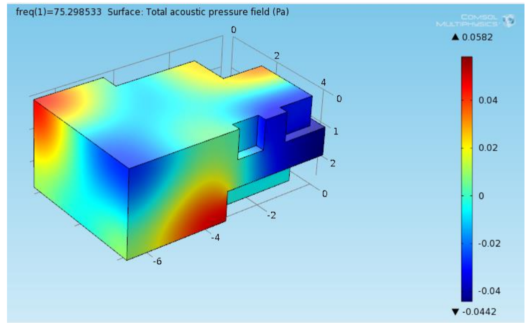


Figure 6 - Pressure Plot from Speakers Driven at 75 Hz

Figure 7, shows the isosurfaces of the pressure waves from the driven speakers. As stated previously, though the values are not exactly the same to those from the modal analysis, they are extremely close.

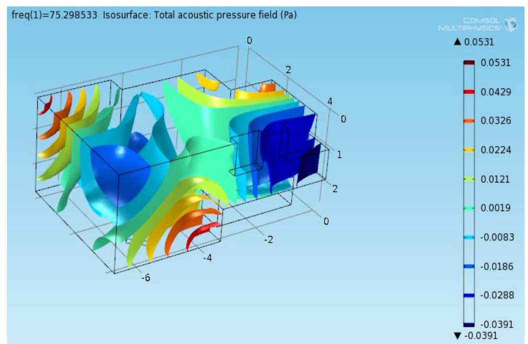


Figure 7 - Isosurfaces at 75 Hz from Speakers

To further this study, the speakers were also loaded at a 1000 Hz to demonstrate how the pressure waves at a higher frequency are shorter and denser.

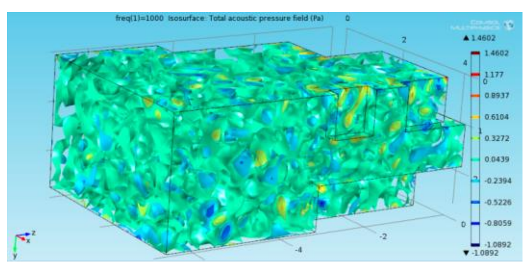


Figure 8 - Isosurfaces at 1000 Hz

Visually comparing the isosurfaces of the modal results **(Figure 4)** and the results gathered from driving two speakers **(Figure 7)** at same frequency it is clear that they are relatively close. This is expected, due to the fact that the speakers were loaded with the Eigenfrequency obtained from the modal analysis. Ultimately this verifies the fact that if the speakers are driven at the Eigenfrequencies, the possibility of resonance is extremely likely.

5. Verification and Validation

5.1 Hand Calculation

To validate the COMSOL simulation, hand calculated results of a one meter cube are compared to results from COMSOL. A one meter cube was chosen for this analysis to verify COMSOL results with published values. The following Eigenfrequency equation for a rectangular room was used to calculate the theoretical values.

$$f = \frac{c}{2}\sqrt{\left(\frac{n_x}{L}\right)^2 + \left(\frac{n_y}{W}\right)^2 + \left(\frac{n_z}{H}\right)^2}$$

Where c is the speed of sound (c=343 m/s), and n is the order of the room mode in the specified direction.

Calculating the first Eigenfrequency of the room in the x direction (1,0,0):

$$f_{(1,0,0)} = \frac{343}{2}\sqrt{\left(\frac{1}{1}\right)^2 + \left(\frac{0}{1}\right)^2 + \left(\frac{0}{1}\right)^2} = 171.5$$

Constructing a one meter cube in COMSOL and solving for the Eigenfrequencies, the following values were obtained:

Table 1: Fonts used in this manuscript

Eigen-Freq.	Degrees of Freedom		
	1168	**7204**	**22976**
1 - (1,0,0)	171.157	171.501	171.500
2 - (0,1,0)	171.518	171.501	171.500
3 - (0,0,1)	171.519	171.501	171.500
4 - (1,1,0)	242.627	242.545	242.539
5 - (1,0,1)	242.635	242.545	242.539
6 - (0,1,1)	242.643	242.545	242.539

The following surface pressure distribution was also obtained.

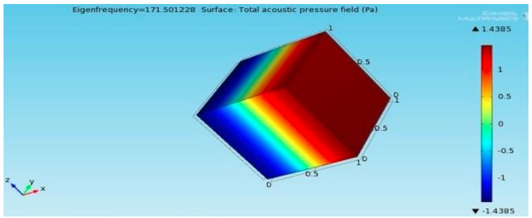


Figure 9 - Pressure Plot of a 1m Cube (171.5 Hz)

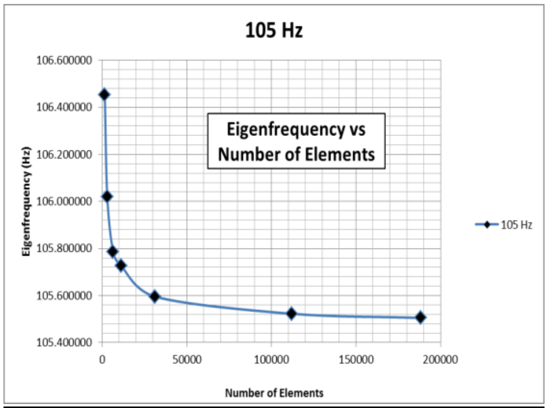
With the theoretical and finite element solutions, a percentage error was calculated between the two, which afforded a percent error on the order of 0.0001%. Thus, it is clear from the above information that the values simulated in COMSOL are extremely close to the theoretical values, which makes this a fairly accurate model. This truth has been extended to the room model simulated, which has a more complex geometry.

5.2 Mesh Independent Study

After increasing to the degrees of freedom multiple times to achieve higher fidelity and convergence, the following table and graph were assembled.

Table 2: Convergence of Modal Frequencies

Eigen-Freq.	# of Elements			
	1472	**11252**	**112115**	**188409**
Freq. 1	75.625	75.366	75.305	75.299
Freq. 2	76.972	76.757	76.718	76.714
Freq. 3	79.596	79.289	79.231	79.222
Freq. 4	81.087	80.647	80.548	80.534
Freq. 5	85.027	84.566	84.449	84.438
Freq. 6	89.539	89.209	89.143	89.137
Freq. 7	96.180	95.698	95.615	95.605
Freq. 8	98.972	98.374	98.176	98.157
Freq. 9	99.627	99.120	99.039	99.030
Freq. 10	102.086	101.464	101.376	101.361
Freq. 11	103.686	102.709	102.522	102.502
Freq. 12	106.453	105.726	105.523	105.505



Graph 1 – Convergence of the 12th Eigenfrequency (~105 Hz)

The above graph shows that as the number of elements increased, the value of the 12th Eigenfrequency leveled off around ~105.5 Hz. The graph only consists of the 12th mode, because the values at this frequency tapered down the most to get a decent plot of convergence. Furthermore, it can be inferred from the above graph that even coarse meshes, consisting of 1500 elements, converged within a single value of the finer mesh, consisting of 200,000 elements, which renders the accuracy of the study. Nevertheless, the graph shows that as the degrees of freedom increase so did the accuracy of the simulation.

7. Conclusions

The acoustics module in COMSOL is an immensely powerful tool for individuals in the acoustics field. Specifically, for those involved in sound production, the pressure acoustics module is an immensely useful tool, as it enables the user to acquire pressure plots given complex geometrical layouts, which would be cumbersome to compute/model otherwise.

This study presented in this paper utilized the acoustics pressure module to determine the natural frequencies of a home recording studio. After obtaining the first natural frequency, speakers in the room were driven at the first eigenfrequency to compare the pressure plots respectively. After visually inspecting the isosurface plots form the two simulations, it is clear that plots are almost identical.

8. References

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