A-Term 2022 Soundport Write-up

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1. Introduction

This term we were able to measure and dimension a full-size guitar, build a model guitar in COMSOL, and design an adjustable simulation to simulate the effects of different sound-port size and placement on the natural frequencies produced by the guitar. Details about our approach for each of these areas are described in the sections below. Included at the end of each section are recommendations and improvements that can be explored and pursued by future groups working on this project.

2. Measuring and Dimensioning the Guitar

To dimension the guitar, we started by tracing around the curvature of a spare full-size guitar back onto a sheet of paper. An approximate mid-line was then drawn through the curvature to create a reference axis. Along this axis, grid lines were drawn at every inch starting at the bottom of the body. At each grid line, the distance from the center axis to the curve was measured. Additional points between grid lines were measured at maxima and minima to more accurately model the curvature. Images of this process are displayed in Figure 1 below:
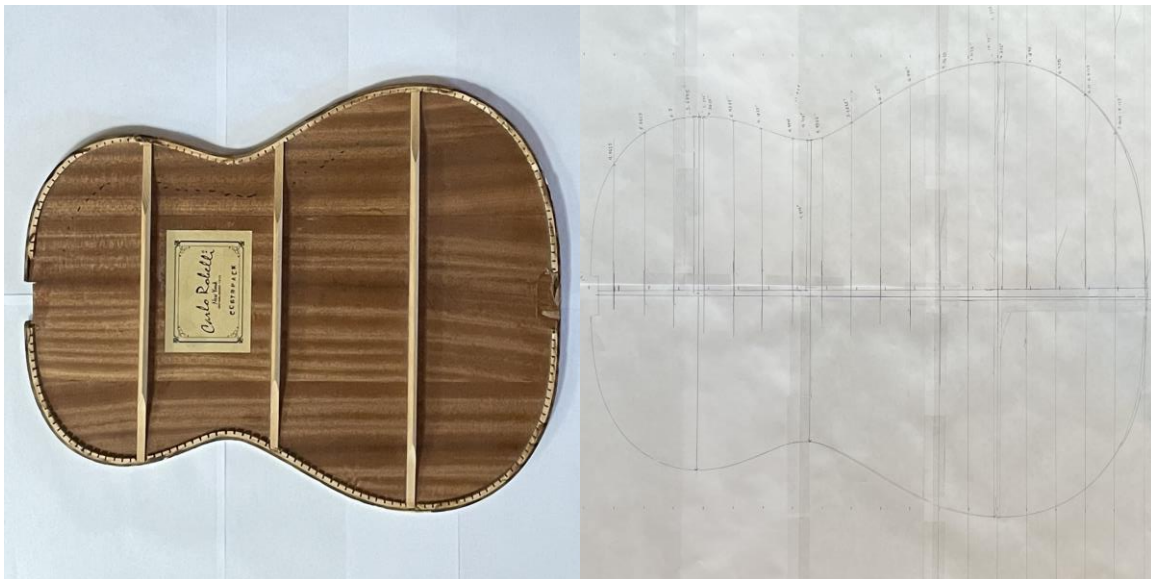

Figure 1: Guitar back and resultant trace with measurements.

These co-ordinates were recorded into an Excel sheet to organize the data, have a basis for model generation in COMSOL, and attempt to find a regression model for the curve. The negative

reciprocals of these points were also added (e.g. [1, 5.125] & [1, -5.125]) to outline the full curvature of the guitar for the modeling process later on. Other critical dimensions were also noted, including the wall thickness, cavity thickness, sound-port radius, and sound-port position, referencing other guitars as needed again for the modeling process later on.

2.1. Recommendations

During this process there was an attempt to draw the curvature in SOLIDWORKS using the sketch picture tool, but due to difficulties in using the tool it was scrapped for the former process. This method however, could be a more efficient and accurate way of creating the curvature and should be considered for future developments in this project. Additionally, it appears that CAD files could be directly imported into COMSOL, which if practical could eliminate much of the difficulty from this process and is also a route worth considering in future developments. We also did not measure the dimensions and locations of the support beams on the back plate, which is an important structural element for acoustic guitars should be measured in following work.

3. Building the Model in COMSOL

Two main methods were used to access the COMSOL software: the computers in the HL 234 lab and the remote desktops under the address arcts-04.wpi.edu. The specific version of the software used was the (Classkit License) COMSOL Multiphysics 6.0. To assist us with using the software and designing a functional simulation, we worked heavily with Professor Adriana Hera in the ARC. Most of our work followed the structure of the violin model used in the COMSOL blog post titled *Analyze Violin Tone and Volume with Multiphysics Modeling* by Linus Andersson. The modeling process we performed is generally outlined below.

The modeling process began by using the modeling wizard option available upon start up to select the fundamental parameters of the simulation. For the space dimension, 3D was selected. For the physics, we added frequency domain, found under pressure acoustics which is found under acoustics, and solid mechanics under structural mechanics. We ignored adding studies at this time and pressed the done button.

We then added a work plane to Geometry 1. To the plane geometry under this work plane, we added a polygon. Using the file data source, we imported a text file exported from our Excel data as a basis for the outline for the polygon. Figure 2 shows the set of coordinates that were imported into COMSOL:
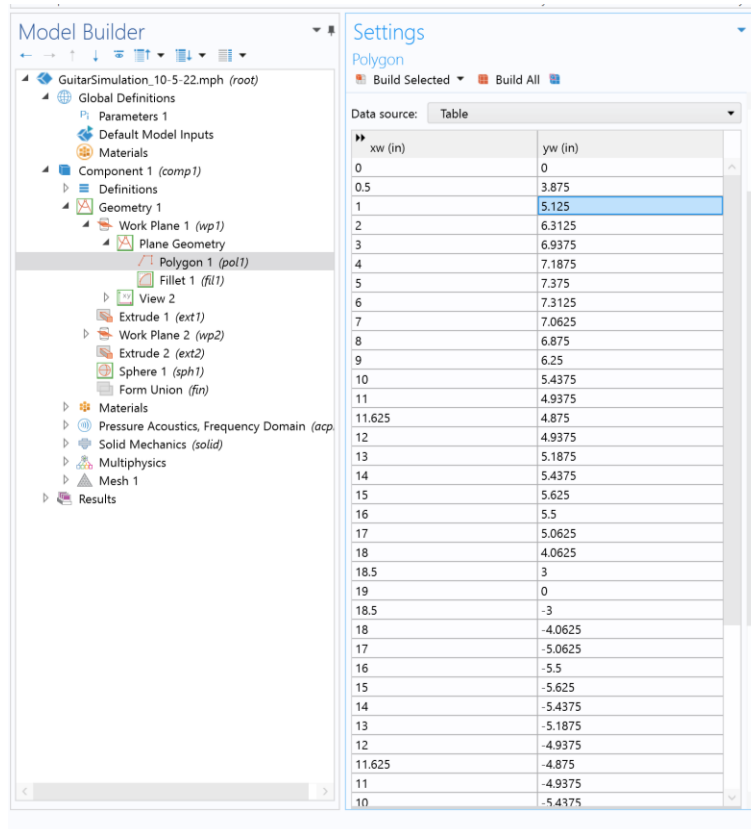
Model Builder

- GuitarSimulation_10-5-22.mph (root)
  - Global Definitions
    - Parameters 1
    - Default Model Inputs
    - Materials
  - Component 1 (comp1)
    - Definitions
    - Geometry 1
      - Work Plane 1 (wp1)
        - Plane Geometry
          - Polygon 1 (pol1)
          - Fillet 1 (fil1)
        - View 2
      - Extrude 1 (ext1)
      - Work Plane 2 (wp2)
      - Extrude 2 (ext2)
      - Sphere 1 (sph1)
      - Form Union (fin)
    - Materials
    - Pressure Acoustics, Frequency Domain (acp)
    - Solid Mechanics (solid)
    - Multiphysics
    - Mesh 1
  - Results

Settings

Polygon

Build Selected ▾   Build All

Data source: Table

xw (in)	yw (in)
0	0
0.5	3.875
1	5.125
2	6.3125
3	6.9375
4	7.1875
5	7.375
6	7.3125
7	7.0625
8	6.875
9	6.25
10	5.4375
11	4.9375
11.625	4.875
12	4.9375
13	5.1875
14	5.4375
15	5.625
16	5.5
17	5.0625
18	4.0625
18.5	3
19	0
18.5	-3
18	-4.0625
17	-5.0625
16	-5.5
15	-5.625
14	-5.4375
13	-5.1875
12	-4.9375
11.625	-4.875
11	-4.9375
10	-5.4375

Figure 2: Perimeter coordinates of the guitar after being imported into COMSOL.

By pressing build all, these points were automatically mapped and connected, forming the shape of the guitar body pictured in Figure 3.
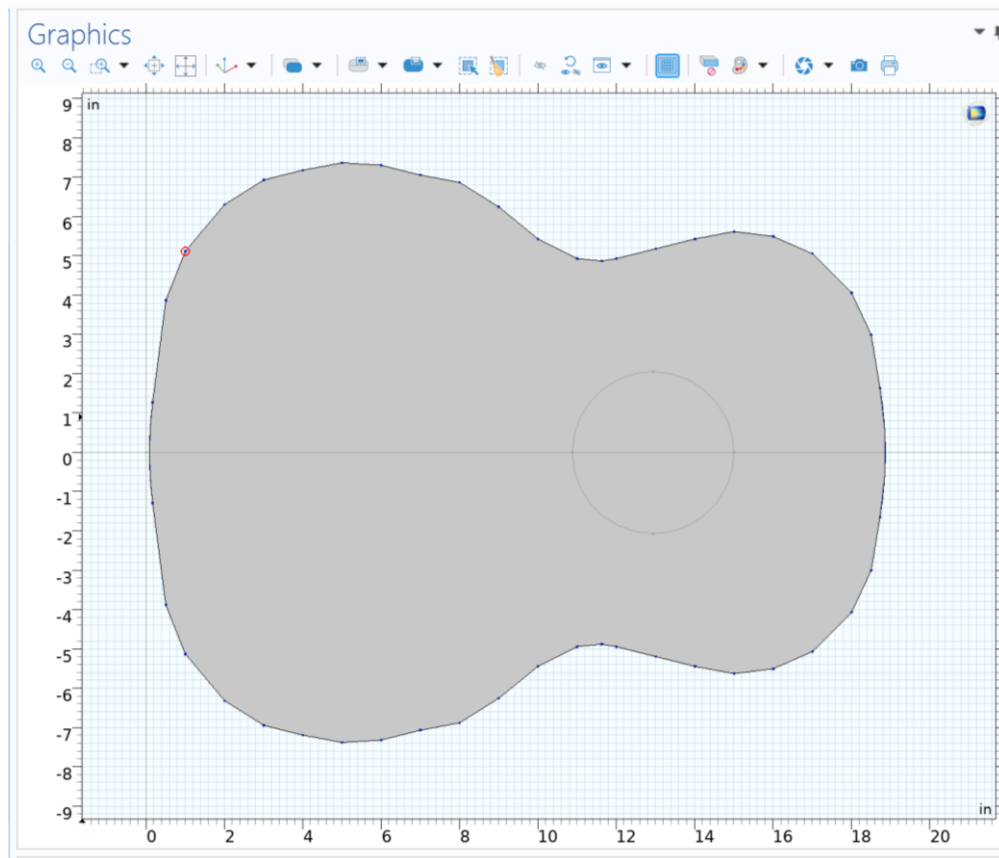
Figure 3: Perimeter of the guitar using the point coordinates and connecting them with lines.

Once we had the perimeter of the guitar mapped out in the 2D plane, we proceeded to build our model into 3D space using parameters. Parameters included values such as the bottom and top plate thicknesses, the air cavity thickness, and the sound-port radius so they could be easily adjusted later on. The parameters we defined are shown in Figure 4 and detailed in the following list:
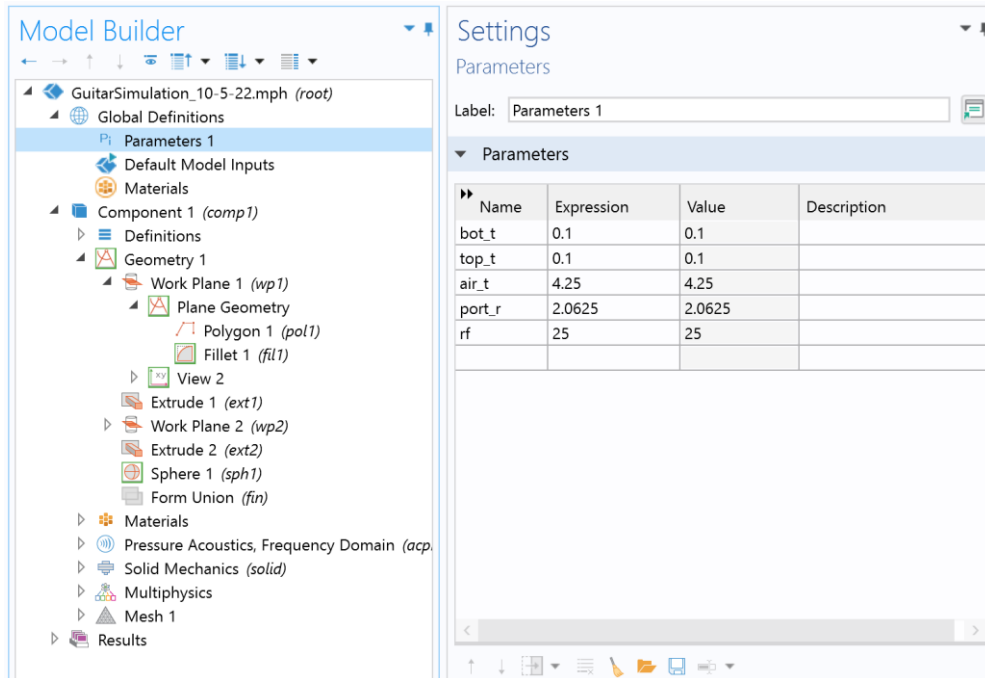
Figure 4: Parameters that define the dimensions of the different features of the guitar (top/bottom layer, air cavity, and sound port)

- **bot_t** = bottom layer thickness of the guitar = 0.1''
- **top_t** = top layer thickness of the guitar = 0.1''
- **air_t** = air cavity thickness (distance between top/bottom layers of the guitar) = 4.25''
- **port_r** = radius of sound port = 2.0625''
- **rf** = radius of sphere creating the external atmosphere = 25''

The next step was to extrude the various features. We created three extrusions from Work Plane 1 using our parameters; one for the bottom plate of the guitar, one for the air cavity, and one for the top plate. The parameters used to define these distances and the resultant model created after hitting the build all button are shown in Figure 5. The vertical line sections represent the sections created by the lines connecting all the coordinates in the 2D plane.
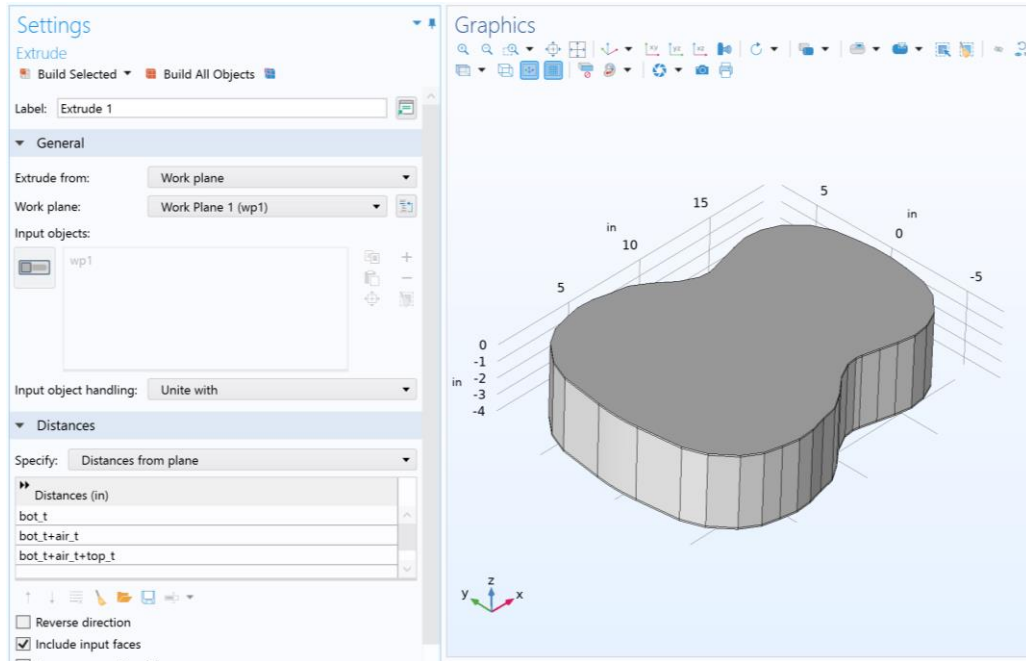
Figure 5: 3D model of the guitar after creating the three extrusions (top/bottom layers, and air cavity)

With the main 3D guitar body built, the next step was to create the sound port following a similar process as above. To do this, a new work plane was created at the at the top plate / air cavity interface by using our parameters to define the z-coordinate. To the plane geometry of this work plane, we added a circle, which we defined the size of and position of using our parameters shown in Figure 6.
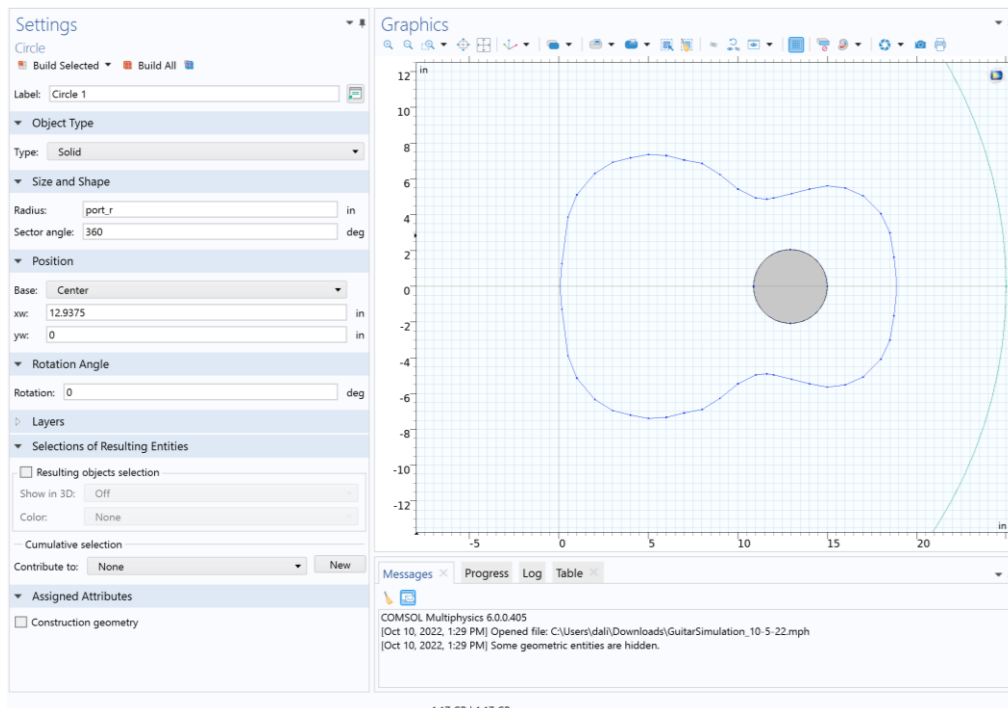
Figure 6: Defined geometry of the sound port hole.

We then extruded this work plane upwards to the thickness of the top plate, again using our parameters. The resulting model after hitting build all is shown in Figure 7.
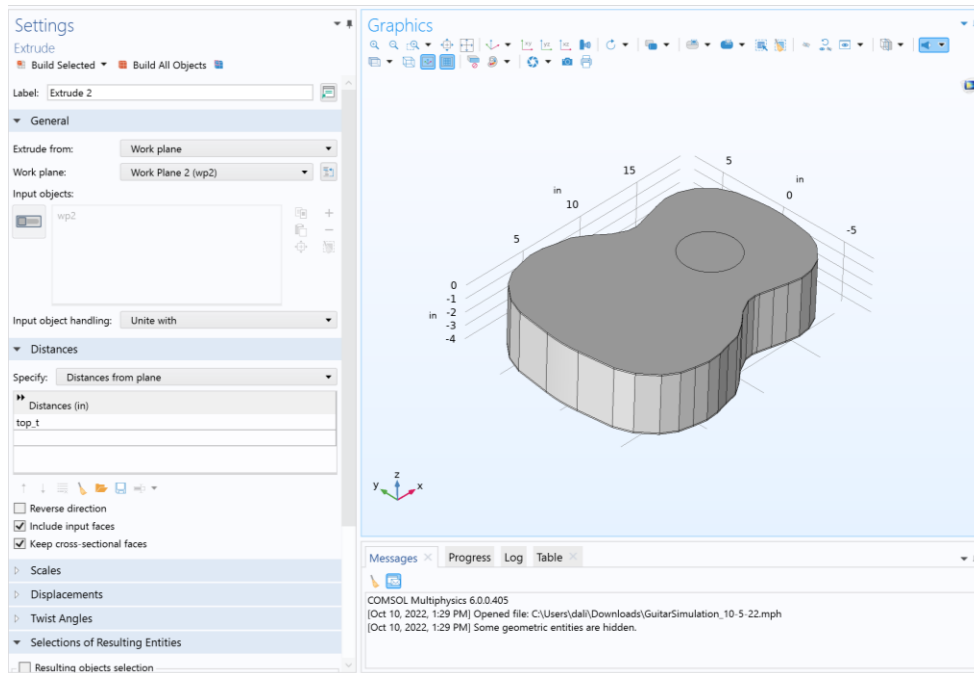
Figure 7: Extruded sound port hole added to the model.

With the sound port added our simplified guitar model was complete, and we could focus on adding the physics and starting the basis for the simulation.

3.1. Recommendations

Our model had several missing features and simplifications which could be added and refined in future work. For one, the model was barely rounded, with straight lines connecting points and fillets only being used on the bottom and top of the guitar to slightly improve the roundness of the guitar. Fillets and other modeling methods may be able to produce a better curvature and thereby a more accurate simulation. Secondly, we left out the supports attached to the back of the guitar which change the structure of the body and also limit the accuracy of the simulation. Thirdly, we also failed to account for the varying thickness of the air cavity for on real guitars the wider end of the guitar typically has a thicker cavity than the area around the neck. Overall improvements should be made in the quality of the model in order to produce more accurate results.

4. Physics and Simulation Design

In order to create a functioning simulation, we had to define the environment and the physics of each component in our system. To create the environment, a sphere was made under Geometry 1 using our rf parameter to define the radius. The radius was set to 25" to be large enough to fully encapsulate the guitar. Figure #8 shows the sphere surrounding the guitar, with an 8th being hidden for visualization purposes.
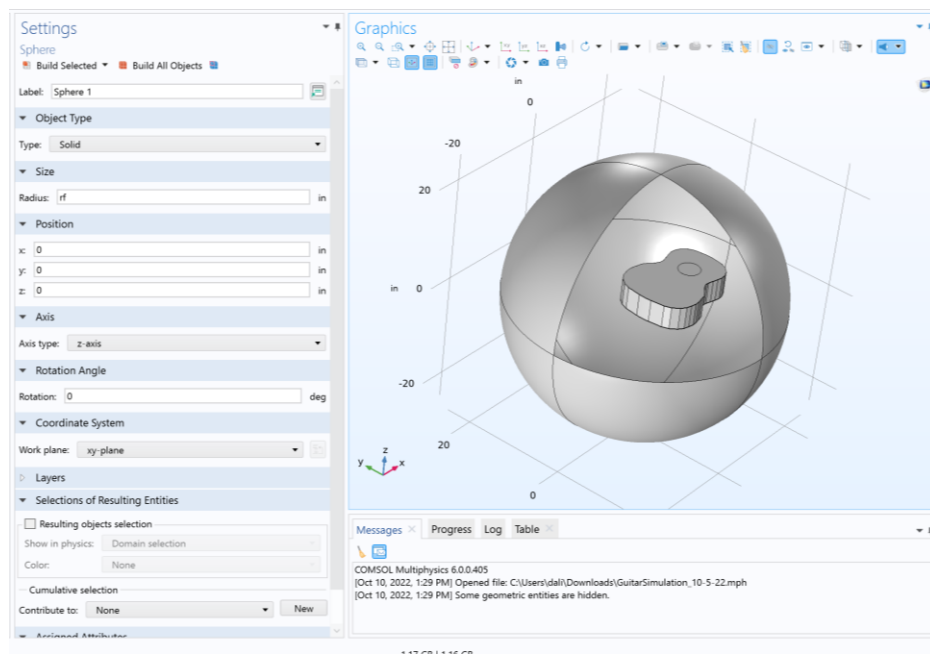

Figure 8: Sphere created for the external environment with our guitar model inside.

Once the sphere was created, we began to assign materials to our geometries using the material library included with the software. We assigned spruce properties to the top plate and back plate extrusions, for our research claimed spruce is a commonly used wood in guitars, and for everything else, including the cavity, environment, and sound port, we assigned air properties. The densities from these properties are outlined below:

- Average density of air utilized in analysis $= \frac{1.225 kg}{m^3}$
- Average density of spruce utilized in analysis $= \frac{470 kg}{m^3}$

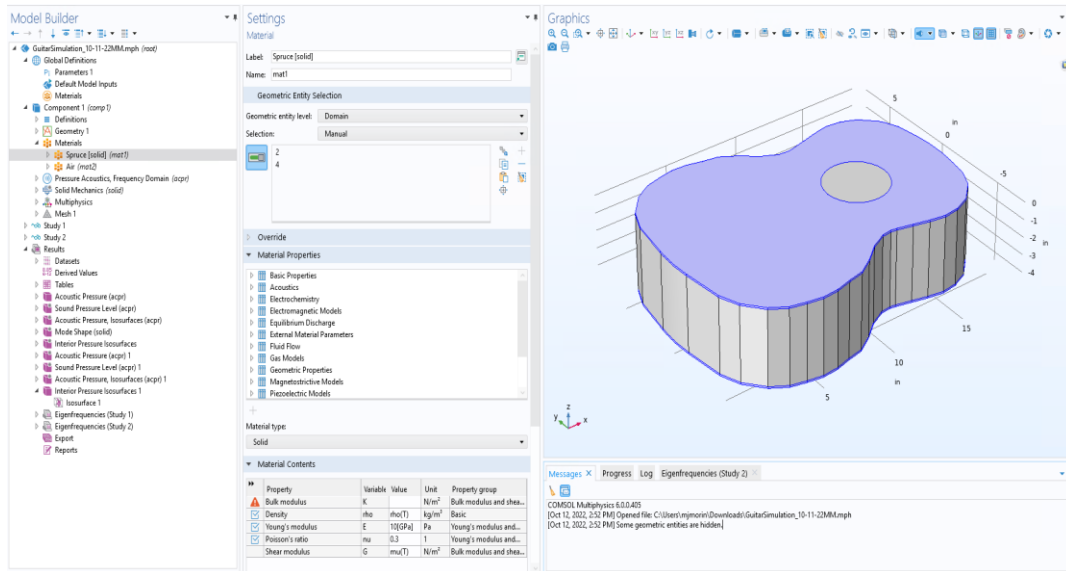Figure 9 shows the materials used and how we assigned them to each element in our system.

Figure 9: Materials (spruce and air) being assigned to the individual components in our system.

Once the materials were added and assigned, it was time to assign the physics to the components in the system. We started by assigning pressure acoustics to our three air-based components, the cavity, environment, and sound port, shown in Figure 10.
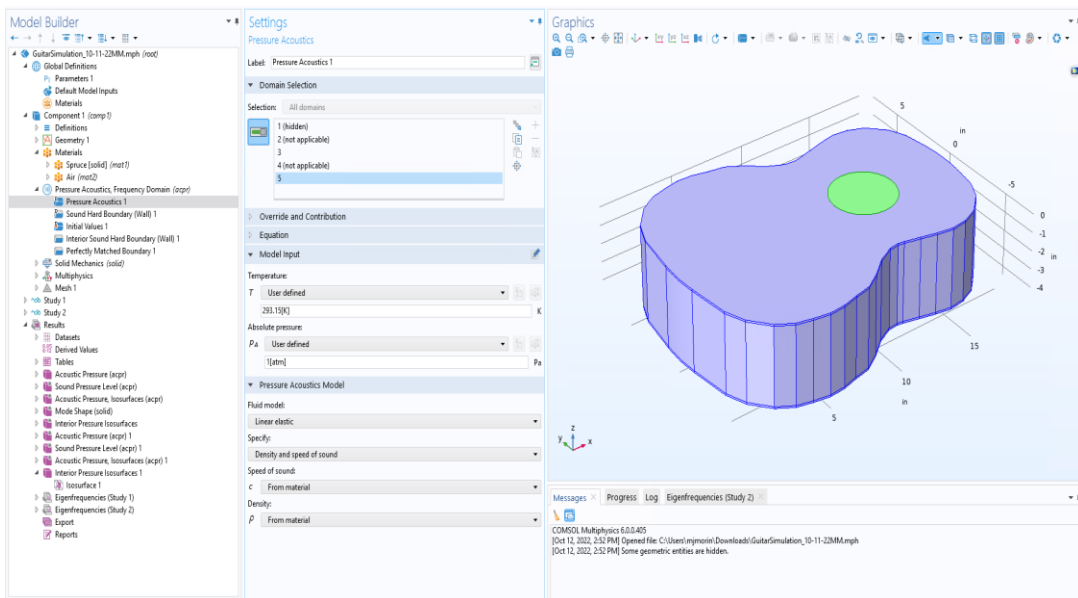

Figure 10: Assignment of pressure acoustics to each of the three air geometries.

We then assigned interior hard boundary wall properties to all of the walls created from our cavity air extrusion, shown in Figure 11.
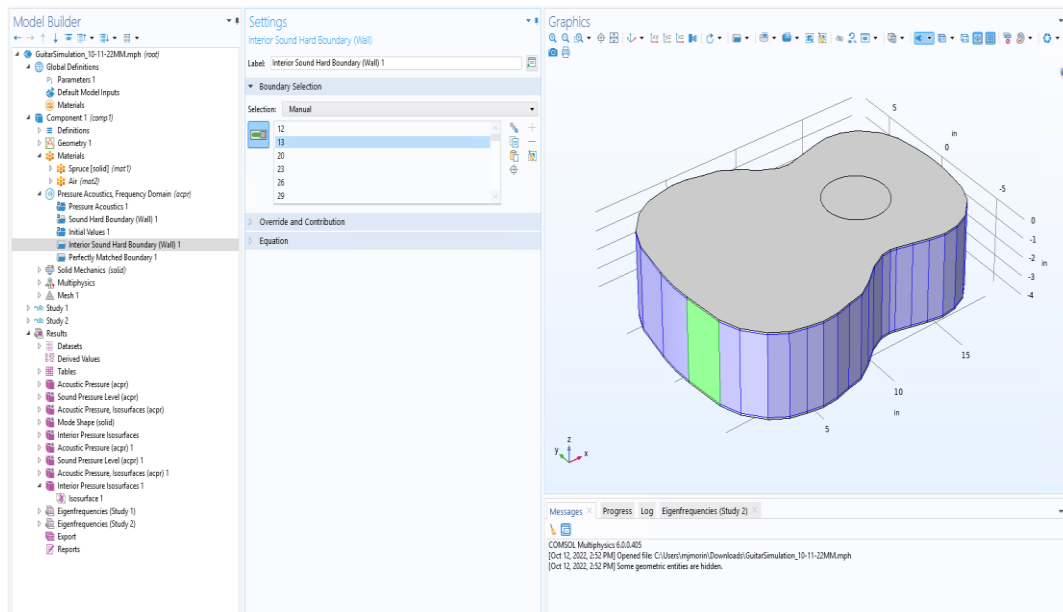
Figure 11: Assignment of hard boundary wall properties to all of the walls of the air cavity. Hard boundaries are rigid are therefore do not deform in the simulation.

The next step after assigning our acoustic physics was to assign our solid mechanics to the other components in the system. Following a similar process to our acoustic physics, we assigned linear elastic material properties to our spruce components, aka the top and bottom plates, shown in Figure 12.
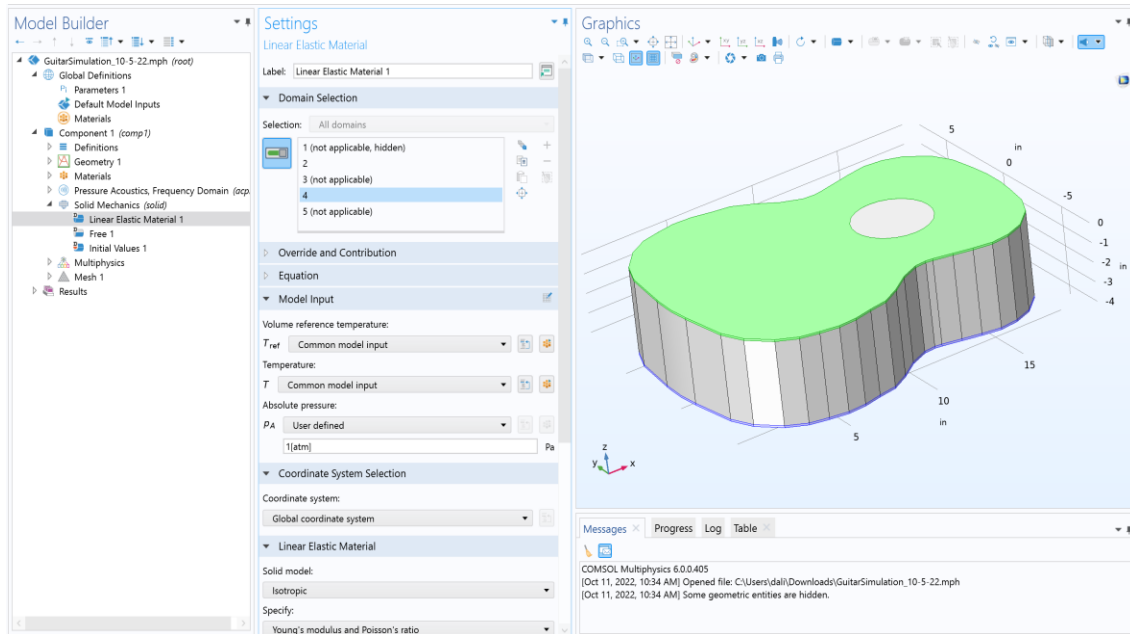
Figure 12: Assignment of linear elastic material properties to the top and bottom plates.

Lastly, the acoustic-structure boundary under multiphysics was added. These assignments cover the sections that are going to be experiencing the external environment. To assign these physics, under the coupled interfaces section, the acoustics domain was assigned to our pressure acoustics assignments and the structure domain was assigned to our solid mechanics assignments, automatically selecting the necessary boundaries in the process. Figure 13 provides a visual explanation of this process.
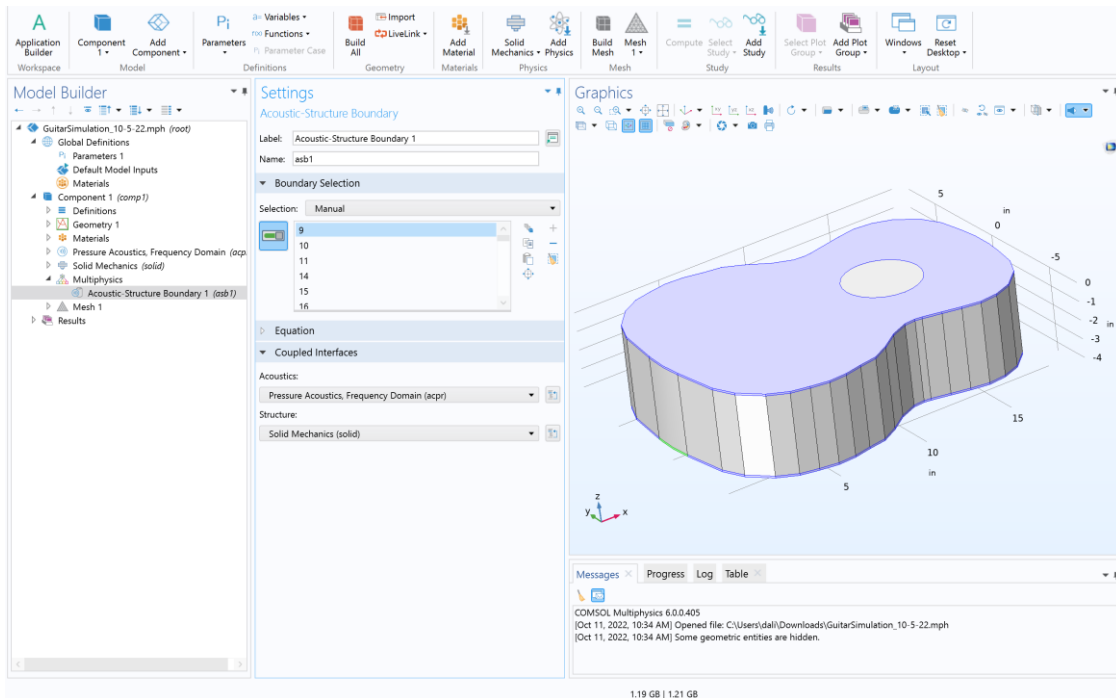
Figure 13: Acoustic-structure boundary multiphysics assignment.

Once the physics were set, it was finally time to prepare the mesh geometry for the simulation. We right clicked on Component 1 and created a Mesh 1 object. Under Mesh 1, the element size was set to coarse. The model was selected and the build all button was hit, creating the mesh. Figure 14 shows the created mesh used in the final analysis.
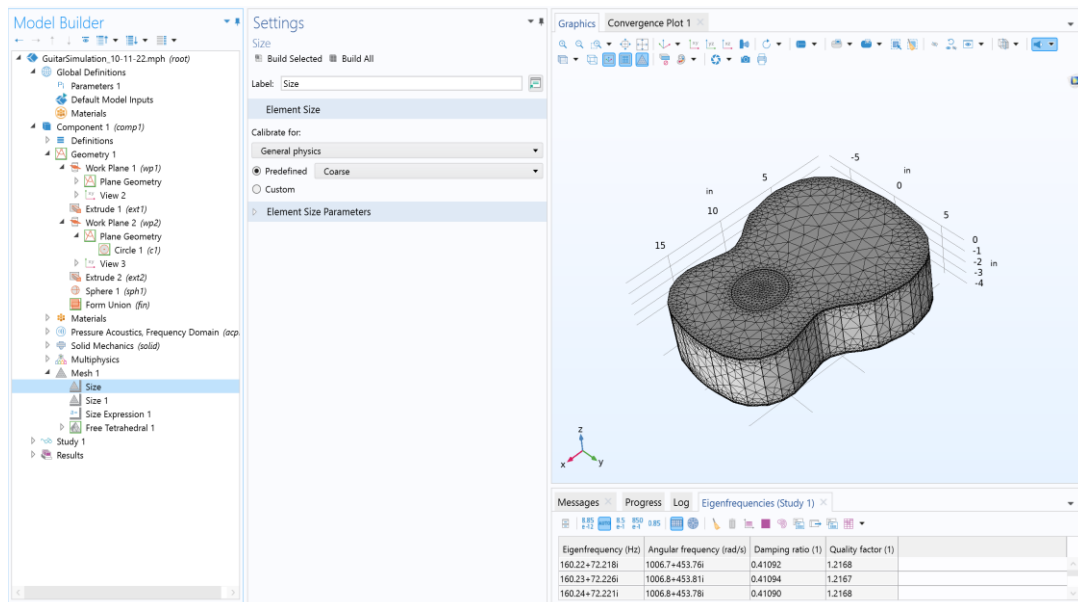
Figure 14: Creation of the mesh.

Once the mesh was created, it was finally time to add the desired studies to create the simulation. We right clicked on the overall file name in the model builder on the left to add our studies. In this case, we added an eigen frequency study with all physics interfaces selected, since we wanted to test and calculate the eigenfrequencies of our guitar model in relation to different placements and sizes of the sound port. Since guitar strings vibrate within the range of 82 HZ and 330 Hz, we searched for frequencies using 250 Hz as our base. Figure 15 shows the parameters we ended up using.
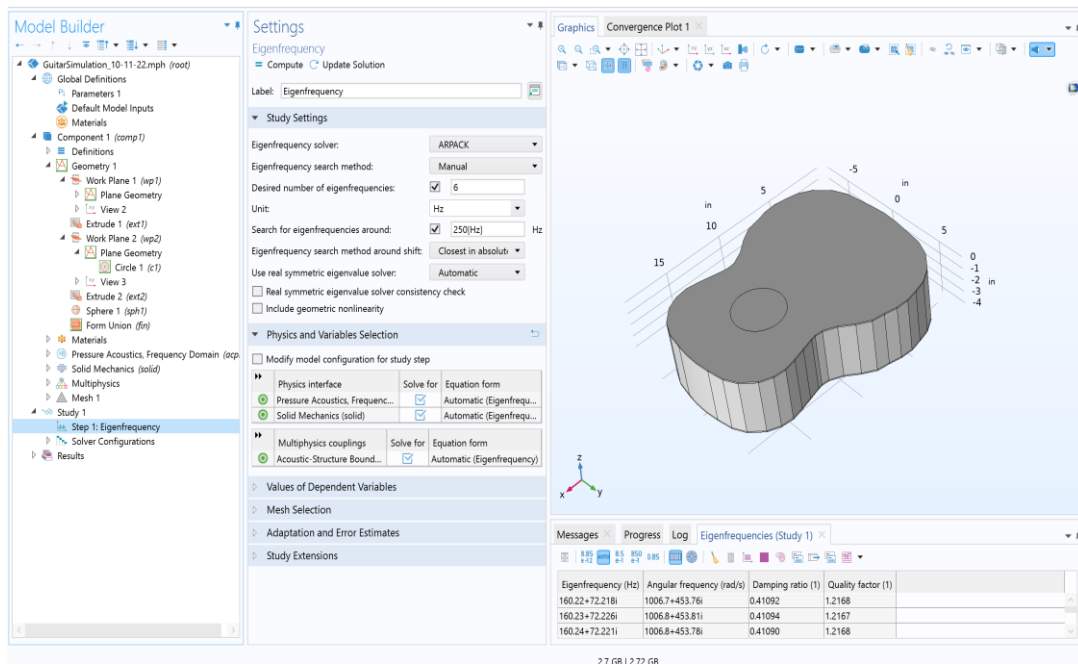

Figure 15: Eigen frequency study parameters.

With our study fully set up, the simulation was ran. After processing, we added a few plots to our results section and played with the settings to better visualize our desired values. Included below in the following figures are some of the plots from our study.
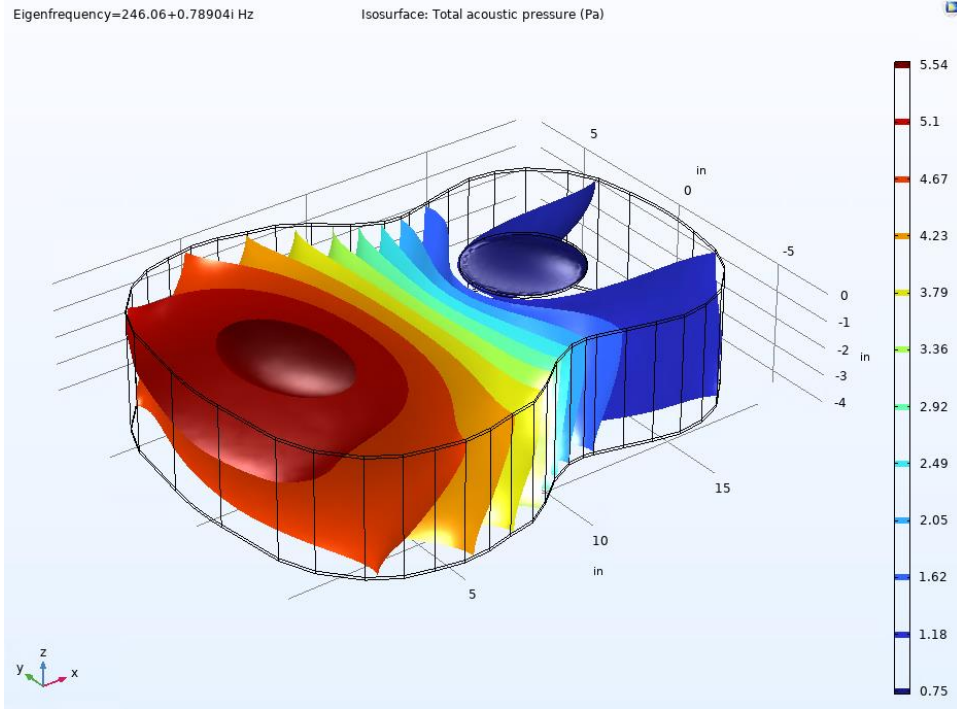
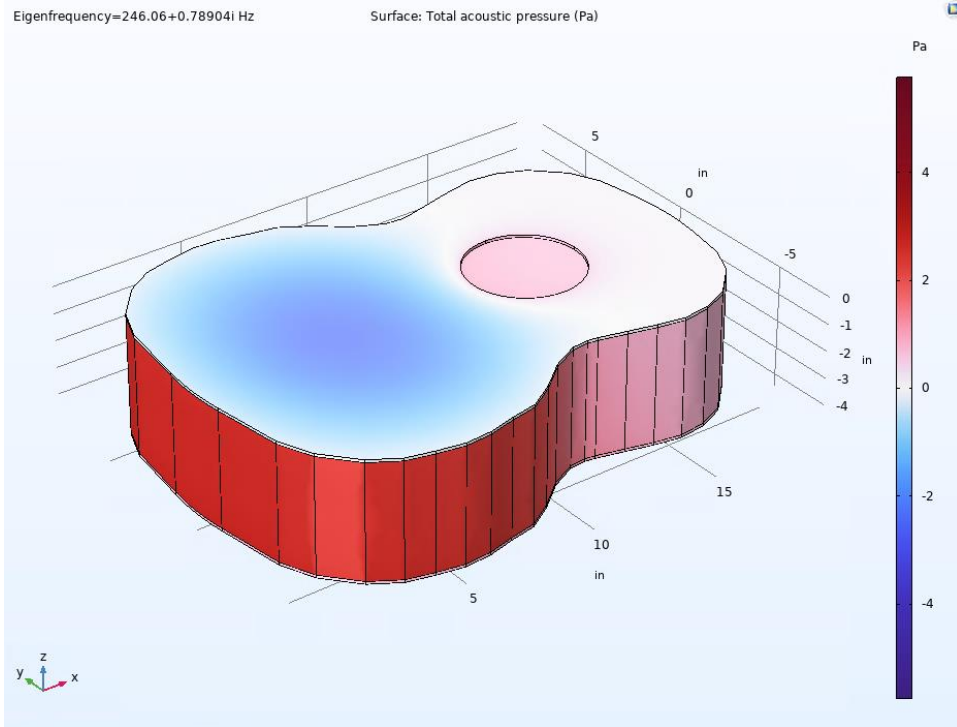**Figure 16:** Internal air pressure plot.

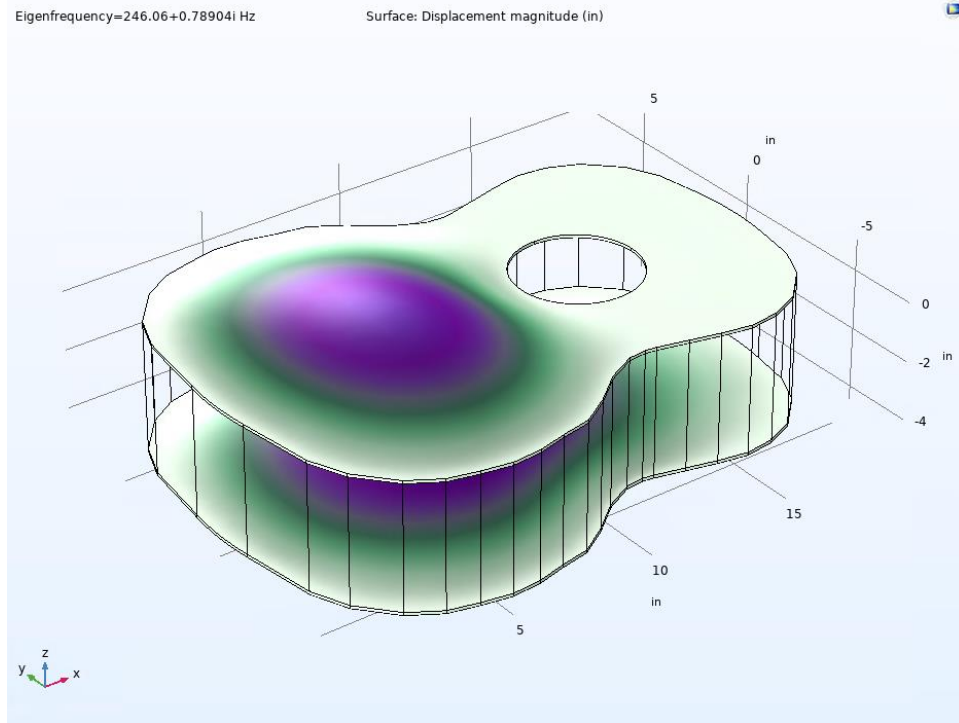**Figure 17:** Acoustic air pressure plot.

Figure 18: Mode shape plot.

4.1. Recommendations

Overall, by the time our simulation was functional, we had little time to meaningfully interpret and plot the data. More plots and studies with various parameters and sound port sizes should be taken to better formulate the mechanics of the sound port. Additionally, we have no clue how accurate the values from these simulations are, so it may be of use to do a verification test, comparing the simulated results to those from a physical experiment.

5. Closing Thoughts

This project was exciting to work with and certainly has the potential to return really useful results. We personally found seven weeks to be really restricting however, limiting the amount we could accomplish. Learning COMSOL is where the bulk of the work and difficulty in this project lied, and we recommend future teams start to play around with the software very early on. Overall, while we were not able to produce the most useful results, we hope our accomplishments and outline in this paper is enough of a basis to help future groups push the work forward and we would love to see this get used eventually to better design and understand guitars.