Assignment

Homework HL1

Nicolò Chillè, Rocco Scarano

Musical Acoustics

POLITECNICO
MILANO 1863

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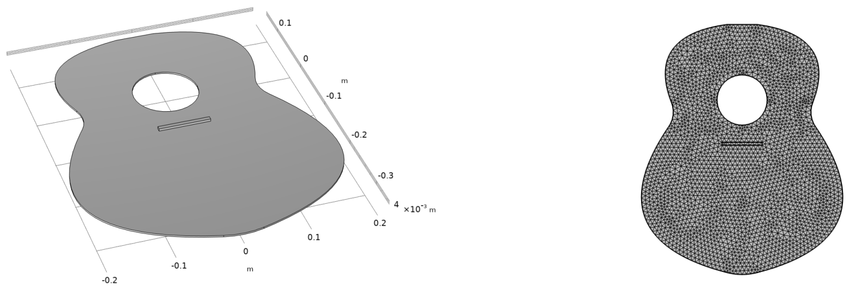
Introduction

In this study, we're going to study the behaviour of a thin plate acting as a soundboard, by simulations in COMSOL environment. We'll analyze its behaviour both in free and bounded conditions and both in free and forced motion.

Characterization of a string instrument sounboard

To get a precise idea of the dimensions of an acoustic guitar, we took inspiration from a soundboard of a Greg Bennett guitar (model number D-8CE). After acquiring measurements, our initial step involved the establishment of a 2D structural representation represented by a rectangular shape. Subsequently, a sequence of points was strategically inserted, enabling the derivation of a continuous curve via interpolation. This curve was symmetrically mirrored. Continuing our modeling endeavor, a foundational plane was introduced, serving as the basis for the extrusion operation to produce a 3D solid resembling the geometric contours of a guitar. Notably, a central disc was purposefully excluded from this volumetric construct to accommodate the specific design attributes of the instrument. In the final stages of the modeling process, we used the fillet function to round the corners and get as close as possible to the shape of the sound box of the guitar. Once the modeling of the sound box was completed, we added a polygon that represents the guitar's bridge.
In the end, we obtain the following component:



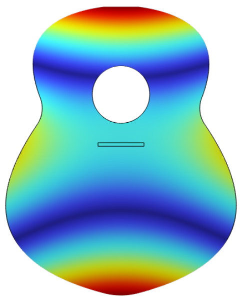
(a) Soundboard shape (b) Normal Thetahedral mesh

Figure 1: Completed Soundboard

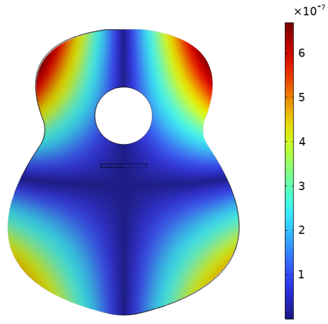
We now proceed to assign the isotropic "Engelmann Spruce" material to the board. To do so, we define a new material for the component, using the values obtained from the table (8), to define its properties (Young's modulus, Shear Modulus, Poisson's ratio and density) using respectively E_L, G_{LR} and ν_{LR}, and we assign it to our component. In the end, we set a ***Free Tetrahedral*** mesh with normal quality to the whole component. We're now ready to perform our studies on the board.

Eigenfrequency simulation in free boundary

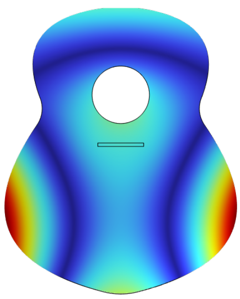
To execute the eigenfrequency simulation, we add a study to our project, in which we're going to perform the ***Eigenfrequency study*** as our first step. We set the analysis to find the first 6 modes of the plate. Here are the obtained results:



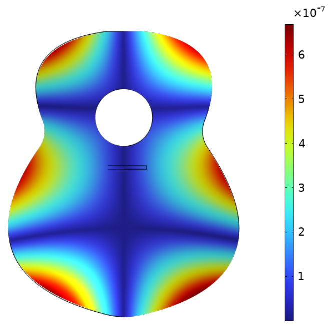
(a) Mode 1: f = 58.15 Hz



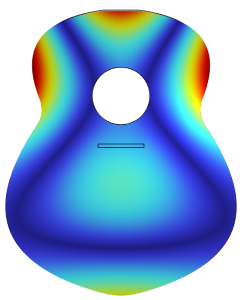
(b) Mode 2: f = 58.69 Hz



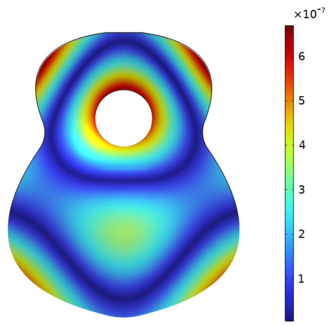
(c) Mode 3: f = 115.75 Hz



(d) Mode 4: f = 139.31 Hz



(e) Mode 5: f = 166.9 Hz

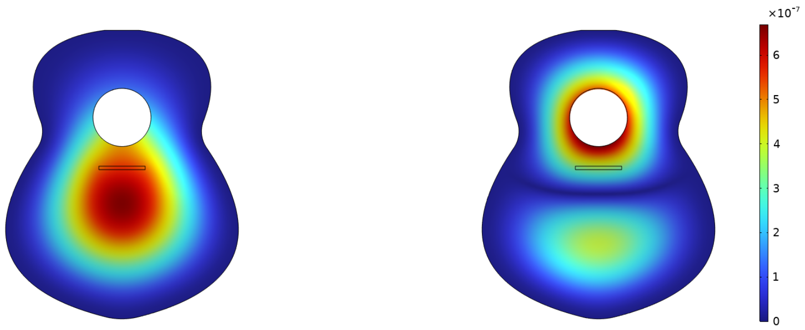


(f) Mode 6: f = 228.59 Hz

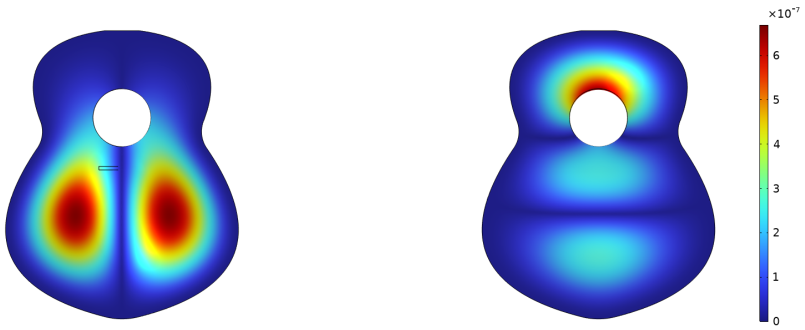
Figure 2: first 6 modes of the plate, isotropic material with free edges.

Perform eigenfrequency simulation applying fixed constraints to the sides (or lower edges) of the plate

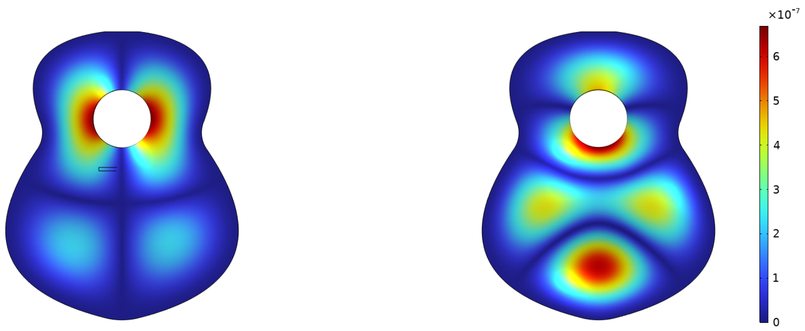
We're now going to add the boundary conditions to our plate. To do so, we add a ***Fixed Constraint*** behaviour to the physics of our component, selecting the external edges of the plate. Here are the obtained results:



(a) Mode 1: f = 177.39 Hz (b) Mode 2: f = 299.43 Hz



(c) Mode 3: f = 379.39 Hz (d) Mode 4: f = 421.13 Hz



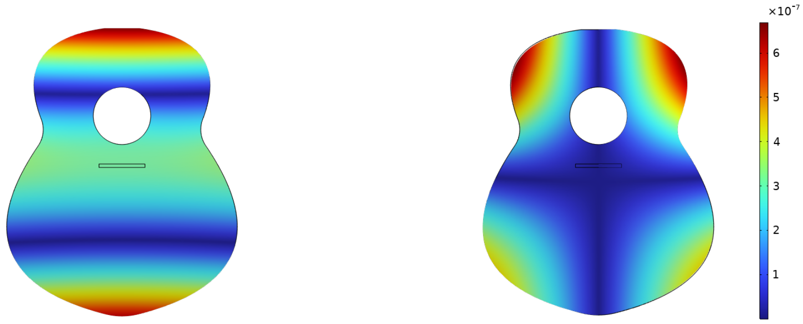
(e) Mode 5: f = 522.54 Hz (f) Mode 6: f = 606.91 Hz

Figure 3: first 6 modes of the plate, isotropic material with clamped edges.

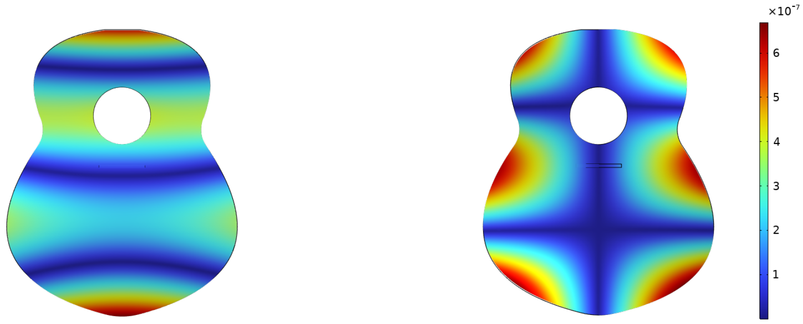
We can notice how, by fixing the edges, the plate moves differently from the free edges configuration. We can also notice how the Eigenfrequencies of these modes results to be higher with respect to the previous ones.

Redefine Engelmann Spruce as an orthotropic material and repeat the previous assignments

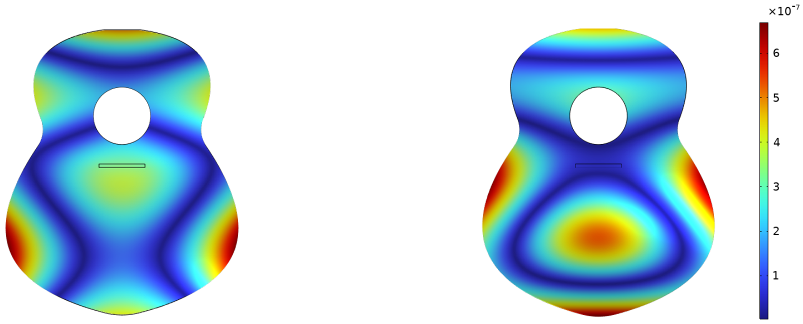
An orthotropic material exhibits different mechanical properties in three orthogonal directions, as it possesses distinct material properties along its principal axes, making it anisotropic. In the following section we will consider the soundboard to be made by this type of material and we repeat the analysis done for the isotropic material.



(a) Mode 1: f = 21.63 Hz (b) Mode 2: f = 33.46 Hz

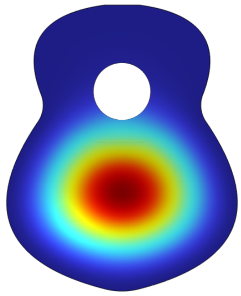


(c) Mode 3: f = 59.22 Hz (d) Mode 4: f = 71.60 Hz

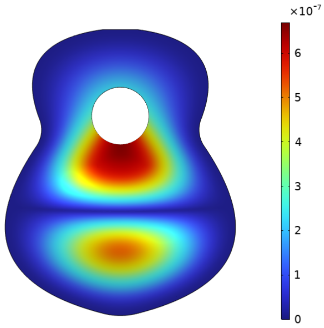


(e) Mode 5: f = 104.06 Hz (f) Mode 6: f = 121.24 Hz

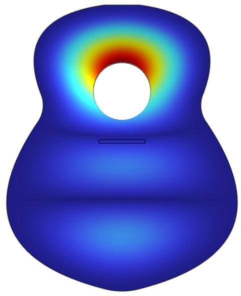
Figure 4: first 6 modes of the plate, orthotropic material with free edges.



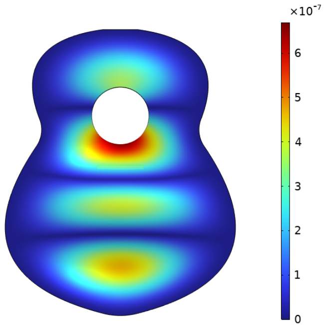
(a) Mode 1: f = 116.82 Hz



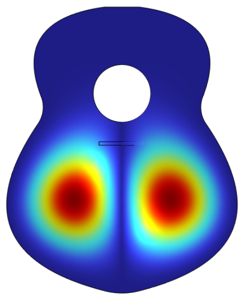
(b) Mode 2: f = 181.08 Hz



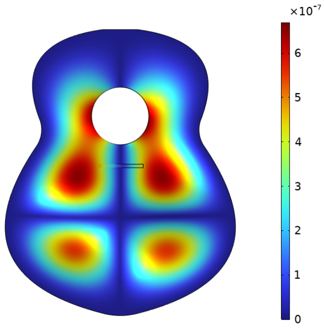
(c) Mode 3: f = 222.81 Hz



(d) Mode 4: f = 273.39 Hz



(e) Mode 5: f = 282.01 Hz



(f) Mode 6: f = 383.18 Hz

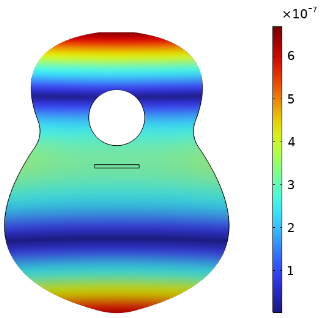
Figure 5: first 6 modes of the plate, orthotropic material with clamped edges.

We can see how, by changing the properties of the material, the mode shapes and fundamental frequencies are different from the isotropic situation studied before, both in the free edges and bounded edges behaviours.

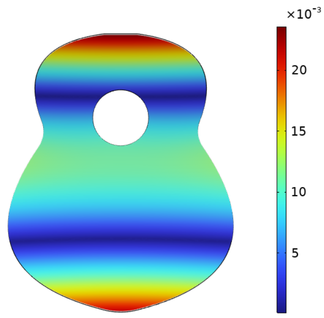
Frequency domain simulation

We now consider the free plate, still in orthotropic material condition, but considering the bridge of the soundboard to be made of Red Maple. We then apply a 1 N/m^2 load to top of the bridge, perpendicular to the application surface. In the end, we perform a frequency domain study, using a sweep in frequencies with settings range(10,3,110) and analysing also the first five fundamental frequencies of the board in free vibration condition.

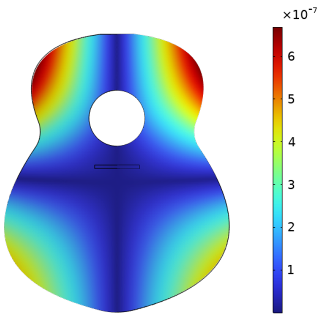
Export plots of the plate displacement and compare them with the ones obtained from the eigenfrequency study



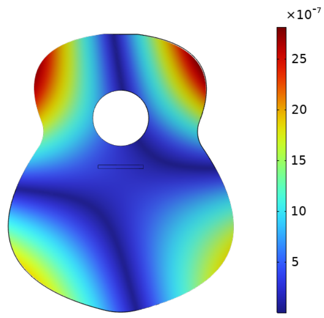
(a) Mode 1 - Unstressed: f = 21.63 Hz



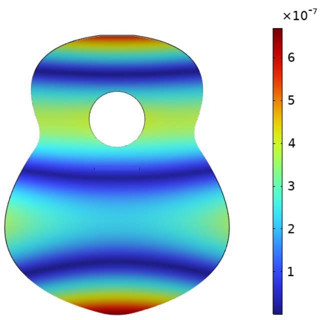
(b) Mode 1 - Stressed: f = 21.63 Hz



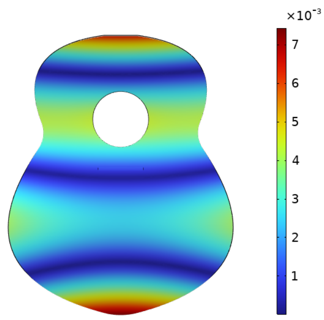
(c) Mode 2 - Unstressed: f = 33.56 Hz



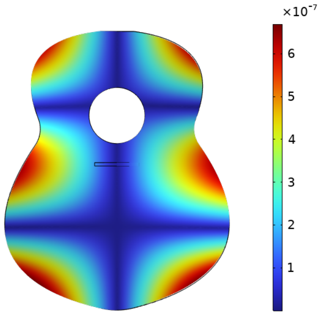
(d) Mode 2 - Stressed: f = 33.56 Hz



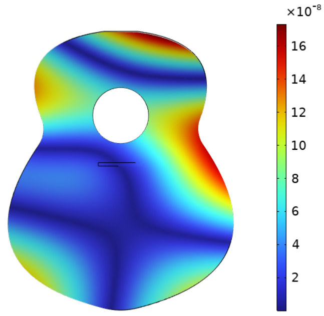
(e) Mode 3 - Unstressed: f = 59.25 Hz



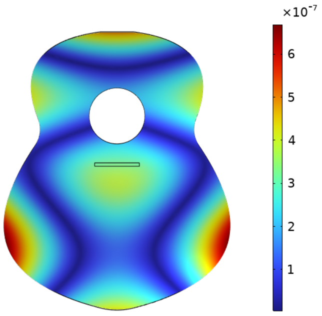
(f) Mode 3 - Stressed: f = 59.25 Hz



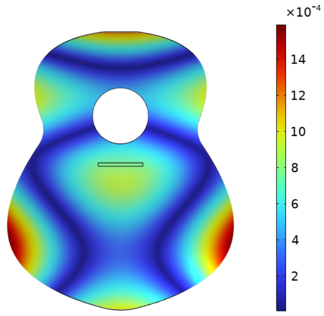
(g) Mode 4 - Unstressed: f = 71.67 Hz



(h) Mode 4 - Stressed: f = 71.67 Hz



(i) Mode 5 - Unstressed: f = 104.03 Hz



(j) Mode 5 - Stressed: f = 104.03 Hz

Figure 6: First 5 modes of the plate, unstressed and stressed condition

We can notice how the first, third and fifth mode are much larger in displacement in the stressed case than in the unstressed one: this is due to the fact that the bridge is located near an anti-node of the mode shape, therefore such modes are more emphasized. We can also notice how, for the second and fourth mode, the mode shape itself looks different. This is because in these modes the bridge is supposed to stay still, but applying a force to it and making it move causes a superposition of other modes, therefore modifying its behaviour.

Plot the velocity, along the direction perpendicular to the plate at the bridge position, as a function of frequency

Having calculated the surface average velocity at the contact area between the bridge and the plate, we can now see from the graph below the obtained results:

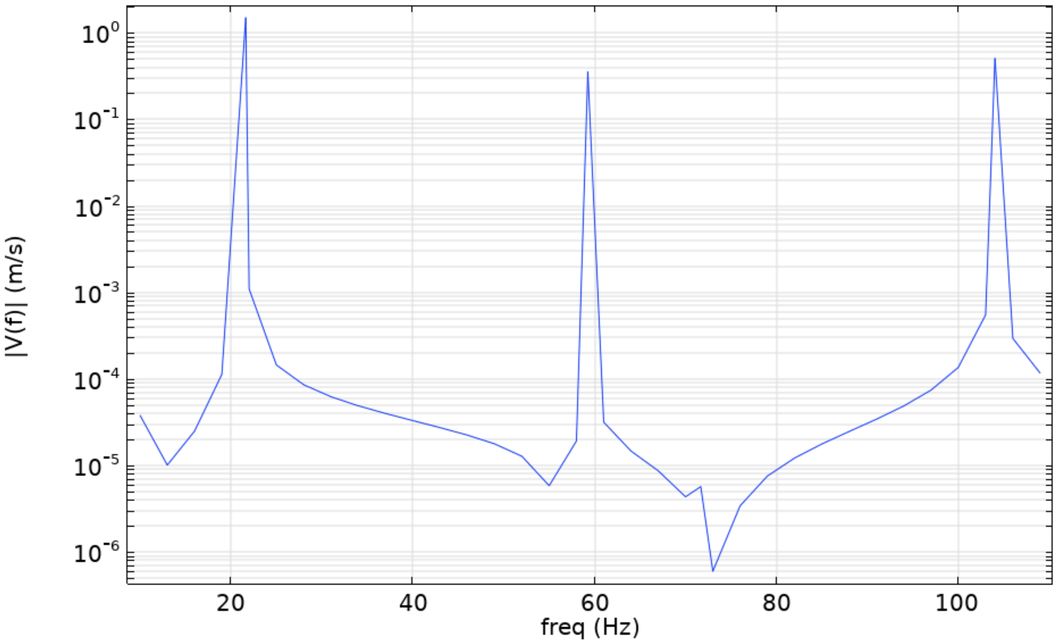


Figure 7: Velocity at contact area between bridge and soundboard, z-direction

We can notice how three peaks appear in the graph: these correspond at the eigenfrequencies of the first, third and fifth mode of the plate, where the modes are emphasized as explained in the previous section. For the second and fourth mode, the velocity is considerably lower because the force is being applied near to a nodal line of the mode shape, therefore such modes won't basically be excited.

Conclusions

Concluding, this study provides a comprehensive understanding of the dynamic behavior and interactions of the plate-string system, addressing the acoustic properties, resonance modes, and tuning requirements. The obtained results offer valuable insights into the design and performance of musical instruments and soundboards, as well as the physics of material interactions in such systems.

Materials Table

Density [kg/m^3]			
Engelmann Spruce	350		
Red Maple	540		
Young's Moduli [GPa]			
	E_L	E_R	E_T
Engelmann Spruce	9.79	1.25	0.58
Red Maple	12.43	1.74	0.83
Shear Moduli [GPa]			
	G_{LR}	G_{RT}	G_{LT}
Engelmann Spruce	1.21	0.10	1.17
Red Maple	1.65	0.30	0.92
Poissons's Ratios			
	ν_{LR}	ν_{RT}	ν_{LT}
Engelmann Spruce	0.422	0.53	0.462
Red Maple	0.434	0.762	0.509

Figure 8: Material's properties table