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HL1 – Comsol Multiphysics

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1 Church Bell - 3D Model

1.1 Model Design

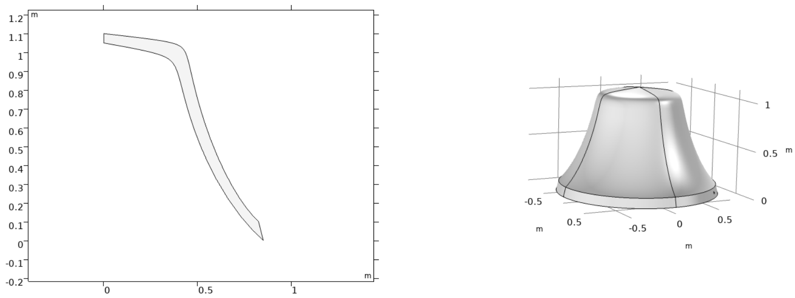

Figure 1: Bézier polygon (on the left) used as a basis for the design and the resulting rotation solid (on the right).

The modeling of the bell started with the drawing of the 2D shape seen in Fig. 1. This is a Bézier polygon, i. e. a closed curve formed by connecting line segments and Bézier curves. In our case we have two cubic Bézier curves connecting two segments, one of which marks the edge of the bell while the other coincides with the intersection of the object with its rotation axis. The actual 3D bell model is indeed obtained by rotating this figure about the $x = 0$ line, and it too can be seen in Fig. 1.

The way this is done in Comsol is by creating a 3D component, then adding a Work Plane node in its geometry, where the above-mentioned Bézier polygon is drawn, followed by a Revolve node to generate the solid.

The most common material for bellfounding is the aptly named “bell metal” which is a kind of bronze with a ratio of copper to tin of roughly 4:1. However, since the bronze alloys available in the Comsol libraries seemed to all have incomplete information regarding their mechanical parameters, we opted for cast iron (from the “Built-in” materials library), which is, by the way, another metal that has been historically used for bells, albeit less frequently.

1.2 Eigenfrequency study

We performed an eigenfrequency study with free boundary conditions. This meant keeping only the default subnodes in the Solid Mechanics node of our model, of which “Free 1” in particular is where the boundary conditions are set. The results are presented in Tab. 1.

The first six results are not eigenfrequencies of the system but they refer to the rigid body motion of the bell. Each of them represents one degree of freedom of a tridimensional system in a free configuration. They should have frequency zero but, because of the computational error, are rather very small numbers. Below these six values, every eigenfrequency shows degeneracy because of the symmetry under axial rotation. Three modeshapes animations can be found in the folder shared with this report: the gifs called ”mode 1” and ”mode 2” show the lowest pair of degenerate modes, while ”mode 9-10” is the eigenshape referred to the last two value of the table.

Eigenfrequencies [Hz]	Angular frequency [rad/s]
$i7.61 \times 10^{-5}$	$i4.78 \times 10^{-4}$
$i1.19 \times 10^{-4}$	$i7.48 \times 10^{-4}$
2.03×10^{-5}	1.28×10^{-4}
5.19×10^{-5}	3.26×10^{-4}
1.1×10^{-4}	6.9×10^{-4}
1.29×10^{-4}	8.13×10^{-4}
111.98	703.6
111.98	703.6
262.72	1650.7
262.72	1650.7
385.48	2422.028
385.48	2422.028
489.14	3073.35
489.14	3073.35
509.56	3201.69
509.56	3201.69

Table 1: Eigenfrequencies of the bell.

1.3 Time domain study

We set up a time-domain study to simulate the response of the object to an impulsive force. The impulse was modeled defining a short gaussian pulse in the Definition node of the component. The area where the impulse was applied was defined by taking the intersection between the bell and a cylinder of radius 1 cm with an axis orthogonal to the one of the bell. A force defined with the gaussian pulse was set to be applied to this area by adding a Boundary Load to the physics of the object.

More precisely, all of this was done twice: once on the edge of the bell and once on its side. For example, for the time domain study that concerned the side excitation, all boundary loads except the gaussian impulse which acts on the side have been disabled. Vice versa in the other case. We report here some snapshots of the results highlighting the time history of the displacement of the bell.

1.4 Frequency domain study

Two harmonic forces were added as boundary loads in the Definition node of the component, one of them impinges on the side while the other one on the edge. In the "frequency response" study node, by enabling one harmonic force at the time, it is possible to compute the frequency response of the bell in the selected range and the deformation for each frequency is stored in the result node, under "deformation freq study" subnode.

1.5 Frequency domain modal study

A similar procedure was followed in order to perform a frequency domain modal study. This, much like the previous case, gives as a result the frequency response

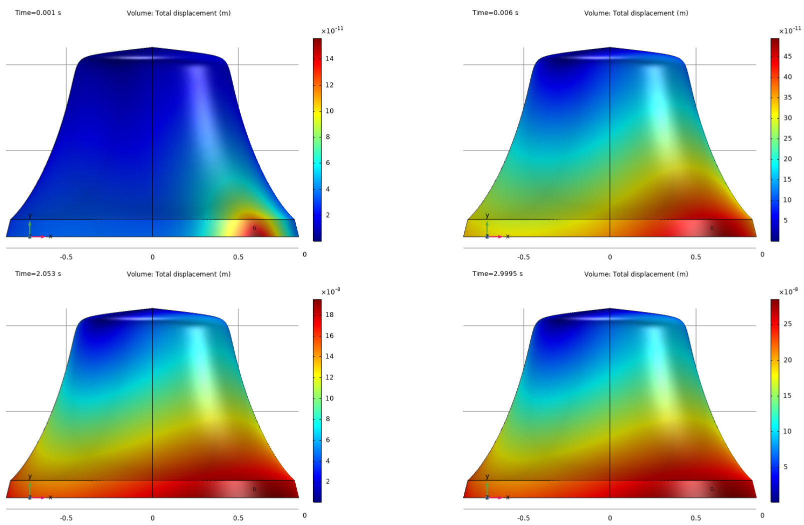

Figure 2: Snapshots of the displacement of the bell when the impulse is applied on the **edge**.

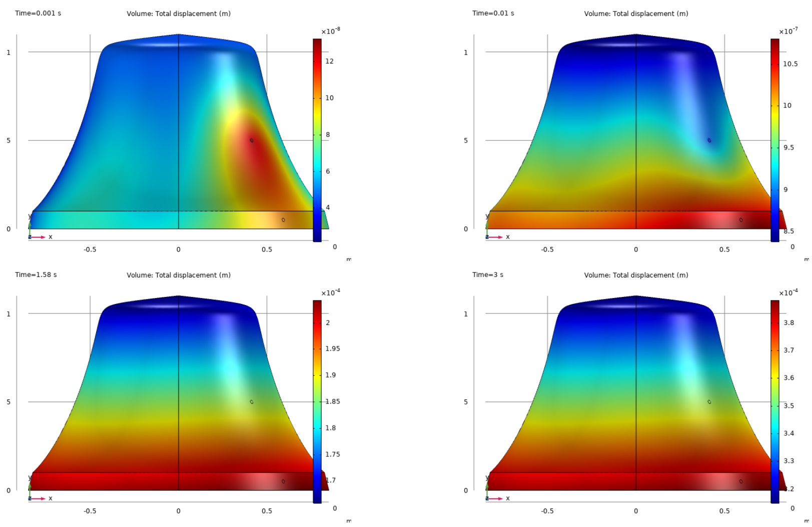

Figure 3: Snapshots of the displacement of the bell when the impulse is applied on the **side**.

of the object (for a given set of frequencies). The main difference is that the modal study computes this response as a superposition of the eigenmodes from the eigenfrequency study. Actually, th predefined modal study in Comsol includes an eigenfrequency study as its first step, so in practice we didn't reuse the results from the study we performed earlier for this, but the eigenmodes were computed a second time. However, since from the first eigenfrequency study the geometry (and therefore the mesh) has been slightly modified, the frequencies at this step are a bit different from the previous results. Moreover, we included 30 modes at this step to obtain an accurate result. In Fig. 4 we report the graphs of the deformation for some of the frequencies that were considered. It can be seen in the Results node that the response is very similar to the one obtained in the frequency domain study. Of course, if the number of modes is decreased, a less refined approximation of the response is expected, as it can be observed in Fig. 5, where we report a plot from a similar study performed with only the first 5 modes. This is especially true at higher frequencies.

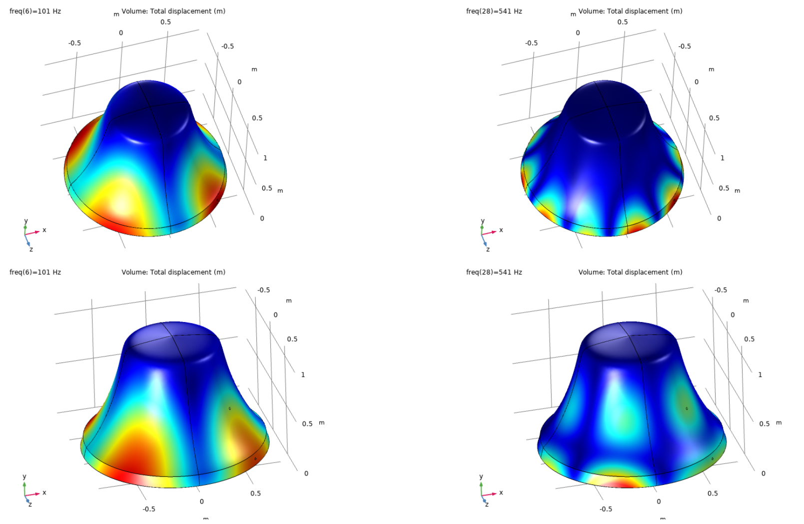

Figure 4: Amplitude of the displacements in the modal study with 30 modes. On the top the excitation is applied at the edge of the bell while at the bottom it is applied at the side.

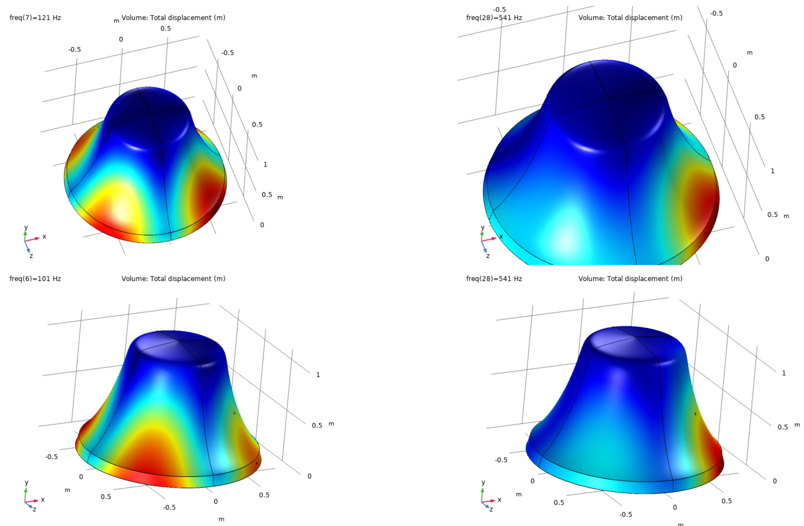

Figure 5: Amplitude of the displacements in the modal study with 5 modes. On the top the excitation is applied at the edge of the bell while at the bottom it is applied at the side.

2 Church Bell - 2D Axisymmetric Model

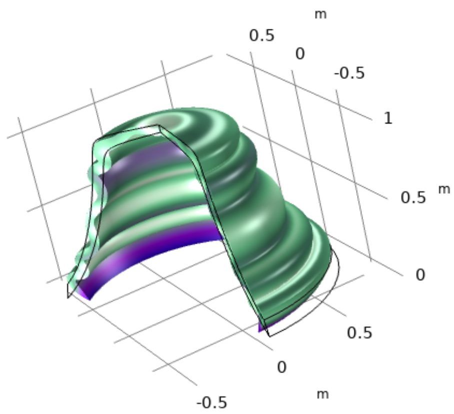

Figure 6: Mode shape with axial symmetry.

In this case we simply imported the same 2D figure as before in the Geometry node of a 2D-axisymmetric component. We then performed an eigenfrequency study much like in the previous case. However, the eigenfrequencies (see Tab. 2) do not appear to be the same as before. The main reason is that for a 2D-axisymmetric component, studies get carried out on the 2D shape and then the results are extrapolated to the entire object under the assumption that we are only looking for axysimmetric properties. When looking for vibration eigenmodes, this means that we are ignoring the modes that do not exhibit this symmetry, which in our case were all the modes studied in Section 1.2.

Eigenfrequencies [Hz]	Angular frequency [rad/s]
1.68×10^{-4}	0.001
767.1	4819.8
1017	6390
1100	6912
1400	8800
1743	10951
1954	12278

Table 2: Eigenfrequencies of the axysimmetric modes.