Assignment

Homework HL1

Federico Caroppo - 10933366,
Gabriele Costa - 10905710

Musical Acoustics

POLITECNICO
MILANO 1863

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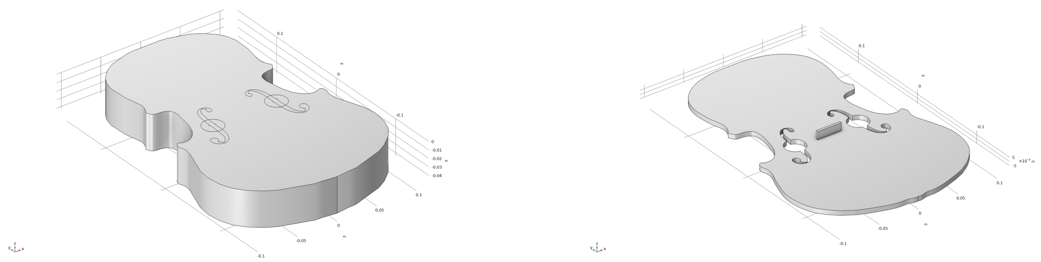
Characterization of a string instrument sounboard

Soundboard design

The soundboard design started with importing a violin body 3D CAD model (Figure 1a). In order to obtain a thin board, we created a block and used a boolean difference operation to cut the exceeding thickness. In order to carve the holes, we extruded the planar figures from the top plane downwards and once again applied a difference operation. At this point, we created a work plane in correspondence with the top face of the board, from which we extruded of a few millimetres a small rectangle, thus simulating a violin bridge. The final result can be observed in Figure 1b.



(a) **(b)**

Figure 1

Starting from a blank material, we created an isotropic version of *Engelmann Spruce* (using density $\rho_E = 350\ ^{kg}/_{m^3}$, $E_L = 9.79\ GPa$, $\nu_{LR} = 0.422$) and assigned it to both the soundboard and the bridge. For the top and bottom boundary surfaces we chose a free triangular mesh, while for the tridimensional domains we employed a tetrahedral mesh (Figure 2).

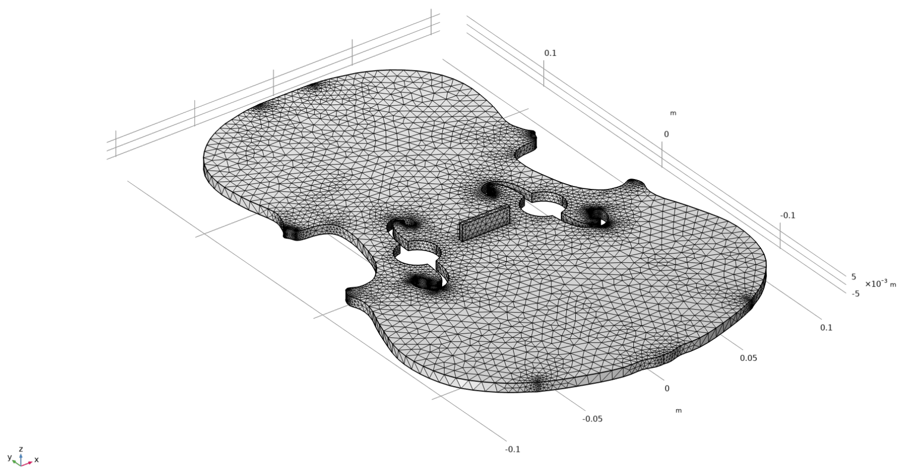
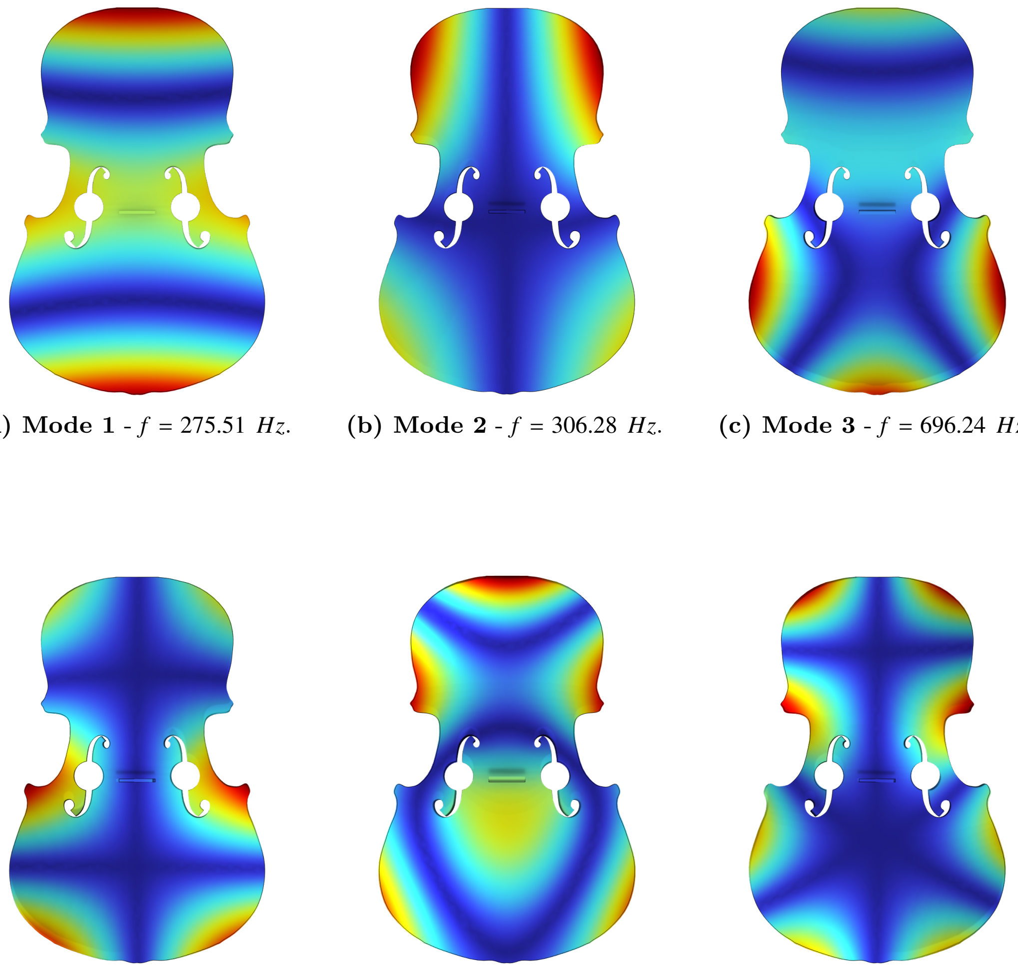


Figure 2

Free boundary eigenfrequency simulation - *Isotropic Material*

After adding a structural mechanics physics to the component, we performed an eigenfrequency simulation keeping free boundaries. The resulting modes are reported in the following figures (Figure 3a - 3f), which chromatically represent the maximum point displacement (upper limit - *red* - around $4 \cdot 10^{-7}\ m$).



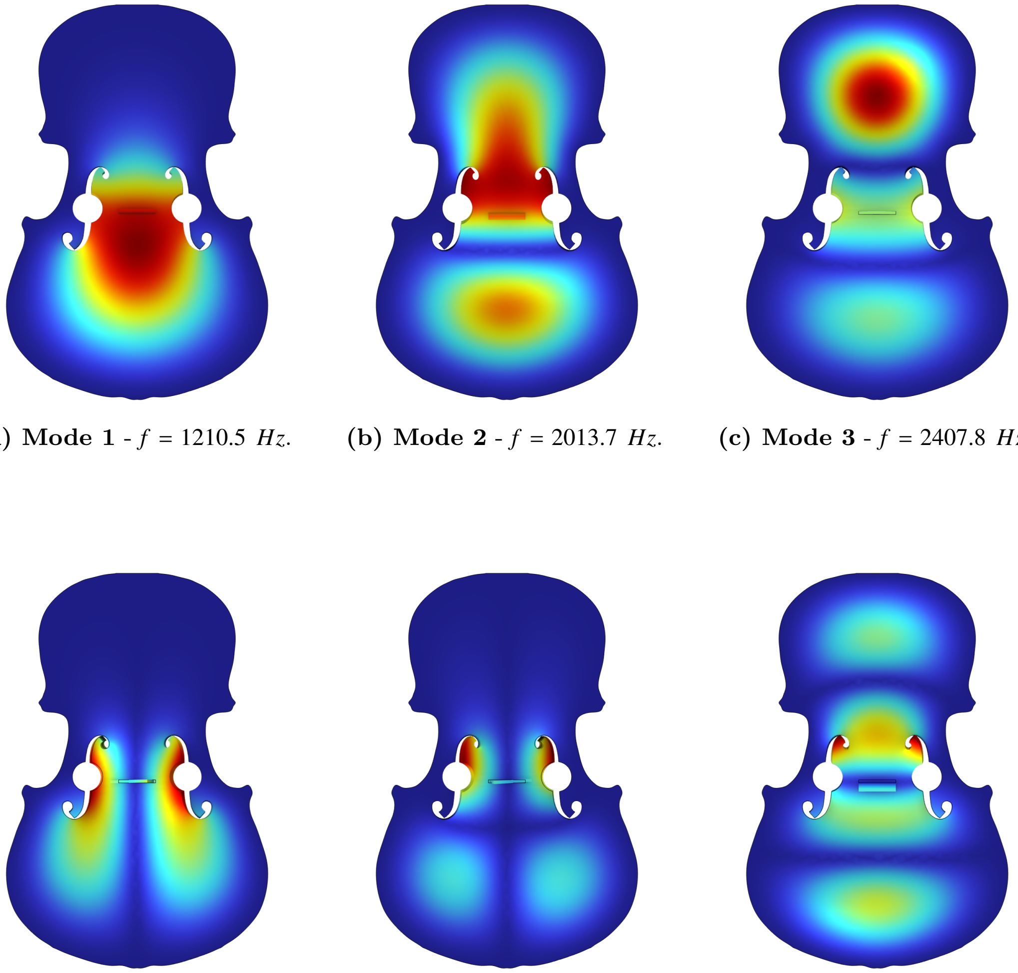
(a) Mode 1 - $f = 275.51\ Hz$. **(b) Mode 2** - $f = 306.28\ Hz$. **(c) Mode 3** - $f = 696.24\ Hz$.

(d) Mode 4 - $f = 840.87\ Hz$. **(e) Mode 5** - $f = 966.21\ Hz$. **(f) Mode 6** - $f = 1395.6\ Hz$.

Figure 3: Free boundary eigenfrequency simulation results (first six modes) for isotropic Engelmann Spruce.

Fixed boundary eigenfrequency simulation - *Isotropic Material*

We repeated the same procedure applying fixed constraints to the external edges of the soundboard. Again, the resulting modes, with a maximum point displacement around $4 \cdot 10^{-7}$ m, are reported in the following figures (Figure 4a - 4f).



(a) Mode 1 - f = 1210.5 Hz. **(b) Mode 2** - f = 2013.7 Hz. **(c) Mode 3** - f = 2407.8 Hz.

(d) Mode 4 - f = 2658.9 Hz. **(e) Mode 5** - f = 3589.7 Hz. **(f) Mode 6** - f = 3645.2 Hz.

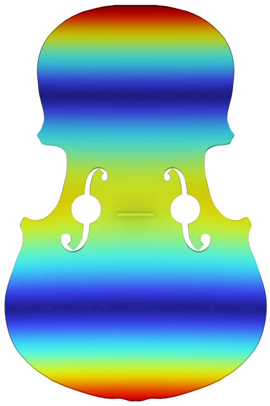
Figure 4: Fixed boundary eigenfrequency simulation results (first six modes) for isotropic Engelmann Spruce.

The steps described in the two previous sections are now to be repeated after redefining Engelmann spruce as an orthotropic material. For technical details about the physical characteristics and constants employed in order to do so, refer to Table 1. Also in these two cases, the upper limits of the maximum point displacement are around $4 \cdot 10^{-7}$ m.

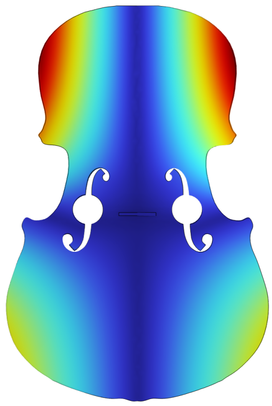
E_L	E_R	E_T	G_{LR}	G_{RT}	G_{LT}	ν_{LR}	ν_{RT}	ν_{LT}
9.79	1.25	0.58	1.21	0.10	1.17	0.422	0.53	0.462

Table 1: Orthotropic Engelmann Spruce.

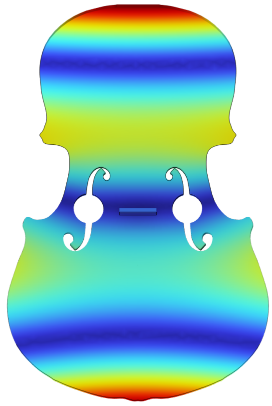
Free boundary eigenfrequency simulation - *Orthotropic Material*



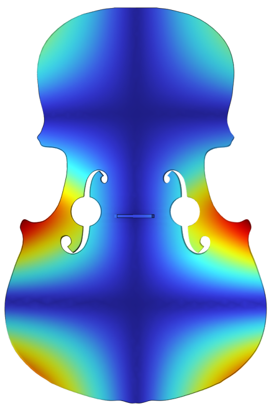
(a) Mode 1 - f = 99.632 Hz.



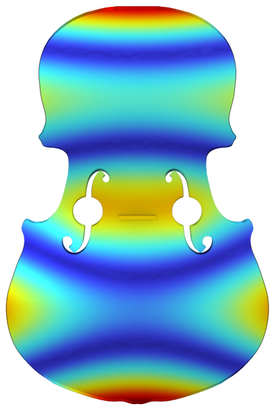
(b) Mode 2 - f = 164.69 Hz.



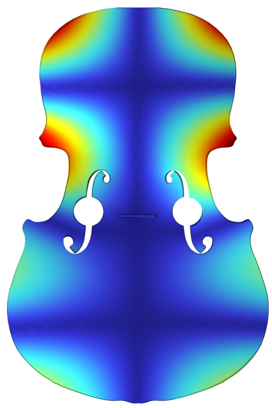
(c) Mode 3 - f = 297.58 Hz.



(d) Mode 4 - f = 458.05 Hz.



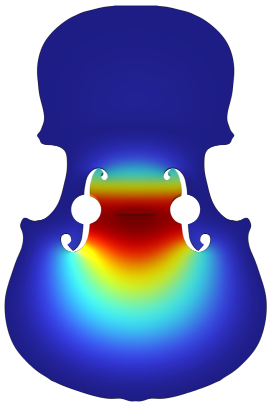
(e) Mode 5 - f = 565.01 Hz.



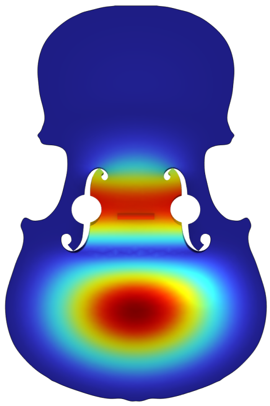
(f) Mode 6 - f = 714.88 Hz.

Figure 5: Free boundary eigenfrequency simulation results (first six modes) for orthotropic Engelmann Spruce.

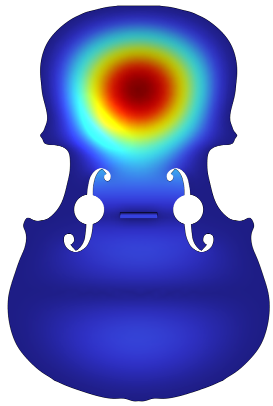
Fixed boundary eigenfrequency simulation - *Orthotropic Material*



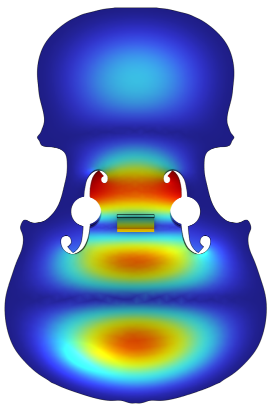
(a) Mode 1 - f = 736.76 Hz.



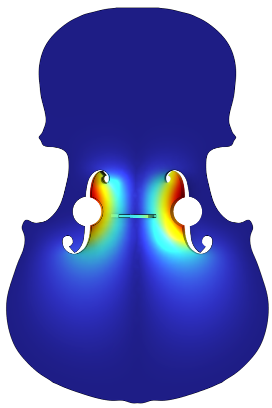
(b) Mode 2 - f = 1004.1 Hz.



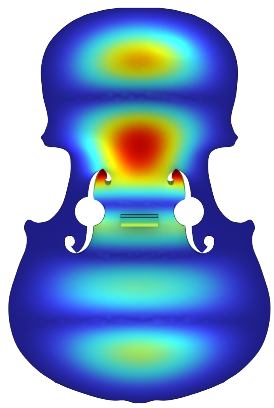
(c) Mode 3 - f = 1482.4 Hz.



(d) Mode 4 - f = 1587.6 Hz.



(e) Mode 5 - f = 1734.8 Hz.

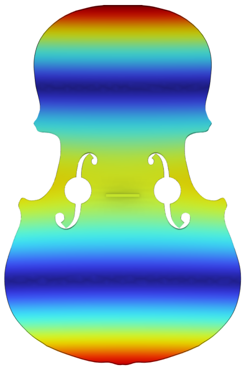


(f) Mode 6 - f = 2101.9 Hz.

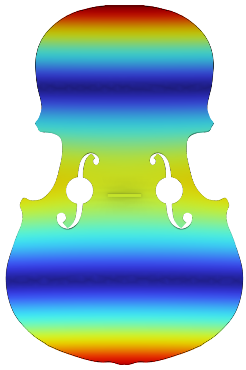
Figure 6: Fixed boundary eigenfrequency simulation results (first six modes) for orthotropic Engelmann Spruce.

Surface load in free boundary frequency domain simulation: ***Orthotropic Material*** (Red Maple)

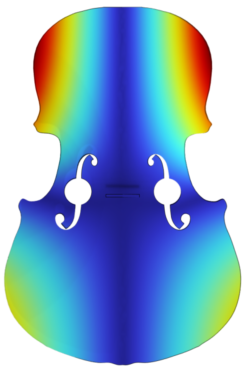
By defining a new blank material, we created the orthotropic Red Maple according to the values in table 2. Then we assigned it to the bridge element, we applied a vertical harmonic force on its top surface and we computed another free boundary eigenfrequency study. As expected, the results are very similar to the one obtained in the previous case, in which it was considered just the Engelmann spruce. This results were used in the study settings "Frequencies" field of the *frequency domain study*: `range(80,52,600) 99.508 164.71 297.56 458 563.7`. We decided to start from 80 Hz and stop at 600 Hz since the first eigenfrequency is around 100 Hz and the fifth one is at around 560 Hz. The results are reported in the pictures below (Figure 7a - 7j).



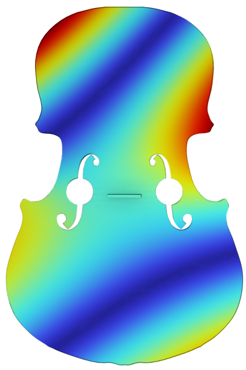
(a) Mode 1 - f = 99.508 Hz. Maximum around $4 \cdot 10^{-7}$ m.



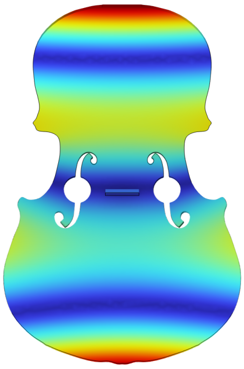
(b) Mode 1 - f_L = 99.508 Hz. Maximum around $1.4 \cdot 10^{-2}$ m.



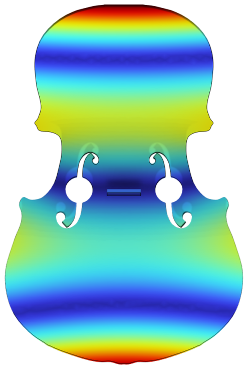
(c) Mode 2 - f = 164.71 Hz. Maximum around $4 \cdot 10^{-7}$ m.



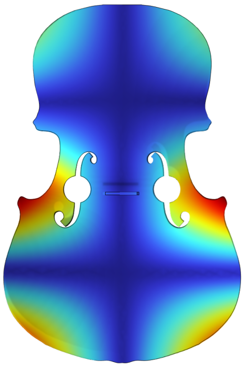
(d) Mode 2 - f_L = 164.71 Hz. Maximum around $6 \cdot 10^{-9}$ m.



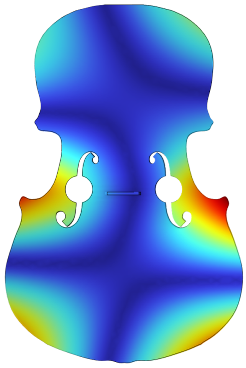
(e) Mode 3 - $f = 297.56$ Hz.
Maximum around $4 \cdot 10^{-7}$ m.



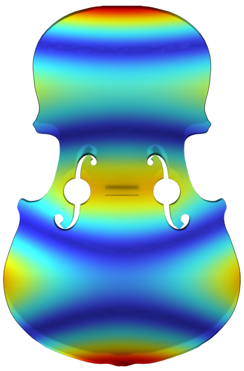
(f) Mode 3 - $f_L = 297.56$ Hz.
Maximum around $7 \cdot 10^{-6}$ m.



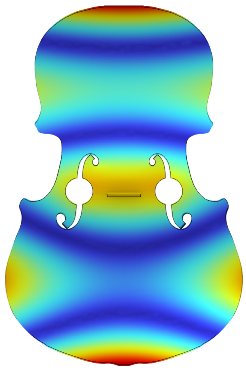
(g) Mode 4 - $f = 458$ Hz.
Maximum around $4 \cdot 10^{-7}$ m.



(h) Mode 4 - $f_L = 458$ Hz.
Maximum around $6 \cdot 10^{-9}$ m.



(i) Mode 5 - $f = 563.7$ Hz.
Maximum around $4 \cdot 10^{-7}$ m.



(j) Mode 5 - $f_L = 563.7$ Hz.
Maximum around $1.6 \cdot 10^{-4}$ m.

Figure 7: On the left: Free boundary eigenfrequency simulation results (first five modes) for orthotropic Engelmann Spruce and orthotropic Red Maple on the bridge. **On the right**: the same modes with the effect of the load on the bridge.

E_L	E_R	E_T	G_{LR}	G_{RT}	G_{LT}	ν_{LR}	ν_{RT}	ν_{LT}
12.43	1.74	0.83	1.65	0.30	0.92	0.434	0.762	0.509

Table 2: Orthotropic Red Maple.

Modes 2 and 4 are the ones in which the load effect on the bridge is most evident. Those are the cases in which, according to the natural modes of the soundboard, the bridge should stand still. By employing an external load, thus forcing it to move anyway, other modes (such as the first one) are introduced and superimposed to the considered mode, hence resulting in a variation in the displacement response amplitude with respect to the free vibration case. This behaviour is also due to the fact that the surface load excites modes (in addition to the cited modes) that present mostly - if not only - *horizontal nodal lines*, which then sum to the ones already present. This phenomenon occurs due to the particular geometry of the contact surface between the bridge and the plate, which is particularly narrow and elongated horizontally. Another interesting result is in the amplitude of the displacements. The results show that the amplitude is much more emphasized when the bridge is near an anti-node of the board, as in modes 1 and 5, while in the other cases it is not as much accentuated, and in modes 2 and 4 it is even reduced.

Surface velocity

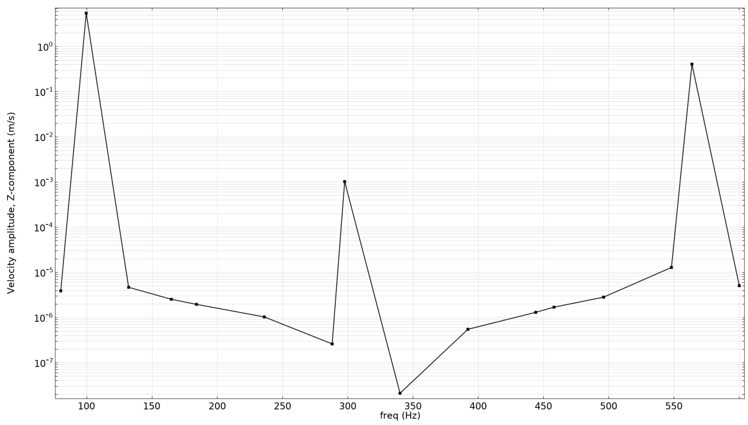


Figure 8: Average values of the Z-component of the surface velocity field (logarithmic scale)

By computing the velocity as the surface average of the velocity field over the common surface between the bridge and the top plate, we obtained the plot in figure 8. We can see that in correspondence with the natural modes of the soundboard the bridge velocity is higher with respect to the one relative to other frequencies. In addition to that, notice how modes 1 and 5 (to a lesser extent even the third one) - odd modes - are the most excited ones, while the other two (2 and 4) are almost ignored. This is due to the fact that in these last cases the bridge is very close to a nodal line of the soundboard: thus, by forcing the system in that spot, those modes are not excited. In contrast, as previously mentioned, in modes 1 and 5 the bridge is approximately in an anti-node, thus achieving the opposite effect.