

CT and modal analysis of the 'Vieuxtemps' Guarneri 'del Gesù'

In the second of a two-part acoustic investigation of the 'Vieuxtemps',
TERRY BORMAN and BEREND STOEL analyse CT scans of the violin,
and find out how the instrument vibrates at different frequencies

In the November 2010 issue Joseph Curtin wrote about sound radiation measurements of the 1741 'Vieuxtemps' Guarneri 'del Gesù' violin. This month we will discuss measurements of the vibration modes and geometry of the 'Vieuxtemps' made using computed tomography (CT) and modal analysis technology (see boxes below). During our research we also studied the 'Jarnowich' Guarneri 'del Gesù' of 1741 and the 1707 'Cathedral' Stradivari. For comparative purposes, we will reference results from these violins, as well as several other Guarneri 'del Gesù' and Stradivari violins tested previously using the same methods.

CT results can be analysed in different formats; for this study we used a visual format (as is typically done in a hospital setting)

COMPUTED TOMOGRAPHY (CT)

CT IS A COMMON TECHNOLOGY in hospitals, where it is used as a non-invasive diagnostic tool. Instrument makers can use CT for the same purpose, to obtain a plethora of information without taking an instrument apart or exposing it to measuring tools. After a simple ride on the CT scanner bed, the instrument is returned to its case and the real job begins with the analysis of thousands of measurements. CT analysis lets us study the instrument in many useful cross-sectional views.

MODAL ANALYSIS

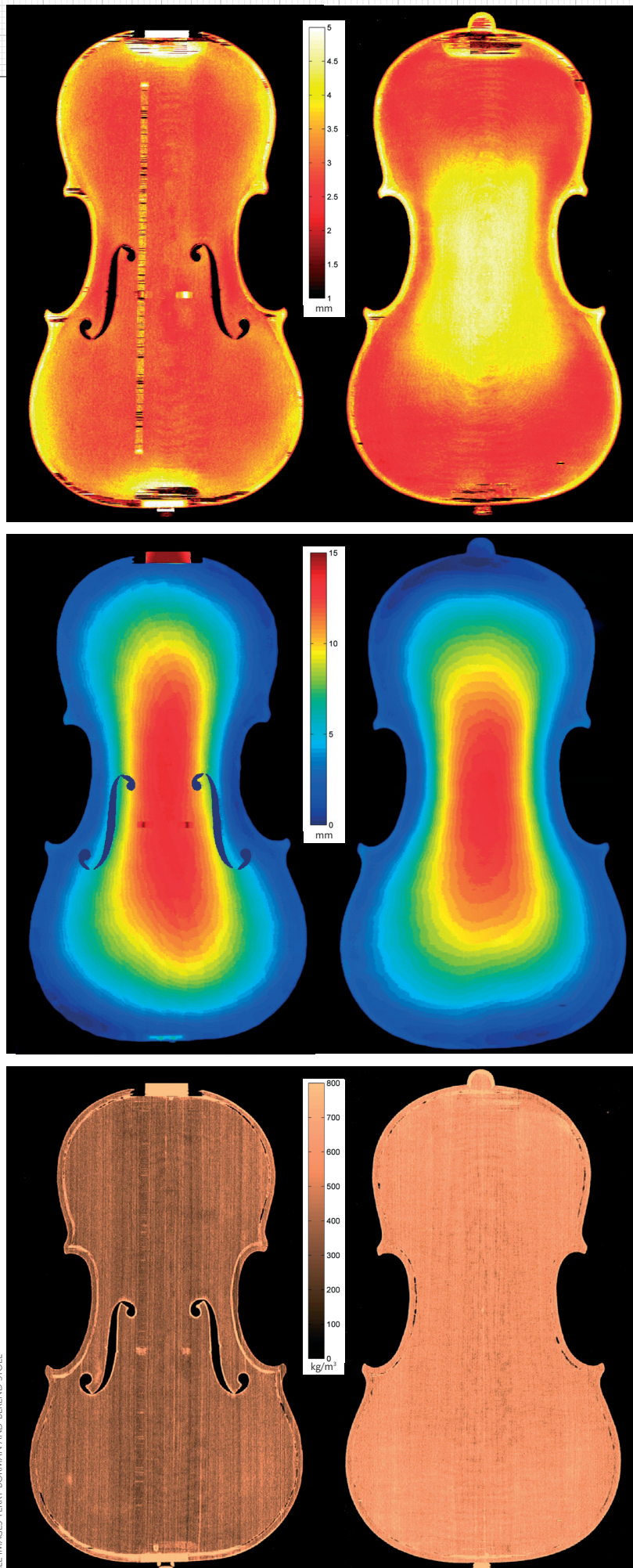
MODAL ANALYSIS IS A WAY of mapping an instrument's vibration patterns. A small sensor is attached to the bridge, and then the front and back plates are gently tapped at several places with a rubber-tipped device. This device measures the amount of energy put into the tap, and the sensor on the bridge measures how much of that energy passes through the instrument and out the bridge. We are effectively playing the violin in reverse, in that under normal circumstances the energy is put into the bridge by the bow and passes through the bridge into the instrument. Computer analysis of the test results can reveal information in many different formats, much like CT scan data.

and a quantitative format (where the results are left in their native format and analysed numerically). Each has distinct advantages and complements the other.

Figure 1 shows the 'Vieuxtemps' in a quantitative manner presented as 'maps' of specific features. As can be seen, the instrument is in strikingly pristine condition; there is very little distortion in the elevation profiles and no discernable repairs in the thickness maps. The internal air volume of the body is 1.97 litres, which is on the large side for Guarneri 'del Gesù' instruments of this period. The total area of the f-holes is 891mm². Both these measurements contribute significantly to the frequency and strength of the A0 vibration mode as described in the November article. The average wood

densities of the top and bottom plates are 0.364g/cm³ and 0.566g/cm³ respectively, which are on the slightly denser side of our previous findings of other Guarneri 'del Gesù' violins. As seen in figure 1, the plates of the 'Vieuxtemps' are noticeably thicker than other 'del Gesù' instruments (particularly the back), which are generally thicker than Stradivari violins. Coupled with the slightly denser woods, this accounts for the 'Vieuxtemps' plate weights being at the high end for classical Cremonese instruments (68.5g for the belly and 114.3g for the back – around 65g for the belly and 100g for the back are more typical).

IN THE NOVEMBER ISSUE Joseph Curtin presented a type of fingerprint of the sound of the 'Vieuxtemps' in the form of a graph depicting the violin's frequency response function, which is reprinted here as figure 2 (see page 70). Each of the peaks in this diagram corresponds to a resonant frequency of the violin body. When a violinist plays the instrument and sweeps through all the possible tones it can produce, each of these resonances equates to a sound oasis, where the instrument vibrates particularly vigorously and this vibration translates itself (usually) into sound. Every violin has a different detailed pattern of these resonant peaks and each resonance matches a particular shape of vibrational contortion of the violin body, called a mode. These shapes can be determined by modal analysis.



► **FIGURE 1** From top, thickness maps, elevation profiles and density maps of the 'Vieuxtemps'

Modal analysis lets us view the motion of the plates at a given natural frequency. The higher the peaks in the frequency response function, the more efficient the mode is at radiating sound. The modes with natural frequencies below approximately 600Hz have been the focus of much of the modal analysis work done to date. These low-frequency primary modes have relatively simple vibration patterns that involve motion in both the top and bottom plates. The first four of these modes are shown in **figure 3** (see page 70). In these illustrations the black colour is motion into the violin and red is motion away from the violin; the stronger the colour the larger the motion.

Another way to view the sound output or physical displacement of an instrument is to break up the total frequency range of interest into clumps called bands, and create bands based on the expected ranges of the primary modes. In **figure 4** (see page 70) we have done this for the displacement of four Guarneri 'del Gesù' and four Stradivari violins. A difference begins to appear in the physical movement (displacement) between the two makers, and if we further distil this data as in **figure 5** (see page 71) a definite trend appears.

IN THE **FIGURE 5** GRAPH, each cluster is averaged and plotted as a single data point with the Stradivari instruments in red and Guarneri 'del Gesù' instruments in blue. The ranges 1, 2, 3, 6 and 7 appear almost identical but ranges 5 (750–950Hz) and particularly 4 (650–750Hz) show significant differences. Ranges 4, 5 and 6 cover the 'transition hill', the frequency range within which the principal movement of the bridge shifts from being predominantly on the bass-bar to being mostly on the soundpost side. Earlier we mentioned that as the modes increase in frequency (further to the right on the figure 4 graph) their shapes become more complex and also less repeatable from one instrument to another. However, band 5 and particularly band 4 are within the range where there is reasonable consistency between instruments. These modes are less understood or studied than the primary modes but the visualisation techniques of modal analysis allow an increased understanding. ►

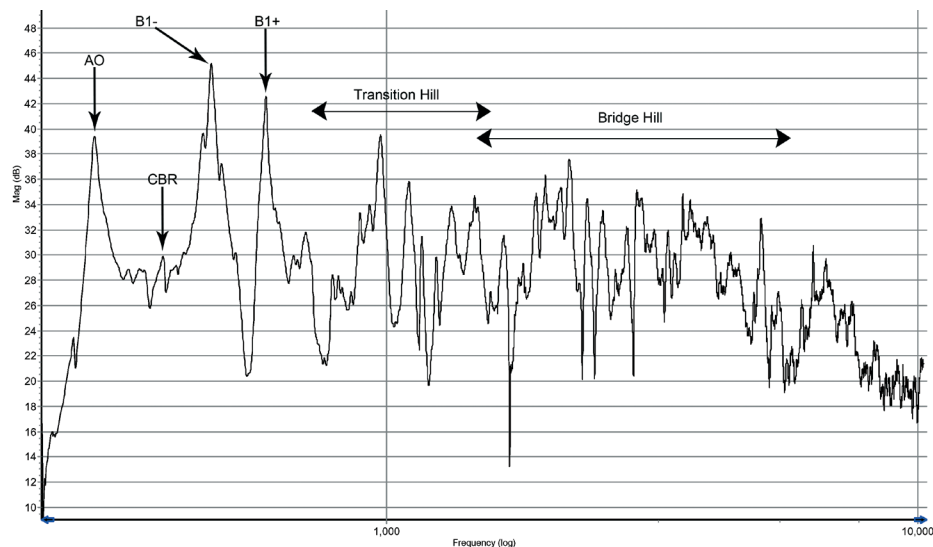


FIGURE 2 Frequency response function of the 'Vieuxtemps'

FIGURE 3 The primary mode shapes of the 'Vieuxtemps' as generated by modal analysis. Red and black depict motion in opposite directions, and the more intense the colour, the higher the amplitude of movement.

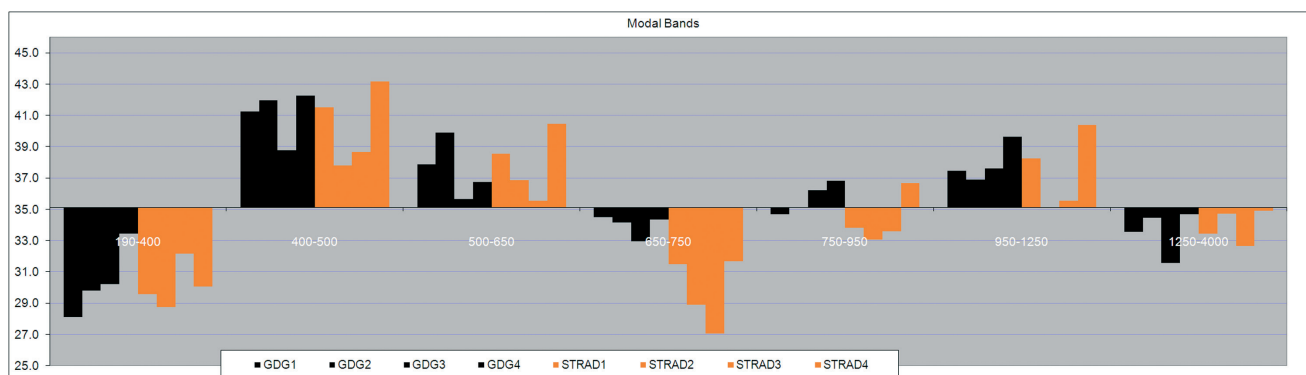
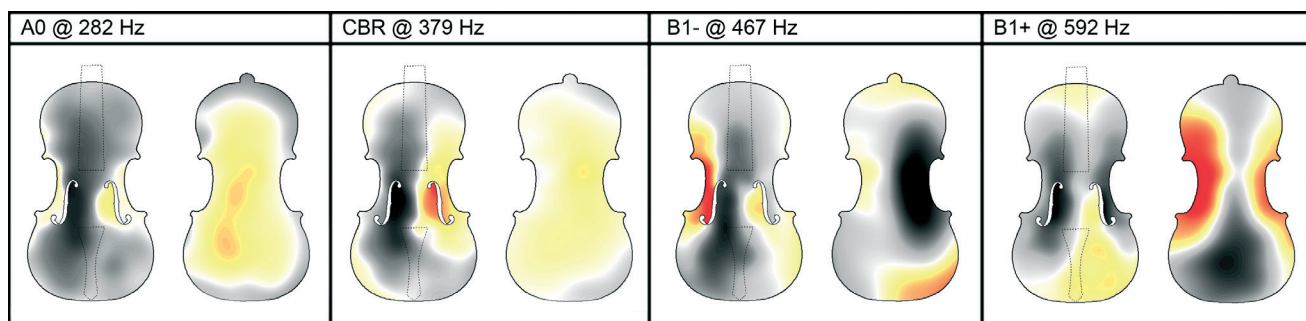
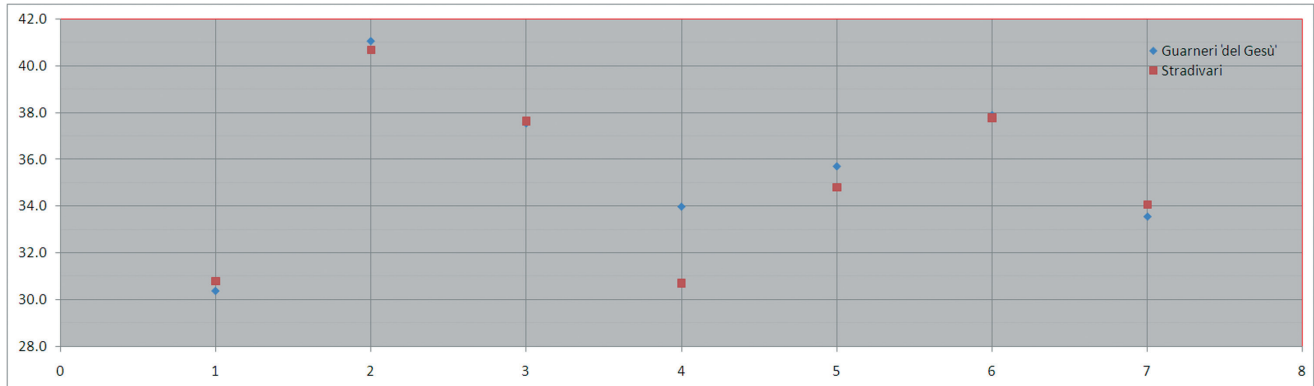


FIGURE 4 Graph showing the strength in decibels (dB) of each of the assigned 'modal bands' for four Guarneri 'del Gesù' violins and four Stradivari violins. The 'Vieuxtemps' is GDG4 (the right-hand black block for each band). The bands are the expected ranges of specific modes: 190–400Hz includes A0 and CBR, 400–500Hz includes B1-, 500–650Hz includes B1+, 650–750Hz includes C4, and the remaining three bands include higher modes which are not discussed in this article.

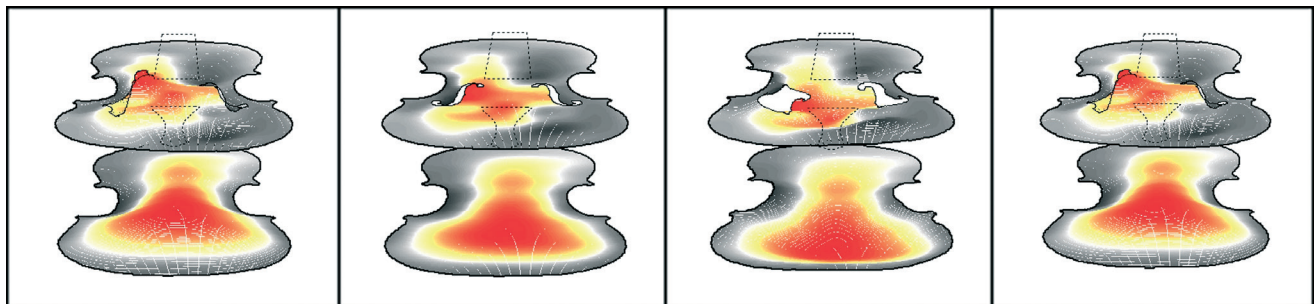
The main mode usually seen in range 4 is referred to as C4 and is illustrated in figure 6. With C4, when the back bulges outwards from the centre of the instrument, the top is almost following it. If the two movements were exactly the same, with opposite areas moving in tandem, the air movement would cancel itself out and little sound would be produced. But this is not the case in the 'Vieuxtemps': the back wins over the front, and there is a net change in volume during the vibration. The data from modal analysis can be used to measure directly the amount of air movement in and

out of an instrument, which is useful when trying to decipher whether a certain mode movement will create sound. Figure 7 shows the amount of air displaced relative to the amount of sound produced and C4 shows up as a clear peak in both curves.

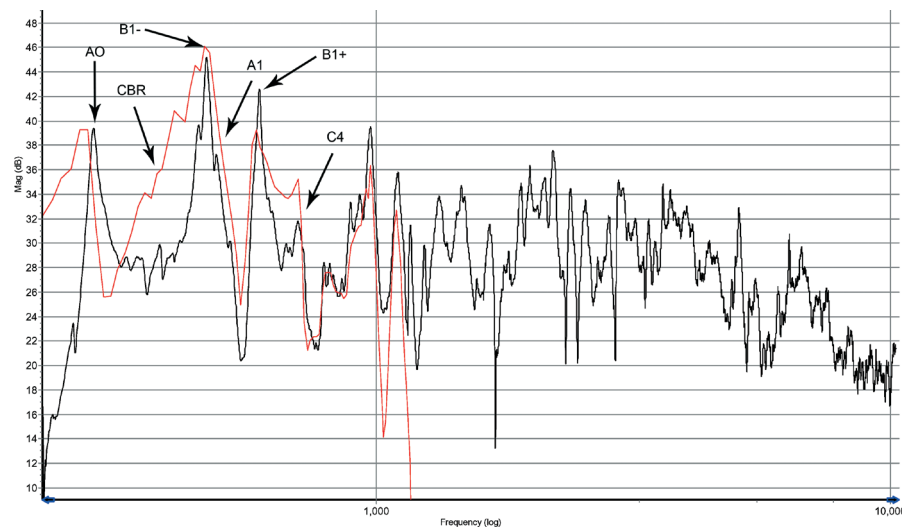
When musicians describe the differences in sound between Stradivari and Guarneri 'del Gesù' instruments, Stradivari is said to be more brilliant, whereas the 'del Gesù' sound is often described as deep, rich and resonant. A0 has been shown to be a large contributor to these sound attributes and, as C4 is structurally more active in



▲ FIGURE 5 Graph of the average level of each of the 'modal bands' (Stradivari in red, Guarneri 'del Gesù' in blue)



▲ FIGURE 6 Mode shape and displacement of the C4 mode of the 'Vieuxtemps'



▶ FIGURE 7 Acoustic radiation of the 'Vieuxtemps' (black line) compared with its volume displacement (red line). At approximately 1,200Hz the violin no longer relies on internal air movement to create sound and instead other mechanisms of sound creation take over. Air volume data has been normalised to the radiation peak of A0.

KEY POINTS

- CT scans show that the plates of the 'Vieuxtemps' are denser and thicker than those of other 'del Gesù' violins tested, resulting in the weight of the 'Vieuxtemps' plates being at the high end for classical Cremonese instruments.
- Modal analysis indicates that the C4 mode, seen in the range 650–750Hz, is structurally more active in Guarneri 'del Gesù' violins than Stradivari instruments, and could be a contributing factor alongside A0 in developing the comparatively deeper and richer 'del Gesù' sound.

Guarneri 'del Gesù' violins than Stradivari instruments, perhaps this also helps develop the 'del Gesù' sound by having another active mode with somewhat similar traits as A0. Our work also shed light on the next two modes of the transition hill of the 'Vieuxtemps', although these results will have to wait for another time. ■

With thanks to Evan Davis, Geoffrey Fushi, George Stoppani, Gary Volker, Nathan Volker, Jim Woodhouse and Northwestern Memorial Hospital

If you missed Joseph Curtin's November 2010 article on the 'Vieuxtemps', you can read it by subscribing to The Strad Archive at www.thestrad.com/StradArchive.asp