THE CELLO TAILPIECE:

HOW IT AFFECTS THE SOUND AND RESPONSE OF THE INSTRUMENT.

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ABSTRACT

The application of modern scientific methods and measuring techniques can extend the empirical knowledge used for centuries by violinmakers for making and adjusting the sound of violins, violas and cellos.
Accessories such as strings and tailpieces have been studied recently with respect to style and historical coherence, after having been somehow neglected by researchers in the past.
These fittings have played an important part in the history of these instruments, but have largely disappeared as they have been modernised.
However, the mechanics of these accessories contribute significantly to sound production in ways that have changed over time with different musical aesthetics and in different technical contexts. There is a need to further elucidate the function and musical contribution of strings and tailpieces.
With this research we are trying to understand the modifications of the cello's sound, as a consequence of tailpiece characteristics (shape of the tailpiece and types of attachments). Modal analysis was used to first investigate the vibration modes of the tailpiece when mounted on a non-reactive rig and then when mounted on a real cello where it can interact with the modes of the instrument's corpus.
In this paper a preliminary study of the effect of the tailpiece cord length will be presented.

1. INTRODUCTION

1.1 History

Since the middle ages, the strings of bowed instruments may have been attached to a pin at the bottom of the sound box (violins, violas, kits, saranghis), or attached to a piece of leather, material or gut string. Iconography shows that in the Renaissance, for violins and viols, a piece of wood cut into an intricate shape at first, then simplified in a flat dove tail shape, has been used. Tailpieces from the 17th, 18th, 19th and 20th century for the viol family as well as for the violin family are kept in the Musée de la musique in Paris, and they show the changes that have taken place over the centuries. The top surface of the tailpiece became more rounded at the end of the 18th century, and that increases the angle of the lateral strings on the bridge, which means a stronger force applied vertically onto the sounding box, from those strings. This shows a want of a bigger sound and a balance between the middle, the treble and the bass strings. A little fret was also added, in order to have a definite "tuning" of the after length of the string, whereas before, the strings didn't have a definite stop at the tailpiece end. Violoncellos, of modern size, were being made before 1700, soon after the invention of overspinning strings with metal, and progressively replaced the old, larger "Basse de violon" which had much thicker gut strings. Today, when set up as modern cello, it has a tailpiece that can be made of hard wood, metal, or plastic, and, most of the time, it has four adjusters to hold and fine tune four thin heavily wound metal strings. Modifications in materials, shapes, weighs of the tailpieces usually followed the evolution of strings.
The attachment cord used to be in gut; it was tried in rigid metal as well, and in the 20th century piano strings have been used, as well as nylon or Kevlar.

1.2 State of the art

In 1993, while working on violin modes, Hutchins [1] mentioned the possibility of tuning the tailpiece to the frequency of modes in the violin itself. A study of the vibrating modes of violin tailpieces was then carried out and published by Bruce Stough in 1996 [2], and he explored all the resonances below 1500 Hz, in which the violin tailpiece moves as a rigid body. He defined 6 degrees of freedom : 1. Torsion around a lengthwise axis (revolution); 2. Rocking around a transverse line; 3. Rotate around a vertical axis; 4. Up and down movement; 5. Left to right movement; 6. Forwards to backwards movement. For the violin tailpiece, Stough found 5 rigid body modes below 1500 Hz: Swing bass side, Swing treble side, Swing under, Rotation around vertical axis, Rotation round an horizontal axis. In 2002, Woodhouse mentions this work [3] and notes specifically that he found the 3 typical modes under the fundamental note of the violin : G (196 Hz) and two others in the bracket 300 to 800 Hz. The frequencies of the modes depend on the mass and on the length of the tailgut.

2. MATERIAL AND METHODS

This work was performed partly on a real cello and partly on a dead rig in order to eliminate cello's influences and evaluate the tailpiece behaviour. The software used to perform modal analysis is GS Software suite developed by George Stoppani himself. The software suite is composed of several subprograms: "Mode shape" permits to set-up a shape and define were the tapping points are chosen on the object, "Acquisition" is the program that calculates the ratio of the accelerometer response to the hammer excitation force, acquires data and stores them separately, "FRF overlay" allows to superpose the results and compare them, "Modefit" allow to mode fitting and "Mode shape" again allowing the measured displacement and acceleration of each point to the equivalent point on the drawn outline of the object, in order to reproduce the movement virtually. The representation in two dimensions of the 3 different planes allows us to analyse the movement.

A modal analysis of a cello tailpiece, mounted on a Stoppani's manufactured cello in playing conditions, was achieved [4]., The study was then followed in France by the construction, in Eric Fouilhé's workshop, of a dead-rig, of the dimensions of the cello string length, body length and bridge dimension in order to isolate the behaviour of the tailpiece from the vibrations of the instrument, and to eliminate as much as possible the coupling between the strings/tailpiece group and the cello.
The study consisted in establishing the different modes on a specimen tailpiece, then to evaluate differences of changes: of mass and of mass distribution by placing magnets on the tailpiece, or in changing the tailcord length. The same changes where then made on a cello which has been played by a musician, and a recording was made, his comments noted, for later analysis.
We will present here the first part of our work, on the determination of the cello tailpiece mode shapes.

3. ACQUISITIONS

3.1 Set up of the experiment

The dead-rig is a rigid cello set up, mounted on an I-beam on which a blank bridge and an end-pin are fixed. The tailpiece is fixed in the usual manner with a tail-string. For the standard test, we have a string length of 69,5 cm. The string angle and the tuning CGDA stay the same for each experiment. There is neither vibrating body nor fingerboard. The bridge is reinforced in order to keep it still. The same tailpiece was measured and the strings are muted with a felt band.
This stand holds the chain: [string length + bridge + after length of the string + tailpiece + tailcord + saddle + endpin] identical to that which is mounted on a real violoncello (see Figure 1). Particular attention was given to the steady fixations of bridge and saddle, which are the contact points to the rig.

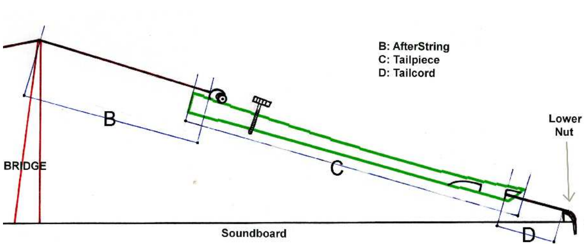

Figure 1: The chain: [bridge + after length of the string + tailpiece + tailcord + saddle]

The system was tested for its mobility, particularly the lower saddle (on which the tailpiece string lies) and the bridge, in the frequency range of the three modes 1 &, 2 and 4, which are the most significant in amplitude. The mobility of the bridge was then found to be less than 5‰ of the tailpiece mobility in the three planes. The lower saddle, on which the tailpiece string lies, can fetch 2% in the vertical plane, normal to the cello table, and 7‰ in lateral mobility left to right of the instrument. We therefore consider the dead rig as sufficiently still to study its vibration without significant influence on coupling of the holding device.
The points where the measurements were to be taken have been carefully chosen according to dimensions of the tailpiece and the wavelengths of the frequencies considered.

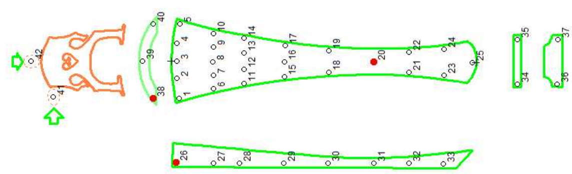

Figure 2: Selected points to hit with the hammer, and accelerometer positions (in red).

3.2 Measurements

In Figure 2 is shown the taping grid with upper and lateral views. The points shown in the grid were hit and in red is shown the positions of the accelerometer for the acquisition in 3 axis. In Figure 3 the set-up is shown. Each point is hammered ten times, and the double bounces taps are automatically detected and suppressed. Two other measurement sets of 42 points were acquired after moving the accelerometer in each of the two other positions (38 for lengthwise motion, and 26 for lateral motion), in order to highlight the three planes directions of vibration. The acquisition rate was chosen at 44.1 kHz, in 24 bits for 65536 samples. The hits were produced by a PCB 4.8 g hammer, model 086E80, and the vibrations recorded by a PCB uni-axial 0,6 g piezoelectric accelerometer model 352A21.

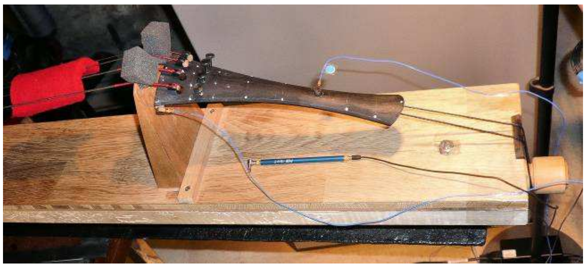

Figure 3: Dead rig, reference tailpiece marked, accelerometer in place and hammer.

Several other sets of measurements where taken with different tailpieces of different materials to give some variability of the frequencies.
Finally, tests have been made in adding mass to the reference tailpiece, and in changing the tail cord length, to study the variation of frequency of the modes. Each time, a new set of measurement was taken.

3.3 Analysis

Once the acquisition completed, the data was observed with the FRF Overlay utility (see Figure 4), highlighting the main modes. We made various averages of the different groups (for the different accelerometer locations).
For the selected modes we used the ModeFit utility of GS Software (see Figure 5) in order to mathematically fit the FRF curves to find the modes with Rational Fraction Polynomial calculations. It is sensible to choose a frequency

resolution that is fine enough to show separate peaks.

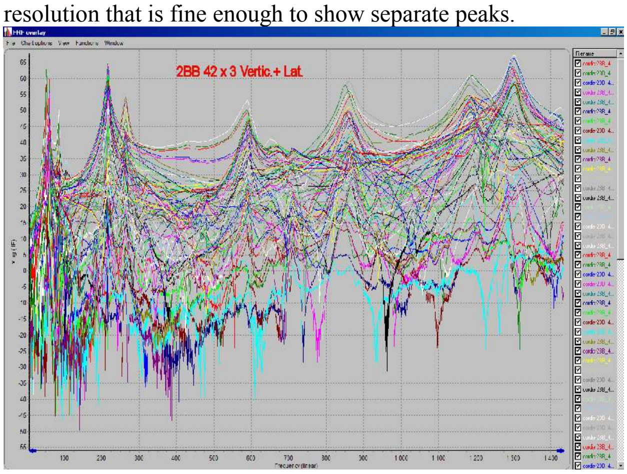

Figure 4: Data observed by FRF Overlay utility of GS Software.

A time window long enough to contain the decay and a sample rate high enough to avoid aliasing of frequencies above the Nyquist frequency were chosen. With a window of 65536 and a 44, 1 kHz acquisition rate we get a frequency resolution of 0, 67 Hz.

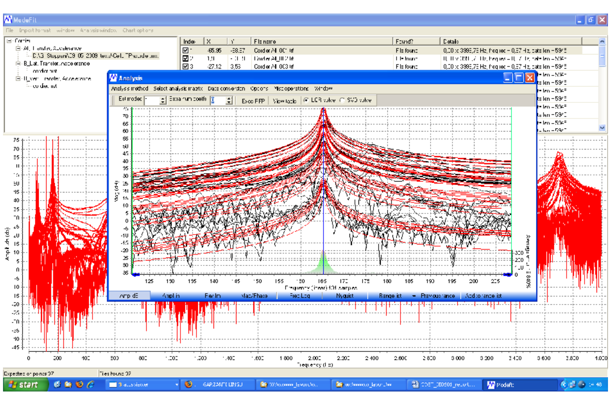

Figure 5: Using the Mode Fit utility of GS Software.

The fitted data of each mode were then used in the GS Mode Shape application in order to attribute the measurements to the 3 planes of our drawing, to simulate the tailpiece behaviour for each single mode.

4. RESULTS:

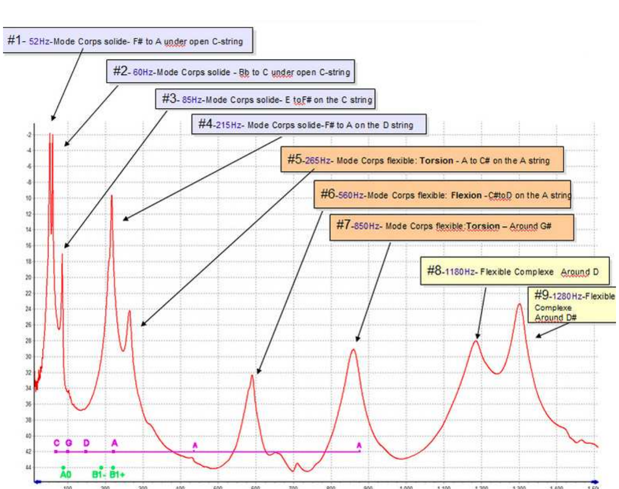

Figure 6: Modes of cello tailpiece, strings and range frequency of the cello, modes of the cello.

A total of 9 modes was found (see Figure 6).
The first four modes of the cello tailpiece are solid body motion modes, the two lowest being found below the lowest C string, while mode 3 is a third or a fourth above, near the Helmholtz A0 mode of the cello.
Then, modes 5, 6 and 7 are flexible modes, implying that the thickness and material of the tailpiece is involved. Their frequencies are within the range of the instrument, the last one being at the top G # near the highest note that can be played on the A string.
The modes 8 and 9 are more complex, involving flexion and motion, and we record them for reference.

4.1 Mode 1

(F#-A under open String C2 at 65.4Hz)

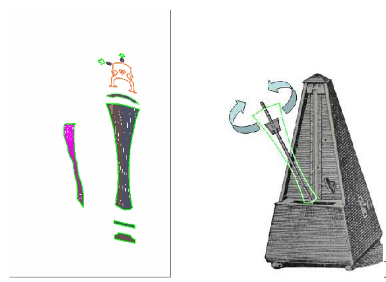

Figure 7: Mode 1

It is a solid body motion with predominant lateral swing, and does not appear or little width vertical tapping.
Looks like a Windscreen wiper the movement (see Figure 7) is nearly on a plan. The amplitude is large, second after mode 2. When the tail cord was crossed over the saddle, the rotation of the tailpiece could be bigger and this mode went down 9 Hz (20 %), which is significant being the frequency resolution 0,67 Hz (see 3.3). With shortening the tailpiece chord, first mode 1 goes down, then it goes up again.

4.2 Mode 2

(B b to C2 at 65.4Hz)

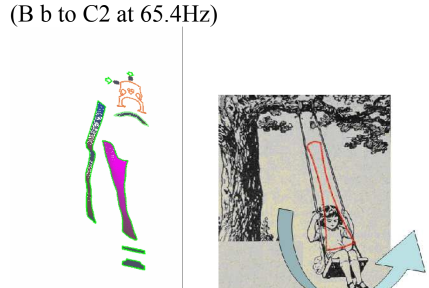

Figure 8: mode 2

It is also a full body mode, with a prominent vertical motion; it looks a bit like a large bat motion, displacing air (see Figure 8). This mode has the strongest amplitude, the peaks are narrow, suggesting a smaller damping than for mode 1.
Crossing the tail cord on the saddle does not affect the frequency. Adding a 30 g mass at 2/3 towards the bottom end of tailpiece,lowers the frequency by 7Hz. Adding a 30 g mass at 1/4 of the upper end of tailpiece lowers by 11 Hz. Shortening the tail cord diminishes the frequency and increases the amplitude. When it is at 4 cm from the bridge, the motion is maximum. When the tailpiece is nearer the saddle, at a normal distance used today, the mode is still lower in frequency.

4.3 Mode 3 or 1 bis

(E to F#, on the C string)

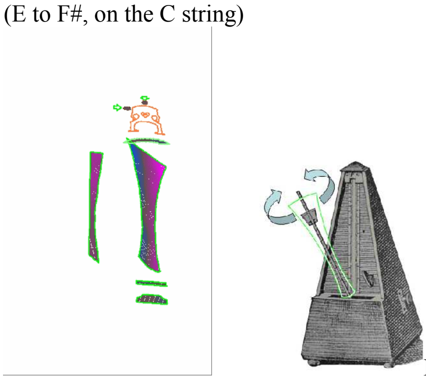

Figure 9; mode 3

It is not very homogeneous mode. Laterally, the strong lever near the saddle, resembles the lateral motion of mode 1 (see Figure 9). Like mode 1, it is a solid body mode, with a lateral pre-eminence, not seen or very little with vertical tapping. Looks like a Windscreen wiper, with a stronger diagonal tendency, the upper treble corner plunging. The amplitude is about half of that of mode 1. Mode 1 and 3 seem attached, going up and down in frequency together with the change of tail cord length or when crossing the tail cord. Mode 3 is near the A0 Helmholtz mode of the cello.

4.4 Mode 4

(F# to A on the D string)

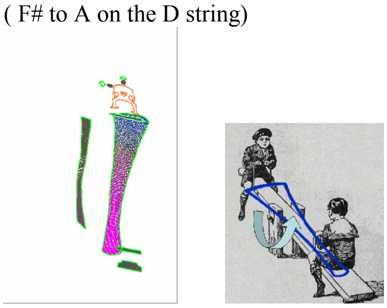

Figure 10: mode 4

It is a full body vertical mode, with a strong seesaw with an axis at the upper third or quarter of the tail piece length, combined with a small torsion of the bottom of tail (see Figure 10). Laterally there is a small flexing with seesaw or torsion.. Powerful motion, maximum amplitude near to that of mode 1&2. It is always associated with mode 5 lateral mode (see below.) Mode 4 is very near the B1+ mode of the cello.

4.5 Mode 5

(A to C# on the A string)

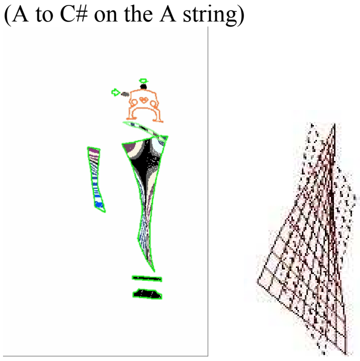

Figure 11: Mode 5

This is the first mode of torsion, (similar to the mode one of a free rectangular plate), with crossed nodal lines and the 4 corners going up and down by diagonal pairs (see Figure 11). Vertically, there is a torsion with a vertical axis normal to the plate at points 12-13. Laterally, it has a strong rocking axis at the same place,but it is a laterally and lengthwise excited mode. Although no RMS is visible in the vertical motion, GSModefit detected one vertical mode.

This mode has a smaller amplitude than mode 4. It is attached to mode 4, (shortening the Tailcord), and is very affected by the change in the string tension. In the free-free mode, its frequency goes up from 265Hz to 937Hz (+250%).

4.6 Mode 6

(C#- D)

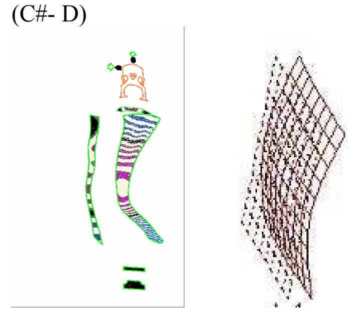

Figure 12: mode 6

Vertically, very sensitive, the 6th mode is also a flexion mode, with a strong bending and one anti node: it looks like a first mode of a beam (see Figure 12). Laterally, the flexing is negligible to feeble also with one anti node. The amplitude is small compared with other modes. The peak is often not clear and possibly there are several peaks superimposed.
When crossing the tail cord on the saddle, the rotation is more supple so the peak is bigger and more defined, and the frequency lowers by 70 Hz.
When adding weight 30 g at 2/3 towards the bottom end of tailpiece, mode 6 seems to be cut in two: one peak lowers by 155 Hz, the other goes up by 60 Hz, both with an increase of amplitude.
When adding weight at 1/4 of the upper end of tailpiece only the upper peak appears, These strong variations are surprising because the weights were added not far from nodal lines.
With shortening the tail cord from 5.5 cm to 1.1 cm, mode 6 increases in frequency + 73 Hz, with two exceptions. Amplitude is halved and the shape of the peak remains unchanged. These modifications resemble modes 4&5.
When the strings are loose, the frequency lowers to 100Hz (-17%), so it takes the place of the first mode of torsion.

4.7 Mode 7

from 827.24Hz to 857.15Hz (around G#)

Vertically, medium to strong torsion.
Laterally, strong seesaw, centered on points 12-13 (see Figure 13).
Typical of a mode 2 torsion of a plate with a strong lateral seesaw. Axis being 2/3 from the top, one side curling up while the other side curls down opposite corners having opposite direction. Amplitude larger than mode 6, peak very pointed and neat. Strong peak appears with lateral excitation, does not exist vertically.
When the tail cord is crossed on the saddle, the peak is attenuated, but the frequency does not move.

When adding mass 30 g: no result because only vertical tapping were done.
With shortening the tail cord, frequency increases by 29 Hz with a slight increase of amplitude.

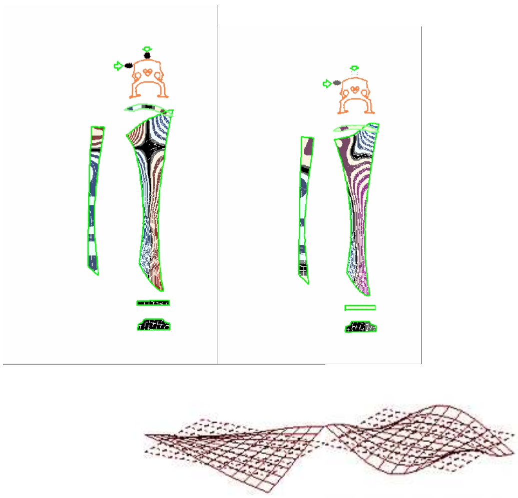

Figure 13: mode 7

4.8 Mode 8

Frequency from 1150Hz to 1189.65Hz (D)

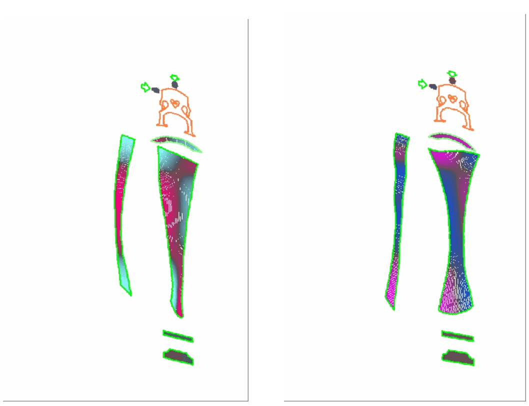

Figure 14: Mode 8.

Vertically, this mode is affected by lateral excitation, there is a swinging from left to right like mode 1, and a torsion with two nodes. Laterally, there is a strong flexing and bending with one anti node (see Figure 14).

4.9 Mode 9

Frequency from 1263Hz to 1332.62Hz (around D#)

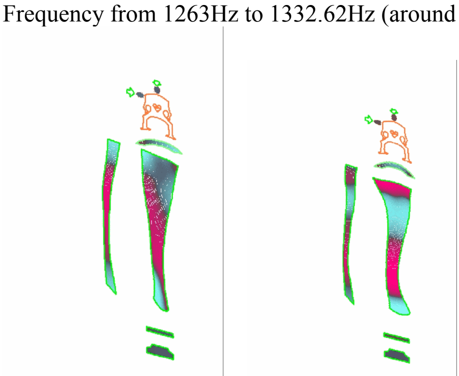

Figure 15: Mode 9.

Vertically, there is a strong twist or a flexing. Laterally, strong bending with one anti node, otherwise complex flexing (see Figure 15). Dominance of vertical motion, no lateral excitation visible.

5. CONCLUSIONS

We succeeded in identifying 9 modes of a reference cello tailpiece under tension on a dead-rig: four full body motion, two torsion modes, one bending mode and two complex modes above the cello's range.
The two first modes are below the lowest note of the cello.
The third mode is near the A0 Helmholtz mode of the cello, while mode 4 is still below the A string, but very near the B1+ mode of the cello.
Changing the tension of the strings influences the first three modes, lowering them by 6%. Adding an extra mass (30g) on the tailpiece lowers these modes, from 9 to 29 % depending where the mass is placed.
Mode 1 and 3 seem attached, going up and down in frequency together with the change of tail cord length or when crossing the tail cord.

The definitions of the modes will be pursued to study their variations to understand the influence of geometry , material, and fixation once on the instrument. Finally the perception of the musician will be studied in order to find how these different set up and modes influence the playing feel.

6. REFERENCES

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