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STUDY OF VIOLIN BOW QUALITY

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Abstract

This research, undertaken at Ircam and subsidized by the French ministry of Culture, is based on the study of a set of prototype bows, made out of carbon fiber composites by one of the authors. Its principal objective is to highlight objective critera of the quality perceived by the violinists, the characteristics of these bows, and the connection with the manufacturing processes. Wooden bows (recently manufactured and older) are also considered, although less systematically, allowing comparisons and suggesting possible modifications of prototypes.
The study consists of two complementary phases. In the first one, a dozen expert violinists were requested to evaluate these bows by dissimilarity judgements between all pairwise combinations of bows, and then to comment on each one (free verbalization). These two tests aim to construct a perceptive space of bow quality.
We then try to link the dimensions of this space to mechanical and physical properties evaluated in the second phase : static properties (mass, centre of gravity, flexion stiffness, torsion, tension of the hair) and dynamic ones (bounce tests, modal analysis). Concurrently, a computer simulation base on a finite element model was developed to help interpret the experimental results and anticipate the manufacturing modifications.
A preliminary list of descriptors based on lexical analysis of the free verbalizations, as well as the development of procedures of functional evaluation for bow makers, are presented.

INTRODUCTION

Thanks to discussions with violinists and bow makers, as well as research work realized on this subject, we know that bow quality is linked with the way the bow can be controlled in playing (playing properties) and with the timbre (sonority of the emitted sounds).
For a violinist, the choice of bow is as much important as the choice of violin. Indeed, the bow is considered as a prolongation of the arm, like an artificial limb. Moreover, there is a constant interaction between musician, violin and bow.
In this study, we focus on twelve prototype bows, made out of carbon fiber composites. They were based on a model of a romantic bow (this model is "good working"), made by the famous bow maker François Tourte. Their characteristics are perfectly controlled and slightly different, in order to make the prototypes representative of diversity of Tourte's bows and bows based on Tourte's methods. For all bows, an effort made to mount ribbons of bow-hair as similarly as possible.

1. PERCEPTION TESTS

1.1. Violinists and bows choice

We asked a dozen expert violinists (soloists or the equivalent) to participate in our tests. They had a very precise perception of bow playing properties and sonority and were able to express their impressions. In order not to make the perception test too long, we had to choose seven prototypes from the twelve. We also decided to add a modern pernambuco bow (made by Stéphane Thomachot) to this selection, to have a kind of reference.

1.2. Test choice – Multidimensional analysis

A study about the quality of trumpets was made at Ircam. As it gave promising results, we decided to adopt the same method [1]. Our psychoacoustic study is based on dissimilarity tests rather than

preference tests. We proposed to the violinist various pairs of bows, and his task was to evaluate, on a scale from 1 to 10, for each pair, the difference between the two bows (1 means that they are almost identical and 10 that they are very different). Violinists were free to choose their criteria for determinating the dissimilarity.
To exploit these results, we used a multidimensional analysis program, called Exscal [2]. This program calculates a geometric space where bow positions are established according to their mutual dissimilarities. The program includes weighting and specificity calculations. Weighting is the importance given by each violinist to each dimension of this space. Specificity represents singular bow characteristics.

1.3. Experiment

All tests took place at Ircam, in the same conditions. The test lasted at the most three hours. First, violinists had to try the eight bows in order to get used to them and with the scale of dissimilarities. Then the test. was carried out. Finally, violinists had to express freely and without time constraints their feelings about each bow. We asked violinists not to take into account, as far as it is possible, the bows esthetic aspects.

1.4. Results

1.4.1.Vocabulary A list of descriptors was extracted from the free comments of the violinists about the bows. The aim of that list would be to create a basis of verbal units which would be significant for all the subjects and would be able to describe differences between bows.
Concerning the playing properties, the vocabulary is rather clear between violinists :

- the stick is well balanced, homogeneous
- the stick presents a good compromise between stiffness and flexibility
- the bow is *responsive* (rapid and clean attacks)

Concerning the sonority, the vocabulary is less clear :

- the sound is *warm*, *soft*, rich in harmonics
- the sound is *wide*, *open* – the projection is good (these subjective attributes refer to the apparent size or space-filling property of sound and were also present in the trumpet players' comments).

1.4.2. Analysis We made several multidimensional analyses with Exscal, with specificity or without, with weighting or without. The best two-dimensional representation was obtained with specificity and without weighting.

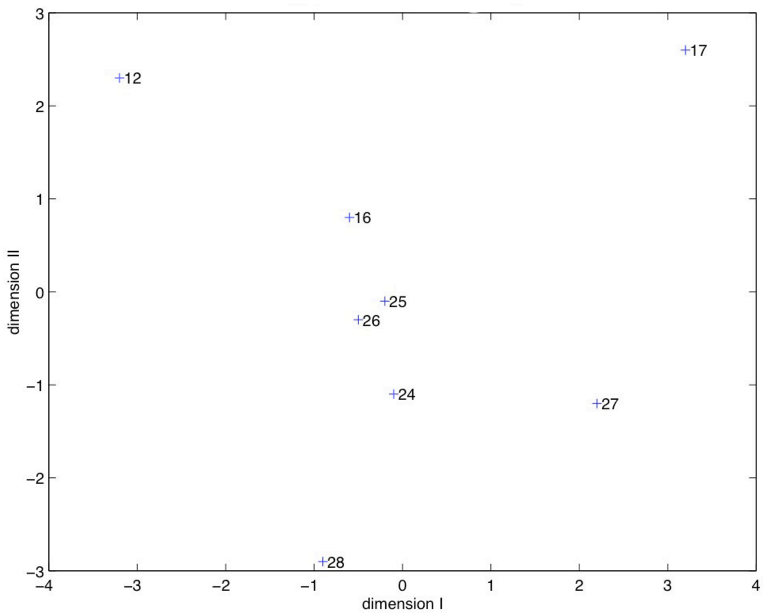

fig.1:results of multidimensional analysis (with specificity and without weighting).

The seven composite bows are numbered 12, 16, 24, 25, 26, 27 and 28. The pernambuco bow is numbered 17.
We tried to interpret the significance of the two dimensions thanks to violinists' free comments.
According to violinists, the balance of the bows 12 and 17, which are at both extremities on dimension I, are very different. The bow 17 seems to be well balanced, homogeneous. On the contrary, the bow 12 reveals unstableness. On dimension I, bow 27, which was also judged well balanced, is close to bow 17. For the others bows, which are situated at the middle of axe I, comments about their balance were not clear or in contradiction. We can deduce from these observations that dimension I represents balance and homogeneity.
The signification of dimension II is less obvious. The bows 17 and 28 are opposed on that dimension. The bow 17 was judged *stiff* and the 28 too *smooth*. Hence that dimension could represent the compromise between stiffness and flexibility.
It's interesting to notice too that the bow 16 has the highest specificity. It could be explained by its high mass and static torsion stiffness from another measurements.

2. MECHANICAL AND PHYSICAL PROPERTIES

In order to find a connection between criteria of quality and manufacturing processes, we studied characteristics of bows. It is generally assumed that playing properties are linked to static properties and sonority to dynamic ones [3].

2.1. Static properties

We made several measurements on the composite bows and some simplified measurements for the wooden bows belonging to the violinists participating to our psychoacoustic test. We measured the mass, the center of gravity, the flexural and torsional stiffness.
For the flexural stiffness, we used a method similar to N.Pickering's one [4] and so we made measurements all along the stick.
We also measured the bow-hair tension because it has a great influence on the behavior of the bow. It's interesting to notice that violinists adjust bow-hair tension very precisely. Some of them play with a high bow-hair tension, depending on their technique.

2.2. Dynamic properties

To evaluate dynamic properties, we thought it could be very helpful to develop a model, concurrently with the measurements, in order to better understand the bow behavior.

2.2.1. Finite element modeling of a violin bow Thanks to the model, we can highlight the different families of bow vibrations (vertical and lateral flexion, torsion, longitudinal for bow-hairs). Moreover, with finite element technique, it's possible to change slightly the bow geometry or the material properties and so to study the influence of such change on the bow vibrations. The model should fit any kind of bow.
Prestressing related to the tension of the bow hair raises the principal difficulty of modeling a violin bow. As the eigen frequencies of a bow are usually a function of the tension of the bow hair, we developed a mechanical model of the bow, built on the linearization of the equations of the movement near the prestressed state.
Compared to a situation without prestress this step introduces into the search of the eigen frequencies and eigen modes an additional term, called geometrical stiffness. This term takes into account the stress field which acts at the state of prestressed equilibrium.
In the case of the bow we numerically evaluate the static deformation of the structure when the bow hair is under tension and calculate the static stress field which belongs to it. We can then deduce the geometrical term of stiffness to add to the traditional modal analysis.

We made a simulation of a bow, clamped rigidly at the frog, with the finite element package Castem2000 [www.cast3m.cea.fr]. We use the following characteristics:

The stick is modelled by linear cubic elements. Each section is broken up into 9 elements. The natural curve of the stick was taken into account as well as the evolution of its profile

- Young modulus : 22.10+9 Pa
- Poisson ratio: 0.37
- mass density : 687 Kg/m3
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The bow hair is modelled by linear shell elements with four nodes.

- Young modulus : 7.10+9 Pa
- Poisson ratio : 0.3
- mass density : 1200 Kg/m3
- thickness : 0.18 mm

The results of this simulation introduce five groups of modes

1. vertical stick flexion, mode 1 (VSF1 - fig 2)
2. vertical bow hair flexion, mode 3 (VHF3 - fig 3)
3. lateral stick flexion, mode 2 (LSF2 - fig 4)
4. lateral bow hair flexion, mode 2 (LHF2 - fig 5)
5. torsion of the bow hair, mode 3 (TH3 - fig 6)

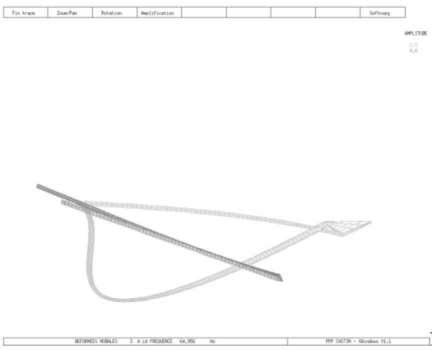
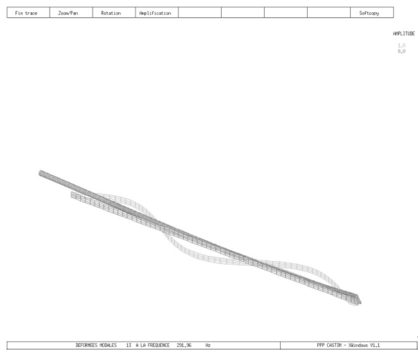


fig. 2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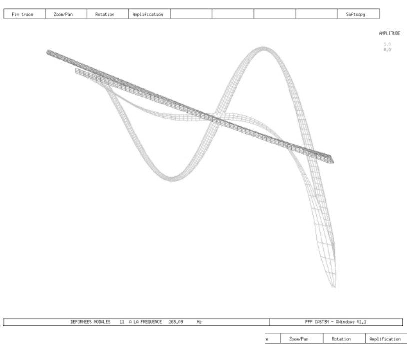
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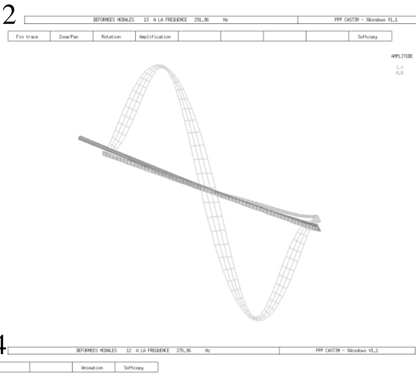
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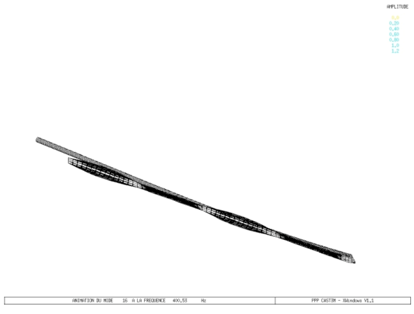
fig. 6

We didn't study simulation results above 1500Hz, so we didn't highlight longitudinal resonances in the bow-hair [5].

2.2.2. Experiment Thanks to a collaboration with the research laboratory of Cité de la Musique Museum in Paris, we could use Brüel&Kjaer modal analysis equipment. As modal analysis requires several hours, we could study until now only one bow clamped at the frog. However, we tried to understand how bow-hair tension affects the mode frequencies of the bow.
We made another kind of experience : the bow was fixed at the frog, we attached a vibration exciter to the stick, near the frog, and an accelerometer was glued at the tip in order to detect the maxima of vibrations. We could change the input signal frequency and we observed the bow movements with a stroboscopic light. This experience is much easier and faster than modal analysis and, moreover, the modes of vibrations are visible to the naked eye. Frequency response functions of the ribbon of bow-hair, are measured with a microphone placed in the near-field at various positions along the bow.

For the bows of the violinists participating in our tests, we made the bounce test a simple, fast and nondestructive measurement to estimate, indirectly, some qualities of the bow [6].

2.2.3. Results We compare results from modal analysis and vibration exciter experience. The bow was N° 27 and the tension on the hair was 60 N. We only considered the first modes.

	LSF0	VSF0	VHF1	VSF1	LHF1
Modal analysis		17	57	74	
Vibrating exciter	13	15.3	56.7	77	77

Table I : mode frequencies (Hz) of bow 27

Results from vibration exciter experiments are rather close to modal analysis (we couldn't measure lateral mode frequencies because output signal was too weak). The slight differences could come from the frog clamping which wasn't exactly the same and from the vibration exciter which could disrupt the movements of the bow.
Thanks to the vibration exciter experiment, we could observe precisely bow-hair motions : the bow-hair is not homogeneous at all, some hairs are more tense than others. Moreover, waves are propagating in the direction of the width of the ribbon.

We also studied the influence of bow-hair tension on the mode frequencies. The results of a simulated modal analysis for different bow-hair tensions (10, 30, 45, 60, 80 and 100 N in abscissa) are plotted in figure 2. (Mode frequencies are not absolute because we couldn't measure and verify the real characteristics of stick material and bow-hair).

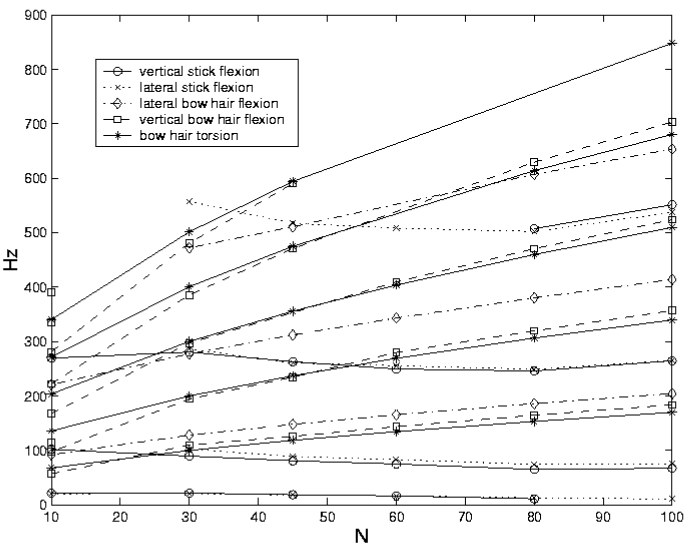

fig.2. : simulated modal analysis for different bow-hair tensions

It is observed that the eigen frequencies of the bow-hair increase with the tension (operation in traction) and that the eigen frequencies of the stick decrease (operation in compression). At the crossing of the various modes of vibration one observes strong coupling between the modes of stick and bow hair.
We can't confirm these frequency evolutions with the experiments. Indeed first stick and even bow-hair modes keep nearly constant with the tension.

4. CONCLUSIONS

Bow quality is a very difficult subject. We tried to make, at the same time, psychoacoustic tests, mechanical measurements and a computer model. In this paper are presented our first results on bow quality perceived by the violinists. From the perception test we begin to construct a perceptive space of bow quality and to suggest a preliminary list of verbal units and descriptors but it would be necessary to go more deeply into our investigations. We didn't manage to correlate mechanical or physical properties to quality criteria. For that, we need to study more precisely bow structure and especially the bow hair which presents complex motions.
We need too to fit the finite element model to the measurements, knowing exactly input parameters such as stick and bow-hair characteristics. By realizing other modal analysis, we could also validate this model.
It's worth carrying on with this study because it could represent a great help for bow-makers.

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