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Making wooden musical instruments
An integration of different forms of knowledge

Proceedings

Editors: Marco A. Pérez & Sandie Le Conte

3rd Annual Conference
COST FP1302 WoodMusICK

Museu de la Música de Barcelona
September 7-9, 2016

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Collaborating with Acousticians, Musicologist & Flute Makers: Towards the Conception of a 19th Century Flute

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Abstract

Professional flute-players recently asked a Parisian flute maker to conceive a period Boehm flute with an open key system, similar to the one inaugurated in 1830. Jointly conducted by acousticians, musicologists and flute makers, the objective of the study is to conceive such a nineteenth century flute. In order to achieve this, our aim is to understand the historical and musical context of flute manufacture, the playing techniques developed by musicians, the acoustic responses of the instrument and the characteristics of the key mechanism. We will be using an interdisciplinary approach, combining musicology and acoustic studies. The former will be using historical documents and academic articles in order to establish a coherent overview of the flute making industry in France in nineteenth century; the latter will be using geometrical surveys, models of admittance and admittance measurements in order to determine the acoustic characteristics of the nineteenth century flute, to identify the elements of flute making specific to each flute maker and to understand the playing techniques developed by the musicians. Furthermore, the understanding of the specific playing techniques developed by the musicians can be improved by the discussion with the professional flute players. Finally, regular discussions with the flute maker are necessary to understand the freedom or the limits of flute manufacture, or by the key mechanism.

1. Introduction

Historic: Until the eighteenth century, transverse flutes are keyless, mainly made of wood and have a cylindrical bore. The first significant changes in flute making appear with Jacques Hotteterre le Romain (ca.1680-ca.1761); the bore becomes cylindrical (for the head) and conical (for the body), various keys are added in order to simplify cross-fingerings and to improve the tuning of the flute [1].

In the history of the flute, the nineteenth century is rife in inventions. Flute makers patent numerous innovations, each trying to offer the best instrument. Without Boehm (1794-1881), the flute was in danger of being abandoned by composers, as it was not compatible with the significant progress of the orchestra. The genius of Boehm was in the implementation of parallel systems to create a new key system, much more convenient and reliable. The Boehm key system allowed the player to access larger holes placed in strategic acoustic positions. The first so-called Boehm flute was built in 1831. It spread in France from 1838 onwards, thanks to a new French version established by Buffet-Crampon and Dorus. Boehm then designed a new flute in 1847, built in metal with a cylindrical bore and a slightly conical head, in order to improve the timbre of the instrument [1].

The technical facility and the acoustics provided by the Boehm mechanism, offering easier intonation and timbre diversity, ensured the future of the flute. Composers became interested and began to compose interesting musical pieces beyond the virtuoso pieces of the nineteenth century, composed mainly to show the skill of the musician without worrying about the timbre of the instrument.

Context: This study was initiated following the request of professional flute-players to conceive a period Boehm flute with an open key system, similar to the one inaugurated in 1832. The research is jointly conducted by acousticians, musicologists and flute makers in order to understand the historical and musical context of flute manufacture, playing techniques developed by musicians, acoustic responses of the instrument, characteristics of the key mechanism, and conceiving a prototype. Furthermore, some comparisons will be established with the modern flute.

2. Methods

We will be using an interdisciplinary approach, combining musicology and acoustic studies. The former will be using historical documents and academic articles in order to establish a coherent overview of the flute making industry in France in nineteenth century; the latter will be using geometrical surveys, models of admittance and admittance measurements in order to determine the acoustic characteristics of the nineteenth century flute, to identify the elements of flute making specific to each flute maker and to understand the playing techniques developed by the musicians.

Furthermore, some interviews have been conducted with professional flute players in order to highlight their expectations about the new flute.

As the preservation of the period sound seems to be a significant characteristic, it would be interesting to study the embouchure of the flute, that most probably plays an important part in the timbre of the instrument. The playing techniques at the embouchure of the instrument can be studied thanks to a specific protocol, described by De la Cuadra, [2].

Finally, regular discussions with the flute maker are necessary to understand the freedom or the limits of flute manufacture, or by the key mechanism. The conception of a first prototype will be conducted with the flute maker, while reflecting on ergonomic problematics.

3. Results

To conduct our study, we worked on 6 flutes from the nineteenth century and one modern flute, each flute is described in the table 1, in terms of date of built, the type of the foot joint and the name of the builder.

Geometry: The first results show geometrical differences between the nineteenth century flutes and a modern flute by Sankyo. The geometrical surveys, Figure 1-left, allow us to confirm that the bore of the nineteenth flute presents a cylindrical head and a conical body varying between 18 and 11mm, while head of the modern flute is parabolic with a cylindrical body varying between 17 and 19mm. Flutes with a D foot

Table 1: Details on the flutes studied

Builder	Date of built	Type of foot joint
Louis Lot	1884	D
Louis Lot	1886	D
Louis Lot	1881	C
Isidore Lot	after 1860	C
Isidore Lot	after 1860	C
Gautrot-Marquet	Between 1875-1883	C
Masspacher		C
Thibouville-Lamy	after 1867	C
Sankyo	2015	C

joint present a variance, in fact the bore of the foot joint is like a divergent cone between 11 and 14 mm; this exception may be a heritage from the baroque flute.

Figure 1-right shows the diameter of the holes and their positions from the top of the flute body for the two flutes.

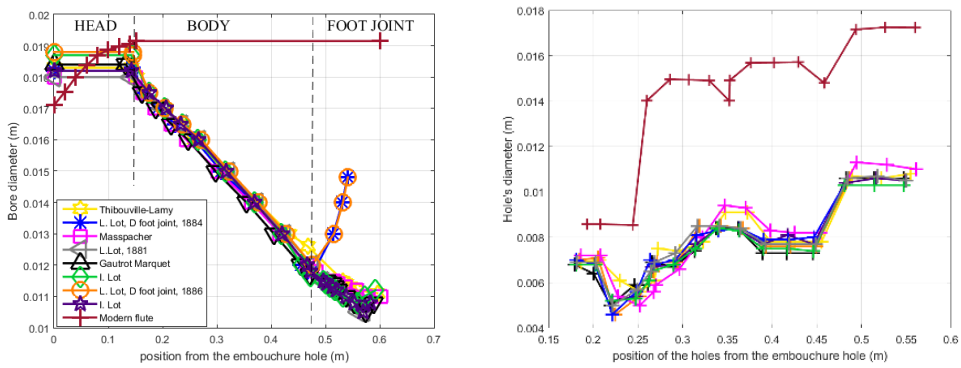

Figure 1: left - bore diameters of the flutes, right – hole's diameter and position from the embouchure hole.

The comparison between the flutes pictured in figure 1-right indicates that the diameter of modern flute finger holes are twice as large as those of the nineteenth century flutes, except for the three first holes which are trill holes or register holes. Consequently, modern flute holes are placed slightly further down the body of the instrument. We also observe differences in the position of the holes for the nineteenth century flutes. However, the diameters of the holes seem to be similar for all measured flutes.

Admittance measurements: The input admittance of the flute can be measured by using an impedance sensor, developed in Le Mans [3]. Thus, the resonance frequencies of the flutes are estimated using the zero crossing of the imaginary part of the admittance. Obviously, the frequencies have to be distinguished from the frequencies played by a musician as our measurements do not take into account the radiation at the embouchure, the influence of the lips, and the influence of the air jet. However, through these measurements we can estimate the musician's control if s/he were to play with an

equal temperament. Figure 2 represents the frequency difference between the resonance frequencies and the equal temperament frequencies in cents for the flutes we measured (L. Lot, Sankyo and Thibouville-Lamy) and for the first two registers.

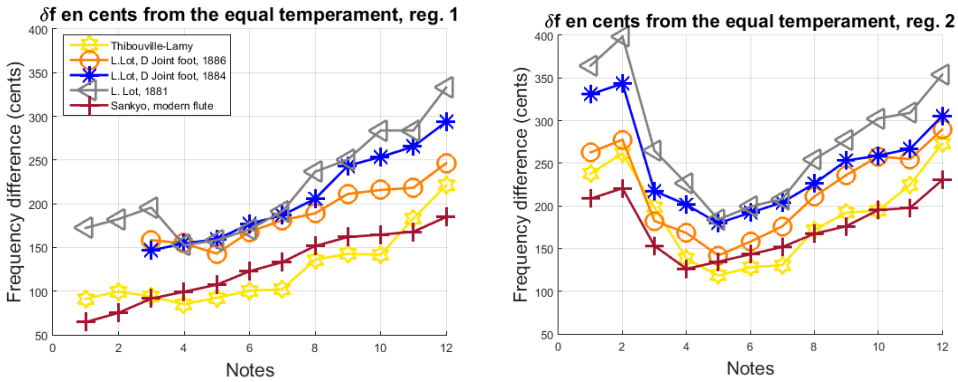

Figure 2: left: Frequency differences between the resonance frequencies and the equal temperament for the register 1. Right: Idem for the register 2.

On figure 2, we can observe that the spaces between two successive notes are more regular for the modern flute than for the nineteenth flutes. Tone control is therefore probably easier for a musician playing the modern flute because it evolves in the same way during the scale. We also note that the flute Thibouville-Lamy seems to have the same pitch as the modern (442 Hz), whereas the others flutes seem to have a lower diapason, around 430 Hz. Finally, we remark that control may be difficult for the flautist between C4 and E4, especially with the grey flute, as the variations fact for this flute are higher. During a scale, the musician will have to adjust his/her control (position of the lips and air jet velocity [2, 4]) in order to compensate around 100 cents for the modern flute and 200 cents for the grey flute. Others acoustical parameters can be studied in the admittance measurements such as the magnitude of the peaks and the spectral composition of the spectrum, in order to estimate the emission facilities or characteristics on the sound.

Admittance model: The admittance of the flute can be modelled using the plane wave theory, described by Pierce [5]. Using the approach of transmission lines, this theory describes the flute as a product of transfer matrices, established by the geometry of the instrument: cylinder, cones, holes, … Each element corresponds to a matrix transfer, as explained by Kergomard in [6], which is multiplied with the others. Thus, we can model the impedance between the head cork and the embouchure, and flute body (as Lefebvre [7], Vauthrin [5]), which we place in parallel with the impedance of the cavity. The impedance obtained is then placed in series with the impedance of the embouchure hole. We then obtain the impedance of the entire flute above the embouchure hole. The admittance of the flute is just the inverse of the impedance. In the same way as previously, we estimate the resonance frequencies and the frequency differences with the equal temperament, figure 3.

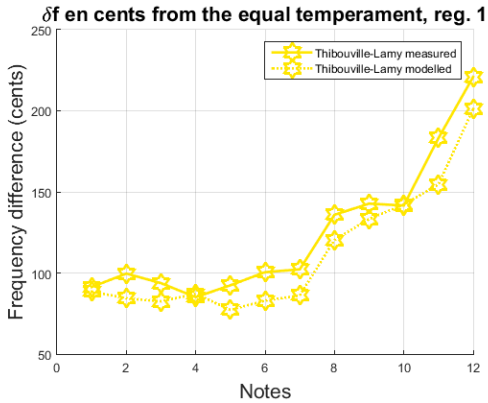

Figure 3: left: Frequency differences between the resonance frequencies and the equal temperament for the register 1, for the Thibouville-Lamy flute measured and modelled.

Figure 3 shows that the resonance frequencies obtained by our model are close to the one obtained by the admittance measurements. However, we note variations of up to 15 cents for some fingerings. These variations may come from the linear acoustics description of the geometry of the holes which does not take into account the undercutting technique [8]. Before using this model to produce a prototype, we need to improve it, to correctly model the measures. We could then use it in order to determine the changes of the flute geometry in order to optimize the prototype in agreement with the musician greetings.

Discussion with the musicians: An important part of the study is to understand the musicians' point of view in order to create an instrument that is attractive to them. To this effect, we interviewed two musicians from different backgrounds, both owners and regular players of period flutes. The first was a historical enthusiast with great interest for period instruments as a collector and amateur musician, the second was a professional musician who was until recently employed by a prestigious period orchestra. The concerns of both musicians, however, were similar in that the main characteristic they wished to see reproduced in a new version of the Boehm conical flute was its distinct sound, before even working on slight tuning adjustments. The amateur flautist was keen for the new flute to retain its sound, "more intimate, softer and less aggressive" than the modern Boehm flute. Similarly, the professional musician expressed his appreciation for the "fine" and "elegant" sound of the French manufactured conical Boehm flutes and was keen for the new flute to retain the slight discrepancies in tuning and timbre as these were musically included in the contemporary repertoire by the composers.

4. Discussion

The first results of the study show the main geometry differences between the nineteenth century and the modern flutes, and their influences on the resonance frequencies of the instrument and on the playing techniques.

The flute can also be modelled with a model based on the linear acoustics, this model needs to be improve in order to use it in order to generate the prototype in agreement with the musicians greetings.

This work will be continued with a study on the sound of the flute, and more particularly on the influence of the embouchure shape, in order to determine the best embouchure geometry to choice in terms of emission facility and sound produced.

Acknowledgement

The authors want to thank the musicians for the loan of their flutes.

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Rethinking the Possibilities of a Notched Flute: The Case of *Quena*

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Abstract

The *quena* is a notched flute from South America. Notched flutes share the same excitation mechanism but differ in several aspects such as the number of holes, the geometry of the notch and the size and shape of the tube. Today the *quena* is an instrument widely played in Latin America both in rural and urban contexts, where it gradually adapted to tonal music. It is in the latter context that we propose to revise the design of the bamboo *quena* from an acoustic perspective, optimizing the position of the toneholes and modifying the geometry of the bore in order to obtain a flexible and adequate instrument not only to play tonal music but also to adapt to the chromatic needs of contemporary music. The analysis is based on a linear model of the acoustical propagation inside the instrument, which is numerically simulated and optimized in order to obtain a new design of the instrument addressing some of the limitations found in the original cylindrical *quenas*.

1. Introduction

The Grove Music Online describes notched flutes as 'an end-blown flute (open or stopped) with a V- or U-shaped notch cut or burnt into its upper rim to facilitate tone production' [1]. Notched flutes are played widely and can be found in Africa, East Asia, the Pacific Islands and Central and South America. One of the most well known notched flutes is the Japanese *shakuhachi*. It is made traditionally out of bamboo and its most common form has four finger holes and one thumbhole. Variants of the notched flutes are found in China, Korea, Vietnam and Taiwan. The *quena* (or *kena*) is a South American notched flute. Like the other flutes, it is an ancient instrument, with a history of over 2000 years [2]. The instrument is mainly found in Peru, Bolivia, northern Chile and northern Argentina and is less frequent in Ecuador, Venezuela, Columbia and the Guyanas. It can be made out of cane, wood or reed and most instruments have six finger holes and one thumb hole [3].

2. Musical and cultural contexts

All these different flutes are used in specific musical and cultural contexts. Notched flutes were played in Peru as far back as the Chavin era (900-200 BCE). The traditional repertoire of the *quena* is closely associated to the dry winter season and is still played in Aymara communities on the Bolivian *altiplano* [2]. The instruments (*kena-kena*), used in these rural communities, are between 50 and 70 cm long, have six finger holes and are played as part of an ensemble. However, *quenas* were not solely confined to a rural environment. Solo playing developed within an urban setting, consolidated around the mid-twentieth century, when Andean music benefitted from a huge rise in popularity thanks to a cosmopolitan pan-Andean music genre created in Paris, where many

Argentinean, Chilean and Bolivian groups recorded and gained popularity in the 1960s [4]. This led to the modification of the instrument in order to cater to artistic needs such as adjusting to a more tempered scale and playing with other instruments. Today, the standardized urban instrument is generally made out a single piece of cane, wood or even plastic and features six finger holes and a thumb hole at the back [2]. Some modern models are also in two parts, with a joint between the head and the body (Garcia, interview 30 May 2016, Paris).

In Chile, the *quena* and the *charango* were used extensively in left-wing *Nueva Canción* groups, identifying themselves with a pan-Andean revolutionary movement [5]. These instruments were so closely associated with this political movement that they were strongly discouraged after the 1973 military coup, overthrowing Allende's democratically elected government [6],(Wang, interview 5 July 2016, Paris). Despite this, traditional instruments were soon openly played by local musicians. One of these groups, Barroco Andino, was formed immediately after the coup and performed a Western Art Music repertoire initially conceived for different instruments (Wang, interview 5 July 2016, Paris). This led the musicians to push their instruments beyond their limits as they started experimenting in order to meet the demands of the music, leading them to an idealised "well-tempered *quena*" (de la Cuadra, interview, 8 February 2016, Paris). The decontexualization of the instrument from its folk and traditional repertoires triggered a movement that led to further modifications. More recently, for example, flautist and Ensamble Antara leader, Alejandro Lavanderos, contacted Paris-based flute maker Jean-Yves Roosen to create a chromatic instrument that would allow composers and musicians to go beyond the instrument's current limits.

3. Influence of the musician on a flute-type instrument

Changes in repertoire imposed by musical, political or cultural change lead musicians and instrument makers to modify their instruments in order to cater to specific musical needs [7], [8]. If we reverse the position and propose an instrument with slight modifications, how will this impact the musician and his/her musical practice? As the one of the main driving questions of this study we wish to understand if the musician welcome change or if it will be problematic and whether a modified instrument will lead to the performance (and composition) of a different repertoire or if the musician will change the performance of his/her current repertoire.

Although the instrument is a separate object to the musician, both are intricately linked. Indeed, an experienced musician will be able to control his/her instrument in such a way that his/her technique will override many technical or structural issues that an instrument may have [9]. The structure of the instrument will influence how the musician controls the instrument but will not impede the musician's production of a precisely targeted emission. We could theorize this in the following figure:

Although understanding the musician's control over the instrument is not the goal of our study, it is an important aspect of our research in order to understand how the physical parameters of the instrument affect him/her.

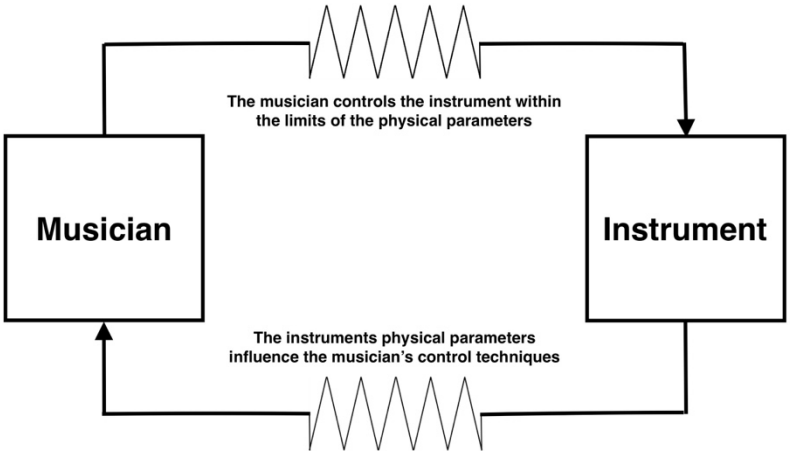

Figure 1: Theorization of the musician/instrument interaction

4. Technical knowledge

In the last decades the knowledge of the physics of flute-like instruments has improved and a new research field, the musician's control over his instrument, has shown to be both attractive and promising [9], [10], [11]. These improvements, together with the possibilities of accurate acoustic impedance measurements and the availability of materializing technologies such as 3D printers and CNC lathes, set up favorable conditions to study and revise the design of musical instruments. Analytical models of non-trivial geometries for instruments from the flute family are too complex to implement. Alternatively, the transmission matrix approach [12] provides a powerful tool to simulate and predict the linear passive acoustic behavior of flutes.

5. Revising the instrument

When conceiving a flute, there are several parameters that the builder can modify in order to obtain a desired intonation (tuning). The most important include the position, size and height of the toneholes, the bore's internal geometry and the shape of the embouchure.

In a previous study [13] we observed that the bore geometry could be crucial in determining the inharmonicity between the first and second register of the instrument. In order to describe more precisely the tuning of the first two registers for every note from a given bore geometry, we simulated several internal bore shapes, cutting the passive end at places where it would produce a tempered scale if the resonator was an ideal cylinder. That is, in places where the length of the nth chromatic note is given by: L/2^(n/12), where L is the length of the bore. For every truncated bore we simulate its acoustic impedance and measure its inharmonicity. Figure 2 shows the simulated response of a set of bores whose internal diameters are displayed on the upper side of the figure with their corresponding inharmonicity below:

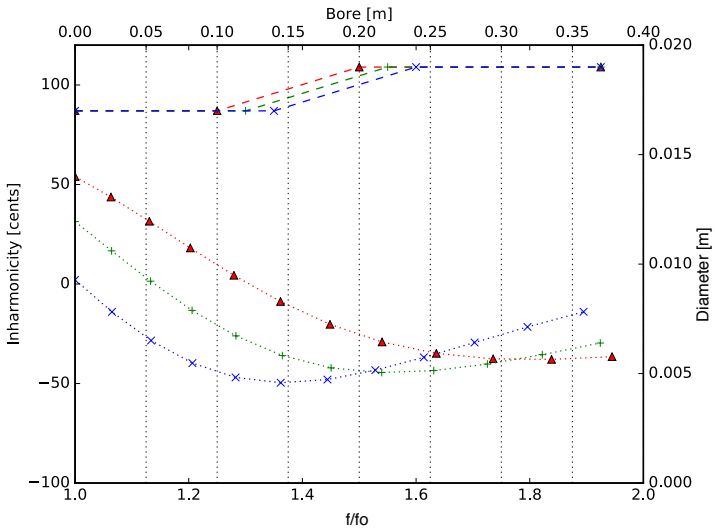

Figure 2: Inharmonicity in relation to the shape of the bore

We observe that the inharmonicity differs greatly among the three geometries and also varies considerably from note to note with differences that can span over a range of over 80 cents. Several bore geometries were simulated in the same way, providing a dictionary of bore shapes with their associated inharmonicities.

Once the geometry of the bore is chosen, the toneholes provide the means to tune the first register and fine-tune the second register. In order to identify how much inharmonicity can be controlled by adjusting the size and height of the toneholes, figure 3 shows a simulation of a 37cm cylindrical bore with one tonehole whose center is positioned at 34.96cm from the embouchure end, that is the length where an interval of a tone would be produced if the bore was truncated.

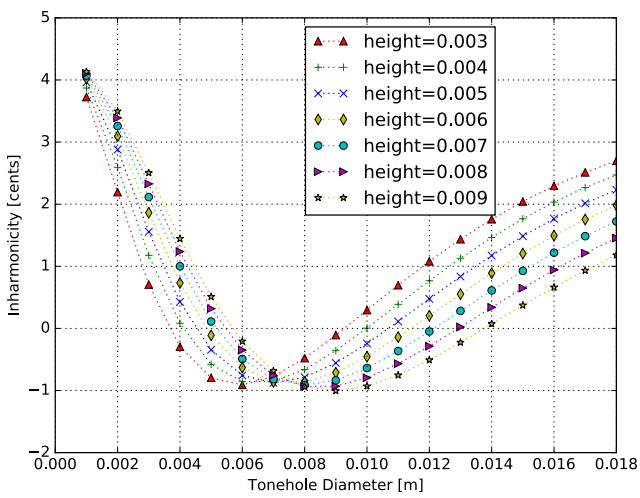

Figure 3: Tonehole inharmonicity in relation to its height and diameter

We notice that toneholes with equivalent inharmonicity can be obtained by correctly choosing a combination of tonehole height and diameter.

The variation of inharmonicity that can be induced by such holes is smaller than 5 cents, which shows that the inharmonicity induced by the bore's internal geometry dominates over that of the toneholes.

With these parameters in mind, two instruments were simulated. The first features an intonation profile emulating the impedance measurements of real instruments (Figure 4, right); the second features a profile calculated to produce a tempered scale with a smooth evolution in the control over the two registers (Figure 5, right).

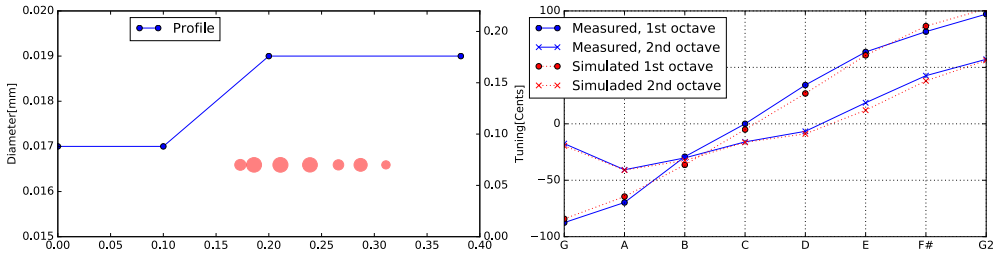

Figure 4: Simulated *quena* based on measurements

Figures 5 and 6 (left) show the bore profile and the size and position of the toneholes calculated to match the desired intonation.

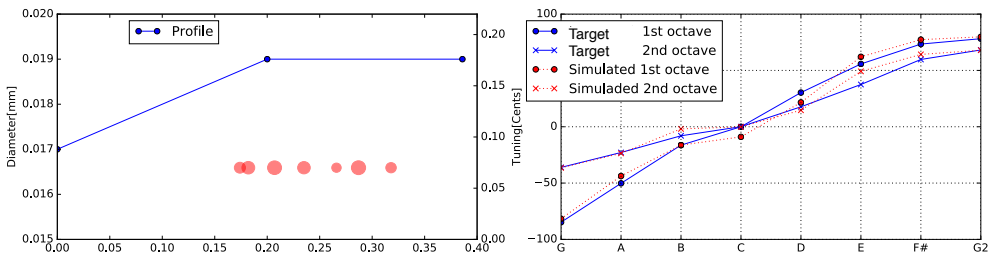

Figure 5: Simulation of the proposed *quena*

In order to address our initial question, posed part 3, we are now in the process of printing both instrument simulations with a 3D printer.

6. Perspectives

Our next step is to measure through motion capture, video, sound and interviews how the musician adapts to the instruments. We are aware of personal differences between musicians and we are currently establishing an experimental protocol including two musicians and their reactions to both instruments within a musical context.

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