ACOUSTICAL ANALYSIS FOR A TXISTU

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Agos Esparza, Asier\textsuperscript{1}; Macho Stadler, Erica\textsuperscript{2}; Elejalde García, María Jesus\textsuperscript{3}
\textsuperscript{1,2,3} Dept. Física Aplicada 1 E.T.S. de Ingeniería de Bilbao (Universidad del País Vasco); Alameda Urquijo s/n, 48013 Bilbao, Spain; \textsuperscript{1} bckagesa@ikasle.ehu.es; \textsuperscript{2} erica.macho@ehu.es; \textsuperscript{3} mariajesus.elejalde@ehu.es

ABSTRACT
The txistu is a Basque recorder with three finger holes and a cylindrical bore. It is usually made up of three different pieces. With only three lateral holes, the player has some difficulties to achieve the correct intonation of the intervals between notes. In this work, we analyze the possible modification of the internal diameter of the bore and how it affects those intervals.

INTRODUCTION
The txistu is a wooden flute family instrument from the Basque Country. Because it is small and has only 3 holes, it is possible to play it with one hand. The musician often accompanies the melody playing a tambour on his own: playing the txistu in one hand and the other hand beats the tambour [1].

Figure 1 shows the txistu used in this work. A metallic mouthpiece conducts the air flow until reaching a metal reed. When the distance between the mouthpiece end and the metal reed varies, moving the reed, the sound slightly changes. The internal bore section is cylindrical and three sound holes are placed in the final part.

Ring finger can be introduced in a metallic ring that usually is at the end of the bore, to hold the instrument. Little finger is used to partially close bore hole when it is necessary. Middle and index fingers are used to close the holes 1 and 2 placed in the front of the bore and the hole 3 is in the back side for the thumb.

![Figure 1.- Prototype of the txistu used without metallic rings.](image)

After several changes since XIII century, most popular txistu is made of ebony and is tuned in F with a total length of 44cm approximately. With only three holes it is necessary to use the same fingering to play more than one note. The musician must increase the velocity of the air flow to play a note with higher frequency. With this over-blowing, more than five notes can be played using the same fingering. However, due to energy losses the frequency of those notes is not always what musician expects.

Theoretically, if the lowest note frequency is f, the overblown note frequencies appear at 2f, 3f, 4f, and so on, obtaining the scale of just intonation. But in a real instrument, the harmonic series is not obtained and the musician must correct the fingering and regulate the velocity of the air flow to get the wanted frequency.

In the first part of this work, the frequencies of the notes obtained with a txistu tuned in F are analyzed, in order to study the intervals between them. In the second part, the effects of the change of the internal diameter of the bore and how it affects those intervals are investigated.
EXPERIMENTAL SETUP
The sounds of the instrument were recorded with a Pre-polarized Free-Field, ½" Microphone (Brüel & Kjær, 4189-A-021) and PULSE analyser (Brüel & Kjær). The microphone was placed at 50cm in front of the txistu. Data have been analysed obtaining FFT spectra with 6400 lines between 0 and 20000Hz.

The instrument used for this study is made of bubinga wood, being its internal diameter 14mm and its length 44cm. Table I shows the location from the end of the instrument and diameter of the holes, and the used fingering positions. For each position, some registers were studied. Each note was recorded three times.

Table I.- Fingering positions used in this work.

<table>
<thead>
<tr>
<th>Position</th>
<th>Bore Hole Diameter 14mm Located: 0mm</th>
<th>Hole 1 Diameter 10mm Located: 58mm</th>
<th>Hole 2 Diameter 9mm Located: 79mm</th>
<th>Hole 3 Diameter 10mm Located: 118mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position 1</td>
<td>○</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Position 2</td>
<td>○</td>
<td>○</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Position 3</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>●</td>
</tr>
<tr>
<td>Position 4</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

In order to study the variation of the intervals with the internal bore diameter, the same measurements were performed with a bubinga ring inside the bore. Ring dimensions were: outside diameter 14mm, inside diameter 12mm, height 5mm. The ring position was varied from the end to the top of the bore in 1cm steps.

RESULTS
In this section, harmonicity and the value of intervals between notes with the same fingering position are studied for the case of cylindrical bore and for the bore with a ring placed at different positions.

Study of the txistu without bore modifications
The stationary spectra of a txistu can be seen in Figure 2. Characteristic features of this sound spectrum can be listed as follows: a series of harmonic partials and a second series of smaller and wider peaks, which are not harmonically related. These small peaks shown in the spectrum demonstrate the presence of acoustic eigenmodes of the pipe.

![Figure 2.- FFT of register 3 with position 1.](image-url)
Table II shows the mean frequencies of the notes obtained for different positions and registers. Depending on the instrument some registers do not appear due to the geometry and position of the holes.

Table II.- Experimental mean frequencies (in Hz) for the notes studied in this work

<table>
<thead>
<tr>
<th>Register</th>
<th>Register</th>
<th>Register</th>
<th>Register</th>
<th>Register</th>
<th>Register</th>
<th>Register</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Position 1</td>
<td>386</td>
<td>773</td>
<td>1173</td>
<td>1568</td>
<td>1943</td>
<td>2330</td>
</tr>
<tr>
<td>Position 2</td>
<td>442</td>
<td>880</td>
<td>1317</td>
<td>1729</td>
<td>2059</td>
<td>2352</td>
</tr>
<tr>
<td>Position 3</td>
<td>471</td>
<td>940</td>
<td>1401</td>
<td>1835</td>
<td>----</td>
<td>2368</td>
</tr>
<tr>
<td>Position 4</td>
<td>526</td>
<td>1051</td>
<td>1554</td>
<td>----</td>
<td>----</td>
<td>----</td>
</tr>
</tbody>
</table>

The degree of inharmonicity was examined by comparing the tsistu resonance frequencies with those expected for a cylinder [2].

A parameter denoted as the harmonicity was estimated as the slope obtained by fitting a linear relationship between \( f_n \) and \( nf_1 \). This graph is shown in Figure 3 for three notes with different positions. The harmonicity value is very close to 1 for all the notes, with a maximum error of 4Hz, so the tsistu is a very harmonic instrument.

![Figure 3: Harmonicity estimation of three notes with different positions.](image)

In music theory, the term interval describes the difference in pitch between two notes. Intervals may be labelled according to the ratio of frequencies of the two pitches. Table III shows the name and the definition of these intervals.

Table III.- Theoretical intervals

<table>
<thead>
<tr>
<th>Interval name</th>
<th>Definition</th>
<th>Value in just intonation scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perfect Octave 1</td>
<td>F2/F1</td>
<td>2</td>
</tr>
<tr>
<td>Perfect Octave 2</td>
<td>F4/F2</td>
<td>2</td>
</tr>
<tr>
<td>Perfect Fifth</td>
<td>F3/F2</td>
<td>3/2</td>
</tr>
<tr>
<td>Perfect Fourth</td>
<td>F4/F3</td>
<td>4/3</td>
</tr>
<tr>
<td>Major Third</td>
<td>F5/F4</td>
<td>5/4</td>
</tr>
<tr>
<td>Minor Third</td>
<td>F6/F5</td>
<td>6/5</td>
</tr>
</tbody>
</table>

In the real instrument, the values of the intervals are not those that the theory predicts. We calculate the deviation of an interval as:

\[
Interval \ shift \ (\%) = 100n'\left(\frac{F_n}{F_{n'}} - \frac{n}{n'}\right) \quad (Eq. 1)
\]

Figure 4 shows the interval shift as a function of the fingering position for the instrument without perturbation.
Biggest deviation is in the interval of major and minor third. Those intervals are related to high registers. Deviation is greater in high frequency notes.

![Figure 4.- Interval shift for cylindrical instrument.](image)

**Study of the txistu with bore modifications**

When the wood ring is introduced inside the bore, some of the notes change their frequencies. One can investigate if the frequency changes affect the instrument harmonicity. Experimental results show that the harmonicity values remain very close to 1 for all the notes. So, modified instrument remains a very harmonic instrument.

A consequence of the frequency variations is the change of some intervals. Theoretical calculations predict that a narrowing in a maximum velocity zone produces a lowering in the frequency [3].

It can be seen immediately that the presence of a perturbation varies the instrument tuning. Figure 5 shows the interval shift for position 1 when the ring is moved between the end and the top of the bore in steps of 1cm. Coloured lines are a polynomial approximation of the experimental points.

![Figure 5.- Interval shift for position 1 moving the ring across the bore.](image)
First octave, showed in blue, has a minimum when the ring is in the middle of the bore. When the ring is at 30cm, the values of the interval shift are reduced and the instrument would sound better. But with another fingering, this position of the ring does not act in the same way, as Figure 6 shows.

Musicians usually consider that deviations must be smaller than ±0.4% for a good intonation [4]. The interval shift values of major and minor thirds are bigger than 3% and the ring does not solve this problem. Musician must correct the fingering or use another fingering for those notes.

Figure 7 shows that the best position of the ring is at 20cm. In this position all intervals have low value, but closer to the theoretical value. When there are not open holes between the ring and the mouthpiece, it seems that changes in the interval shift are periodical. The frequency of those periods is higher when high frequency notes, that have a higher number of nodal points,
are involved. Next fingering position is played with all holes open and, as Figure 8 shows, periodical changes start in position 12.4cm.

![Image](image.png)

**Figure 8.- Interval shift for position 4 moving the ring across the bore.**

**CONCLUSIONS**

This work analyzes the influence of a wood ring with outside diameter of 14mm, inside diameter of 12mm, and height of 5mm inside the cylindrical bore of a txistu. Starting with a prototype made of bubinga, without ring, interval between different registers with the same fingering are compared with theoretical value obtained from the scale of just intonation.

First conclusion is that harmonicity of the notes is near the perfect value 1, but some interval shift, obtained between registers with the same fingering, are bigger than the value 0.4% accepted by musicians for a good intonation.

When the ring is introduced inside the bore, changes in harmonicity are very small, but changes in interval shift are appreciable. Those changes are different for each position of the ring and different for each fingering. When there are not open holes between the ring and the mouthpiece changes in the interval shift are quite periodic. The frequency of those periods is higher when high frequency notes are involved.

With the ring at 30cm from the end of the bore, interval shift for the position with all holes closed is the smallest, but this is not the case for another fingering. With only one ring, it is not possible to obtain a better intonation for all fingering positions. It is necessary to make perturbations at different positions of the bore to correct the values of interval shift. That can be interesting for a future work.

**References:**


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