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# Study the mouthpiece of the txistu

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The txistu is a three finger holed recorder from the Basque Country. The evolution of the txistu involves different kinds of wood, bore length, finger hole positioning and it being made of two or three pieces. Also, the unique mouthpiece, made up by a metal small piece of pipe and a metal reed which was introduced centuries ago. The distance between the pipe and the reed can be adjusted to fit the user's preferences. The shape and inclination of the reed, finding the value of the harmonic content and the sonority of the final note in different cases will all be studied by using a blowing machine and data acquisition software.

# 1 Introduction

The txistu is one of the most evolved instruments in the family of recorders and tabor pipes. It consists in a 41.5 centimeters bore with inside diameter of 14 millimeters. It has three side holes at the end of the bore. The main reason of the foresaid evolution is due to the mouthpiece. The metal conduct promotes the airflow against a metal reed and the player can change the distance between the conduct and the reed, modifying the instrument according to the needs of the musician. With some new instruments, the player can change the angle between the conduct and the reed with two small screws placed in the upper part of the mouthpiece. However this mechanism can cause significant damage to the wood in the particular region.

In this work the pitch and spectral centroid have been measured for different configurations of the mouthpiece in order to find which of them has the most effect on the final sound of the txistu.

Experiments were made with the three side holes closed and different configurations for the mouthpiece of the txistu. Four characteristics of the txistu were changed. These four parts include varying the distances from the end of the conduct to the reed (L), the height of the reed over the air conduct (H), and using different reed shapes (flat and sharp) and different conducts for the air jet. The conduct is conic and it has an input area (A_in) where the lips of the player are placed on and an output area (A_out) where the air jet flows against the reed as can be seen in figures 1, 2 and 3.

# 2 Experimental Setup

The blowing machine was the 8MS11 from ACI. The air flows inside a pipe, with an electric resistance inside. This resistance can be controlled analogically to increase or decrease the temperature of the air. There is a valve to change the air flow. In order to provide a steady pressure, the pipe ends at 5 litre cavity, to which the mouthpiece of the txistu was connected. A Digitron manometer model 2001P measured the pressure and a thermometer model CI-6605A from Pasco measured the temperature.

The main txistu prototype was made especially for this study. It has a wider hole than usual for the air conduct. This allows the use of different conducts and to modify the height.

In the experiments, the pressure was increased manually from 0 mbar until the pressure that corresponds to the end of the sixth register, usually around 50 mbar. The sound was recorded at each pressure, using a Bruel & Kjaer microphone model 4189-A-021 and the Pulse 11 software, also by Bruel & Kjaer. The FFT spectra were taken for 6400 frequencies between 0 to 20 kHz. These data were analyzed using Matlab to find the value of the centroid, pitch variation and other properties.

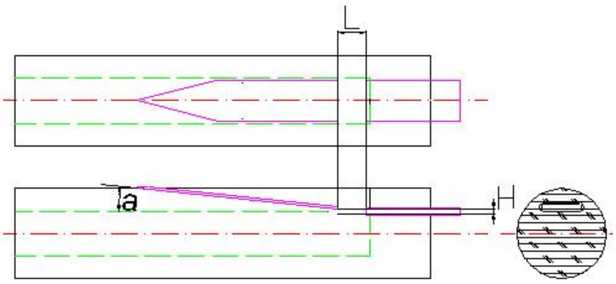

Fig. 1 Upper, lateral and frontal view of the mouthpiece.

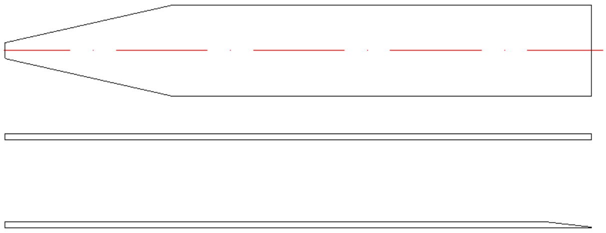

Fig. 2 Upper view of a reed and lateral view of two different reeds, flat and sharp.

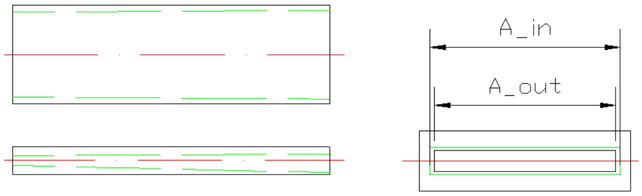

Fig. 3 Upper, lateral and front view of a conic conduct for the air jet at different scales.

| Conduct | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| A_in ($mm^2$) | 15.0 | 28.2 | 14.4 | 14.4 | 23.2 |
| A_out ($mm^2$) | 14.7 | 14.8 | 14.2 | 14.2 | 12.7 |

Table 1 A_in and A_out of different conducts.

# 3 Measurements and Results

The first measurement was made using a standard configuration of the mouthpiece: L = 6 mm, H = 0.5mm, a = 3 degrees, flat reed and conduct number 1. Constant temperature of the air was placed at 27 ºC and the pressure of the airflow was 4.45 mbar throughout the process. Eleven measurements were taken, closing the air flow each time. The result was that the fundamental frequency for every note was 1156.25 Hz and the difference in the fundamental frequency between the notes was less than 3.125 Hz, which is the limitation that the FFT gives when using 6400 different frequencies between 0 and 20 KHz.

The normalized centroid was calculated using the first six partials of the notes (N=6).

$$Normalized\ Centroid = \frac{\sum_{i=1}^{N} F(i) * P(i)}{F(1)\sum_{i=1}^{N} P(i)} \quad (1)$$

Where F(i) is the frequency of the partial and P(i) is the sound pressure level of the i$^{th}$ partial.

The variations of the normalized centroid are between 1.22 and 1.27. Smaller variations than 0.15 in the value of the centroid are not perceptible [1].

The experiment was repeated with the same configuration of the mouthpiece, a pressure of 6.6 mbar and the temperature changing from 25.5 to 42 ºC. There was 16 Hz increase of the fundamental frequency when the temperature was grown. However, when the temperature variation was around two degrees, the variation of the frequency was less than the experimental error of 3.125 Hz. Due to this, the temperature during all the following experiments was held at 30 ºC varying one degree above and below.

## 3.1 Registers

The next case uses the configuration of the mouthpiece with L = 6 mm, H = 0.5mm, a = 3 degrees, flat reed and conduct number 1. The pressure of the air will change. When pressure increases, the note will change to the next register that has double frequency.

The different notes appear at higher frequencies as the pressure increases and they follow the harmonic scale. The first one has frequency (f), the second one is nearly 2*f and them 3*f, 4*f and so on. The first six notes or registers of the instrument are showed in the figure 4.

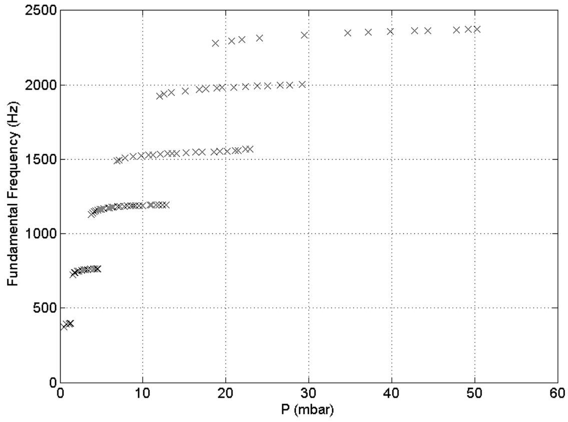

Fig. 4 Notes for a txistu with closed holes varying pressure, with L = 6 mm, H = 0.5mm, a = 3 degrees, flat reed and conduct number 1.

Figure 4 shows that some notes could appear at the same pressure. The player must regulate the attack to play the required note. When the pressure is increased by a blowing machine like in this case, the note will sound until the overblowing happens. Then the next register will appear and the pressure could be decreased without losing the new note until the minimum pressure for this sound is found.

The range of pressure in which each note can be played is greater in high registers. In the next section it will be discussed, how this range can change with L.

For a given note, when the pressure is higher, the frequency would increase. This effect can be seen in the figure 5 with variation of the pitch in cents for the third register. Zero deviation is in the frequency of the equal temperament scale for this note.

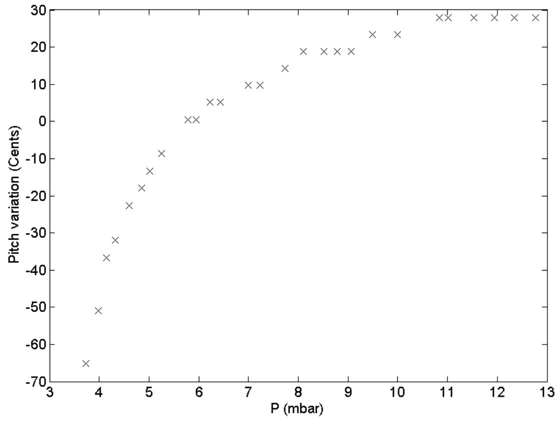

Fig 5 Pitch variation for a note with 1174.65 Hz in the equal temperament scale varying pressure.

Pitch variation is greater near the minimum pressure limit and stabilizes near the upper limit. This may be one of the reasons why musicians used to play near the upper limit of the notes, because in this region the pitch variation is lesser when the pressure is not constant.

With a change in pressure the tuning changes, but this difference is not so clear in the normalized centroid, as the figure 6 shows.

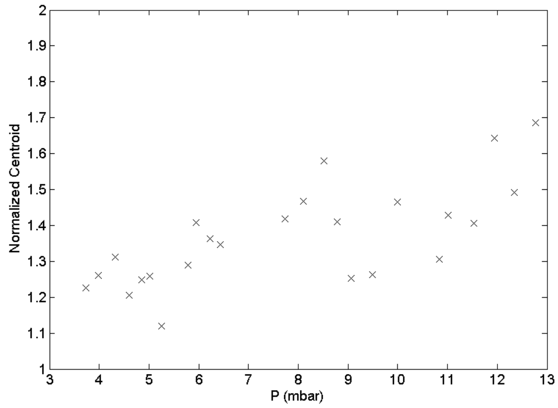

Fig. 6 Normalized Centroid of the third register, with L = 6 mm, H = 0.5mm, a = 3 degrees, flat reed and conduct number 1.

The value of the centroid seems to rise when the pressure increases. The sound pressure level of the first partial is still very powerful compared with the sound pressure levels of the next 5 partials. This same effect has been observed in the other notes with the same configuration of the mouthpiece.

## 3.2 Effect of changes in L distance

L is the distance from the end of the air conduct to the beginning of the metal reed and is easy to be changed by moving the reed up or down. Measurements were taken for four different values of L, from 4 millimeters to 7 millimeters. The pitch variation for the third register is showed in figure 7 for different values of the distance L.

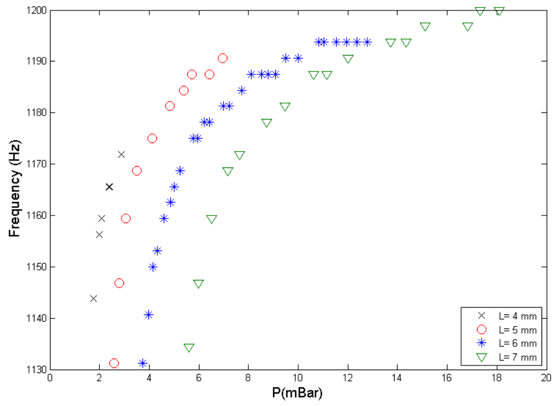

Fig. 7 Fundamental frequency variation of the third register for different values of de distance L.

If L has a small value, the note starts with little pressure and the range of pressures in which the note will sound is small. When the value of L is greater, the ratio between the speed of the airflow and the distance L is smaller and the pressure must be larger for the ratio to be equal to the value with the small L [2].

The upper limit of this note can change from 4 mbar to more than 15 mbar. The distance L has a great importance in the way that the instrument can be played and it is a must to find a proper distance that allows the musician to play the way that he or she chose.

The pressure change does not change the harmonicity of the instrument [3]. The same effect happens in the second partials and others. The second partial can be seen in the figure 8.

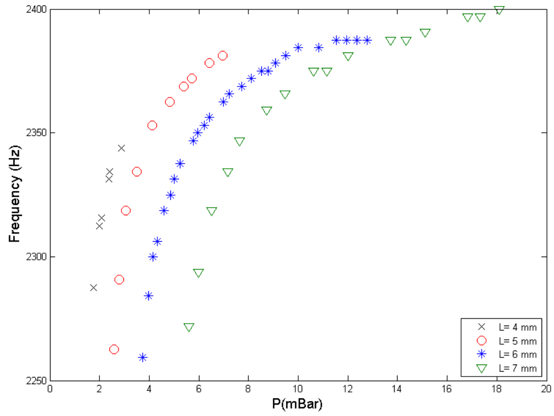

Fig. 8 Frequency variation of the second partial of the third register for different values of de distance L.

Table 2 shows the sound pressure level of the first partial and the normalized centroid at two different points.

| L (mm) | 4 | 5 | 6 | 7 |
|---|---|---|---|---|
| Min P (mbar) | 1.8 | 2.6 | 3.7 | 5.6 |
| Lp (dB) | 68.3 | 63.6 | 69.0 | 72.2 |
| N. Centroid | 1.2 | 1.3 | 1.2 | 1.2 |
| | | | | |
| Max P (mbar) | 2.9 | 6.4 | 12.8 | 18.1 |
| Lp (dB) | 75.8 | 82.6 | 77.0 | 83.5 |
| N. Centroid | 1.2 | 1.3 | 1.7 | 1.8 |

Table 2 Values of the sound pressure level and normalized centroid when the pressure is minimum and maximum for the third register and different values of L.

When L is 4 millimeters, the third register starts at 1.8 mbar. At this point the sound pressure level is 68.3 dB. For this value of L, the variation of the pressure is small (1.1 mbar) and variation on the normalized centroid is small too.

If the distance L is 6 or 7 millimeters, the minimum pressure to play the third register is higher. The difference between the maximum and minimum is greater. In those cases, when the pressure is increased, the first partial grows, but other partials, whose does not appear at minimum frequencies, have a significant sound pressure level as figure 13 will show. Those high partials make the normalized centroid grow, because the domination of the first partial is not as big as before. The sound is richer for a low note, as the third register is, when the distance L is big enough to play it with more pressure and make the normalized centroid value bigger. Differences in the normalized centroid are 0.6 when L is 7 millimeter which is perceptible.

## 3.3 Effect of changes in H distance

The distance H is the height of the reed over the air conduct. If the lower part of the hole of the air conduct is at the same level of the lower part of the reed, H is zero. Experiments were carried out for three values of H: 0, 0.5 and 0.6 millimeters. The figure 9 shows the frequency variation for the same previously discussed note.

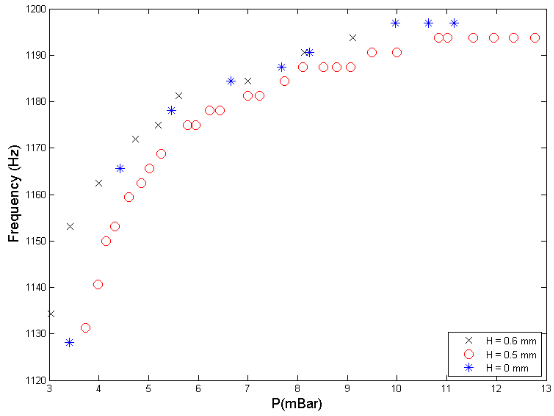

Fig. 9 Fundamental frequency of the third register for different values of H.

The differences between those measurements are smaller than those obtained for the distance L, however the changes done in H were also smaller than the changes made in L. Experience tells that for big changes in H the sound disappears, as when the air jet does not enter into the bore, there is no excitation of the eigenfrequencies of the bore. With small changes in H like those presented here, there are no significant effects in the fundamental frequency.

The normalized centroid is usually between 1.2 and 1.5 and small changes in H do not show any effect of significant importance. However, these changes can affect the sound pressure level of higher partials, going down for some values of H.

## 3.4 Reed Shape

The metal reed of the txistu is attached to the upper part of the bore, which can be replaced to try and find a better sound with another reed with different shape. In this case, two different reeds were measured. The first one is a common reed (reed 1) and the second is sharp as it is showed in figure 2. This second reed was placed with the sharp part down (reed 2) and the sharp part up (reed 3). The figure 10 shows results for the fundamental frequency.

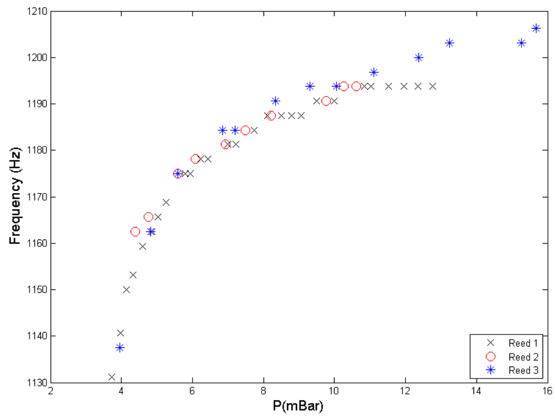

Fig. 10 Fundamental frequency of the third register with L = 6 mm, H = 0.5mm, a = 3 degrees conduct number 1 and different reed shapes.

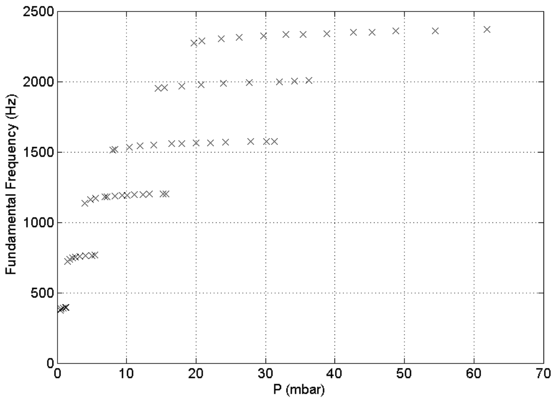

Fig. 11 Notes for a txistu with closed holes varying pressure with L = 6 mm, H = 0.5mm, a = 3 degrees conduct 1 and reed 2.

With reed 2 the range of pressure for this note is greater. All registers of this reed are showed in figure 11.

These pressure ranges were greater when the first reed was used. It is possible that the shape of this reed helps the air jet pass through the bore, making the path smoother. The centroid values remained the same.

## 3.5 Conduct Shape

The player's lips are placed on the metal conduct, which used to be wider in the entry part. The exact dimensions were mentioned earlier in the table 1. Experiments with four different shapes of the conduct were done. The figure 12 shows the fundamental frequency of the third register for different conducts.

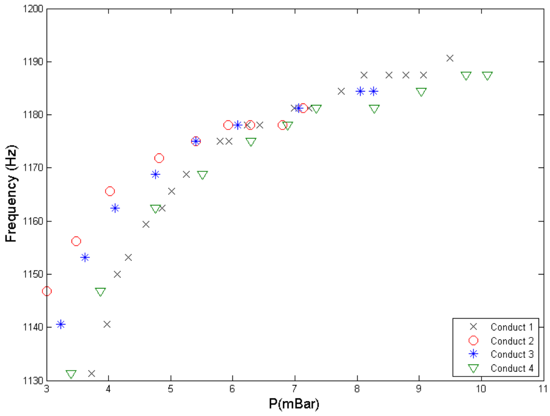

Fig. 12 Fundamental frequency of the third register with L = 6 mm, H = 0.5mm, a = 3 degrees, reed 1 and different conduct shapes.

Figure 12 shows that when the second conduct is placed, the note ends at relatively low pressures. That is due to the shape of the second conduct, which has a very large input area. For the same pressure at the entry, the air speed will be higher at the end of the conduct. Consequently high frequency notes can be played with less effort. Most of txistu conducts have bigger input area than output area. The conduct 2 was made with bigger difference between these areas.

For other conducts the shape was barely changed, with results showing little difference between them. The normalized centroid remained in the same values.

Finally, a different mouthpiece was measured. The conduct of the new mouthpiece was made of silver and it is numbered as 5 in the table 1. The distance L was 5.5 millimeters and H was zero. It had a wider part (perpendicular to L) between the conduct and the reed. Several musicians said that this mouthpiece is better and has a good response and a powerful sound. The centroid value is not as higher as expected, but when the measurements were performed, the spectra showed more partials than with the mouthpiece used before. The richer timbre quality is associated to the appearance of higher partials.

The silver conduct is smoother and the rectangle in the input and output areas are much better than the first one, who has an oval shape. This silver output of the conduct 5 makes a better air jet going against the reed and in junction with the wider part and smoother walls in the wood between the conduct and the reed. More partials appear at high frequencies as can be seen in the figures 13 and 14. The output area is smaller in this case.

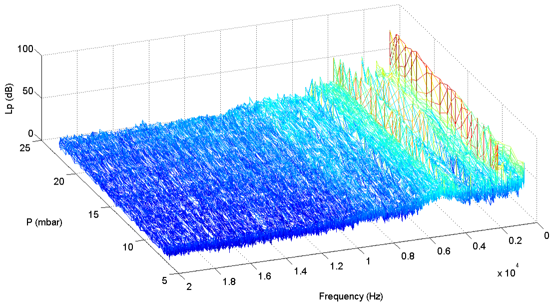

Fig 13 FFT of the fourth register with L = 6 mm, H = 0.5mm, a = 3 degrees conduct 1, reed 1 and different values of pressure.

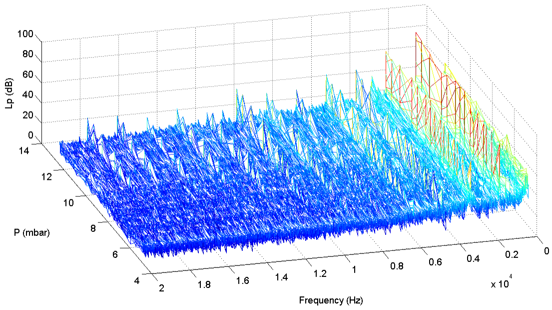

Fig 14 FFT of the fourth register with L = 5.5 mm, H = 0 mm, a = 3 degrees conduct 5, reed 1 and different values of pressure.

Figures 13 and 14 demonstrate how a proper conduct with a rectangle shape can affect the final sound of the instrument. The partials at high frequencies appear when the pressure is increased and they make the sound brighter.

## 4 Conclusions

Experiments were made for different configurations for a mouthpiece of the txistu. Four characteristics of the txistu were changed. These four parts include varying the distances from the end of the conduct to the reed (L), the height of the reed over the air conduct (H), and using different reed shapes and different conducts for the air jet.

Changes in the distance L modify the range of pressures in which each note sounds. When L is of large value, the pressure must be increased to get the same note and there are more pressure values in which this note sounds. A small L makes high notes easier to be played, because less pressure is needed. The low notes could not be played with great sound pressure level, because when the pressure is increased the instrument plays the next register. The player can adjust this distance easily, usually taking values around 5.5 millimeters of distance L.

Small changes in H do not affect the fundamental frequency and the sound pressure level of the first partial. However, they can affect other partials for some values of H. The normalized centroid is clearly dominated by the first partial making it complicated to qualify the changes in a sound with the value of the centroid.

There are no major differences when using reeds with a sharp edge, possibly due to the presence of a gap in the wood behind the reed.

The shape of the mouthpiece makes significant changes to the steady state of the instrument. A conduct with a big input area can be played using lower values of pressure even for large values of L. The shape of the wooden walls and the output area are important for the number of partials in the steady state. A smooth shape of the air jet can affect the response and the brightness of the instrument.

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## References

[1] R. A. Kendall and E.C. Carterette, “Difference threshold for timbre related to spectral centroid”, in *Proceedings of the 4th International Conference on Music Perception and Cognition*, (1996).

[2] N. H. Fletcher T. D. Rossing, “The physics of musical instruments” *Springer*, ISBN 0-387-98374-0 (2000)

[3] N. H. Fletcher, “Harmonic?Anharmonic?Inharmonic?” *American Journal of Physics* 70,1205-1207 (2002)