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How do flute players adapt their control to modifications of the flute bore ? *†‡

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Abstract

Skilled players can adapt their control parameters according to the response of the instrument they are playing. In the case of the flute, the lip and face position relative to the mouthpiece is the main adjustment used for a fine control of the pitch, while the detailed geometry of the flute bore determines the intonation profile of the instrument along its tessiture. Using the negative bore concept, we apply controlled modifications of the intonation profile of the flute. Skilled players are then invited to play on different profiles of the same instrument while the geometrical and hydrodynamical control parameters are monitored.

Keywords: Flute, Negative bore, Control, Adaptation

1 INTRODUCTION

Analysis of the acoustical response of wind instruments through the calculated or measured input impedance has become very popular during the last decades. Excellent results have been achieved in the case of reed instruments like the clarinet, while the tuning of brass instruments has also been studied with great success. In the case of the recorder and the flue organ pipe, the question of the exact prediction of the acoustical influence of the geometry at the blowing end has recently been studied by Ernoult, providing excellent quantitative prediction of the passive resonance frequencies.

Despite these promising results, the prediction of the passive resonances on flute-like instruments where the jet is formed between the lips provides limited information: calculation of the resonance frequencies from the input impedance for transverse flute, quena or shakuhachi predicts pitches from one to several semitones sharper than the notes played! The reason for this discrepancy is the presence of the lips and face of the player at the blowing end of the instrument. This changes drastically the radiation properties, and therefore the radiation impedance or the acoustic length correction associated with the imaginary part of the radiation impedance.

Indeed, the adjustment of the lips and face position appears to be the main resource used by flute players to fine-tune their instruments. In real-time flutists adjust their lips position to fine-tune the pitch they are hearing, closing a controlled feedback loop. From this perspective, the pitch of a note played is the result of the intonation of the flute itself together with the influence of the player's control strategy [1].

In order to analyse the players control strategy, we carry global modifications of the intonation profile of the flute over its entire compass and observe the adaptation of flute players.

2 Experiment

In order to study the adaptation of the control of the flute player, the first question to answer is how to modify the global acoustical response of the instrument, without changing important details such as the precise geometry of the blowing hole. The next step is to define the control parameters that need to be monitored during playing. Last, since the player is engaged in a continuous real-time adjustment including sound perception, the playing task needs to be carefully designed.

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2.1 How to modify the global response of the flute ?

Modern Boehm flute are built starting from a 19mm diameter cylinder. Only the mouthpiece shows a finely tuned tapering, from 17mm at the embouchure hole to 19mm diameter at the slide connecting the mouthpiece to the rest of the instrument. Because of its position at the input of the instrument, this tapering affects all the notes of the tessitura, in pitch, sound quality and dynamic response of the instrument.

We developed the *negative bore* concept in order to allow a controled modification of the flute's bore. This is achieved by using a cylindrical mouthpiece in which a spine shaped plug is inserted. The inserted plug is calculated in order to obtain the same open passage as would provide a tapered bore. For a cylindrical mouthpiece of radius R, the radius of the negative plug $r_n(x)$ equivalent to a tapered bore of radius $r_b(x)$ writes as:

$$r_n^2 = R^2 - r_b^2 \tag{1}$$

Figure 1. The *negative* bore concept: a negative plug is inserted in a cylindrical bore in order to provide the same open passage as that in a tapered bore. *up:* the geometry of a standard headjoint; *down:* a *negative* equivalent headjoint with the inserted plug.

Figure 1 presents the negative bore concept. It is interesting to note that the concept allows for bores with profiles that are difficult to build using traditional instrument making tools and techniques. The *negative* allows to modify only the flute bore, without altering any other part of the instrument, such as the shape of the blowing hole.

The method was validated by creating mouthpieces with *negatives* that emulate several existing headjoints. Flute players were asked compare *negatives* and original headjoints on one single flute body. Informal tests showed that, while *negative* mouthpieces were different from originals in the detailed geometry of the blowing hole, they were perceived as similar in their overall pitch structure.

Thus, for this paper three different *negative* inserts were built and labelled as follows:

- *c*: is a thick and long insert. It corresponds to a mouthpiece with diameter variations much stronger than usual
- *m*: corresponds to a standard bore, designed after measurements on several brands of flutes
- *f*: is a thin and rather short insert. It corresponds to a mouthpiece with almost cylindrical bore.

2.2 Control parameters

We follow here the work presented by de la Cuadra [1], [4] and Ernoult [2], the control parameters analysed in order to study the adaptation of the player to different flute bores are summarized in figure **??**:

- the blowing pressure p_m as measured in the players mouth
- the lips to edge distance W as estimated through automatic image analysis. This distance corresponds to the jet length.
- the coverage angle β is also estimated by means of automatic image analysis.

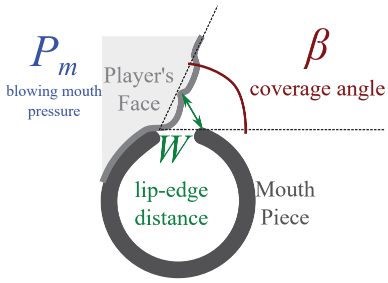

Figure 2. The main control parameters analyzed throughout the study are the blowing pressure, the lip-edge distance and the coverage angle.

The sound produced by the instrument and the player is also recorded, first as the inner acoustic pressure field, allowing for amplitude and spectral estimations, and second as the radiated acoustic pressure. Pitch, spectra and amplitudes are then calculated from the acoustic signals.

2.3 Playing task

Two players with formal training in classical flute playing and an extensive concert experience have been invited to play on a cylindrical mouthpiece with negative inserts mounted on a Yamaha YFL-382 flute body. They were asked to play different musical excerpts, and the analysis carried in this paper is focused on the scale task shown in figure 3. They were presented the tool used to modify the flute acoustic response and were allowed to practice in order to get used to the set-up. When starting the measurements, the negative insert was changed and the players were not informed of which negative insert was plugged in the flute.

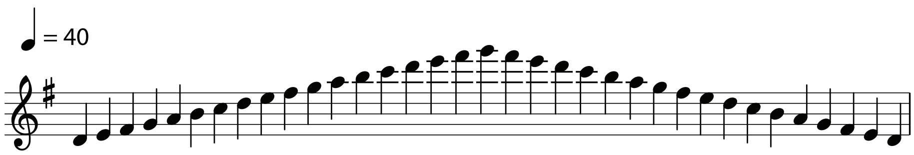

Figure 3. The musical excerpt analysed in this study.

The musical task analysed in this paper is a G-major scale, played slowly, with an emphasis on intonation. For this excerpt, a Korg OT-120 tuner is placed in view of the player to help with intonation. G major scale was chosen in order to avoid C sharp, known to show intonation difficulties. The reference pitch of the tuner is adjusted according to the intonation of $A3$. Due to warm summer conditions, this tuning was found sharp, up to $446Hz$. Because some players tend to use alternate fingerings for pitch correction, players were here asked to use only standard fingerings.

3 Results

Preliminary results are discussed, comparing data obtained with the three negative inserts for each player. First the sounding result is discussed, then the control data.

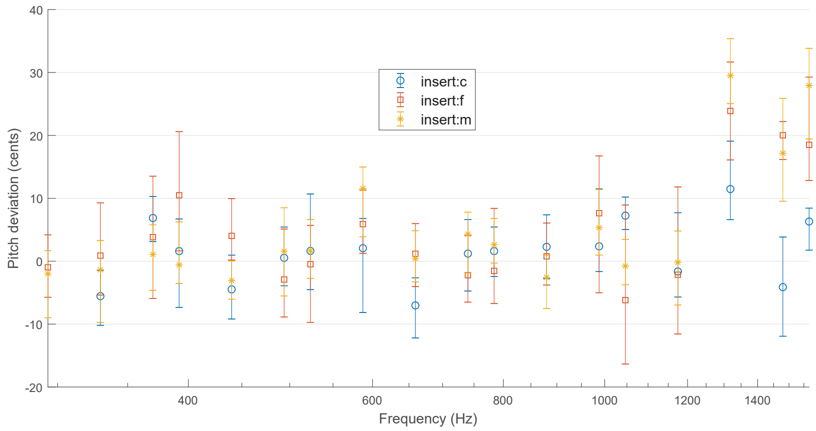

Figure 4. For each note of the scale played, the frequency detected is compared to the frequency corresponding to the equal temperament. The ratio of these frequencies is expressed in cents.

Analysis of the intonation is presented for one player on figure 4. It shows that, independently of the insert plugged, the player managed to maintain the intonation within ± 10 cents of the equal temperament, except for the three higher notes (E to G). It is interesting to note that insert c allows the player to maintain the expected intonation even for these three higher notes. A spectral centroid of the sound produced was also estimated throughout the scale, and showed small enough differences, indicating that the players did somehow produce a standard tone quality. This indicates that the three negative inserts used offered "playable" conditions, allowing to compare the control data.

The analysis of the control data indicate that the blowing pressure pattern used by the players is not affected when changing the acoustics response of the instrument. Changes are mainly concentrated on the two geometrical parameters, the jet to labium distance W as shown on figure 5, and on the coverage angle β as shown on figure 6.

As discussed by de la Cuadra, the dimensionless jet velocity $\theta = U_j/fW$, with U_j the jet velocity and f the playing frequency, is a good indication of the player's strategy. The two players maintain their individual target in terms of dimensionless blowing velocity, as can be seen for one of them on figure 7, related to only small changes in sound production. The dimensionless jet velocities show individual profile for each player, independent of the flute bore: it is a nice summary of each player's idea. This observation is in line with the observation on the sound production: despite changes in some of the control parameters in order to adapt to the modifications of the flute response, the players maintain a similar global hydrodynamical control of the sound production, resulting in a similar sound production.

4 PERSPECTIVES

The study presented should be considered as a preliminary study, intended at testing hypothesis on the balance between different parameters in the sound production in flute playing. The main hypothesis is that the player, whenever it is possible, compensates for changes in the instrument's response. The data analyzed indicate that this compensation can be tracked, mainly in terms of geometrical parameters.

This study also validates the set-up used and the efficiency of the *negative bore* concept, allowing for further experiments, involving more players and a developed musical task.

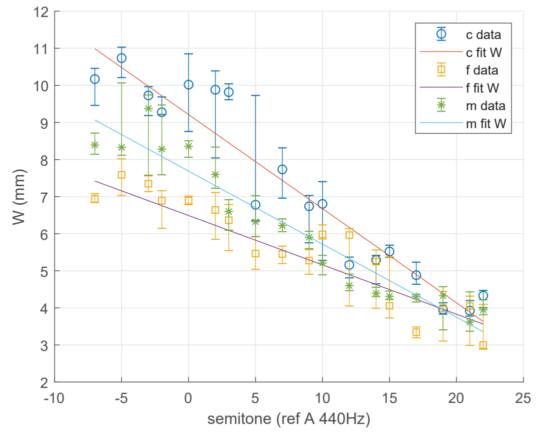

Figure 5. For each note of the scale played, the lip-edge distance W is estimated from image analysis. The player changes this distance to adapt to the acoustic response of the instrument.

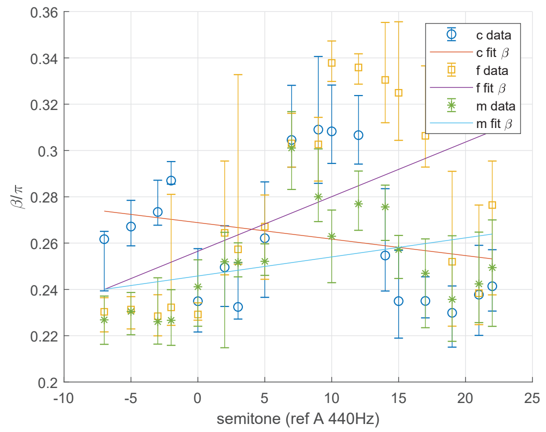

Figure 6. For each note of the scale played, the coverage angle β is estimated from image detection. The player shows quite different strategies to adapt to changes in the acoustic response of the flute.

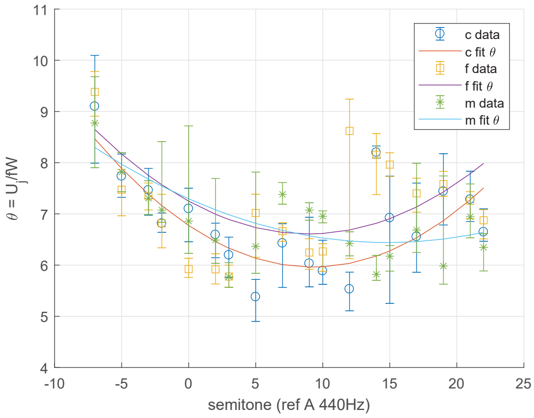

Figure 7. For each note of the scale played, the dimensionless velocity θ is estimated. The player shows quite similar patterns, independently of the acoustic response of the flute.

The experiment presented rises questions regarding the reference each player has in mind: indeed, the results are related to the "distance" between the configuration proposed and each players' individual usual conditions, for example in terms of the global tuning of the instrument. Experimentation with different bores shows that the different configurations can be adapted to different goals like, for instance "fast playing" (possibly corresponding to the smallest possible changes in control), or "sound tonal balance" over the tessitura. This also rises the question of the direction in which standard bores go.

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