INFLUENCE OF MOUTHPIECE GEOMETRY ON SAXOPHONE PLAYING

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ABSTRACT

The hypothesis to be tested in this paper is whether there is a measurable difference in radiated sound (in terms of spectral centroid and sound pressure level) and in playability, when playing mouthpieces with different internal geometries. In-vivo radiated sound and blowing pressure measurements were carried out on a panel of five different mouthpieces while playing the same note sequence. The results revealed a scarce influence of the mouthpiece geometry on the radiated sound in terms of pressure root mean square amplitude and spectral centroid. Larger differences were found in the measured mouth pressure for several mouthpiece pairs. Playability (also called ease of playing) was quantified through an effort ratio, corresponding to the ratio of blowing pressure over radiated sound *rms*. This showed non-negligible difference among some of the models in good agreement with the perception of the player. In particular differences between the original reference mouthpiece (commercial mouthpiece) and the modified (3D printed) mouthpieces were observed at the attack and end of the note for several notes. Only for specific notes, differences were detected for a longer time interval. In general the reference mouthpiece showed a lower effort ratio (higher ease of playing) with respect to the modified mouthpieces. The effort ratio seems to be a valid quantitative parameter for the characterization of a mouthpiece.

1. INTRODUCTION

It is generally agreed upon among saxophone players and instrument makers that the mouthpiece of the saxophone strongly influences the sound quality and the experience of the player, in terms ease of playing and the ability to modify the sound characteristics

Several researchers have attempted to identify the connection between the internal geometry of the mouthpieces and the sound quality of the coupled mouthpiece-instrument system. Among these, Benade [1] presented the effect of cavity dimensions on the brightness of the produced sound. Wynman [2] performed acoustic measurements on five different geometrical-types of alto saxophone mouthpiece models and found connections between baffle shape and tone color. An interesting overview of mouthpiece investigations can be found in the PhD thesis of Scavone [3], which describes the modeling of single-reed wind instruments in waveguides domain.

Recently, a team of researchers at Delft University of Technology has started using 3D printing techniques for the manufacturing of saxophone mouthpieces [4]. These techniques offer advantages compared to standard manufacturing techniques in terms of reducing production costs and achievable geometrical complexity [5].

The first application focused on modifications of the mouthpiece baffle according to aerodynamic findings [6] and musician considerations. The aim was to improve the acoustic properties of a mouthpiece according to specific sound requirements by exploiting the capabilities of 3D printing. This paper presents an analysis of sound and pressure measurements, carried out at the Institute of Musical Acoustics of the University of Music and performing Arts, Vienna on a panel of mouthpieces produced at TU Delft. Modifications in this case were made to both the baffle geometry and the size of the cavity. The aim of the tests is to identify the differences in radiated sound and mouth pressure among mouthpieces with different baffle and cavity geometries.

2. METHODOLOGY

Measurements were performed on a panel of five mouthpieces: one original commercial mouthpiece and five 3D printed copies of it, with modified baffle and chamber geometries. In particular: One original Vandoren v16, aperture 6, small chamber, modified by hand by Lebayle (the length of the table under the mouthpiece was decreased,
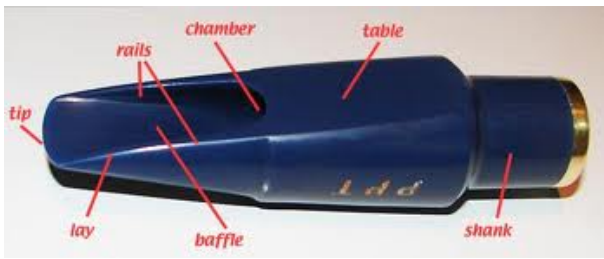
Figure 1: Different parts of a saxophone mouthpiece

increasing the projection of the mouthpiece) used as reference mouthpiece, a 3D printed copy of the latter one (description of the production are described in subsection 2.1), one with a narrower cylindrical chamber, one with a conical chamber, and one with a baffle ramp. Figure 2 shows the internal profile of the latter four mouthpieces.

2.1. Mouthpiece production

The Vandoren v16 was chosen as reference mouthpiece for the geometrical modifications and a 3D scan of it was made at TU Delft using a Phoenix Nanotom S CT scanner (http://www.ge-mcs.com /en /radiography-x-ray /ct-computed-tomography /nanotom-s.html). The scanned model was reconstructed in SolidWorks and modifications have then been made to the baffle and chamber of the original mouthpiece shape as shown in Figure 2. For producing these mouthpieces an Objet Eden 260 machine was used. The machine is able to produce objects up to the size of 600 x 252 x 200 mm at a resolution of 600dpi and layer thickness of 16 micrometer. The material used was a biocompatible resin marketed by Objet as MED610. It is a rigid transparent material developed and approved for prolonged contact with human tissue (http://objet.com /3d-printing-materials /bio-compatible).

The printed mouthpieces were polished using fine sand paper to remove support material without altering the geometry of the mouthpiece. The final surface roughness of the printed models is slightly higher than the original mouthpiece. This factor is considered to have minor influence on the radiated sound. The geometry of the reconstructed mouthpiece differed in the order of a fraction of a millimeter with respect to the scanned original mouthpiece by visual inspection in CAD environment. No geometrical measurements have been made after the printing.

2.2. Measurement setup

The tests consisted of in-vivo (with a player) far-field acoustic measurements and blowing pressure measurements. A professional player played his saxophone (Yamaha Custom YAS-855) with these mouthpieces, using a Légère plastic reed, StudioCut, strength 2.5. He played a written C major scale from C_4 to C_6 (on alto saxophone key, i.e. $F\#$ first octave corresponds to concert A_4 (440 Hz) note) with a metronome set at 120 bpm. Figure 3 shows how the scale was played. The scale was played five consec-
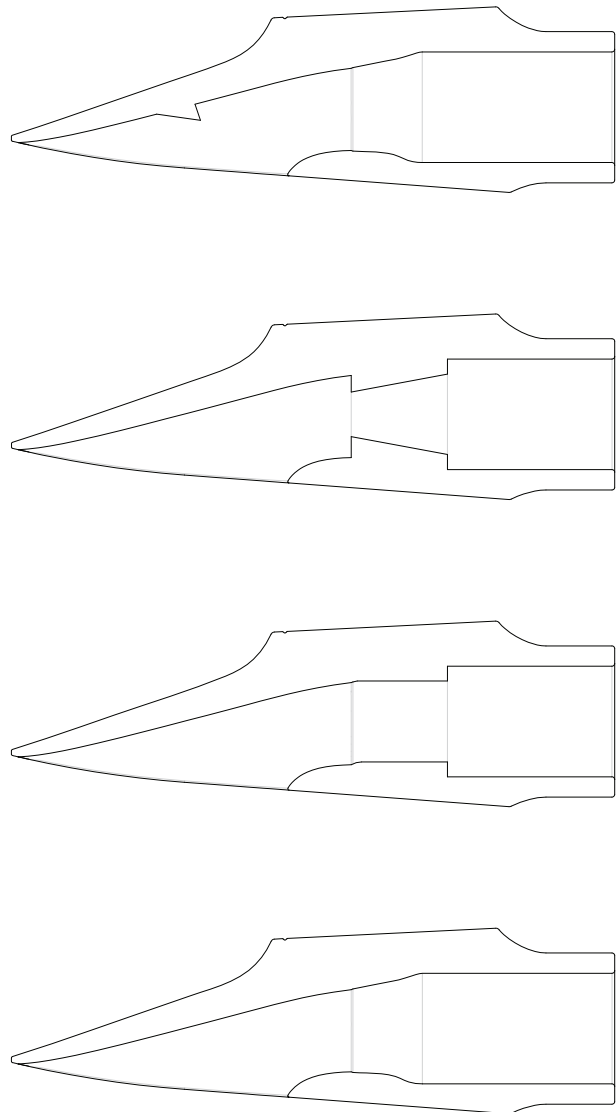

Figure 2: Internal profiles of the four mouthpieces that were 3D printed. From top to bottom: ramp baffle , conical chamber, cylindrical chamber, copy.

utive times on each mouthpiece, each time is called trial. It was noticed that the strength of the plastic reed was not affected by consecutive playing. The player carefully positioned the reed in the same position with respect to the mouthpiece for all the different tested mouthpieces.

The following signals were recorded:

- the radiated sound was recorded with a ROGA microphone model RG-50 placed in the far field at an angle of 45° and a distance of 1.5 m above the player.

- the mouth pressure was measured with an ENDEVCO pressure transducer model 8507C-2. This was placed inside the mouth of the player beside the mouthpiece (details of the set-up are described in Ref. [7]).

- the metronome signal.

Figure 3: Order and duration of notes of the C major scale played during the recordings (alto saxophone key, i.e. $F\#$ first octave corresponds to concert A_4 (440 Hz) note)

The signals from the microphone and metronome were connected to a Phantom preamplifier model MPA 2017. The level of the microphone signal from the preamplifier was adjusted to be as high as possible without saturating (when playing forte). This adjustment was done once at the beginning of the measurement. The signals from the ENDEVCO sensor were connected to an ENDEVCO DC differential voltage amplifier model 136. The outputs from the preamplifiers were then connected to an ADAT HD24 digital recorder, which converted the signals from analog to digital, and into an optical interface, before being connected to an RME computer sound card model DIGI96/8 PST. The computer to which all signals were fed was running a LabView script which recorded all signals in a multitrack wave file with a sampling frequency $f_s =48$ kHz.

The recordings were separated into five trials, where each trial was one played instance of the full scale, and was approximately 32 seconds long.

2.3. Signal Analysis

The segments recorded from the microphone placed on the far field were analyses using the MQ analysis method [8] [9] coded in Matlab. This analysis delivers an analysis file with information about the amplitudes $A_k[n]$ and frequencies $f_k[n]$ of the k peaks that are present at every time frame n. In this case, the time difference between two frames was approximately 5.3 ms, giving a total of just under 6000 frames per segment.

With the information delivered by the analysis file, the following parameters were calculated for each time frame:

- P_{rad} radiated pressure root-mean-square:

$$P_{rad}[n] = 20 \cdot log_{10} \left(\sqrt{\sum_{k=1}^{K} A_k^2[n]} \right) \quad \text{[dB]}$$

(1)

- Normalized spectral centroid:

$$NSC[n] = \frac{\sum_{k=1}^{K} k \cdot A_k[n]}{\sum_{k=1}^{K} A_k[n]}$$

(2)

Calculations of P_{rad} amplitude and normalized spectral centroid vs time for all segments were saved in a file. The *rms* of the mouth pressure measured by the ENDEVCO sensor was also calculated as described above.

Depending on the amplitude of P_{rad}, each frame was labeled as belonging to the transient (amplitude increasing at the beginning of the note), the steady state (remaining more or less steady oscillating around a constant value) or the end of the note (decreasing at the end of the note), respectively [10].

3. RESULTS AND DISCUSSION

The calculations were divided into five groups, according to which mouthpiece (1. conical, 2. copy, 3. cylindrical, 4. ramp and 5. original), which of the fifteen notes, and which of the five trials was played. All the frames of the steady state of same note for all the trials were taken and a one way ANOVA test was performed along the five mouthpieces.

3.1. Radiated sound

The p-value from the statistical analysis was used to indicate when statistical differences were found with respect to the original mouthpiece. A value $p > 0.05$ indicates that there is no significant difference between the actual measurement and the reference measurement. The comparison of the five trials, for all the mouthpieces, gave a p-value > 0.05 which confirmed that there was no statistical difference between the trials played for the same mouthpiece.

Figure 4 and Figure 5 show the plots of the NSC over time for the mouthpiece pairs: conical mouthpiece (in blue) vs original mouthpiece (in red) (Figure 4) and cylindrical (in blue) vs original mouthpiece is (in red) (Figure 5).

The x-axis of the following figures corresponds to the time in seconds in which the note sequence, shown in Figure 3, was played. Whenever the values are different from zero there is a note playing; the zero intervals are pauses between one note and the next.

The black bars are the confidence interval of the difference within the mouthpiece pair, when $p < 0.05$. The error bars are shown only in the steady state of the notes.
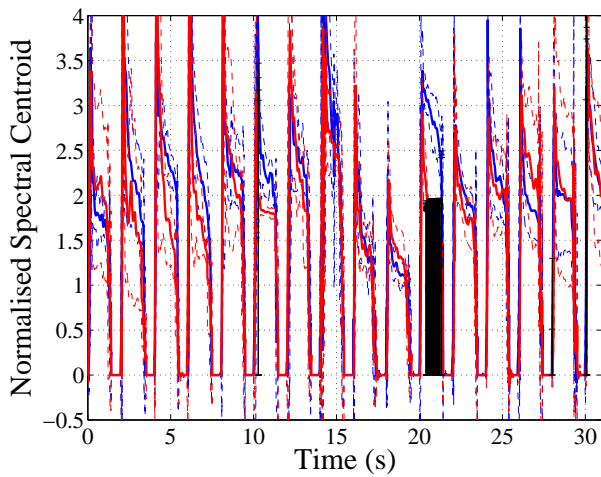
Figure 4: Normalized spectral centroid for mouthpieces conical (in blue) and original (in red)
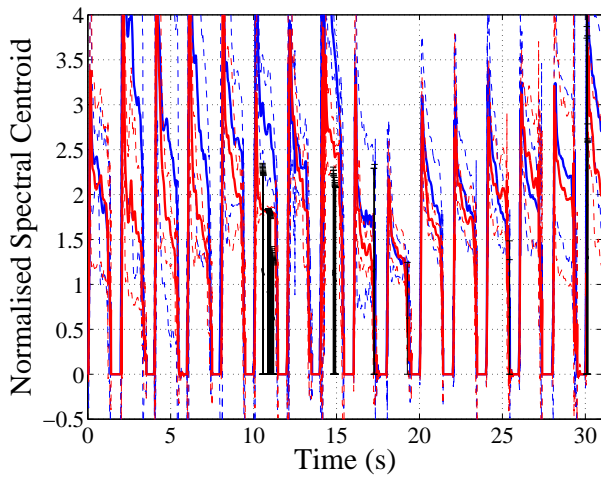
Differences in NSC were limited to notes: E_4, for the pair cylindrical-original and note E_5, for pair conical-original.

Other mouthpiece pairs gave no statistical differences in NSC and are therefore not presented.

These plots give an indication that while the ease of playing experienced by the player was different for the different mouthpieces, P_{rad} and spectral centroid remained mostly constant independently of the mouthpiece.

3.2. Mouth pressure

An ANOVA analysis was made also on the mouth pressure measured by the transducer in the mouth of the player. The results are shown for the pairs: copy-original, copy-cylindrical and copy-ramp. These pairs are the ones producing the highest differences in the analysis. No mouth pressure data are available for the conical mouthpiece due to a problem during acquisition.
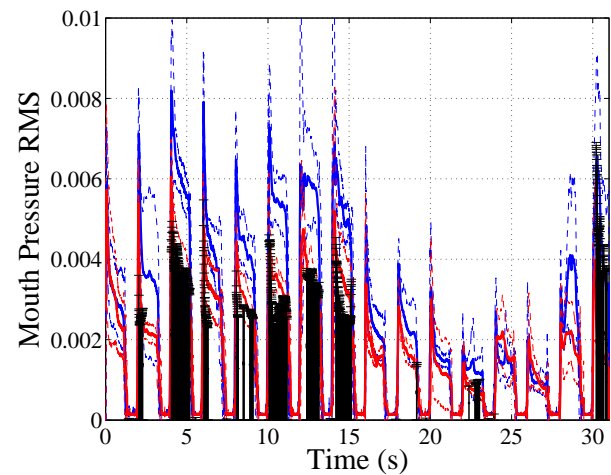

Figure 5: Normalized spectral centroid for mouthpieces cylindrical (in blue) and original (in red)

Figure 6: Mouth pressure rms for the copy mouthpiece (blue) and original (red)

Differences in the mouth pressure for the pair copy-original extend over most of notes A_4, E_4, D_4 and C_4. The copy mouthpiece requires higher blowing pressure, especially in the first part of the sequence (lower pitch notes).

Since the copy mouthpiece is meant to be an exact copy of the original mouthpiece and no noticeable differences were observed between the reconstructed and scanned mouthpieces, it is hypothesized that the differences are caused by slight geometrical distortion during the printing process or surface refining.
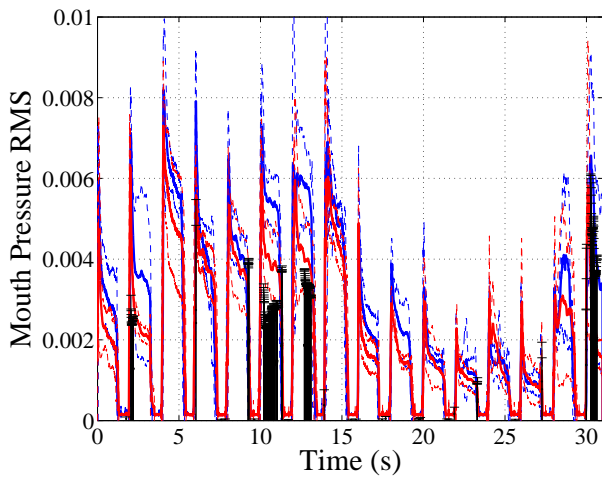

Figure 7: Mouth pressure rms for the copy mouthpiece (blue) and cylindrical (red)
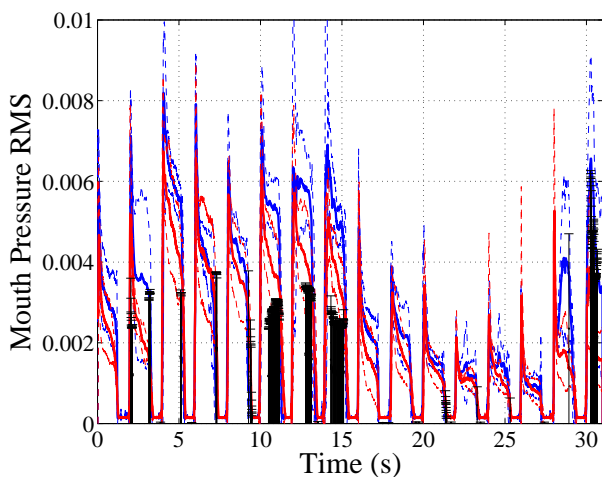

Figure 8: Mouth pressure rms for the copy mouthpiece (blue) and ramp (red)

The largest differences for the ramp-copy pair are found in the notes E_4, D_4 and C_4, in particular towards the end of the note.

3.3. Ease of playing

In order to investigate the playability of the mouthpieces an "effort" ratio was calculated:

$$E = \frac{P_m}{P_{rad}} \qquad (3)$$

where E is the effort ratio, P_m is the *rms* of the mouth pressure or blowing pressure, and P_{rad} is the *rms* of the radiated sound measured by the ROGA microphone in the far field. A smaller ratio (less effort) would mean that less blowing pressure is needed to obtain the same P_{rad} output. Conversely, a smaller effort ratio would be obtained if, using the same blowing pressure, one mouthpiece gave a higher P_{rad} value than the other.

The effort ratio E was calculated for the whole duration of each note and an ANOVA test was performed in the steady state for the various mouthpieces with respect to the reference mouthpiece and across the trials for the same mouthpiece.

Plots of the effort ratio, for only the mouthpieces giving a p-value < 0.05 with respect to the reference mouthpiece, are shown in Figure 9 and Figure 10. As already mentioned, no pressure data are available for the conical mouthpiece, therefore this mouthpiece is excluded by the following analysis. The showed data are averages of the five played instances (trials).
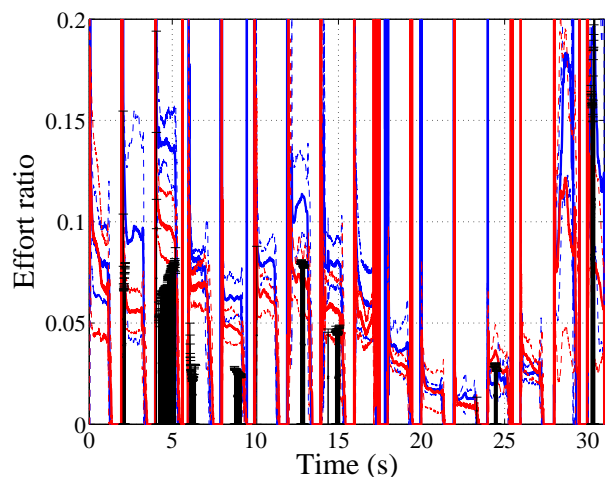

Figure 9: Effort ratio for the pair: copy (blue) vs original (red)

In Figure 9 the effort ratio (thick line) plus minus standard deviation (dashed line) are shown for the mouthpiece original (red) and the copy mouthpiece (blue).

Looking at the error bars the main differences are found for notes: A4 (during most of the note), G4 (at the beginning), F4 , D4 and C4 (at the end), G5 (in the middle). The highest values of the effort ratio are found at the beginning of the note, during the attack, when the mouth pressure value is relatively high compared to the radiated sound.

From the comparison between the effort ratio in Figure 9 and the mouth pressure in Figure 6 for the copy-original pair, it can be noticed that the effort ratio futures smaller differences than the mouth pressure. This might be due to a different response of the two mouthpieces. The copy mouhtpiece requires higher blowing pressure
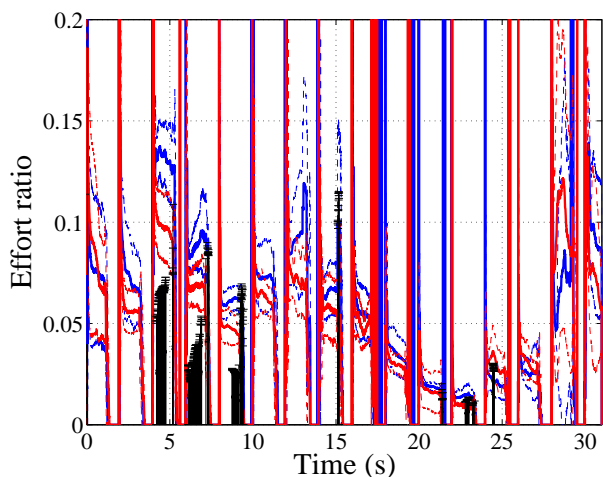
Figure 10: Effort ratio for the pair: ramp (blue) vs original (red)

for some notes but this also produces a higher radiated sound rms. Measurement of the air flux entering the mouthpiece might help explaining the differences.

Figure 10 shows the differences in effort ratio between the baffle ramp mouthpiece and the original. In this case differences are found for notes A4 (during the first half), G4 (during most of the note), and F4 (at the end).

No relevant statistical differences in effort ratio were found for the other mouthpiece pairs.

The player experienced that the copy mouthpiece was the hardest to play. This can be explained by the fact that the overall level of the differences with respect to the original mouthpiece is higher and more extended for the copy mouthpiece compared to the other mouthpieces.

4. CONCLUSIONS

It is hypothesized that different mouthpiece internal shapes determine differences in radiated sound and ease of playing.

A panel of five mouthpieces with modified baffle and chamber geometries was measured through in-vivo measurements with one player. Radiated sound (P_{rad}) and mouth pressure (P_m) were acquired while the player was playing on a fixed note sequence and compared with an ANOVA test.

The radiated sound and normalized spectral centroid remained almost the same for all mouthpieces, despite their obvious geometrical differences.

However non-negligible differences were observed for the mouth pressure in particular at the lower register.

Since the player reported a significant difference in the playability of the mouthpieces, especially between mouthpieces "Original" and "Copy", an effort ratio E was defined, as the ratio of blowing pressure over radiated sound rms, and compared with the aid of an ANOVA test.

A higher difference in the effort between these two

mouthpieces was found compared to the other pairs, while the difference among trials on the same mouthpiece was not significant. We found that the effort ratio is therefore correlated with the playability of the mouthpiece and seems to be a useful parameter in classifying different mouthpieces.

In order to generalize these results, further investigations are required with more players in order to assess the response of different players to the different mouthpiece geometries.

Also geometric measurements on the printed mouthpieces will be made and compared with the scanned mouthpiece to check the effect of printing on the final shape.

Furthermore a more thorough analysis is required lo link the differences in effort ratio of specific notes to geometric differences of the mouthpieces from an acoustic and aerodynamic point of view.

Acknowledgments

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