DOI: 10.61782/fa.2023.0171

EFFECTS OF THE BORE DIAMETER ON OSCILLATION THRESHOLD PRESSURE AND TONE QUALITY OF CLARINET MOUTHPIECES

Tsukasa Yoshinaga[1*] **Aoi Soejima**[1] **Tetsuro Shoji**[2]
Akira Miki[2] **Hiroshi Yokoyama**[1] **Akiyoshi Iida**[1]
[1] Department of Mechanical Engineering, Toyohashi University of Technology, Japan
[2] Yamaha Corporation, Japan

ABSTRACT

The effects of the mouthpiece bore diameter on oscillation threshold pressure and tone quality are investigated by using an artificial blower and rapid prototyping. The bore diameter of the clarinet mouthpiece was reduced from 15.3 mm of original commercial resin mouthpiece to 11.3 mm, and we made those with acrylic resin using rapid prototyping. The artificial blowing system consists of a pressure chamber connected to a straight cylindrical resonator, an artificial lip with a force gauge, a pressure sensor, and pressure valves. The lip force was fixed at several values and the chamber pressure was systematically changed to explore the oscillation threshold pressure at each lip force. First, the prototyped mouthpiece with the original bore diameter was compared with the commercial mouthpiece, and results showed that the prototyped mouthpiece produced sounds with narrower pressure and lip force ranges than the commercial mouthpiece. This suggests the material properties and surface roughness influence the oscillation threshold. The comparison with different bore diameters demonstrated that the mouthpiece with the smaller bore diameter produced sounds with wider pressure ranges at the particular lip force, whereas the spectral centroids became higher which indicates the playability with brighter timbre.

Keywords: *clarinet, artificial blower, mouthpiece bore.*

1. INTRODUCTION

The single-reed woodwind instruments produce sounds with interactions among the airflow from the mouth, the reed oscillation, and the acoustic resonances in the resonator. To improve the sound quality and playing flexibility of the instruments, many attempts have been made to clarify the effects of instrument geometry on sound generation. In particular, the mouthpiece geometry has been known to largely influence the timbral quality in many ways, and its effects were widely discussed [1-3]. Pillinger [4] measured the sound quality of artificially blown mouthpieces with various shapes of different makers and explored the better design of clarinet mouthpieces. In addition, he investigated the effects of material properties, like density and hardness, on the tone quality by utilizing polymer casting. Ozdemir et al., [5-6] parametrically changed the mouthpiece geometry using rapid prototyping, and playing characteristics were investigated by the artificial blowing machine as well as a user's case study.

In previous studies, artificial blowing machines were widely used to clarify the sound quality under certain and stable conditions in a repeatable way [7]. Almeida et al., [8] changed the blowing pressure, lip force, lip position, and reed hardness in the artificial blower and visualized the acoustic characteristics at each playing condition in two-dimensional maps. Additionally, sound production during transient phases like tonguing was investigated by using the artificial blower [9-10]. However, there are still few investigations on how each clarinet's mouthpiece geometry affects the sound quality, and an understanding for better sound quality is still lacking.

Therefore, in this study, we focus on the clarinet mouthpiece bore geometry and clarify the effects of bore diameter changes on the oscillation threshold pressure and tone quality by using the artificial blower.

---

[*] ***Corresponding author***: *yoshinaga@me.tut.ac.jp*

2. MATERIALS AND METHODS

The clarinet mouthpiece and simple resonator were set in the artificial blower as depicted in Fig. 1. The clarinet mouthpiece was connected to a resonator called SAXONETT (JRS700, Jupiter) with tone hole covers. The resonator is a straight cylinder, and the inner diameter is 13.3 mm. The total length from the mouthpiece tip to the resonator outlet is 307 mm. A plastic reed, whose material is a mixture of polypropylene resin and cellulose wood fiber (Strength M, Forestone Japan Co., Ltd., Japan), was used in this study. The Young's modulus and density of the reed are 5.5×10^9 Pa and 1140 kg/m^3, respectively. Only one reed was repeatedly used throughout this experiment. The mouthpiece with a reed was set in the pressure chamber (V = 1367 cm^3) of the artificial blower, and the lip forces were imposed on the reed at 9.5 mm from the reed tip through the artificial lip made of urethane foam (H0-3K, EXSEAL Co., Ltd., Japan) and the artificial teeth made of 1-mm-acrylic board. The force on the reed was adjusted by an X-Y stage, and its amplitude was measured by a load cell (eDPU-50N, IMADA CO., LTD., Japan). The pressure chamber was relatively large compared to the actual human mouth volume, however, the jet flow from the air tube does not interfere with the reed oscillation, and stable reed oscillation can be achieved. Details are reported in [11-12].

The stable airflow was supplied from a compressor (SOL-2039, Misumi, Japan), through a pressure regulator (IR2000, SMC, Japan) and a mass flow meter (PFM750-01, SMC, Japan). The pressure inside the chamber was measured by a pressure sensor (DP-101, Panasonic, Japan). The sound produced by the instrument was recorded at 100 mm from the resonator outlet by a 1/2-inch free-field microphone (NL-51, Rion, Japan).

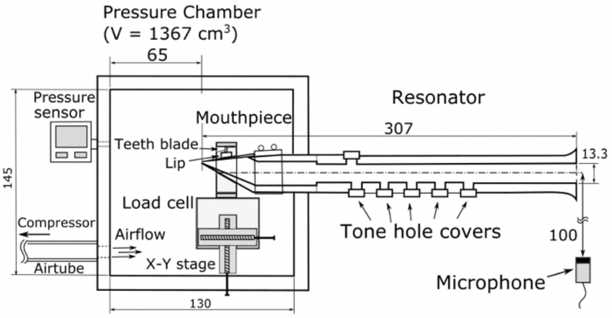

Figure 1. Artificial blower and experimental setups. Unit of dimension is mm.

The three-dimensional mouthpiece geometry is shown in Fig. 2. The bore outlet diameter d was varied from 15.3 mm of the original commercial mouthpiece (4C, Yamaha, Japan) to 11.3 mm. The bore face was smoothly connected from the throat of the mouthpiece to the bore outlet with varied diameters in CAD software, and three mouthpieces (d = 11.3, 13.3, and 15.3 mm) were made with acrylic resin using rapid prototyping (Form 3, Formlabs, USA). At the cork part, three O-rings were set to prevent air leakage. The original commercial resin mouthpiece was also used for the experiment to clarify the effects of material properties and surface roughness on sound production.

To measure the oscillation threshold pressure in the artificial blower, the following steps were taken for each mouthpiece. First, the initial lip force was put on the reed, and the resonator outlet was closed by an experimenter's hand. This procedure was taken because there is no tonguing equipment in the chamber and the chamber pressure cannot be rapidly increased like a human mouth. A finger was just put on the outlet hole with a diameter of 13.3 mm to prevent airflow through the resonator. Then, the pressure in the chamber was increased by opening the pressure regulator. After reaching a certain pressure that can initiate the oscillation, the hand at the resonator outlet was released, and the reed oscillation was initiated. Then, the oscillation threshold pressure was explored by changing the pressure with the pressure regulator. The pressure was increased or decreased, and once the stable oscillation was achieved, the sound pressure, chamber pressure, and lip force were recorded. We confirmed that this condition can be repeatedly made, and the results were not different each time. We defined the threshold as the maximum and minimum pressures that could sustain the constant sound amplitude. The maximum pressure was set to 8 kPa to prevent air leakage in this study. The initial lip force was changed from 0.3 to 2 N which reproduces from small to loud playing conditions.

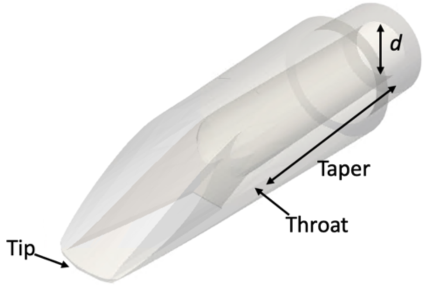

Figure 2. Mouthpiece geometry and bore diameter d.

3. RESULTS AND DISCUSSION

3.1 Effects of rapid prototyping

The material properties and surface roughness of the mouthpiece were tested by comparing the prototyped mouthpiece with the original commercial resin mouthpiece. The sound amplitudes at each chamber pressure and lip force with the resin mouthpiece (d = 15.3 mm) are plotted in Fig. 3. The oscillation thresholds are plotted with the solid lines. With the increase of the lip force, the lower threshold pressure decreased from 4.5 kPa of weaker lip forces (0.3 N) to 2 kPa of stronger lip forces (2 N). The upper threshold also decreased from 8 kPa to 2.2 kPa with the increase of the lip force up to 2 N. The sound amplitudes were increased with the increment of the chamber pressure. These tendencies were similar to the previous study [8]. However, the playable range of the lip force was smaller than that in the previous study, and this is probably due to the difference in the mechanisms of applying force and material properties of the artificial lips. The fundamental frequencies were ranged approximately from 268 Hz for weaker lip forces to 272 Hz for stronger lip forces.

The pressure amplitudes measured with the prototyped mouthpiece are shown in Fig. 4. The geometry of the prototyped mouthpiece is almost the same as that of the resin mouthpiece, and the thresholds of the resin mouthpiece are plotted with dotted lines. Under the weaker lip forces (≤ 1 N), the lower threshold pressure was increased by approximately 1.5 kPa compared to the resin mouthpiece. In contrast, the upper threshold of stronger lip forces (≥ 1.6 N) was decreased by approximately 0.5 kPa. Overall, the area of the playable region was reduced in the prototyped mouthpiece, although the tendency remained similar. This indicates the prototyped mouthpiece had lower playing flexibility than the commercial mouthpiece. A previous study suggested that a prototyped trombone mouthpiece had the similar sound quality to the traditional ones [13], and further improvement of the rapid prototyping is needed to realize the same quality of the commercial mouthpieces for the single-reed instrument.

3.2 Effects of the bore diameter

The upper and lower oscillation thresholds of the prototyped mouthpieces with different bore diameters are plotted in Fig. 5. With decrease of the bore diameter from d = 15.3 to 11.3 mm, the lower threshold of the pressure decreased from 4.5 kPa of d = 15.3 mm to 3.3 kPa of d = 11.3 mm when the lip force was 1 N. In contrast, with the

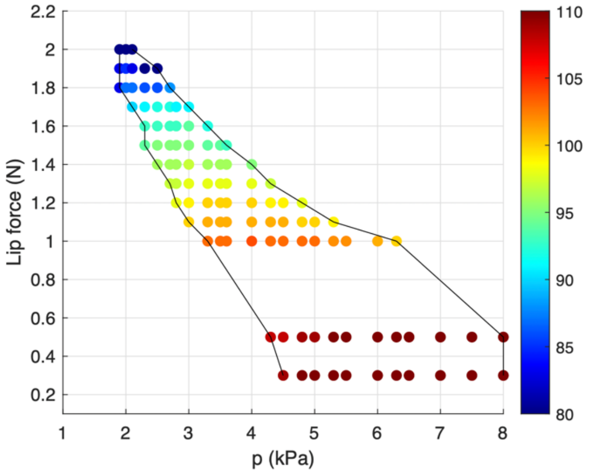

Figure 3. Amplitudes of sounds produced by the commercial resin mouthpiece with different chamber pressure p and lip force. The color bar indicates dB SPL.

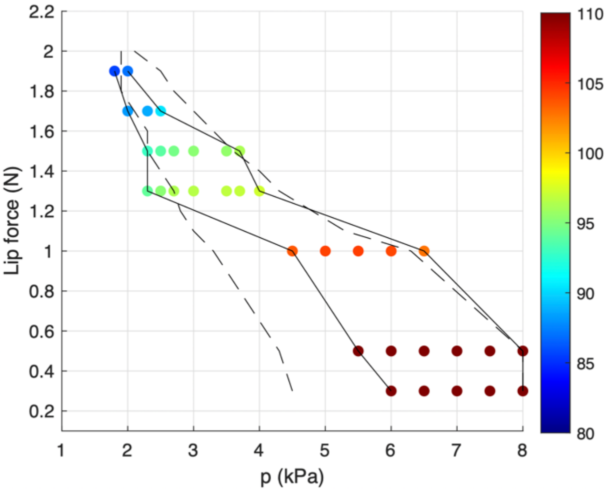

Figure 4. Amplitudes of sounds produced by the prototyped mouthpiece with d = 15.3 mm. The thresholds of the commercial mouthpiece are plotted by dotted lines. The color bar indicates dB SPL.

lip forces larger than 1.5 N, the stable oscillation could not be achieved with d = 13.3 and 11.3 mm. These results indicate that, for the smaller bores, the playing flexibility increases with the lip forces around 1 N of the middle-amplitude range. In contrast, when players produce small-amplitude tones with stronger lip forces, the playing flexibility decreases with the smaller bore diameters.

The spectral centroids (spectral means) of the produced sounds, when the lip force was 0.3 N, are shown in Fig. 6. The spectral centroids are known to correlate with the timbral brightness [14], and higher values indicate brighter sounds. In the overall playable pressure range, the spectral centroid increased with the decrease of the bore diameter *d*. The previous numerical simulation study demonstrated that the turbulent vortex tubes and vortex rings are produced near the mouthpiece outlet when the outlet diameter was small [15]. Therefore, the high-frequency sounds (including broadband noise) were probably generated by the larger number of vortices near the mouthpiece outlet, and the spectral centroids were increased with smaller bore diameters. This phenomenon was observed only with lower lip forces (~ 0.3 N) because the air flow rate was larger in the lower lip force range.

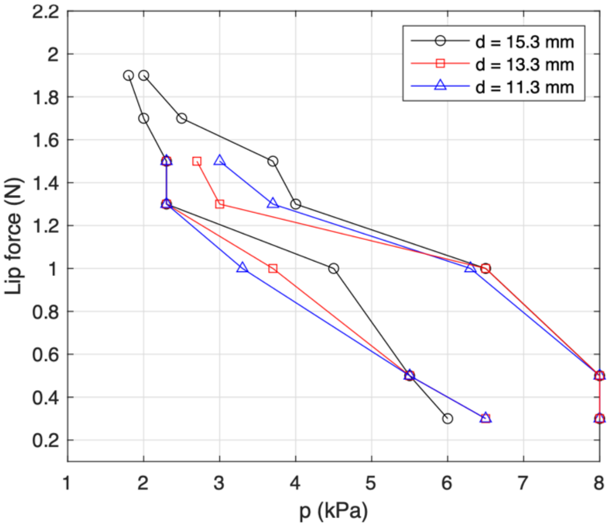

Figure 5. The oscillation threshold of the prototyped mouthpieces with different bore diameters from 11.3 to 15.3 mm. The lines on the left side show the lower thresholds, whereas the lines on the right side show the upper thresholds.

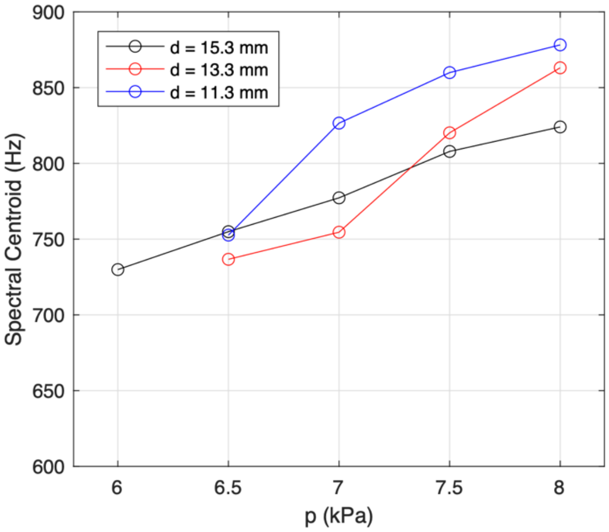

Figure 6. Spectral centroids of the produced sounds with the lip force of 0.3 N.

4. CONCLUSIONS

In this study, the effects of mouthpiece bore diameters on the oscillation threshold pressure and tone quality are investigated by using the artificial blowing machine and rapid prototyping. The prototyped mouthpiece produced sounds with narrower pressure and lip force ranges than the commercial resin mouthpiece. Further prototyping with different equipment or material is needed to improve the playing quality of the prototyped mouthpiece. The comparison with different bore diameters showed that the mouthpiece with smaller bore diameters produced sounds with narrower pressure ranges for stronger lip forces, whereas the spectral centroids became higher when the lip force was 0.3 N. These results indicate that the mouthpiece with smaller bore diameters can be used for a player who requires brighter timbre. However, further design improvement is needed to widen the playable ranges with the smaller bore diameter.

5. ACKNOWLEDGMENTS

This study is partly supported by JSPS grant-in-aid for early-career scientists (Grant number: 23K17195) and MEXT as “Program for Promoting Researches on the Supercomputer Fugaku” (Project ID: hp230032).

6. REFERENCES

[1] Wehner, W. L.: "The effect of interior shape and size of clarinet mouthpieces on intonation and tone quality," *J. Res. Music Educ.* vol. 11, no. 2, pp.131-136, 1963.

[2] Gibson, L.: "Fundamentals of Acoustical Design of the Soprano Clarinet," *Music Educators Journal*, vol. 54, no. 6, pp. 113-115, 1968.

[3] Backus, J.: "The clarinet reed and its relation to the clarinet mouthpiece," *J. Acoust. Soc. Am.*, vol. 64, pp. S170-S171, 1978.

[4] Pillinger,E.: "The effects of design on the tone and response of clarinet mouthpieces," *Doctoral dissertation, London Guildhall University*, 2000.

[5] Ozdemir, M., Cascini, G.: "An experiment-driven mass-personalisation model: Application to saxophone mouthpiece production," *Proc of the Design Society: DESIGN Conference*, pp. 1037-1046, 2020.

[6] Ozdemir, M., Chatziioannou, V., Verlinden, J., Cascini, G., Pàmies-Vilà, M.: "Towards 3D printed saxophone mouthpiece personalization: Acoustical analysis of design variations," *Acta Acust.*, vol. 5, no. 46, pp. 1-18, 2021.

[7] Backus, J.: "Vibrations of the reed and the air column in the clarinet," *J. Acoust. Soc. Am.*, vol. 33 no. 6, pp. 806-809, 1961.

[8] Almeida, A., George, D., Smith, J., Wolfe, J.: "The clarinet: How blowing pressure, lip force, lip position and reed "hardness" affect pitch, sound level, and spectrum," *J. Acoust. Soc. Am.*, vol. 134, no. 3, pp. 2247-2255, 2013.

[9] Li, W., Almeida, A., Smith, J., Wolfe, J.: "The effect of blowing pressure, lip force and tonguing on transients: A study using a clarinet-playing machine," *J. Acoust. Soc. Am.*, vol. 140, no. 2, pp. 1089-1100, 2016.

[10] Chatziioannou, V., Schmutzhard, S., Pàmies-Vilà, M., Hofmann, A.: "Investigating clarinet articulation using a physical model and an artificial blowing machine," *Acta Acust. United Acust.*, vol. 105, no. 4, pp. 682-694, 2019.

[11] Yokoyama, H., Kobayashi, M., Iida, A.: "Analysis of flow and acoustic radiation in reed instruments by compressible flow simulation," *Acoust. Sci. Tech*. vol. 41, no. 5, pp. 739-750, 2020.

[12] Yoshinaga, T., Yokoyama, H., Shoji, T., Miki, A., Iida, A.: "Global numerical simulation of fluid-structure-acoustic interaction in a single-reed instrument," *J. Acoust. Soc. Am.*, vol. 149, no. 3, pp. 1623-1632, 2021.

[13] Bacciaglia, A., Ceruti, A., Liverani, A.: "Evaluation of 3D printed mouthpieces for musical instruments," *Rapid Prototyping Journal*, vol. 26, no. 3, pp. 577-584, 2020.

[14] Schubert, E., Wolfe, J.: "Does timbral brightness scale with frequency and spectral centroid?" *Acta Acust. united Acust*., vol. 92, no. 5, pp. 820-825, 2006.

[15] Yoshinaga, T., Yokoyama, H., Shoji, T., Miki, A., Iida, A.: "Numerical investigation of effects of mouthpiece geometry on flow and sound generation in a single-reed instrument," *Proc. of International Congress of Acoustics (ICA2022)*, ABS-0031, pp. 1-8, 2022.