DOI: 10.61782/fa.2025.0509

FORUM ACUSTICUM EURONOISE 2025

IS IT POSSIBLE TO PREDICT SINGLE CANE REED MOUTHPIECE INTERACTION BY MEASURING THE REED ALONE?

Amélie Gaillard[1*] **Marie tahon**[2] **Camille Urban**[1,2]
Emmanuel Brasseur[1] **Bruno Gazengel**[1]
[1] Laboratoire d'Acoustique de l'Université du Mans (LAUM), UMR 6613
Institut d'Acoustique-Graduate School (IA-GS), CNRS, Le Mans Université
Avenue O. Messiaen, CEDEX 09, F-72085 Le Mans, France
[2] LIUM, Le Mans University

ABSTRACT

This paper deals with the experimental characterization of single cane reeds. According to some authors, the reed stiffness symmetry of the unmounted reed may explain it's perceived quality. Other studies show that the non-linear stiffness of a reed mounted on a mouthpiece partially explains it's behavior in playing situations. According to these results, the aim of this work is to study the link between measurements performed on unmounted and mounted reeds.

We adapted two experimental test rigs to characterize 90 reeds with 3 different strengths. The first is dedicated to unmounted reeds. It enables to measure the local stiffness at a known distance from the reed tip by imposing a displacement and measuring the force. The second test rig focuses on the reed mouthpiece interaction. Using a force sensor and a camera, it enables to estimate the nonlinear characteristics between lip force and reed channel area.

Using these numerous measurements, we investigate the relation between the indicators by the use of statistical analysis and machine learning techniques. These methods enable to show several correlations between parameters obtained from unmounted and mounted reed measurements.

**Corresponding author*: *amelie.gaillard@univ-lemans.fr.*

Keywords: *clarinet, reed, measurements*

1. INTRODUCTION

Woodwinds instruments use a small piece of cane or synthetic material to produce a sound. According to musicians, this piece is very important for the control and the quality of sound and this was already said by Frederic Berr in 1836 [1] "Une bonne anche est un point capital pour l'exécutant, puisque la qualité du son dépend de sa confection et du choix du roseau ; aussi a-t-on dit qu'une bonne anche faisait la moitié du talent de l'exécutant" (A good reed is essential for the performer, since the quality of the sound depends on the way it is made and the choice of reed; it has been said that a good reed is half the talent of the performer.)

Today single reeds are made in an industrial manner so that the reed can be described by three parameters, its brand, its cut and its strength. However, even if the manufacturing process is very accurate, different reeds sold as identical (same brand, cut, strength) can be perceived as extremely different by musicians. This is even the case when the reed is chosen to be adapted to the mouthpiece tip opening [2]. Indeed the mouthpiece plays an important role in the ease of playing (linked to the oscillation threshold) and in the external sound pressure level and in the pitch variation [3].

According to previous results [4], the strength of the reed (obtained thanks to a measurement of the reed stiffness at a certain distance from the reed tip) is correlated with the subjective descriptor "ease of playing" but the strength does not enable to predict all musicians sensations. This explains the variability of musicians perception when they play identical reeds. The variability in the perception may be due to the reed symmetry [5,6] or to the interaction between the reed and the mouthpiece [7, 8].

For this reason, the work proposed in this paper aims at characterizing the reed thanks to two different experimental methods. First, measurements of the reed alone are conducted. They enable to estimate two different reed compliances (local and transfer compliance). Second, the interaction between the reed and the mouthpiece is analyzed by estimating the reed channel surface —the front surface between the mouthpiece tip and the reed— as a function of the force applied on the reed as described by Gaillard et al. [8]. Finally, relations between the two data sets are searched in order to investigate to what extend measurement on the reed alone can give information the reed-mouthpiece interaction.

The second half of this study covers measurement methods. Data analysis methodologies are discussed in Section 3, while Section 4 presents results obtained with 89 reeds before concluding and providing work perspectives.

2. MEASUREMENT TECHNIQUES

Two experimental set-ups were used. The first test rig uses a rod to apply a force on a clamped reed. It measures the local stiffness at various reed points and the deflection of the reed tip (figure 1). The second device (figure 6) consists of a mouthpiece, an artificial lip, and a reed. It allows to measure the nonlinear relationship between the opening of the reed channel and the force applied by the lip on the reed.

2.1 Measurements of the reed alone

The experimental set-up used to characterize the reed alone is described in figure 1. The thick part of the reed is clamped and its free length is set at ℓ = 2.7 cm. This length is controlled using a removable stop giving good repeatability during measurements. A camera (Imagine Source DMK 37BUX252) takes pictures of the reed tip, in order to capture the deflection $z_t(y_t)$ along y axis (tip displacement). A pointed rod that can move in the three directions in space imposes a known displacement z_p at the coordinates (x_p, y_p). The position of the rod in the reference frame linked to the reed is controlled in the y direction using a calibration procedure to compensate for any defects in the positioning of the reed on the bench. A sensor (Omega LCM703-5) measures the force F_p applied by the pointed rod to the reed for different positions along the z axis.

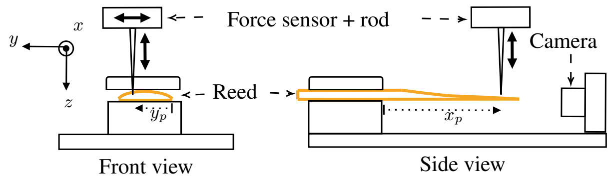

Figure 1. Schematic diagram of the bench used to measure the local stiffness and the tip deflection of a single reed.

Thanks to this test rig, two types of reed measurements are performed simultaneously : reed local stiffness (the compliance inverse) and reed tip deflection. The measurement procedure involves positioning the rod tip over the reed and then displacing it according to z. The force is recorded and a picture of reed tip is captured (as presented in figure 2.a). This automatic procedure is repeated for 4 positions along z and 9 points along y centered on the middle of the reed. This choice results from a compromise between the accuracy and the duration of the measurement. Indeed, as a large amount of reeds will be measured, the maximum measurement time for one reed is set to 10 minutes.

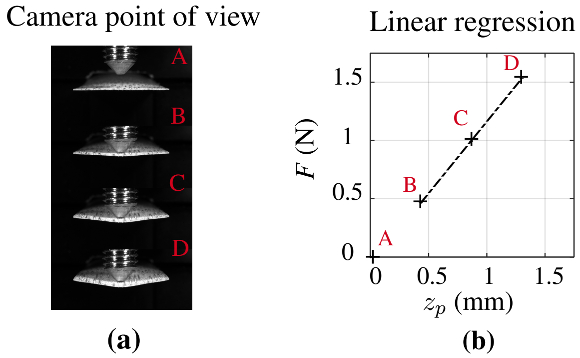

Figure 2. (a) Four rod positions and resulting in reed deflection (b) Estimation of local stiffness by linear regression between force and displacement imposed by the rod.

2.1.1 *Measurement of local stiffness*

For this measurement, a linear regression estimates the local stiffness K at coordinates (x_p, y_p) using the rod im-

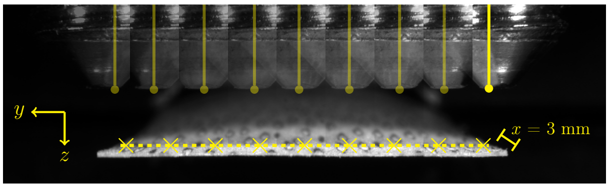

Figure 3. Nine points (yellow crosses) along the reed width y from y_0 (left) to y_8 (right) at $x = \ell - x_p = 3$ mm from the reed tip.

posed displacement and the measured force.

The local stiffness is measured for the nine y_p leading to the estimation of reed stiffness profile. The stiffness is modeled by a parabola described in a previous article [9] with three coefficients K_0, K_1 and y_0 leading to the theoretical stiffness $\hat{K} = K_0 + K_1(y_p - y_0)^2$. We also include $\Delta K = K(y_8) - K(y_0)$ to capture the symmetry of the reed.

2.1.2 *Measurement of transfer compliance*

In this measurement, only the force applied by the rod and the reed tip deflection are used as shown in figure 4. The reed tip deflection $z_t(y_t)$ is obtained with an image processing. For each z_p, the image is converted in black and white using a threshold value according to Almeida [10]. The contour between the white (reed) and dark zones (air) is obtained by thresholding the gradient of each y slice between the left and right side of the reed.

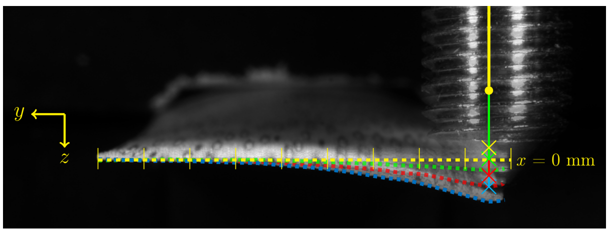

Figure 4. Four reed tip deflections (colored dotted lines) caused by four vertical displacements of the rod. The reed is at rest for the first displacement as in Figure 3, in yellow in both figures.

The full contour is interpolated to extract the reed tip deflection $z_t(y_t)$ at the nine segments between the small yellow vertical bars in Figure 4. Finally, these measurements result in a bunch of 4 z_p (rod displacements) $\times$ 9 y_p (rod positions) $\times$ 9 y_t (reed tip average deflection) $= 324$ deflection values for a reed. This enables to get first the reed tip profile at rest $z_r(y_t)$ (no force). Second it leads to the transfer compliance $c_{tp} = \frac{z_t}{F_p}$ at different rod positions y_p and tip positions y_t using a least mean square regression for 3 rod positions z_p. An example of such a transfer compliance matrix $\boldsymbol{C_{tp}}$ is given in figure 5.

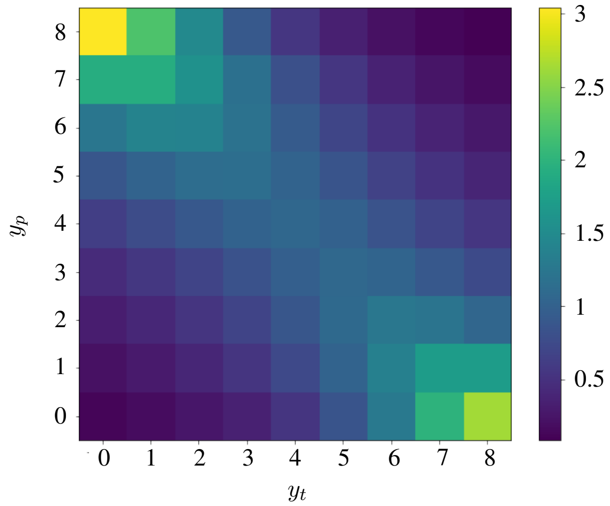

Figure 5. Example of compliance matrix $\boldsymbol{C_{tp}}$ (mm.N^{-1}) for reed 1.

2.2 Characterization of reed mouthpiece interaction

The second test rig (figure 6) is used to characterize the interaction between the mouthpiece and the reed. A mouthpiece (Vandoren BD4 - tip opening = 115.5 1/100 mm), on which a reed is held by a ligature (Vandoren Optimum), is fixed to the test rig. An artificial rectangular silicone lip (30 mm $\times$10 mm $\times$7 mm) moves along the x-axis (parallel to the height of the reed). In this case, the force F_L applied by the artificial lip is measured with a force sensor (Omega LCM703-5). A camera takes pictures of the reed channel for every lip force. This method of measurement is very similar to the one proposed by Taillard [7] but enables to measure the lip force (instead of lip position) automatically on a large number of reeds. It is the same as described in [8].

The lip is moved in steps of 0.2 mm along the z axis thanks to a manual micrometric screw leading to 31 force values. When the lip is in its first position, it does not touch the reed and the channel is fully opened. For each position of the lip until the channel is completely closed,

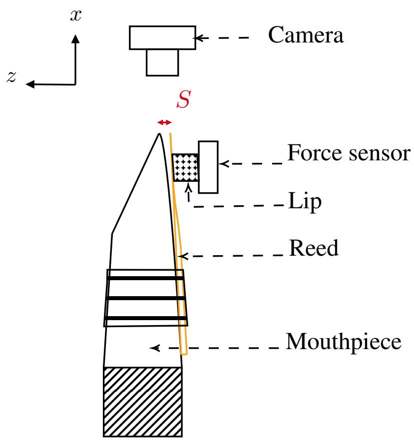

Figure 6. Test rig used to characterize the reed-mouthpiece interaction.

the force signal is recorded and a photo of the channel is taken. In this experiment, the presence of the artificial lip can create light reflections that make the processing more tricky than for the previous experiment. First, the image with the reed at rest is analyzed. The grayscale image is converted into a binary image choosing a threshold value which enables to get a reed contour having a width similar to the mouthpiece contour width, the contours being detected using the function *bwboundaries* of Octave software [11]. Then, for each force, each image is cropped such that the lip and the sides of the reed are not seen. Each image is converted into a binary image choosing a threshold value which enables to get a reed perimeter similar to the perimeter of the reed at rest. The contours of the mouthpiece and reed are detected and the height of the reed channel is estimated along the reed width. An example of a measurement obtained with this system is shown in Figure 7 (crosses). In addition to the total channel surface, the surface is also estimated for 9 different parts centered on y_t, distributed in a similar way to the reed alone.

As the lip positions are imposed, the lip forces are all distinct from all reeds, so it is not practical to study the raw data collected by image processing. Then, for every reed, the 10 (9 segments and total) surface area are modeled as proposed by Gazengel et al. [12]. Using this model, each characteristic is divided into three parts as shown in figure 7 (blue curve). For low lip forces, the linear part of the curve can be approximated by a straight line (in red in figure 7). Its y-intercept indicates the opening surface at rest S_{00} (without lip force). The x-intercept indicates the maximum closing force F_M. At intermediate forces, the reed bends on the curved rails of the mouthpiece. This part can be approximated by a parabola with length E (elbow). Finally, for high forces, the entire reed is in contact with the mouthpiece, leading to complete closure of the channel or to a residual leakage S_{inf}. If there is not any leakage, the measured area should be zero but because of lightning, sometimes the image processing can lead to a residual leakage which is not physical. This piece-wise function is defined by the 4 coefficients S_{00}, F_M, E and S_{inf}. It is of class C^1, and its derivative is continuous.

An example showing the 9 opening sections as a function of F_L is given in figure 8.

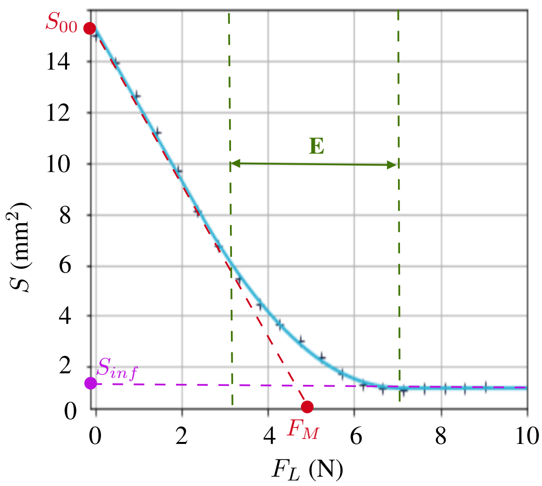

Figure 7. Total opening section of the channel with measurements (crosses), model (blue curve) and associated parameters.

3. DATA ANALYSIS

Eighty-nine reeds were randomly selected among commercial reeds. They are all of the same cut *V12* from the same manufacturer *Vandoren* but of three different strengths: 2 1/2 (29 reeds), 3 (30 reeds) and 3 1/2 (30 reeds). All the reeds were measured with the two test-rigs presented above.

The following data analysis has been realized to confirm and explore the relation between measurements on the reed alone and in interaction with the mouthpiece. All the code used to compute the different parameters and to

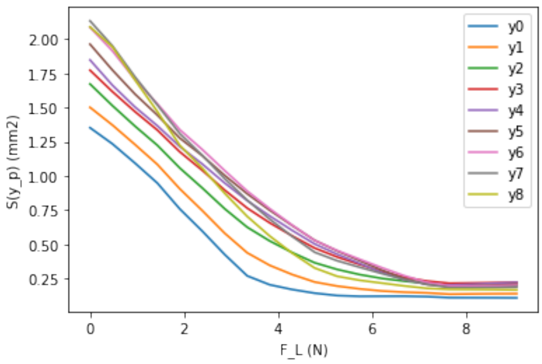

Figure 8. Example of nonlinear characteristics obtained by analyzing 9 opening sections $S(y_p)$ as a function of the lip force for reed 1.

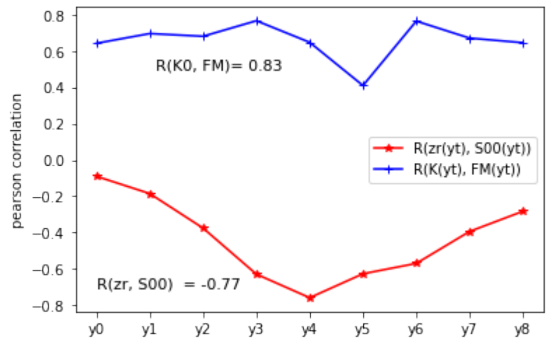

Figure 9. Red curve : $\rho(z_t(y_t), S_{00}(y_t))$ for the reed deflection at rest. Blue curve: Pearson correlation $\rho(K(y_t), F_m(y_t))$ between the reed local stiffness $K(y_t)$ and maximum force $F_M(y_t)$.

analyze the code is made available [1] . In this exploratory work, we mainly used correlations, however, more advanced techniques using mutual information or PCA are currently under investigation.

3.1 Reed tip position at rest

The reed tip position at rest is not supposed to vary according with the test rigs. Therefore we expect a high correlation between the reed tip deflection $z_r(y_t)$ of the reed alone, and the S_{00} parameter obtained in interaction with mouthpiece (segmented and total). We observe that the correlation between the mean rest deflection $\bar{z}_r$ of the reed and the S_{00} of the total opening section is high ($R = -0.77$). However, when comes to the local correlation, the highest correlations are found for the middle of the reed ($t = 4,\ y_t = 0$) which might due to the shape of the mouthpiece (red curve, figure 9).

3.2 Local stiffness

We first investigate how the reed stiffness parameters are correlated. We confirm that the correlation between stiffness K_0 and K_1 is high (0.953), and also the correlation between symmetry parameters y_0 and ΔK (0.867). However all other correlations are rather low (< 0.09). We also explore the relations between the local stiffness $K(y_t)$ (reed alone) and the maximum force $F_M(y_t)$ (reed is in contact with the mouthpiece). First, the Pearson correlation between K_0 and F_M associated to the total area is high (0.83). Then, the Pearson correlation for each position y_t is given by the blue curve in figure 9. We observe that the local stiffness $K(y_t)$ is strongly correlated with the force $F_M(y_t)$, thus confirming the consistency of the measures between the two rigs. Unfortunately, the correlation between y_0 or ΔK and E parameter are too low (< 0.17) to conclude to a relation between asymmetry of the reed alone and the bending of the reed on the mouthpiece.

[1] https://git-lium.univ-lemans.fr/tahon/reedsml.git

3.3 Transfer compliance

Finally we analyze, the correlations between each of the 81 compliances c_{tp} (for a position of the rod y_p and a position of the reed tip y_t) and the equivalent parameters $S_{00},\ F_M,\ E,\ S_{inf}$ describing the total opening section between the reed and mouthpiece. Figure 10 shows the results.

We observe that S_{00} and S_{inf} are not correlated to the compliance at any position on the y axis. On the contrary, F_M and E are highly correlated with the 81 transfer compliance. Moreover, the correlation coefficient between F_M and E being 0.54, it suggests that the bending of the reed on the mouthpiece depends on the maximum force F_M. More precisely, the highest correlations between F_M and c_{tp} can be found when the rod is in the middle of the reed, for any position in the reed ($p = 3 \ldots 6,\ \forall t$). When the rod is applied at the edge of the reed ($p = 1, 2, 8, 9$), the correlation reaches its maximum value close to the rod position (2 to 3 segments around the rod position).

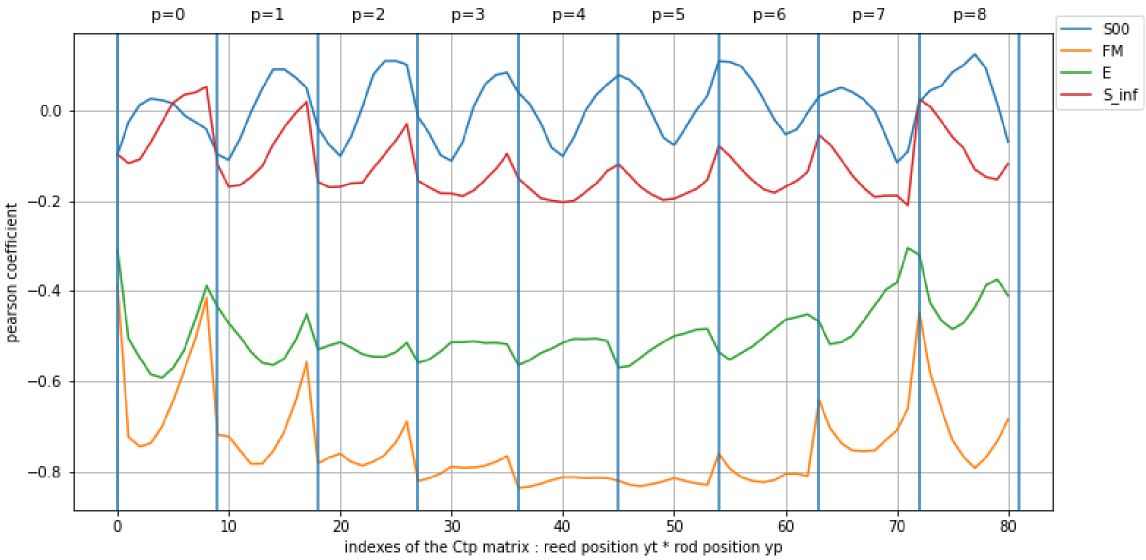

Figure 10. Pearson coefficient between the transfer compliance c_{tp} and the four mouthpiece-reed interaction parameters. The abscissa corresponds to the flatten matrix coordinates : $9 \times p + t$. For instance, if the rod position is at $p = 2$ and the observation of the reed deflection is at $t = 1$, the abscissa will be $2 \times 9 + 1$. Blue vertical lines indicates a change of position of the rod y_p.

4. CONCLUSION

This study used two different test rigs to experimentally characterize 89 clarinet reeds.

The first employs a clamped reed with a pointed tip that exerts force at a predetermined distance from the reed tip. First, it enables the measurement of local stiffness. Second, an image processing measures the reed tip displacement. This enables to get the reed tip position at rest and the transfer compliance matrix (ratio between the tip displacement and force at different coordinates). The local stiffness can be described by a parabola (3 parameters).

The second test rig employs a reed mounted on a clarinet mouthpiece, with an artificial lip exerting a force on the reed. It uses image processing to measure the height of the reed channel. This leads to the nonlinear characteristics (force-section) that are modeled using 4 parameters.

The analysis of the relation between the 2 data sets shows that the reed tip position at rest is consistent for both test rigs. The maximum local stiffness K_0 is strongly correlated to the maximum force F_M derived from the total opening section measured on the mouthpiece. At this stage, the asymmetry measured on the reed alone does not correlate with any parameter obtained with the reed + mouthpiece system. The transfer compliance is highly correlated with the maximum force F_M of the total opening section when the point force is applied in the middle of the reed, indicating that the force applied on the sides have a small effect on F_M. Finally, the correlation coefficient between F_M and the elbow E suggests that the bending of the reed on the mouthpiece depends on the maximum force F_M.

Deeper investigations will be conducted with more advanced data analysis such as Principal Components Analysis and entropy based approaches. Future work will use these two test rigs in parallel to perceptive tests in order to try to determine a link between physical parameters and subjective descriptors.

5. REFERENCES

[1] F. Berr, *Traité complet de la clarinette à quatorze clefs: manuel indispensable aux personnes qui professent cet instrument et à celles qui l'étudient*. Source gallica.bnf.fr BnF, 1836.

[2] "The saxophone mouthpiece tip opening." `https://syos.co/en/blogs/news/`

the-saxophone-mouthpiece-tip-opening. Accessed: 01-28-2025.

[3] M. Ozdemir, V. Chatziioannou, J. Verlinden, G. Cascini, and M. Pàmies-Vilà, "Towards 3d printed saxophone mouthpiece personalization: Acoustical analysis of design variations," *Acta Acustica*, vol. 5, p. 46, 2021.

[4] B. Gazengel, J. Dalmont, and J. Petiot, "Link between objective and subjective characterizations of Bb clarinet reeds," *Applied Acoustics*, vol. 106, 2016.

[5] C. Kemp and G. Scavone, "Mechanical, anatomical and modeling techniques for alto saxophone reed evaluation and classification," *Wood Science and Technology*, vol. 54, pp. 1677–1704, Nov. 2020.

[6] F. Pinard, B. Laine, and H. Vach, "Musical quality assessment of clarinet reeds using optical holography," *The Journal of the Acoustical Society of America*, vol. 113, no. 3, pp. 1736–1742, 2003.

[7] P.-A. Taillard, *Theoretical and experimental study of the role of the reed in clarinet playing*. PhD thesis, Le Mans Université, 2018.

[8] A. Gaillard, B. Gazengel, and V. Koehl, "Research of perceptual descriptors discriminating clarinet reeds of identical stiffness," in *INTER-NOISE and NOISE-CON Congress and Conference Proceedings*, vol. 270, pp. 2993–3000, Institute of Noise Control Engineering, 2024.

[9] A. Gaillard, V. Koehl, and B. Gazengel, "Link between stiffness symmetry and perceived quality of clarinet cane reeds," in *Forum Acusticum 2023, the 10th European Congress on Acoustics*, pp. 2729–2733, 2023.

[10] A. Almeida, C. Vergez, and R. Caussé, "Experimental investigation of reed instrument functioning through image analysis of reed opening," *Acta acustica united with acustica*, vol. 93, no. 4, pp. 645–658, 2007.

[11] J. W. Eaton, D. Bateman, S. Hauberg, and R. Wehbring, *GNU Octave version 8.4.0 manual: a high-level interactive language for numerical computations*, 2023.

[12] B. Gazengel, J.-P. Dalmont, A. Gaillard, E. Brasseur, and P.-A. Taillard, "Characterization of single reed mouthpiece interaction in quasi-static regime," *Acta Acustica*, vol. 9, p. 5, 2025.