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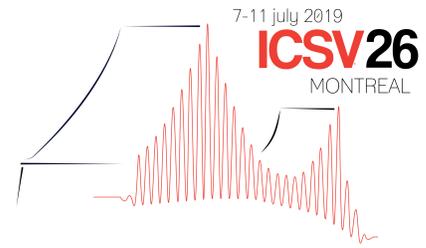
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## EXPERIMENTAL CHARACTERISATIONS OF SINGLE CANE REEDS

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Single cane reeds used for playing clarinets or saxophones are described by makers by their strength and shapes (cutting). For reeds assumed to be identical according to the maker (same strength and shape), strong differences in the perceived quality are expressed by musicians. In this context, the experimental characterization of reeds (from the perceptive and objective sides) is a key issue for reed makers in order to better predict reed musical abilities. This paper presents and discuss different measurement methods. These methods can be divided into two families, measurement of the reed alone through static or dynamic measurements in order to derive stiffness and modal parameters, measurement of the "embouchure" (reed+mouthpiece+lip) alone through static or quasi-static measurements in order to estimate the non linear characteristics, the non linear reed stiffness or other mechanical parameters. Finally it appears that the most efficient characterisation of the "embouchure" is probably a static measurement.

Keywords : musical acoustics, reed, clarinet, saxophone

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### 1. Introduction

Musical instruments such as the clarinet or the saxophone use a single reed that makes it possible to produce sound using a constant pressure in the musician's mouth. The reed is a slat of cane reed or synthetic material defined by a specific strength (given by a number of a letter) and a specific cut (different cut corresponding to different aesthetics). Reeds are mounted on mouthpieces defined by an opening and with other physical properties which are generally not given by the maker such as length of the table and shape of the baffle inside.

For a player, different reeds of the same brand, cut and strength mounted on the same mouthpiece can be perceived as different. Consequently, reed makers need to improve the characterization of reeds with objective indicators that better satisfy musician's expectations.

Academic research have been done on this subject for almost twenty years and deals with different aspects such as :

- modeling the mechanical behavior of the reed alone [1]

- modeling the reed mounted on a mouthpiece and in contact with the musician's lip [2, 3],
- experimental characterization of the reed along [4, 1, 5]
- experimental characterization of the reed mounted on a mouthpiece and played by a real or artificial player [6, 7]
- experimental estimation of subjective descriptors [8]

The reed is a mechanical system which can be modelled as a pure stiffness or a mass-damping-stiffness (Single Degree of Freedom system) system for low amplitude [2, 9]. For higher displacement it is necessary to take into account the effect of the mouthpiece lay and to consider a non linear stiffness [10]. The effect of the lip can also be considered. These models enable to deduce numerical values of stiffness, damping and mass from experimental characterizations.

Reed makers implicitly consider the reed as a linear spring by measuring only the strength which is proportional to the mechanical stiffness obtained for a localized force. The reed can also be measured using a vibroacoustic bench with a low level acoustic excitation. This measurement leads to an estimation of the equivalent stiffness, mass and damping [4, 6].

Finally, different studies deal with the definition of subjective descriptors. Results obtained up to now show that the perceptive space describing single cane reeds is a 2D space (ease of playing, timbre) for which the two descriptors are highly correlated [8].

In this paper we recall and compare the results obtained in previous publications and done in recent works. Section 2 recalls the physical models describing the reed mechanical behaviour and the flow entering in the instrument. Section 3 presents results obtained when characterizing reeds alone using dynamic measurements. Section 4 presents different techniques enabling to characterize the reeds on a mouthpiece (with an artificial lip) without playing. In section 5, the results obtained in sections 3 and 4 are discussed and future work are proposed.

## 2. Physical model of single cane reed instruments

Single cane reed instruments consist of two main parts, the resonator described by its impedance [11] and the exciter (figure 1), made of the mouthpiece, the reed, the lip and the musician. We recall here the usual models describing the exciter.

### 2.1 Model of the reed

The reed can be modeled as different elementary physical systems, more or less complex such as a 2D mechanical system (thin plate), 1D system (clamped beam), 0D (Single Degree Of Freedom system) or K model (stiffness without mass and damping) [2, 4, 6].

For the 0D and K model cases, the simplest models consider the shock between the reed and the mouthpiece as inelastic. However, the stiffness can be considered as nonlinear in order to take into account the bending of the reed on the mouthpiece lay (figure 1b). Assuming this behavior, the reed position can be written as a function of  $\Delta p = p_m - p$ ,

$$M\ddot{y} + R\dot{y} + Ky = -\Delta p, \quad (1)$$

where  $M$ ,  $R$ ,  $K$  are respectively the mass, damping coefficient and stiffness of the reed. These parameters can be considered as constant or dependent of  $y$ . For example in [6], the stiffness is given by writing the reed motion as

$$Ky + K_c[y - y_c]^2 = -\Delta p, \quad (2)$$

where  $K$  is the effective stiffness per unit area,  $K_c$ ,  $y_c$  are constant and  $y_c$  is the displacement value above which the contact between reed and mouthpiece becomes active.

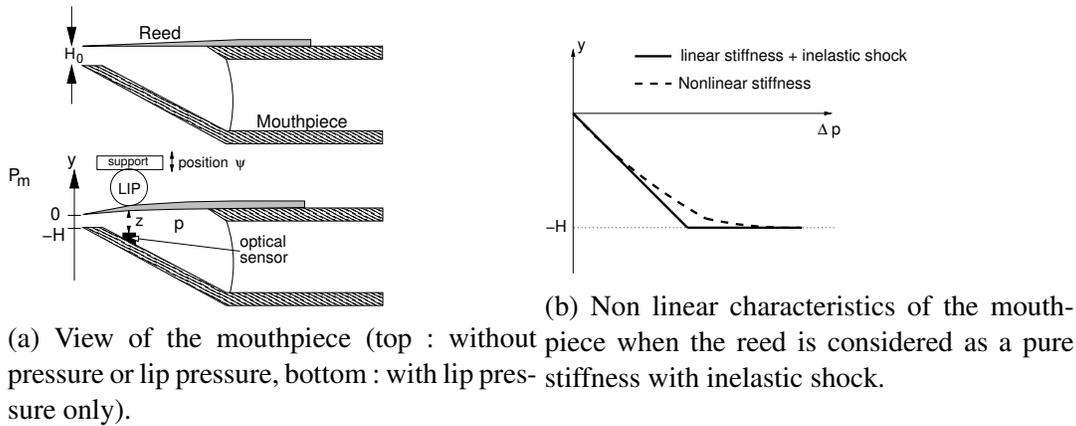


FIGURE 1 – View of mouthpiece and characteristic of the reed.

A recent work [3] shows an equivalence can be found between the pressure drop  $\Delta p = p_m - p$  and the vertical position of an artificial lip support  $\psi$  so that an equivalent pressure  $x$  can be defined as a linear combination of  $\Delta p$  and lip support position as  $x = \Delta p + \mu(\psi - \psi_0)$  where  $\mu$  is a positive constant  $\psi_0$  is an arbitrary reference position.

## 2.2 Model of the flow entering the instrument

The flow entering the mouthpiece can be modeled using Bernoulli equation [3]. When assuming that the reed mass and damping effects are ignored (pure stiffness) with inelastic shock on the mouthpiece, the flow can be written

$$U = \begin{cases} w(H + \frac{\Delta p}{K})\sqrt{\frac{2|\Delta p|}{\rho}}, & \Delta p < kH, \\ U = 0, & \Delta p \geq kH, \end{cases} \quad (3)$$

where  $w$  is the effective width of the reed and  $H$  the opening at rest after the musician has pressed the reed with his lip, meaning that the opening at rest  $H$  depends on the reed stiffness, the mouthpiece lay and the lip mechanical properties. The nonlinear characteristics  $U = f(\Delta p)$  is shown in figure 2.

## 2.3 Effect of exciter parameters on playing

Considering a basic model of a clarinet (Raman model, [12]) which assumes

- the reed to behave as a spring without inertia and without damping, characterized by a linear stiffness and an opening at rest,
- losses in the resonator which are independent of the frequency,

the threshold pressure  $p_{th}$  (linked to the ease of playing) is proportional to  $KH$  and is  $p_{th} = \frac{KH}{3}$  when the losses are ignored.

This elementary model shows that the player can control the threshold pressure by

- choosing a specific reed stiffness (correlated to the strength indicated by the manufacturer),
- pressing more or less the reed on the mouthpiece in order to adjust the opening at rest  $H$  for this specific stiffness  $K$ .

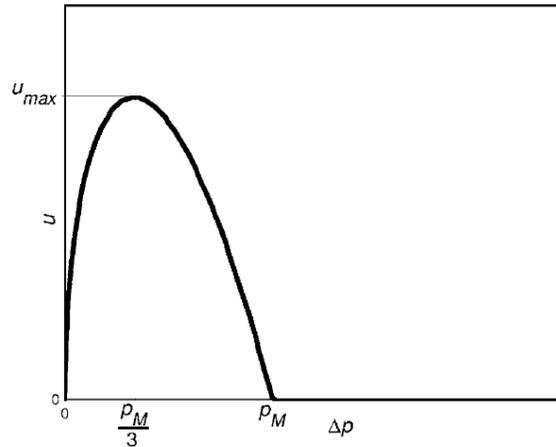


FIGURE 2 – Non linear characteristics of the mouthpiece when the reed is considered as a stiffness (without inertia, without damping) with inelastic shock (from [12]). In this figure  $P_M = KH$ .

### 3. Characterisation of reed alone

This section presents the results obtained when characterising the reed alone. In this case, the reed is placed on a bench which creates an acoustic field on one side of the vamp, the other side being coupled to free air. The vibrating length is fixed and can be different from playing situations.

The measurements were done in two different manners. First a optical sensor was positioned at three different points (right, left, center) near the tip of the reed [4] and the characteristics of the first vibration mode were estimated. This experiment is called “Vibroacoustic analysis” (figure 3).

In another experiment [1], called “Modal analysis”, the reeds were placed on a clarinet mouthpiece excited by a loudspeaker and the vibration of reeds was measured thanks to holography in order to deduce resonance frequencies and vibration modes (figure 4). The main results show that :

- For the “vibroacoustic analysis”, the study of 50 reeds with similar strength and 150 with very similar strength shows no significant difference between static stiffness (measured by the manufacturer) and dynamic stiffness (measured by vibroacoustic analysis). The correlation coefficient between the measured stiffness (static, dynamic) and the ease of playing estimated by subjective testing is  $R = 0.75$ .
- For the modal analysis by digital holography, a viscoelastic model of the reed-material allows to reconstruct quite correctly the observed resonance frequencies and confirms previous results obtained by Guimezanes [13]. However, no evident relationship with the musical subjective evaluation by the clarinet player has been found.

As a conclusion, the measurement of the reed alone using an acoustic excitation enables to measure the dynamic stiffness and to build a viscoelastic model of the reed. However this technique can lead to different stiffness estimations according to the vibrating length. It does not reproduce the bending of the reed against the lay nor the effect of the lip and does not give any estimation about the opening at rest  $H$ .

### 4. Characterisation of reed, mouthpiece and lip system

In this section, the characterisation of the exciter (reed + mouthpiece + lip) alone is presented. For this experiment the artificial lip can be placed at different positions  $\psi$  in the vertical direction ( $y$  direction), its position along the horizontal direction being constant (see figure 1a). This is done in [3] using two

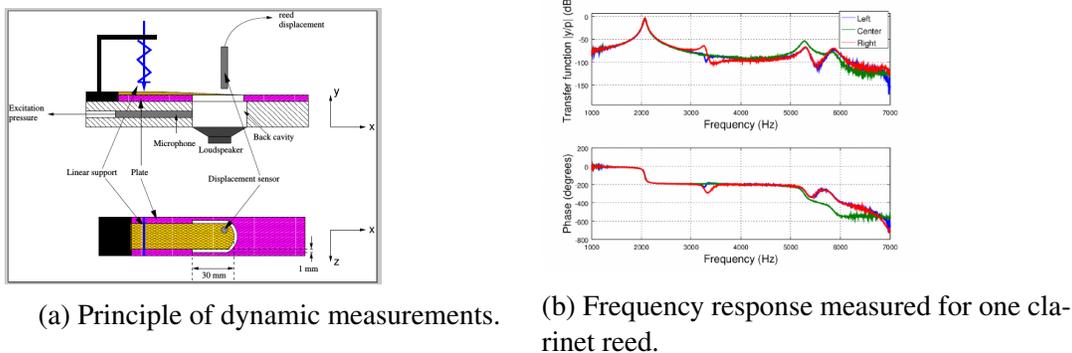


FIGURE 3 – Vibroacoustic characterisation of clarinet reeds (from [4]).

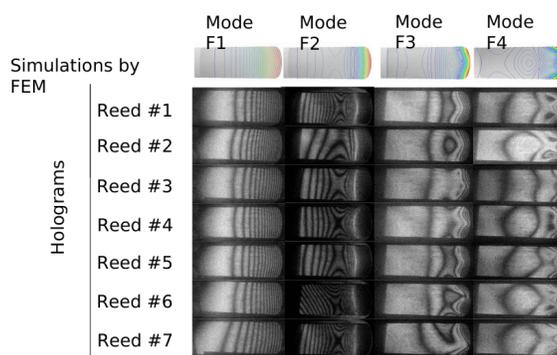


FIGURE 4 – Results of dynamic measurements with holography. Comparison with simulation by FEM (from [1]).

different approaches, a quasi-static measurement and a static measurement.

### 4.1 Quasistatic measurement

A quasi static measurement is performed using a bottle equipped with a diaphragm (figure 5a) and an instrumented mouthpiece. This mouthpiece is equipped with two optical sensor measuring the reed tip position on both sides (right / left at about 2 mm from the tip) as shown in figure 1a. This enables to deduce the effective aeraulic section of the channel (slit between reed and mouthpiece) and the nonlinear characteristics of the exciter for different lip positions as a function of  $\psi$  and  $\Delta p$ .

Figure 5b shows the nonlinear characteristics estimated from the measurement performed with the “bottle method”. This characteristics contains all the information concerning stiffness  $K$  and opening at rest  $H$ . It also contains the information about the nonlinear stiffness for high values of  $\Delta p$ . This characteristics can be used for doing physical simulation of the instrument but it does not consider nor the equivalent damping neither the equivalent mass of the reed.

Figure 6 shows the reed deflection measured with optical sensors on both sides and the aeraulic section estimated with the “bottle method” as a function of the mean reed deflection obtained in figure 6a. This results show that there is an equivalence between the pressure drop  $\Delta p$  and the lip position  $\psi$ .

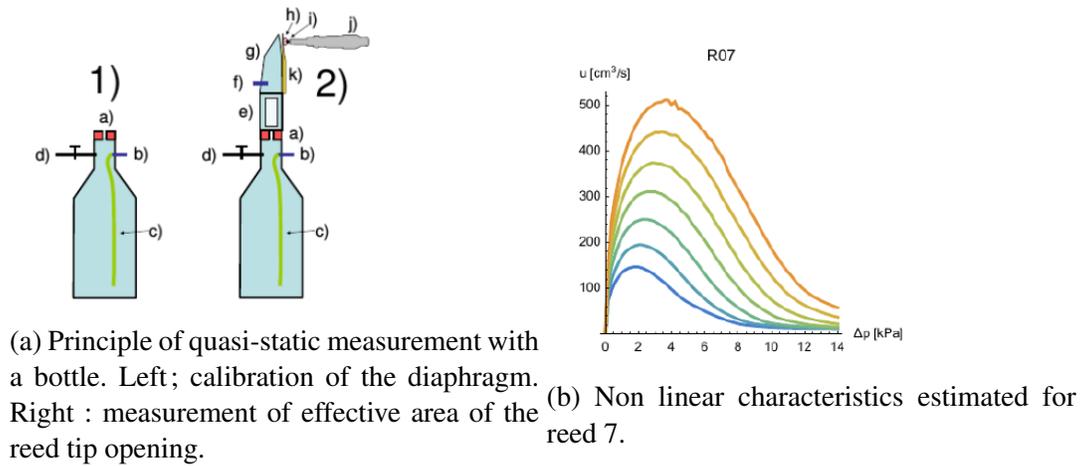


FIGURE 5 – Principle of the “bottle experiment” and example of non linear characteristics obtained with this method (from [3]).

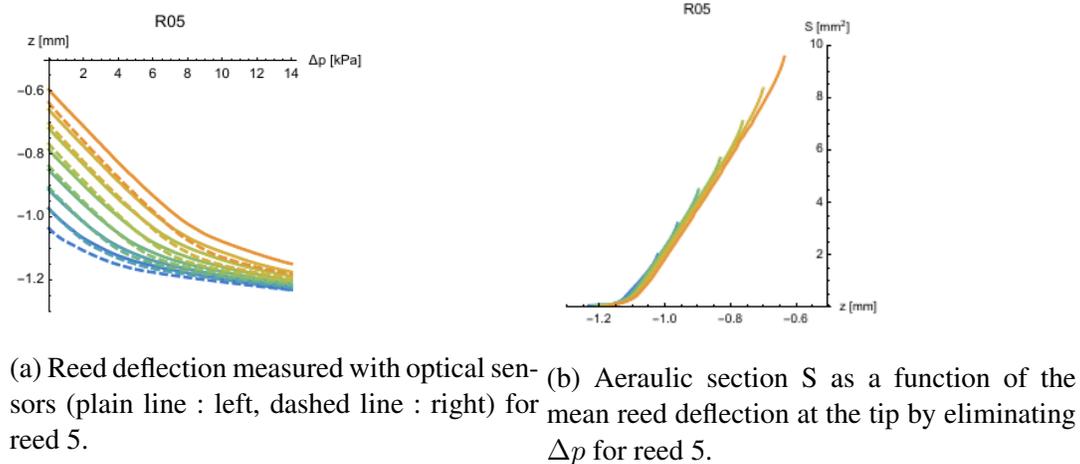


FIGURE 6 – Examples of reed deflection and aeraulic section obtained with the “bottle method” (from [3]).

## 4.2 Static measurement

A static measurement is performed using photographs of the slot between the reed tip and the mouthpiece (figure 7a). This enables to estimate the reed tip profile for different lip positions  $\psi$  (figure 7b).

Figure 7b shows the slot between the reed tip and the mouthpiece for four different reeds and different lip positions  $\psi$ , the reed being closed for  $y = -1.2 \text{ mm}$ . These four reeds have different characteristics : reed 6 is soft, reed 7 is hard, reed 2 has a small value of opening at rest  $H$  (closed reed) and reed 5 has a large value of  $H$  (opened reed). The analysis of the average tip over the reed width enables to characterise the stiffness  $K$  and the opening at rest  $H$ . This results shows that the measurement of the slot between the reed and the mouthpiece using photographs enables to deduce the stiffness and the opening at rest, which gives the nonlinear characteristic thanks to equation 3.

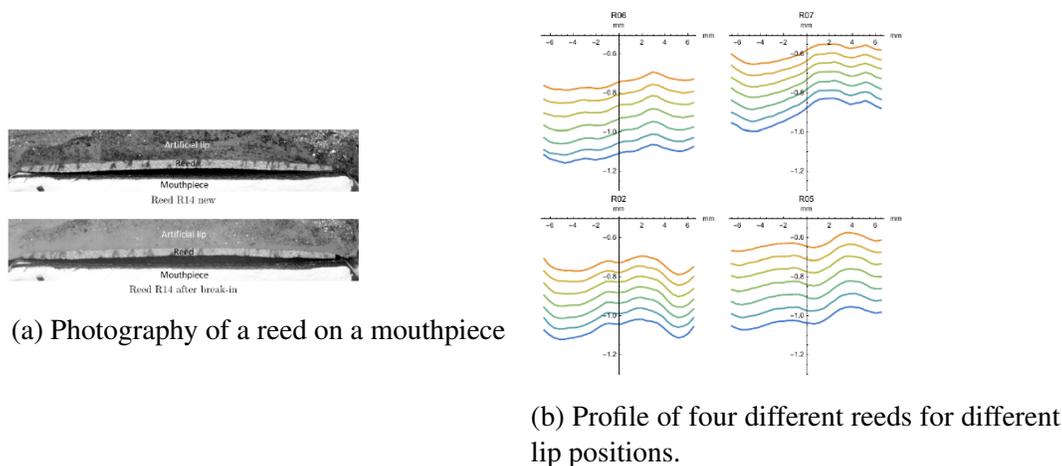


FIGURE 7 – Principle of the static measurement (from [3]).

## 5. Discussion

This paper gives a summary of different work done in order to characterise experimentally single cane reeds and to derive objective parameters that can explain subjective descriptors. The main results obtained up to now are the following :

- **Reed alone** : the measurement of dynamic stiffness does not explain better the ease of playing than the static stiffness. However the vibroacoustic measurement with holography enables to assess a equivalent viscoelastic model of the reed. This measurement is not useful for reed makers who can use a static measurement but it can be helpful in order to characterise the equivalent microscopic mechanical properties of reeds even if it is not a need for industrial applications.
- **Exciter alone** : the static measurement (opening of the reed) and the quasi-static measurement (nonlinear characteristic) give an estimation of the reed stiffness (which can be nonlinear) and of the opening at rest. Results concerning subjective descriptors obtained in [3] with only one player show that these two physical parameters are strongly correlated with subjective descriptors and emphasizes the importance of the opening at rest position (without lip). These results, which should be confirmed with other players, show that the static or quasistatic measurement seem to be a promising way for characterising reeds in order to meet the musicians needs.

In the future, an artificial player developed in [14] will be used for static, quasistatic and dynamic measurements. This way, this experiment should enable, as done in [6] with a musician, to deduce equivalent reed parameters (opening at rest, nonlinear stiffness, damping, mass) for different lip positions.

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