EXPERIMENTAL RESEARCH ON DOUBLE REED PHYSICAL PROPERTIES

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ABSTRACT

Physical modeling of musical instruments is usually based on simplified assumptions about the behavior of the instrument, so that only the essential information necessary to correctly describe the sound produced by the instrument is kept. Such models are able to describe the sound of single-reed instruments, for example.

A simplified reed model is in fact quite generic and its assumptions can also be applied to double-reed instruments. Such a simple model, however, was proven not to be sufficient, and a double-reed model must include a more complete description of the physics of the reed.

This article presents some of the experimental work being done on double-reed instruments. Measurements such as geometric characterization of the reed aim to allow consolidation of hypothesis previously tested in physical models. The determination of the non-linear characteristic is a key-point in the description of the reed behavior.

1. INTRODUCTION

History of physical modeling of reed instruments begins in 1963, when Backus [1] published his first mathematical model of a clarinet. This mathematical model was first applied to sound-synthesis by Schumacher [2]. In spite of its simplicity, this model was able to produce realistic sounds and is currently used in sound synthesis by physical modeling.

In these models, the instrument is seen as a modular system, the exciter (reed and mouthpiece) being modeled separately from the resonator and sharing common physical variables with it. The resonator is usually modeled as a one-dimensional waveguide with boundary conditions that confer the resonance properties of the bore.

Although the bore can have different geometries, a one dimensional waveguide can be described in terms of its input impedance $Z_{in}(\omega)$ or alternatively its reflection function $r(t)$, which can be obtained from the former using a function of its Fourier Transform. This description remains valid as long as we restrict ourselves to linear acoustic propagation.

Modeling of reed-models coupled to conical resonators was tried out by Barjau [3] , to study the timbral influence of conical resonators on the behavior of the instrument.

The simplest exciter model consists of a valve controlled by the pressure difference between its inside (reed pressure p_r) and its outside (mouth pressure p_m). The valve is seen as a harmonic oscillator:

$$m\frac{\partial^2 z}{\partial t^2} + r\frac{\partial z}{\partial t} + k(z-h) = p_r - p_m \quad (1)$$

In this equation, m is the mass of the valve , r is its damping and k its stiffness, all of them considered per unit effective surface. z is the valve opening. In fact, usually both m and r are neglected because playing frequencies are small compared to the reed resonance frequency ($\omega_r \simeq \sqrt{\frac{k}{m}}$).

The pressure difference ($p_m - p_r$) induces a flow through the valve opening section ($S_r = 2zl_r$) which can be described by a simple model like Bernoulli:

$$q = S_r\sqrt{\frac{2}{\rho}(p_m - p_r)} \quad (2)$$

In a clarinet the initial jet produced in the reed channel (between the reed and the mouthpiece) arrives in a much larger chamber and completely looses its kinetic energy without recovering potential energy. The flow is created by the pressure difference between the mouth and the reed, and this (p_r) has the same value as the pressure at the input of the bore.

In a double reed the conicity angle is so gentle that the flow can attach to the wall without losing all of its initial kinetic energy by turbulent mixing. Nevertheless, the extended flow which can attach to the reed walls can undergo further head loss before reaching the resonator. Depending on the complexity of the boundary conditions applied to the flow, new phenomena [4] might need to be taken into account, such as jet separation due to greater conicity [5]. Usually these features can be reduced to a head loss establishing a difference between the pressure inside the reed p_r and the acoustic pressure at the beginning of the bore p.

These considerations lack experimental evidence. In fact, experimental data about double-reeds is scarce and usually restricted to phenomenological considerations about the time-varying properties of the instrument [6] [7]. A short comparison of this data with the behavior of our model can be found in [8]. Further experimental data and techniques, though in preliminary form are presented in the rest of the article.

2. REED CHARACTERIZATION

In a Backus-like wind instrument model, the whole resonator can be characterized at its input by the flow variables p and q. Similarly, the two relevant variables from the point of view of the instrument acoustics are the reed output pressure (p) and flow (q), which therefore establish the coupling between the exiter and the resonator. During a period, the two of them are related by a non-linear function called the *characteristic*.

In the first graph of figure 1 we have plotted the characteristic of a single reed. The reed has a maximum output flow and it is beyond this value that the reed can begin its oscillation. The shape of the actual trajectory of the variables during a period slightly changes with the frequency but for the lowest frequencies it is reasonable to suppose that the dynamic terms in eq. 1 will not have a

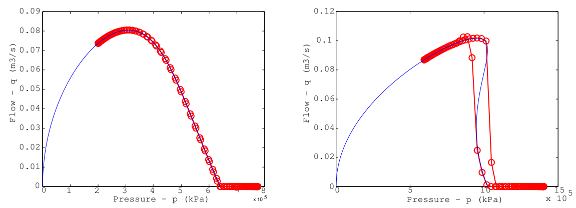

Figure 1: Simulated flow characteristic curves for single-reeds and double-reeds. Markers indicate the trajectory of the instrument's variables during a cycle

big relevance compared to the stiffness and pressure terms. Otherwise, the trajectory will not be superposed to the theoretical curve.

In the case of a double reed, we have seen in section 1 that an additional head-loss must be considered. This fact modifies the characteristic pulling the maximum of the characteristic curve towards the high pressures (fig. 1), so that it can become hysteretic [4]. This in fact can introduce some qualitative changes in the final waveform that will be produced by the instrument [9].

Another way to identify the appearance of hysteresis in the characteristic curve is to analyze a similar curve which relates the pressure to the opening of the reed. By comparing fig. 1 with fig. 2 we see the relationship between the flow characteristic and the reed opening characteristic.

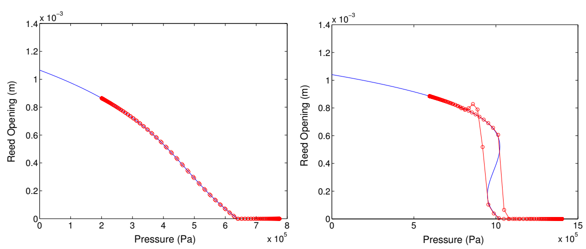

Figure 2: Reed opening characteristic curves calculated with the same model as in figure 1

3. EXPERIMENTAL CHARACTERIZATION

In this section we will introduce some experimental methods to try to verify theoretical hypothesis about the flow inside the reed, or the reed characteristics. Rather than direct observation of time variation of physical quantities of the exciter which are often difficult to interpret in terms of physical principles we prefered to simplify the behavior of the instrument so as to gather information about the physical principles involved in the functioning of the instrument.

3.1. Artificial Mouth

In our experiments we study a physical system (instrument) which is usually operated directly by humans. Although the skilled instrumentist has a remarkable proficiency of the control of this system, it is difficult for him to have a prolongated control of all the variables the system depends on during the whole experiment. Artificial mouths provide easier control over individual parameters while simplifying the observation.

Artificial mouths are currently used in the study of wind instruments. A few examples can be found in literature. It was first used by Backus [10] in the conception of his first clarinet model, and it was adapted and perfectioned for the study of other reed instruments [11] , as well as for brass instruments [12] .

Pressure supply Lungs provide a pressure source to the reed, which is almost constant during a certain amount of time. In laboratory, lungs are replaced by a compressed air source maintained at a certain pressure level which can be regulated.

Mouth Cavity constitutes a resonator whose importance is usually considered as negligible with respect to instrument's impedance, althoug this hypothesis is still under investigation by C. Fritz.

Lips provide a way to control the physical properties of the reed. In particular, by varying the pressure of the lips over the reed, the instrumentist can vary the mass and stiffness of the vibrating end of the reed. Lips are also the main source of damping in equation 1. Special care is thus taken in trying to reproduce the lip's geometry and material properties. Lips are replaced by two cylindrical latex tubes filled with water whose pressure can be controlled.

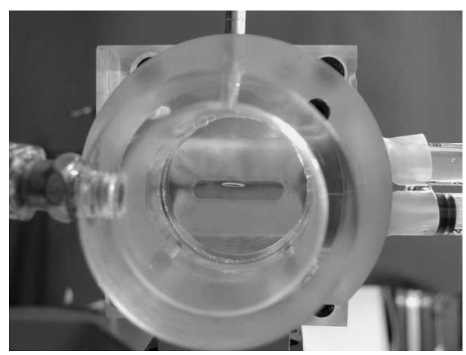

Figure 3: The artificial mouth used in double-reed measurements

The current artificial mouth used in our experiments (fig. 3) is built from *Althuglass* blocks and derived from [13]. The mouth cavity is a cylinder. From one of its bases the mouth's inside can be observed or filmed. The other base is uncovered so that one side of the lips is submitted to the mouth pressure.

The reed is placed between the two latex lips and can be kept in place by a plastic cap which also helps to keep the system leak-proof.

3.2. Determination of the non-linear characteristic

The current artificial mouth provides an easy way to observe the reed opening (z) during playing regimes (see [8]) but also in static regimes, for example. For instance, if we can vary the pressure while preventing the reed from oscillating, we are able to determine the whole characteristic curve, from the closed reed until the rest position.

A method of preventing reed oscillations is described by S. Ollivier in his PhD thesis [14]: pressure oscillations that can propagate throughout the reed and be reflected at its end, are damped by a cover with a small perforated diaphragm. This works as an acoustic resistance which prevents all sound waves from being reflected back to the reed tip.

This technique was used successfully [14] to determine the $q(p)$ characteristic of clarinet and saxophone embouchures in the static regime.

The diaphragm, however, introduces further headloss upstream of the reed. This means that if the diaphragm is undersized, the total characteristic will have the shape of (II) in figure 1, even for a single reed.

3.2.1. Experimental setup

Measurement of the reed opening (area and distance between reeds) was based on images captured by a video camera placed in front of the vibrating reed.

Image analysis consists in the recognition of the slit entrance, which is done by selecting the darker area near a point which is user-defined (from one of the pictures of the series), and some simple measurements of area (pixel-counting) and width of the black spot corresponding to the slit.

3.2.2. Measured reed opening characteristics

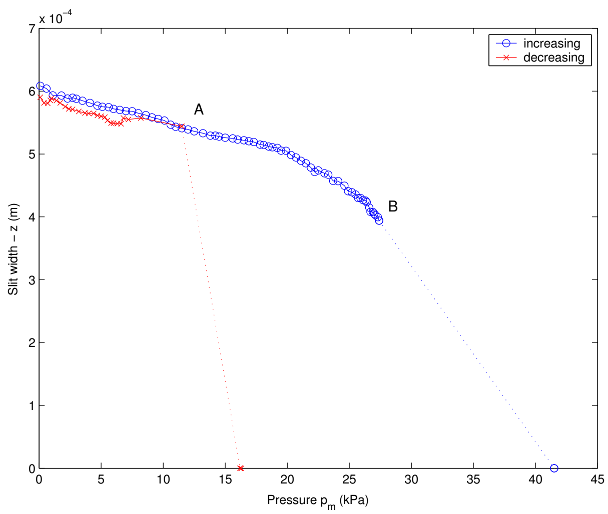

Figure 4: Measured reed opening characteristics

The measured $z(p)$ characteristic on a double reed (fig. 4) shows invariably a great amount of hysteresis, the closing pressure being almost twice as the opening pressure. Comparison of these results to those obtained on single reeds seems to indicate that a stronger head loss takes place in double reeds generating steeper transitions from open to closed reed.

The experiment itself is demonstrative of this fact: while the reed motion from 0 kPa to point B is difficult to observe, once this point is achieved the reed suddenly shuts. During instrument playing the same is expected to happen when the incoming pressure wave reaches the reed, assuming a quasi-static theory for the reed behavior.

One advantage of measuring the reed position characteristic instead of the flow characteristic is that it will soon be possible to compare it to a dynamic characteristic (measured in playing condition). In fact it is easier to follow the quick variations of the reed opening than those of the flow.

4. REED GEOMETRY

One of the key aspects in describing the flow inside the reed is to precisely know the boundary conditions of the flow. In particular, sudden section variations can induce the formation of a free jet that will dissipate its kinetic energy by turbulent mixing, as in the case of the clarinet. Narrow ducts bring the boundary layers closer together so that they can change the flow description [15]. It is therefore crucial to undertake a complete measurement of the duct geometry, and if possible, its variation during the closing and opening cycle.

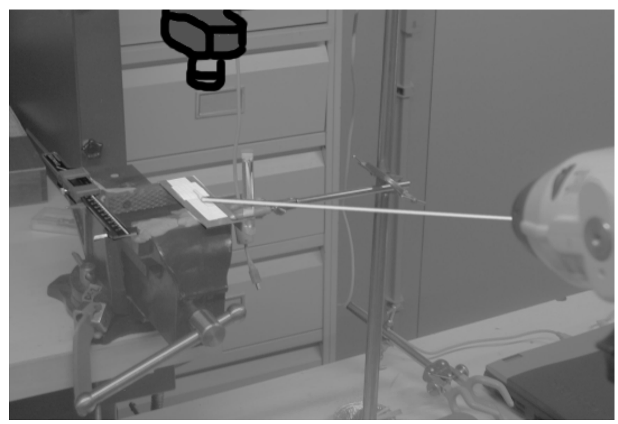

Figure 5: Experimental setup

The inside of several types of double reed was cast into a silicon material. These casts are then used to digitally reconstruct the inside reed profile with the following technique (fig 5):

The cast lies on an accurately moving table (A), whose displacement can be precisely measured (B). The table and the cast are illuminated by a laser beam (C) expanded by a transparent cylinder (E) and striking the table with a small angle (20 deg.). This laser plane would trace an arc of a circumeference (due to the presence of E) over the table if the cast wasn't present (the baseline , A on figure 6). Images are captured from above the reed (D), the direction of observation being perpendicular to the table.

Several images (fig. 6) of the laser plane are captured for different displacements of the cast (about 1 mm). These correspond to sections of the reed parallel to each other. The photographs are then inserted into the computer in order to extract the beam deviation at each point. The cast three-dimensional model is reconstructed from the whole set of photographs of the complete reed.

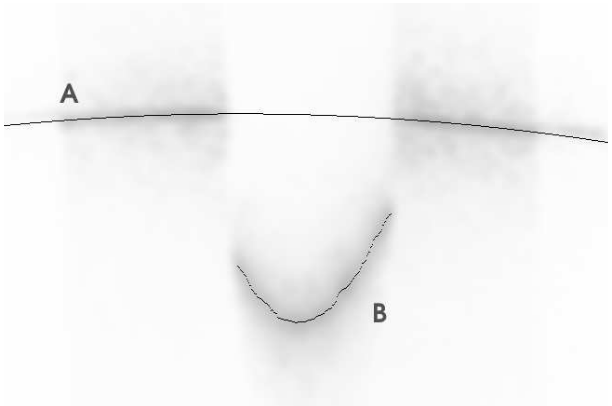

Figure 6: Laser line illuminating the reed cast and computer recognition of the line: A – baseline; B – line deviated by the cast

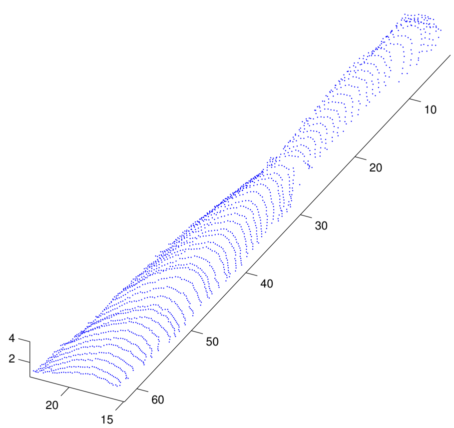

Figure 7: Three-dimensional reconstitution of a reed cast

5. CONCLUDING REMARKS

Although the conclusions are rather crude at the moment, we have highlighted the potential of experimentation on reed instruments to a developement of the theory of double-reed instruments behavior. The knowlege of the geometry of the reed will allow the formulation of theories and simulation on the flow inside the reed. Further measurements on the variation of pressure along the reed provide a way to validate these theories.

On the other hand, the anlysis of the reed characteristic provides a description of its behavior regardless of its causes. It is thus a valuable tool for checking the relevance of the current focus on the flow on the reed behavior, by comparing it to a model based on simplified mechanics for the reed and extended description of the flow.

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