Several ways to stop a note in a clarinet - a comparative view of note extinctions

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In a self-sustained instrument, the sound is maintained as long as energy is supplied to the oscillating system, and the control parameters are kept in a range that permits a periodic regime. Stopping a note is thus a voluntary action, in opposition to what can happen in plucked strings, membranophones, xylophones etc.
In a reed instrument two basic methods of stopping the note can be identified, although usually the musician will use a combination of these. One is to stop the oscillation of the reed by using the tongue, or less likely by using a stronger biting force that can close the reed. The other is to cut the supply in air from the lungs, or to reduce it below a critical level that is called the threshold of oscillation. These two methods have very different consequences on the characteristics of the sound of the note extinction.
Using simulations and experiments, this presentation identifies the main characteristics of each of the extinction methods. Whenever possible, an investigation into the causes of the effects identified in the description are justified with basic models or further experiments.

1 Introduction

A usual simplified view of the clarinet considers it as being controlled by the musician via two basic parameters, one describing the force of the lips on the reed (which bends the reed against the lay), and the other the blowing pressure, inside the mouth of the musician.

When musicians stop the sound they can act on these two parameters, either instantly or gradually. A harsh stop is usually performed via tonguing, which can be seen as a sudden reduction of the opening of the reed, and in a basic model it can be modeled as a sudden increase of the lip force parameter to the point it completely closes the reed opening. Another more natural way of stopping a note is to reduce the pressure without significantly affecting the lip force.

These two orthogonal actions (via lip force or mouth pressure) can be studied as archetypal cases. However quick, the results in the sound are never instantaneous, but differ from one case to the other. The time interval between the moment the musician intends to stop the note until the sound stops will be referred to in this paper as the extinction of the note.

The main aim of this work is to describe the extinction of the note in both the archetypal situations of stopping the reed with tonguing and with a pressure reduction, and to do an unexhaustive comparison with note extinctions in real musical contexts. Both experimental measurements and time-domain simulations will be used in this study. The next section (sect. 2) starts by describing the experimental apparatus used for the measurement of pressure signals in the instrument, followed by a description of the simulation models and algorithms. Section 3 analyses the case of a note stopped by tonguing (or lip force) and traces a comparison with the natural decay rate of the sound in the resonator. A few effects on the pitch and amplitude are also shown in experiments and time-domain simulations. The case of pressure stops is analysed in section 4, and finally a comparative view of both cases and "natural" extinctions in real contexts is drawn in the concluding section.

2 Materials and methods

The current work consists of a comparative view of the behavior of musical instruments (original or simplified) and simulated models of those. They are described in the following sections.

2.1 Apparatus for measuring sound and gesture

The basic apparatus used in these measurements consists of a mouthpiece and barrel to which were fitted pressure sensors (fig. 1). One of these measures the sound inside the barrel, and the other is fitted along the solid edge of the mouthpiece in order to measure static and variable pressure inside the mouth.

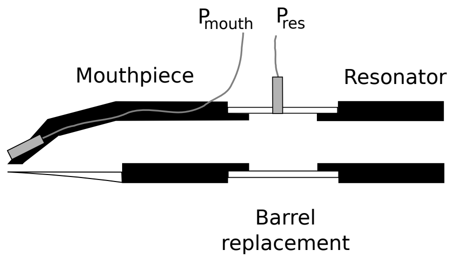

Figure 1: Device used for recording of mouth pressure (P_{mouth}) and resonator pressure signals (P_{res}).

This apparatus is fitted either to a real clarinet resonator or to a straight PVC tube.

2.2 Time-domain simulation methods

The synthesis scheme used for the simulation of note extinctions is that proposed in [1]. The sound signal under consideration is the mouthpiece pressure $p_e(t)$. In the simulations, all variables are dimensionless, using usual conventions for the clarinet model [2]. In particular, pressures are divided by the beating pressure P_M (the minimum static pressure at which the reed closes against the reed), so that:

$$\gamma = \frac{P_m}{P_M}; \qquad p_e(t) = \frac{P_e(t)}{P_M} \tag{1}$$

and ζ is a parameter that includes the force of the lip on the reed via the reed displacement at rest H:

$$\zeta = Z_c\, U_A/P_M = Z_c w H \sqrt{\frac{2}{\rho P_M}} \tag{2}$$

with Z_c the characteristic impedance at the input of the bore, w the effective width of the reed, and U_A the maximum flow admitted by the reed valve.

The aim of the next two sections is to compare the transients produced by Heaviside functions applied on the blowing pressure (γ) and on the admissible volume flow (controlled by ζ).

3 Note stops by flow interruption

In most reed instruments, the tongue is used often for articulation purposes, in particular to stop and start a note. The tonguing can be more or less pronounced, but in extreme cases it can completely stop the reed from vibrating and can block the intake of air into the instrument. This situation is studied here. A musician was asked to abruptly stop the note by severe tonguing the instrument. The results are displayed in figure 2: the blowing pressure and the acoustic pressure inside the resonator (top image, green and blue curves respectively), and a logarithmic plot of the latter (bottom image).

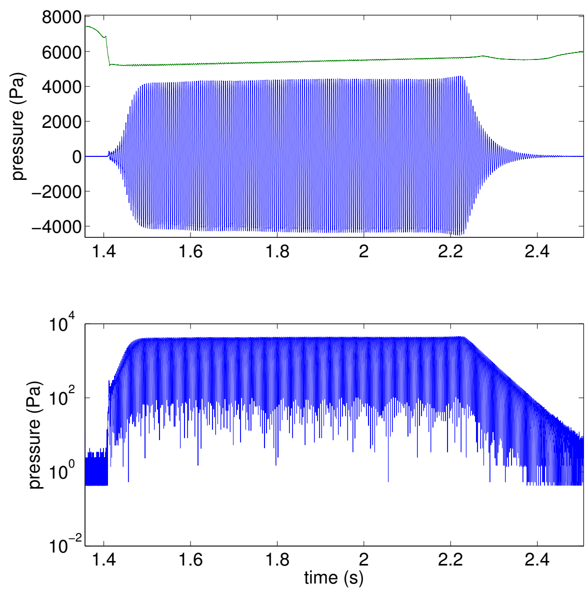

Figure 2: Experimental measurements of the pressure inside the resonator in linear (top graphic) and logarithmic scale (bottom graphic) of a note played on a straight-tube-resonator clarinet and stopped suddenly using the tongue. This particular example was measured on a different device than the remaining examples, with the purpose of showing the mouth pressure (top line).

The oscillation is seen not to stop immediately, but rather to decay with an envelope that is very close to an exponential, as seen on a logarithmic plot where the decay is linear. On the device used in experiments of figure 3 (different than the one in figure 2), for repeated measurements, this exponential decay was seen to take around 67 ms to decrease by 20 dB.

It can also be verified that the blowing pressure is not significantly altered when the tongue acts upon the reed.

A frequency analysis (fig. 3) shows that the partial with lower frequency is the one that decays slower. When the decay starts, the instantaneous frequency jumps from the playing note to a different value.

These two observations are also present in the numerical simulations of an extinction where the reed parameter jumps from its constant value during playing to a closed position (see section 3.1).

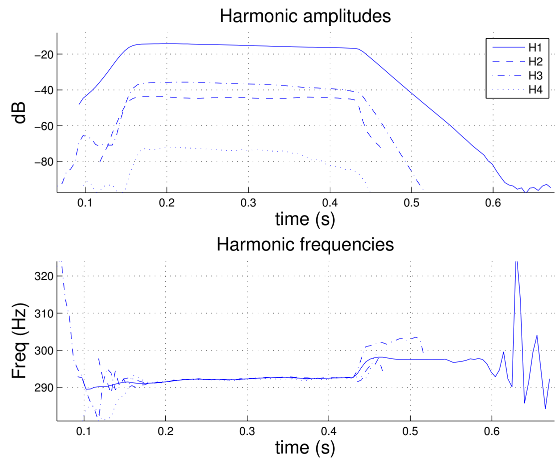

Figure 3: Frequential analysis of the note in figure 2 showing individual harmonic components obtained by heterodyne detection (top), and short-time frequency obtained using a phase vocoder method (bottom)

3.1 Numerical stops via a jump in ζ

The measurements described previously can be related to a transient on ζ. This parameter is suddenly changed from the constant value used for the production of the note ($\zeta > 0$) to a closed reed $\zeta = 0$.

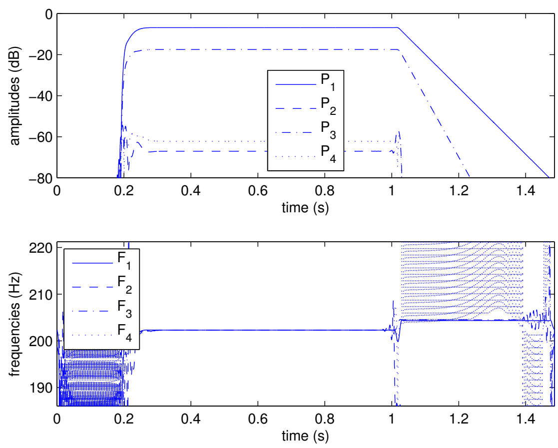

Figure 4: Numerical simulation of the transient on ζ. Top: amplitudes of the first four partials of the mouthpiece pressure. Bottom: frequencies of the first four partials divided by their rank. $\zeta = 0.6$, $\gamma = 0.45$.

The top pictures of figure 4 reveal, from $t = 1s$, a linear decrease of the amplitudes P_i of partial i (in dB) with respect to time. This corresponds to an exponential decrease of the P_i in a linear scale, as expected for a damped linear system. It has been checked that the slopes of decrease for each P_i during the transient do not depend on the control parameters ζ and γ . Moreover, as expected since $\zeta = 0$ cancels all the nonlinear effects of the coupling with the exciter, these slopes are exactly the same as those measured in figure 5 on a frequency analysis of a simulated impulse response.

As far as the instantaneous frequencies F_i are concerned, shortly after the beginning of the extinction transient, they jump exactly to the resonance frequencies of the resonator, as expected. This is also seen in measurements of the tongue stop of figure 3.

3.2 Relation to decay time of the resonator

In both numerical and experimental cases above, during the extinction the amplitude seems to evolve as in a free damped oscillator, and it is reasonable to expect that the parameters of the oscillation, including damping, are given by the modal parameters of the acoustic modes.

A natural decay time of the resonator closed at one end and open at the other can be obtained both from theory or measurement. By neglecting acoustic radiation in the first acoustic mode of the resonator, or any other losses, the attenuation of the sound wave is due to visco-thermal losses in the boundary layer of the plane-wave. Using Benade's approximation to Rayleigh's formulas, the attenuation in amplitude for a wave propagating on a tube of radius a measured in m over a length L corresponds to a factor

$$\exp(-\alpha L) = \exp\left(-\frac{3\times 10^{-5}\sqrt{f}}{a}L\right) \qquad (3)$$

where f is the frequency of the wave in Hz. If the wave propagates at speed c, the attenuation per time t is

$$\exp(-\alpha ct) = \exp\left(-\frac{3\times 10^{-5}\sqrt{f}}{a}ct\right) \qquad (4)$$

In the case of the resonator used in the above experiments, the radius is that of the main bore of the clarinet, 7.5 mm, providing an attenuation factor $\alpha c = 19.7 s^{-1}$, which corresponds to 117 ms for a decay of -20 dB. This value is higher than that obtained in the measurements in the examples below, but comparable to the measurement in figure 2.

The decay time can also be measured using an impulsive excitation of the closed-open resonator. This method has the advantage of allowing to compare to other end terminations. Instead of the rigid termination, the measurement can be performed on a clarinet with a reed, either pressed against the mouthpiece, or open in its natural position.

3.2.1 Numerical simulation of a resonator impulse response

Simulations of an impulse response of the instrument show that the "natural" decay of the resonator is the same as the one obtained in the extinction of the note in figure 2. Figure 5 shows, on top, the variations in a log scale of the amplitudes with respect to the time of the first four partials of the inverse Fourier transform of the impedance (impulse response), in the bottom the instantaneous frequency of the partials divided by their rank.

In this case, the extinction time can be adjusted by using different simulated or measured resonator impedances. In this case the impedance is simulated according to the theory, which explains that the theoretical value of the extinction time (117ms for -20 dB, see section 3.2) is obtained.

3.2.2 Time measurements of the decay time in an closed-open resonator

The decay time of the resonator can also be checked by exciting the resonator with an impulsive source of pressure or flow. An example of a measurement of the natural decay, similar to those in [3]) is shown in figure 6. Different methods of excitation were tried (see also [3]), giving decay times that are significantly shorter than those obtained in the previous measurements, simulations and calculations. Measurements of decay provide times of 65-70 ms for a decay of 20 dB. This value is consistent with the extinction time measured in the same device (sect. 3), although higher values were observed experimantally in other devices.

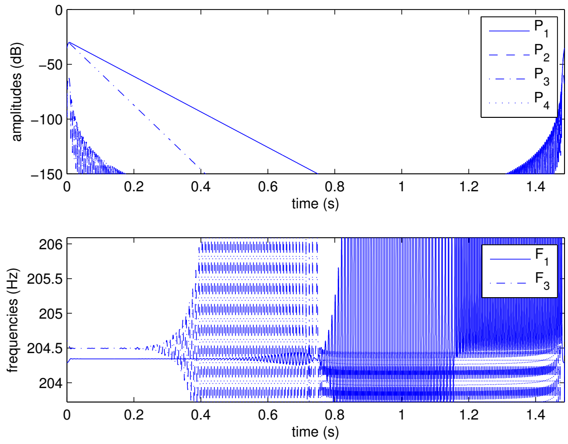

Figure 5: Numerical simulation of the impulse response. Top: amplitudes of the first four partials. Bottom: frequencies of partials 1 and 3 divided by their rank.

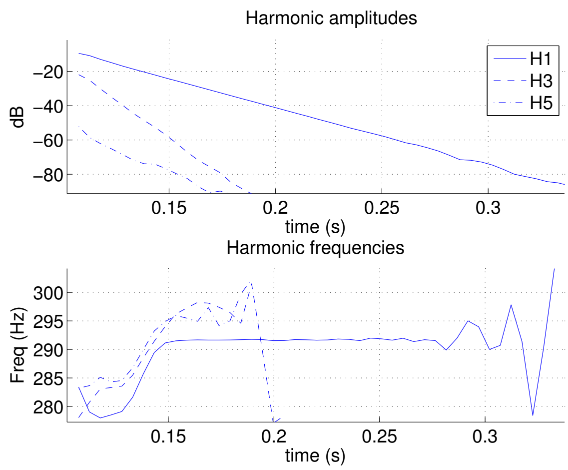

Figure 6: Measurement of the natural decay in the resonator for an impulsive excitation (by tapping with finger on the open edge of the resonator)

4 Note stops by pressure reduction

When no action is taken with the tongue to stop the flow, and the pressure is forced to decrease as quickly as possible by the musician (figure 7), the observed extinction in the sound is much more abrupt than that observed in figure 2. This is also a rather unusual situation in musical conditions, but a more natural breath stop produces similar sound results.

Figure 8 also shows for numerical simulations a very different scenario at the extinction from that analysed in section 3. First of all, the extinction transient is far more

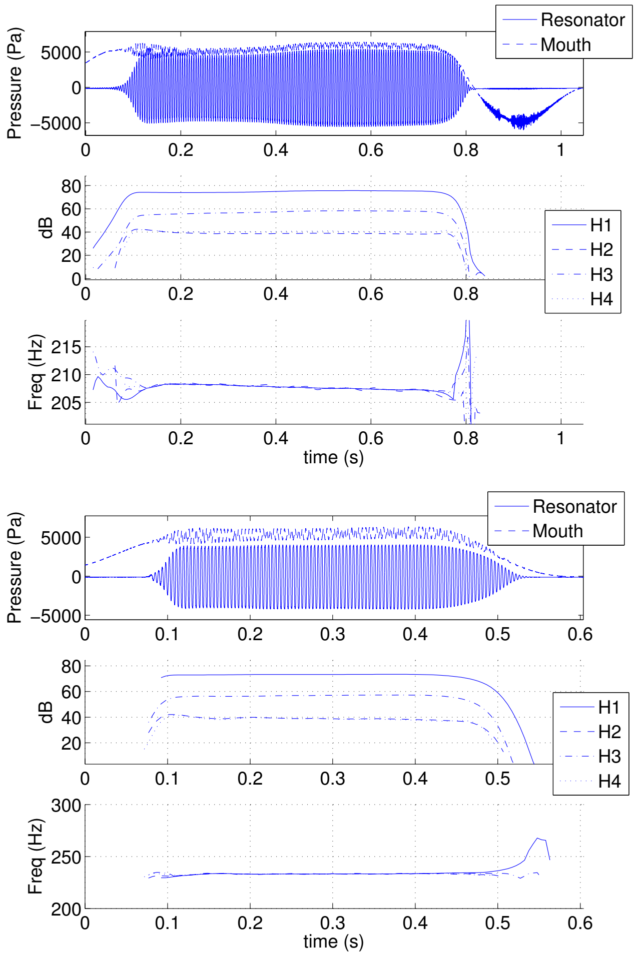

Figure 7: Experimental results : note stopped by an abrupt reduction of the presure (top: forced, bottom: more natural note stop).

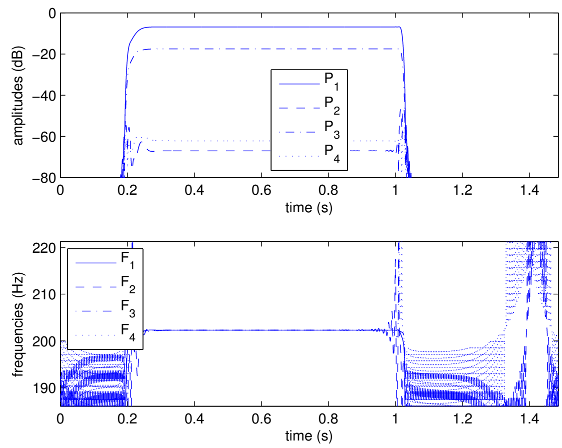

Figure 8: Simulation results. Transient on γ. Top: amplitudes of the first four partials of the mouthpiece pressure. Bottom: frequencies of the first four partials divided by their rank. $\zeta = 0.6$, $\gamma = 0.45$.

rapid than in the previous cases. Moreover, a closer look at the top picture reveals that the decrease of the instantaneous amplitudes P_i is no longer linear. This is the sign that the nonlinear coupling between the exciter and the resonator is still active. Indeed, even if the blowing pressure is set to $\gamma = 0$ at the beginning of the transient, the volume flow at the input of the bore does not vanish.

The evolution of the instantaneous frequencies is hardly distinguishable on the bottom picture of figure 8 because of the very short transient, but F_1 seems to decrease rapidly, whereas the first natural resonance frequency of the bore is above the playing frequency.

Morover, a complementary set of simulations has shown that the duration of the transient depends neither on the reed resonance features nor the values of the control parameters during the steady-state

A transient on γ can be related to a throat attack or extinction with no modification of the embouchure or the tongue position.

5 Conclusions

The type of command plays a very important role on extinction transient. A pressure transient (transient on γ) leads to a very fast extinction of the sound since a nonlinear functioning of the system remains. A reed channel closing transient (transient on ζ) leads to a decrease of the partials directly related to the quality factor of the impedance peaks, since the functioning of the system is linear once the reed channel is closed. Behaviors obtained are coherent between simulations and experiments, as it has been shown in [4] for the saxophone. In the model used, the dimensionless parameters γ and ζ were primary defined from stationnary hypotheses that allow to relate them with physical controls used by the musician. Though ζ is mostly related to the reed channel opening at rest, it can be used as a way to simulate for sound synthesis purposes a tonguing effet that rapidly liberates or obturates the reed channel opening.

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