Study of the extinction of a note in reed instruments

A. Almeida

Laboratoire d'acoustique de l'université du Maine, Bât. IAM - UFR Sciences Avenue Olivier Messiaen 72085 Le Mans Cedex 9
andre.almeida@univ-lemans.fr

In a musical note, the transient is a starting or ending period in which the sound builds up or is extinguished. Though usually brief, it is important for the recognition of the timbre of a musical instrument. In sustained musical instruments such as wind instruments or bowed strings the transient can be controlled by the actions of the musician, by changing key parameters such as blowing pressure or bowing force. This study focuses on the extinction transients in reed instruments. Firstly, the most relevant methods for characterising the extinction of the note are briefly discussed. The extinction duration of recorded notes using different playing techniques is related to the natural damping coefficient of the resonator with different boundary conditions. Analysis of time-variation of the overall sound intensity and individual partials in recorded note endings will be compared to simulations and theoretical models of reed instruments.

1 Introduction

Apart from the information of pitch and intensity, the characterisation of a note includes a more subjective aspect called the timbre. The timbre is what allows to distinguish between a same note played by different instruments, and different playing modes in a same instrument.

A note produced by a self-sustained instrument (such as most wind instruments and bowed strings) can be divided into three periods: attack, sustain and extinction. These are easily identified in a large-scale time plot of the sound envelope: The attack corresponds to a rapid growth of the sound intensity, the sustained period to a roughly constant intensity, and the extinction to a more or less prolonged decrease in intensity from the sustained part to silence.

The sustained part has been the subject of several works in the past [1], allowing for the characterisation of different aspects such as the fundamental frequency, amplitude and harmonic content, and their dependence on the playing parameters (for instance mouth pressure and reed biting force in a reed instrument) [2] [3]. Yet, even if the transients are an important aspect of the timbre of the instrument, not much work exists that can predict the duration or evolution of the harmonic content in a musical note, nor its dependence on the playing parameters. A notable exception is found for the violin [4] and recent works have been focusing on the attack transient of clarinet notes [5] [6].

An important aspect of transients is their duration (i. e. the time taken for the oscillation to increase or decrease from silence to the sustained amplitude), and probably the shape of this decrease: in free-oscillating instruments this decrease is usually close to an exponential with a negative time constant. In a self-sustained instrument, the musician has an added control over the intensity by choosing the correct time-evolution of the playing parameters.

The aim of this article is to determine whether the extinction of a musical note in a clarinet is determined by the natural decrease in energy from the oscillating regime to silence, or conversely, if the musician controls this decrease or lastly by a mix of the two.

In the next section, the natural decay coefficient is measured in the resonator of an instrument, by applying an instantaneous excitation. Then the extinction period is characterised regarding overall extinction times and for each of the first harmonic components, as well as evolution of fundamental frequencies. Note extinctions are compared to free oscillation decays.

2 Damping in a free oscillation

In this section, an oscillation is excited in a resonator that replaces the body of a clarinet by tapping on its end with a finger and immediately removing it. The resonator is in fact a straight tube with a diameter (15 mm) close to that of a real clarinet, and attached on one end to a clarinet mouthpiece. The total acoustic length is 420 mm. The pressure inside the resonator is measured using a 1/4” B&K microphone, providing a signal whose amplitude is roughly a sinusoid multiplied by an exponential (fig. 1).

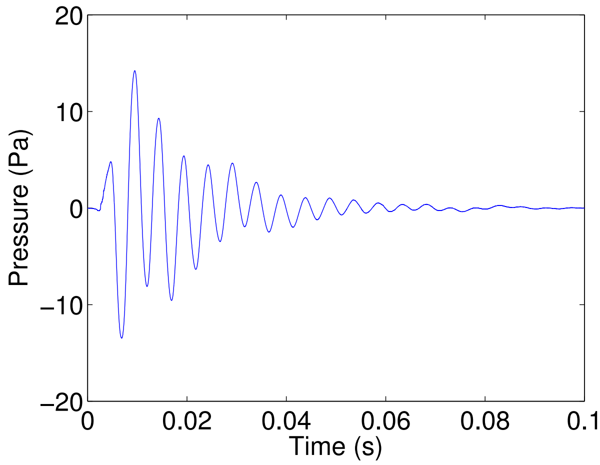

Figure 1: Resonator pressure obtained after an impulse excitation by a finger tap at an extremity of the resonator

The clarinet mouthpiece was fitted with 3 different reed replacements: one was a rigid plate placed at the same position of a reed at rest, secondly a normal reed at rest position (both having an opening slit of about 1 mm), then a completely closed mouthpiece using a rigid termination. The first two terminations implied a free-oscillation frequency of 330 Hz, and the closed termination a frequency of 205 Hz (figure 2.

The envelope of the pressure inside the resonator is calculated within windows of 800 samples (16 ms and about 4 periods in most reed-like termination cases). The mean value is removed per window, and the squared signal is smoothed using a Blackman window function. A plot using a logarithmic scale (fig. 3) shows that the signal is in fact very close to an exponential, and allows to extract the time constant of the extinction (parameter α in a model $x_{env}(t) = x_0 e^{-\alpha t}$). The starting amplitude values of x_0 were arbitrary and could vary by a factor of 3.

This analysis procedure is repeated for about 30 excitations for each case. The results for the meaningful trials are shown in figure 6 together with the results of section 3. meaningless trials were those not having a sufficiently long oscillating signal or with frequencies far from the average frequency (usually due to a bad excitation procedure, for instance leaving the finger for a longer time after the tap).

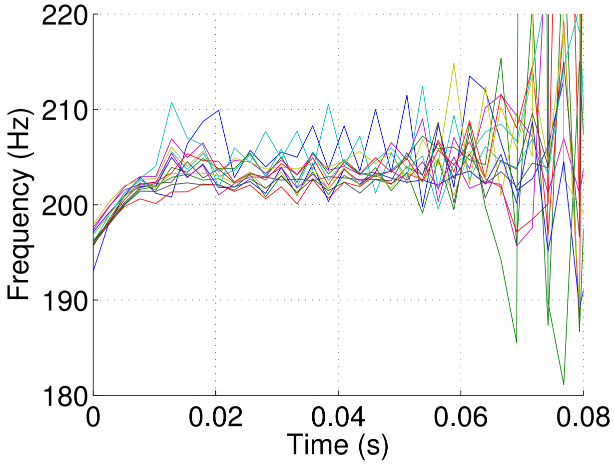

Figure 2: Evolution of fundamental frequency after an impulse excitation on a closed pipe. Several trials are plotted in the same graphic.

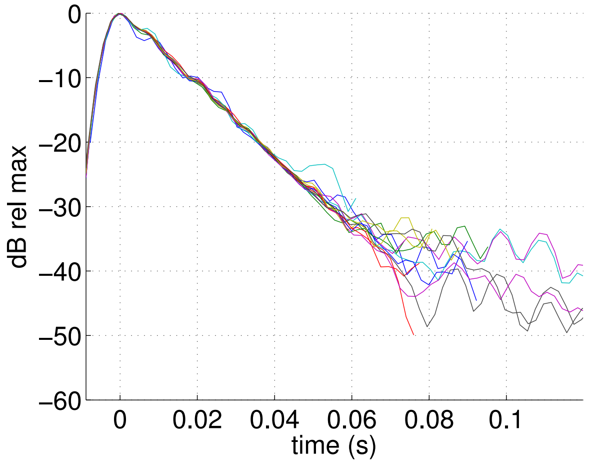

Figure 3: Logarithmic plot of the envelope of the resonator pressure from figure and linear regression on the log signal. Several trials are plotted in the same graphic to show the relatively small dispersion of the profiles

A slight increase in the time constant is noticeable for the soft reed: 73 s^{-1} (std. dev 9 s^{-1}) for the soft reed vs 67 s^{-1} (std. dev 6.6 s^{-1}), showing that the effect of the reed damping is noticeable in the extinction of a free oscillation.

For comparison, the theoretical values for thermal losses for the case of our acoustic system can be calculated via a simplified formula for visco-thermal losses [7] written in the form

$$\alpha = \frac{\alpha_1}{R}\sqrt{\frac{l_v}{c}} + \alpha_2\frac{l_v}{R^2}$$

This yields an attenuation coefficient of 0.0197 m^{-1}, which applied to the propagation of the sound in air corresponds to a time-wise coefficient of 18.2 s−1, a much lower attenuation than that measured in our acoustic system.

The aim of the next section is to check whether the trace of these differences is noticeable in the extinction of a played note.

3 Ending a sustained note

The sound produced by a self-sustained instrument cannot easily be stopped instantly, nor would there be a musical interest in doing so. How fast is the decay of the sound after the musician intends to stop the note is the question addressed in this section. These results will be compared to the ones in previous section, corresponding to the decay of an oscillation in a free resonator.

Instead of a typical note in a musical context, the interpreter was asked to stop the note using three different techniques:

1. by blocking the movement with the tongue (tongued extinction)

2. by decreasing the mouth pressure as quickly as possible without changing his/her embouchure (blow extinction)

3. by releasing the reed as quickly as possible by opening the jaw without reducing the mouth pressure (embouchure extinction)

The intent in these gesture directions is that the instrument is played as close as possible to the following archetypal termination conditions from the point of view of the resonator:

1. a rigid closed termination (null flow)

2. no change in the embouchure (ζ) parameter with an abrupt drop in pressure

3. sudden transition to the free-reed, zero mouth-pressure condition.

Because these are idealised conditions, a secondary aim of the experiment was to measure the speed at which these transitions could be realised, in particular how quickly the blowing pressure could be dropped form the steady pressure during the note to the atmospheric pressure. A miniature Endevco pressure sensor (capable of measuring both static and dynamic pressure up to 100 kHz) was glued to the mouthpiece of the clarinet in such a position that it remains inside the mouth of the musician while playing. This was recorded simultaneously to the resonator pressure, measured using the technique described in the previous section.

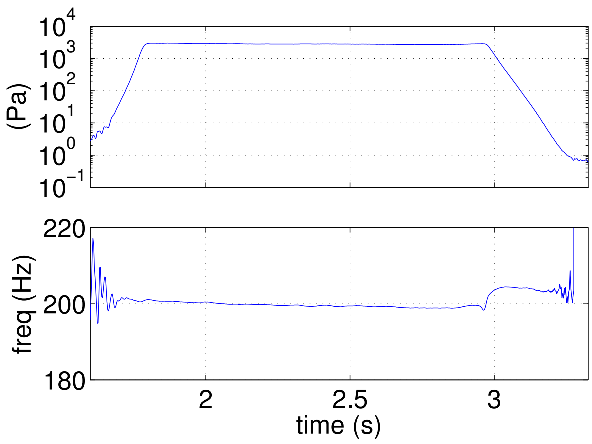

Figure 4: Profile of the fundamental frequency during an extinction performed with a tongued note stop

Tongued extinctions The extinction times measured in the 3 contexts provide a wide range of variation of extinction times and profiles. In the first scenario (tongue extinction) the decrease in amplitude has a distinct exponential profile (fig. 4), with a coefficient that remains more or less constant throughout the extinction (in some of the trials a slight increase in the attenuation coefficient towards the tail of the exponential was noticed). Among different trials, the coefficient was seen to vary more than those measured in free-oscillation decays.

It is interesting to notice that the extinction is much longer than those observed in free oscillation decays. Indeed the values of the decay coefficient range from 25 to 31 s−1, a value much closer to that predicted by theory (see section 2). This difference is surprising if we consider that, after the tongue blocks the reed, the instrument should behave as a freely oscillating resonator with a rigid termination.

Another interesting observation consists in the change in pitch observed after the reed is blocked by the tongue (lower graphic in figure 4). The lower frequency while the note is being played can be understood as a consequence of an effective increase in length due to the flow induced by the reed in its movement.

Blow and embouchure extinctions The last two scenarios of note extinction have similar characteristics, although with different characteristic decay times. Both produce a decay profile which is quite different from the exponential ones observed in the previous cases. When observed in a log scale, it can be seen that the "decay coefficient" (the slope in a logarithmic plot) increases steadily until the end of the decay (fig. 5). Although it is not possible to define the decay coefficient, the highest slope observed in the logarithmic plot was used as a characteristic decay time. The reason for this is that, should the decay tend towards a free-oscillation case, the final stage (and the steepest) of the decay would correspond to this regime. The observations show however that the extinction is much faster than any of those observed in free oscillation decays, either because a non-linear mechanism is still in play at these values of resonator pressure (higher than those of the free-oscillation trials), or because there is some added attenuation by the lips, for instance.

In most trials, the envelope seems to follow closely the

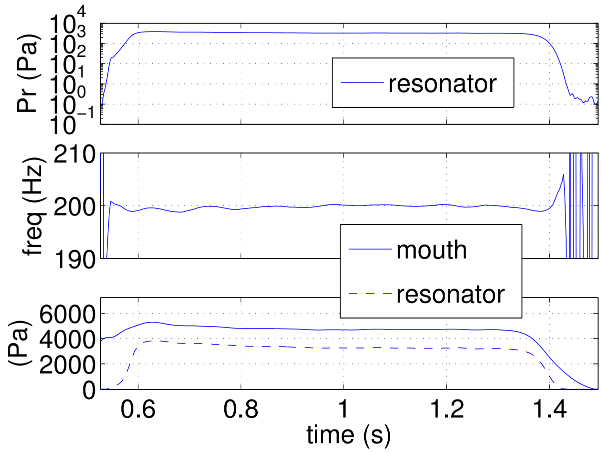

Figure 5: Extinction profiles for a blow extinction case. Top graph shows the envelope of the pressure inside the resonator; middle: fundamental frequency; bottom: comparison of the mouth pressure profile to the resonator envelope, same data as in top but in linear scale.

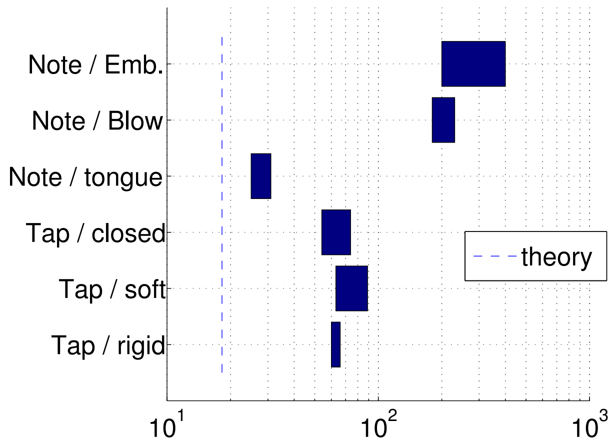

Figure 6: Overview of decay and extinction coefficients observed in this work

evolution of the mouth pressure. Indeed, experimental work on measuring thresholds of oscillation show that the oscillation stops much closer to the predicted static threshold when decreasing the mouth pressure than it starts when increasing it from a non-oscillating regime [8]. If the attenuation is sufficiently high, the oscillation would be expected to end before the mouth pressure falls to zero, because the oscillation threshold would have been crossed. In "embouchure extinction" scenarios, the maximum decay coefficients rise to 400-500 s−1 with much larger dispersions, as it is a cumbersome and unusual gesture for a musician. . .

A comparison of the decay times observed in the different scenarios covered in this work is shown in figure 6, with the theoretical value shown as a vertical dashed line.

3.1 Mouth pressure decay times

Although the aim of this study was to observe extinction profiles for drastic changes in control parameters, there are obviously some physiological limits to the rate of decrease of the blowing pressure. The examples shown are quite representative of the quickest decrease times for mouth pressure, even if different techniques were tried. Typical values are of the magnitude of 40-50 ms to decrease from 90% to 10% of the pressure applied by the musician while playing a note.

4 Conclusion

This preliminary work provides some observations on different extinction profiles that can be obtained by varying the technique for stopping a note. Blocking the reed with tongue allows for a long decaying exponential with a constant coefficient, whereas quickly reducing the blowing pressure produces a sigmoid-shaped sound envelope. In the latter case the extinction starts by decaying slowly, while following the mouth pressure decay, then finishes abruptly as a highly-damped exponential.

Typical decay times in tongued note stops are congruent with the visco-thermal loss theory, although they are longer than those measured on a freely decaying oscillation in the same acoustic system (although in different conditions). This discrepancy could be due to the excitation process (or the fact of having to move and remove a finger close to the resonator. Further work will do similar comparisons on different instruments or resonator replacements.

Mouth pressure decay times are limited by physiological constraints. The release time of the pressure provided for a note cannot be performed quicker than 40 ms. Mechanical blowing machines will be used in future projects to provide for quicker decay times.

Acknowledgments

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