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The Influence of Transients on the Perceived Playability of Brass Instruments

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ABSTRACT

We know that the starting transient of a note is very important for the listener in determining the character of the note, and that this is also true of inter-note transients, or slurs. These transients, and the ease with which they can be executed, play an important role for the player in assessing the quality of a brass instrument. A skilled player may be able to make a slurred transient, for example, played on a poor instrument sound convincing to the listener, but is likely to prefer an instrument on which the same slur can be performed more easily. Recent studies using high speed video cameras, and mouthpieces designed to allow optical access, have revealed much about the mechanics of the brass player's lips and the initiation of the coupling between the lips and the air column, for both starting transients and slurs. In this paper, through the exploitation of a recently developed time domain model of brass instruments, we explore upward and downward slurs from one note to another. Of particular interest is the ease with which the player can slur over larger intervals which encompass one or more intermediate resonant modes.

INTRODUCTION

When sounding a note on an instrument one of the main features that enables the listener to identify the instrument being played is the starting transient (Grey and Moorer 1977). The study by Luce and Clark shows that in the case of brass instruments the starting transient, as played on a wide range of different types of brass instruments, typically lasted for around 50ms (Luce and Clark 1967).

Although the starting transient is of great significance in brass instrument playing this is only one type of transient. In this study we explore the transition between two slurred notes, and concentrate on the transition between non-adjacent resonant modes of the instrument. A player attempting to slur between resonant modes is aiming to produce a smooth transition, which can be more challenging when there are one or more intermediate resonant modes (for example, an octave slur between the 4th and 8th resonant modes). If the tube length remains fixed during the transition the player must slur between the resonant modes by only altering the lips and the flow of air into the instrument; these type of transitions are generally referred to as lip-slurs.

When determining the quality of an instrument the player relies heavily upon the perceived playability of the instrument. A player will assess a number of qualities when choosing an instrument including timbre, intonation, the ease with which the player can start a note and move between notes.

There is a strong coupling between the player's lips and the air column within the instrument when the player has established a note on a brass instrument. This strong coupling is not fully established until after the starting transient, as the player must force the lips to oscillate at or near the desired frequency. This oscillation of the lips must be sustained until the pressure wave propagates to the end of the instrument and is partially reflected back to the player's lips. If the frequency and phase are correct then a constructive reinforcement is established (Benade 1976).

During a lip-slur, the player's lips must decouple from the co-operative regime of the first note, start the second note and establish another co-operative regime. It is the behaviour of the system during this process that we are concerned with here.

Using experimental measurements and a simple one dimensional finite difference model, the behaviour of the system during lip-slurs over an octave interval is explored in this paper. The first section explains the background modelling theory based on Webster's equation, and describes the radiation condition and the finite difference scheme used. The model input parameters are discussed in the following section, with examples of the measured data used for these parameters. The model output results are then compared with experimental data and conclusions drawn.

WEBSTER'S EQUATION AND ACOUSTIC TUBE MODELLING

A standard model of one-dimensional linear wave propagation in an acoustic tube (Morse and Ingard 1968) can be derived from the linearised fluid dynamic equations of conservation of mass and momentum:

$$\frac{S}{\rho c^2}p_t = -u_x \qquad \frac{\rho}{S}u_t = -p_x \qquad t \geq 0, x \in [0,L] \qquad (1)$$

where $u(x,t)$ and $p(x,t)$ are the volume velocity and pressure respectively at any point x and at time t and subscripts t and x refer to time and space differentiation, respectively. Density and wave speed are ρ and c respectively, $S(x)$ is the cross-sectional area of the tube (more precisely, the area of an isophase surface of a propagating wavefront) at position x, and L is the length of the tube. See Figure 1.

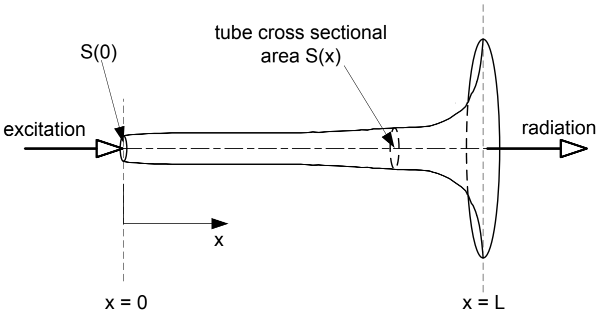

Figure 1: Schematic of the 1-D horn model, with excitation at the mouthpiece and radiated sound from the bell.

>From this first-order system a single second order system is often derived and referred to as Webster's equation (Webster 1919):

$$S\Psi_{tt} = c^2(S\Psi_x)_x \tag{2}$$

where Ψ is a velocity potential, and where $p = \rho\Psi_t$, $u = -S\Psi_x$.

As well as serving as a basic tool in wind instrument modelling, this equation is the starting point for a number of speech synthesis algorithms (Rabiner and Schafer 1978), such as the Kelly-Lochbaum model (Kelly and Lochbaum 1962).

There are many assumptions which lead to this model: linearity, losslessness, slow spatial variation in *S(x)* and smallness of radial dimensions relative to wavelengths.

Through the introduction of the variables $x' = x/L$, $p' = p/\rho c^2$, and $u' = u/cS_0$, and in addition a dimensionless area function $S' = S/S_0$, where S_0 is a reference surface area, such as $S_0 = S(x = 0)$, the system may be written, in scaled form, as

$$\frac{1}{S}u_t = -\gamma p_x \qquad Sp_t = -\gamma u_x \qquad t \geq 0, x \in [0,1] \tag{3}$$

where $\gamma = c/L$.

At the radiating end of the tube, a standard approximation to an unflanged tube end is employed (Atig et al. 2004), (Rabiner and Schafer 1978). The model of the lips is a standard oscillator model subject to a nonlinear pressure/flow relationship (Bernoulli's Law) (Cullen et al. 2000). Not modelled here are viscothermal losses within the instrument; this is a very important effect, especially in portions of the bore of small radius (the throat); as will be seen, the omission of this feature leads to some unphysical behaviour in simulated transients.

A Simple Finite Difference Scheme

Suppose that Ψ_l^n is a grid function, defined for integer l and n, representing an approximation to $\Psi(x,t)$ at $x = lh$, and $t = nk$, where k is a time step, and where h is a grid spacing; $f_s = 1/k$ is the sample rate. A simple difference scheme for Webster's equation (3) follows as

$$\Psi_l^{n+1} = \frac{2(S_{l+1}+S_l)}{S_{l-1}+2S_l+S_{l+1}}\Psi_{l+1}^n + \frac{2(S_l+S_{l-1})}{S_{l-1}+2S_l+S_{l+1}}\Psi_{l-1}^n - \Psi_l^{n-1} \tag{4}$$

where S_l is the surface area at position lh.

A necessary condition for stability is that the grid spacing h satisfy

$$h \geq \gamma k \tag{5}$$

MODEL INPUT PARAMETERS

The input parameters to the model come from experimental data. They include the bore profile of the instrument together with information about the reed (ie the player's lips), including reed area, mass and resonant frequency, and also information about the pressure in the oral cavity of the player. Many of these parameters are time dependent and their values have been based on earlier experimental work carried out by the authors (Chick and Logie 2009),(Logie et al. 2010).

Examples of the instantaneous frequency during upward and downward slurs between the notes D_3 and D_4 are shown in Figure 2, together with the resonant frequency of the reed. The model presented here assumes that the lips of the player act as an 'outward-swinging door' (Fletcher 1999).

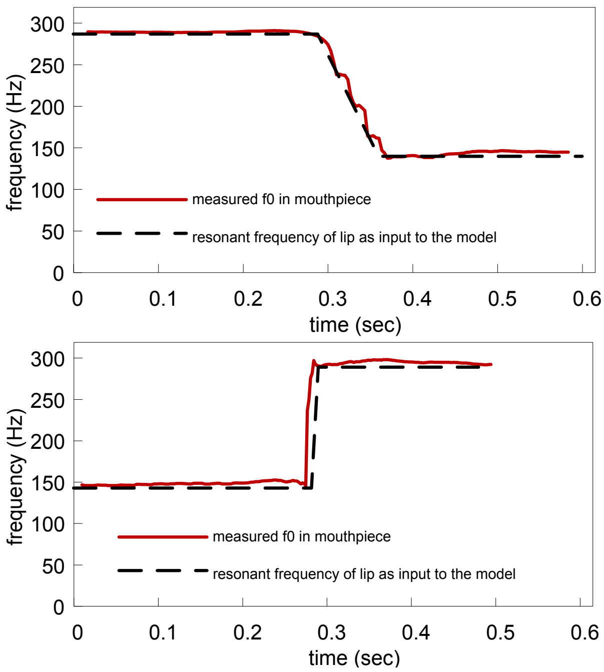

Figure 2: Instantaneous frequency of the pressure signal measured in the mouthpiece together with the resonant frequency of the lips used as input to the model, Top: downward slur from D_4 to D_3, Bottom: a upward slur from D_3 to D_4.

The blowing pressure recorded in a player's mouth during a slur between D_3 to D_4 is shown in Figure 3, together with the simplified pressure profiles used as input to the model.

RESULTS

The player has control over a large number of variable parameters when sounding a note on a brass instrument. When performing a lip-slur a number of these parameters are altered, some subtly and others more drastically. With such a large number of parameters to define and adjust, modelling slurred transitions is not a simple process, and many factors influence the output of the model. Presented here are the preliminary results from the time domain finite difference scheme model described earlier.

Figure 4 shows the experimentally measured radiated pressure and instantaneous frequency for an upward slur between the

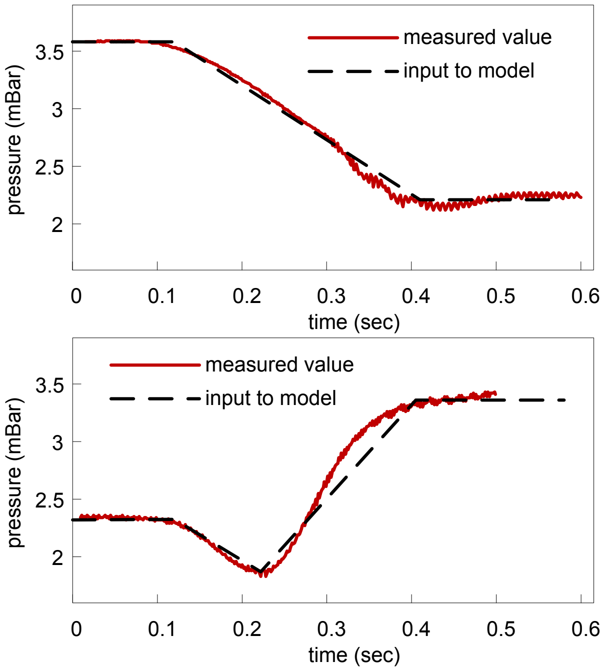

Figure 3: Pressure histories measured in the player's mouth together with the simplified profile used as input to the model, Top: downward slur from D_4 to D_3, Bottom: upwnward slur from D_3 to D_4.

notes D_3 and D_4 played on a horn. It can be seen that the pressure signal has a very small amplitude during the transition and a sharp change in frequency between the initial and final sounded notes.

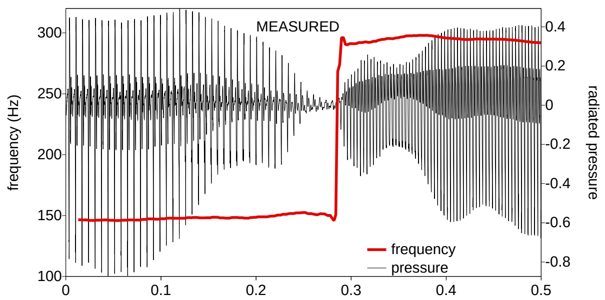

Figure 4: Measured radiated pressure and instantaneous frequency signals recorded at the bell during a upward slur from D_3 to D_4.

The model output for an upward slur between the notes D_3 and D_4 can be seen in Figure 5. Unlike the measured pressure signal for an upward slur, there is a significant amplitude signal throughout the transition. A possible cause of this increased amplitude signal could be the lack of viscothermal losses in the model. As the resonant frequency of the lips decreases, between the initial and final notes, the intermediate resonances will be excited. In the model it appears that these intermediate resonances ring on for several cycles after they have been excited, again because there are no losses within the instrument. The instantaneous frequency result from the model output shows that the model does not give as smooth and direct transition between the two notes as the real player.

Figure 6 shows the measured radiated pressure and instantaneous frequency for the experimentally measured downward slur from notes D_4 to D_3. It has been found in previous work (Logie et al. 2010) that the results show significantly different characteristics for upward and downward slurs on a horn. We

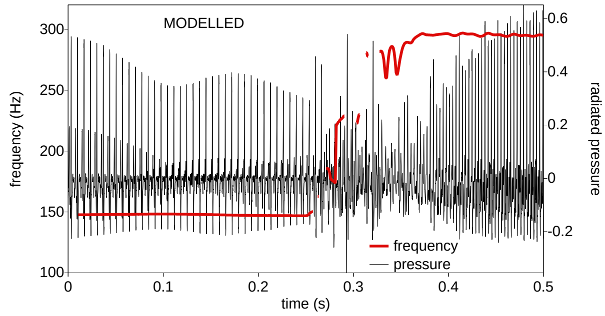

Figure 5: Modelled radiated pressure and instantaneous frequency signals during a upward slur from D_3 to D_4.

can see from Figure 6 that during the transition the amplitude of the pressure signal during the transition does not decrease to the same extent as for the upward slur and that the instantaneous frequency shows marked steps during the transition. The steps in the frequency signal correspond approximately to the pitches of intermediate resonant modes of the instrument; the 5th, 6th and 7th modes.

The modelled output of a downward slur from D_4 to D_3 is shown in Figure 7. It can be seen that the system auto-oscillates throughout the transition and again has a reasonably large amplitude pressure signal during the transition. The lack of losses within the instrument are again influencing the transition and giving rise to the intermediate resonances and transients ringing on. The quality factor corresponding to the resonance of the player's lips in the model is unrealistically high; this is necessary in order to achieve self-sustained oscillation because of the lack of internal losses in the resonator. The high quality factor will in turn make it more difficult for the model to slide between resonances of the instrument.

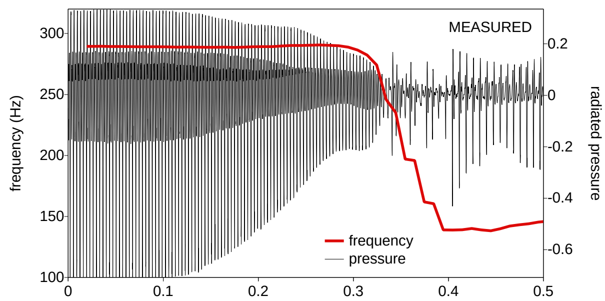

Figure 6: Measured radiated pressure and instantaneous frequency signals recorded at the bell during a downward slur from D_4 to D_3.

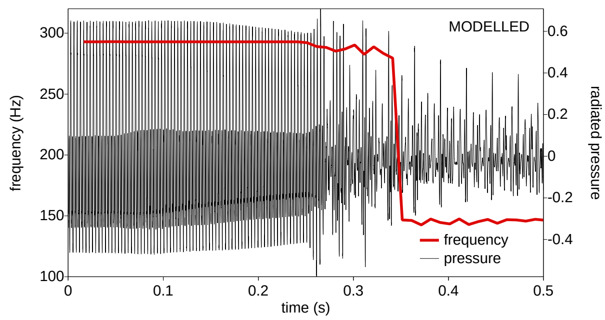

Figure 7: Modeled radiated pressure and instantaneous frequency signals during a downward slur from D_4 to D_3.

CONCLUSIONS

In this study we have used a newly developed time domain model to explore slurred transients on the horn.

On listening to the output from the model, for both upward and downward transitions, the sound resembles a reasonable slur played on a horn. It can be seen from the results that there is a steady state motion of the initial and final notes and a transition region. The transition region is not being modelled exactly in accordance with the experimental data; however, as a preliminary study of using this time domain model to explore such features it has been successful. The model has shown clear interactions between the resonant modes of the instrument and auto-oscillation sustained between the initial and final notes.

FURTHER WORK

The principal area of further work is to incorporate a suitable viscothermal loss model into the modelling software. Viscothermal losses within the instrument, although not the most significant source of loss, are very important, and the inclusion of this in the model will allow the behaviour of the system to be more accurately modelled. They are, however, extremely difficult to incorporate in a time/space PDE model suitable for time integration, as they generally rely on temporal fraction derivative terms; filter-based approaches have been investigated recently—see, e.g., recent work by Mignot (Mignot et al. 2010).

It would be extremely interesting to investigate the effect that small changes in the bore profiles of brass instruments have on slurring. Direct time/space domain modelling lends itself to this area of study, since it is much easier to change the bore profile as an input parameter than to locate a number of instruments with slightly differing bore profiles.

Another area which would be of great interest to investigate is the exploration of different approaches to slurring by different players; a significant difference in approach between players has already been observed in playing upward slurs.

This work is looking to the long term goal of fully understanding the relationship between the player's opinion on the quality of a given instrument and the measurable features of its construction and acoustical behaviour. When evaluating the 'responsiveness' and hence quality of an instrument, players rely heavily upon the ease with which notes can be started and specific slurring techniques initiated and controlled. Being able to compare experimental measurements of such features with output from a time domain model is invaluable in the study of this area of brass instrument acoustics.

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