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# 10ème Congrès Français d'Acoustique

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## Upward and downward slurred transients on brass instruments: why is one not simply the inverse of the other?

Shona Logie<sup>1</sup>, John Chick<sup>2</sup>, Sam Stevenson<sup>1</sup>, Murray Campbell<sup>1</sup>

<sup>1</sup> School of Physics, University of Edinburgh, UK, {shona.logie, samuel.stevenson, dmc}@ed.ac.uk

<sup>2</sup> School of Engineering, University of Edinburgh, UK, john.chick@ed.ac.uk

Recent experimental research on the transient behaviour of brass player's lips, when slurring between two notes, has shown that the player uses significantly different techniques for slurring upwards than for slurring downwards. This is particularly noticeable when the player moves between larger intervals : to or from the fourth resonant mode to the eighth mode, for example. This study explores the physics behind these different slurring mechanisms through the analysis of experimental data from high speed video capture synchronised with pressure data measured in the mouthpiece and at the bell exit. Predictions based on recently developed time domain models of brasswind instruments are compared with the experimentally observed phenomena.

### 1 Introduction

It is widely acknowledged that the starting transient is of great importance for the listener in differentiating between musical sounds made by two different instruments, as noted by Grey and Moorer for example [1]. In the case of brass instruments, the classic study by Luce and Clark presented a spectral analysis of the radiated sound at the start, or 'attack', of notes played on a wide range of different types of brass instrument, and established that the starting transient lasted, typically, for around 50ms [2].

However, this is only one type of transient. In this paper we aim to explore the transition between two slurred notes sounded on a brass instrument, and in particular, the transition that occurs when the player attempts a smooth transition between non-adjacent resonant modes such as an octave slur between the 3rd and 6th modes or between the 4th and 8th modes. Slurs such as these, between different modes of a fixed tube length are generally referred to as lip-slurs.

When assessing the qualities of a note sounded on a musical instrument the transient, either in starting a note or between slurred notes, is one of the most important features. This is true not only for the listener but also for the player. For a brass player evaluating a new instrument, he or she will be concerned with issues such as intonation and timbre, the responsiveness of the instrument to start a note, and also the ease with which the player can move between notes, including slurred intervals such as those described here.

Different players have different approaches to producing a smooth sounding slur. For example, the well known horn teacher Philip Farkas advocates a technique in which the player practices a glissando 'catching' the intermediate resonances en route from the first note to the second as shown in Figure 1. The speed of the glissando is increased until a smooth musical slur is achieved

[3]. An alternative approach is to stop the first note and discreetly start the second note as quickly as possible, producing the aural illusion of one note moving smoothly to the next.



FIGURE 1 – Philip Farkas' pedagogic exercise for the production of "full sounding, velvety slurs" [3].

When sounding a note on a brass instrument the player establishes a strong coupling between the air column and the vibrating lips. In the case of a starting transient the player forces his or her lips to 'buzz' at or near the desired frequency, and to sustain this buzzing for the time it takes for the sounding wave to travel from the player's lips to the bell of the instrument, where some of the sound is radiated to atmosphere, and some is reflected back down the instrument. If the frequency and phase are correct then a constructive reinforcement is established, as described by Benade [4].

When slurring between different resonant modes the player needs to uncouple the lips from one co-operative regime and initiate a second co-operative regime. The aim of this work is to better understand the mechanics of this transition by analyzing data from high speed video capture of the brass player's lips, synchronised with pressure data measured in the mouthpiece and at the bell exit.

### 2 Experimental Procedure

The instrument used for these experiments is an orchestral horn, a Conn 28D, F/Bb double horn, circa

2000. This is a popular and widely used professional level instrument.

The tests focused on slurs between the two notes  $D_3$  and  $D_4$ . In one set of tests the player used valve combinations on the horn which crooked the instrument into 14ft D (giving a horn approximately 4.42m in length [5]), such that the player was slurring between the 4th and 8th resonant modes. In a second set of tests valve combinations were used which crooked the horn into 11ft G (approx 3.26m), such that the player was slurring between the 3rd and the 6th resonant modes.

Two skilled horn players were used to each carry out this simple test matrix.

## 2.1 Experimental Set-up

To gain optical access to the player's lips a specially designed mouthpiece has been used, similar in concept to that described by Richards [6]. The cup of the mouthpiece is machined from perspex with an optical glass window approximately parallel to the face of the player, as shown in Figure 2. The dimensions of the rim, cup volume, and shank (including throat and backbore) are based on those of a Paxman 4C mouthpiece. Clearly the shape of the cup is very different from that of a conventional mouthpiece, but we have assumed that the cup volume is the most important design parameter [7].

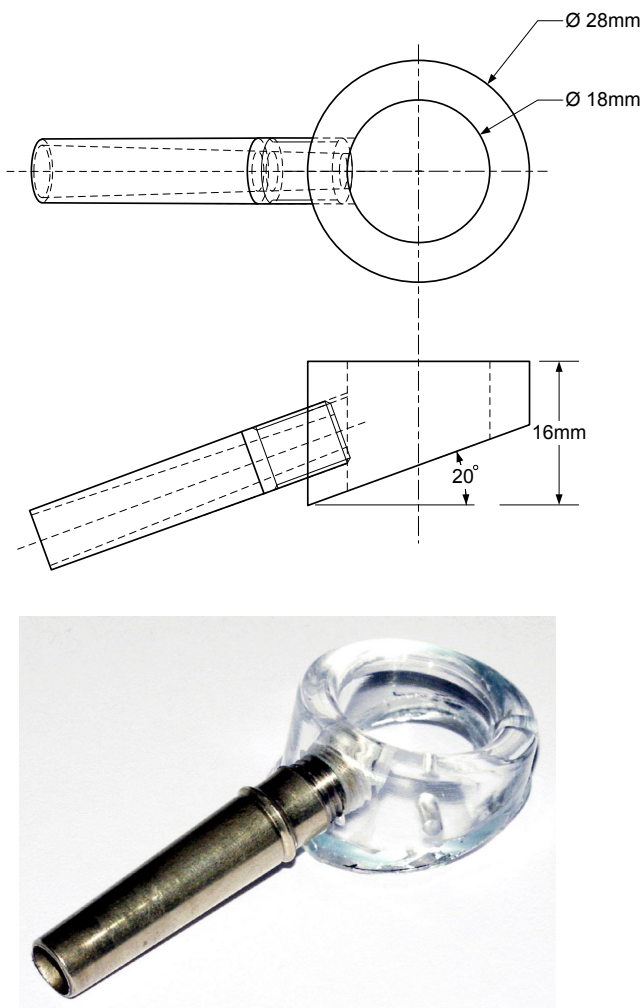


FIGURE 2 – Schematic and photograph of the horn mouthpiece, modified to provide optical access.

The test facility is shown in Figure 3. A high speed camera, taking 5000 frames per second, is focused on the player's lips through the optical glass window in the mouthpiece. Additional illumination is provided by a fibre optic cold light source.

A 106B PCB Piezotronics dynamic pressure transducer, with short probe attachment inserted through a 2mm diameter hole in the side of the mouthpiece, was used to measure the pressure in the mouthpiece. Radiated sound from the bell of the instrument was measured using a Bruël and Kjær 4192 pressure-field microphone, located one bell diameter from the plane of the bell of the instrument. Signals from both transducers were fed to a Bruël and Kjær PULSE system for data acquisition and synchronisation with the high speed video data.

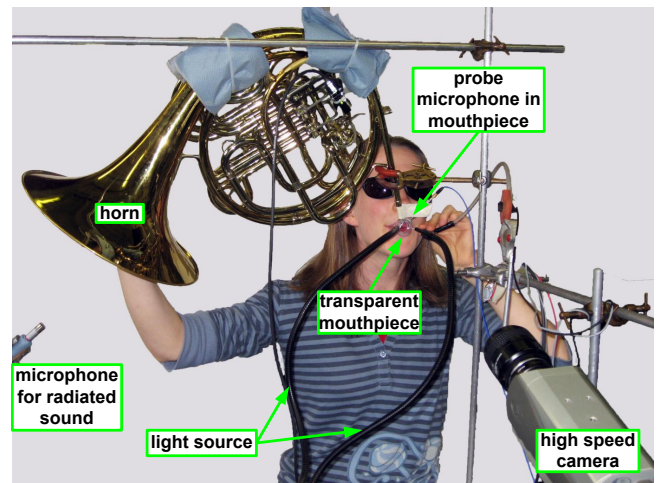


FIGURE 3 – Experimental set-up.

## 2.2 Analysis of Experimental Data

A MATLAB script was used for post processing of the video data to estimate the open area of the lips. Each frame was 'binarised' such that each pixel with a greyscale value below a certain threshold level was set to black, ie the open area of the lips, as shown in Figure 4. These pixels were counted for each image sequentially, giving open area as a function of time.

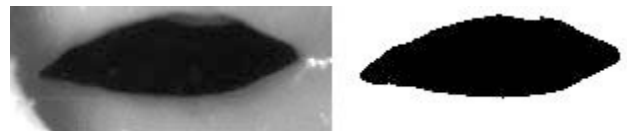


FIGURE 4 – Single frame from the high-speed camera and the processed image showing the open area.

Frequency analysis and estimation of instantaneous fundamental frequency was carried out using *Praat* phonetics software [8].

## 3 Results

Examples of the measured data for an upwards slur between notes  $D_3$  and  $D_4$ , sounded on a 4.42m long horn (ie pitched in D) are shown in Figures 5 and 6. These are played by two different players, each with a different

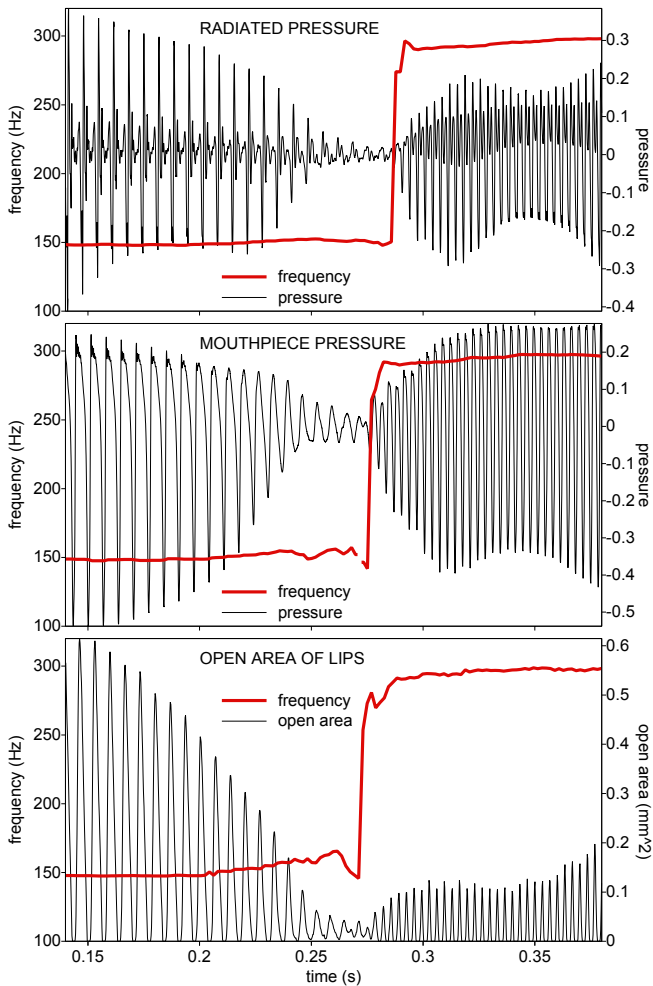


FIGURE 5 – Synchronised signals and instantaneous frequency for lip slurs from  $D_3$  to  $D_4$ , played by player A on a 4.42m D-horn.

approach to performing these types of slurred interval as described above. Player A, in Figure 5, effectively stops the note  $D_3$  and quickly starts the note  $D_4$ . This is achieved by a combination of numerous parameters, including changes in the tension of the lips, blowing pressure, jaw and tongue positions. When asked about their approach to carrying out this type of slur, Player A stated that there was no conscious intent to stop the first note in order to restart on the second note, and that the sensation was actually one of continuously sounding (or blowing through) the instrument during the transient. In fact, the radiated sound becomes almost inaudible for a period of 20–25ms before the note  $D_4$  begins to sound.

The approach of player B is to adopt the technique suggested by Farkas [3], and to consciously practice sounding the intermediate resonances, increasing the speed that these are played at until a smooth slur is produced. Figure 6 shows that the same slur for player B lasts significantly longer than that of player A. We can see from the pressure signals measured in the bell and mouthpiece, that the intensity of the sound does not diminish as much as that of player A, and that although there is some unevenness, the frequency moves more progressively between notes. Careful inspection of the data from all of the upward slurs from player B revealed no discernable sounding of intermediate resonances.

At the time these experiments were performed, both

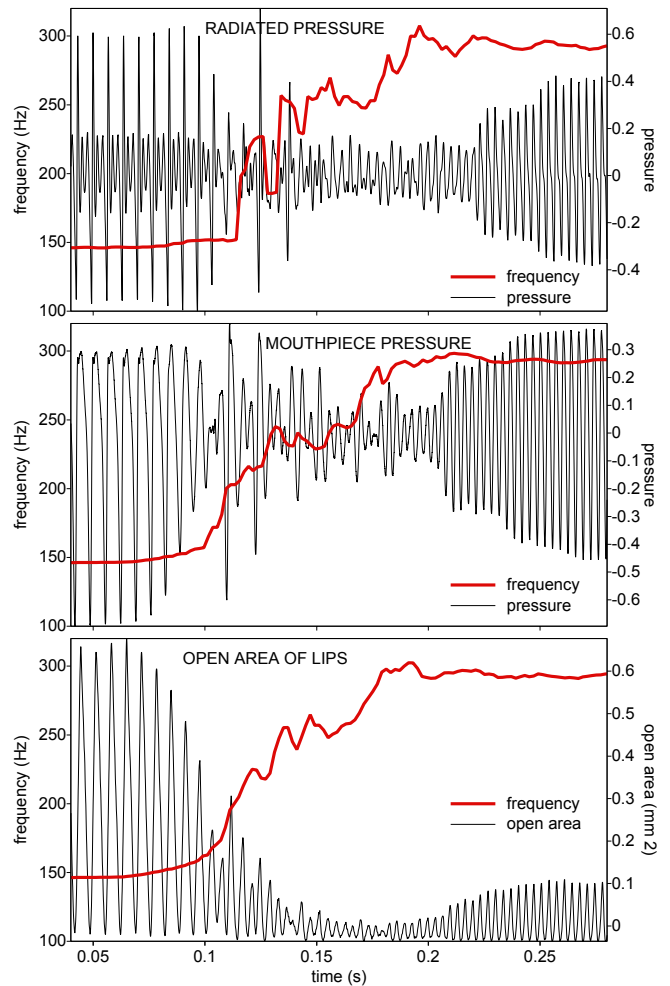


FIGURE 6 – Synchronised signals and instantaneous frequency for lip slurs from  $D_3$  to  $D_4$ , played by player B on a 4.42m D-horn.

of these different styles of upward slurs sounded ‘clean’, smooth and musically satisfactory to the players and other researchers present in the acoustics laboratory. Closer inspection of the signal recorded by the microphone close to the bell exit indicated that there was audible noise present in the upward slurs of player B.

Figures 5 and 6 are examples of slurs between the 4th and 8th resonant modes sounded on the 4.42m long D-horn. The same tests were carried out on a shorter length of tubing, ie with a valve combination giving a 3.26m long G-horn. On this length of instrument the same octave slur between  $D_3$  and  $D_4$  is achieved by sounding the 3rd and 6th resonant modes. Analysis of the experimental data from these tests produced results which were very similar to those for the longer horn.

Figure 7 shows an example of data taken from a downward slur from  $D_4$  to  $D_3$  played on the 4.42m D-horn. This example is typical of results from both players A and B. The behaviour of the lips and pressure signals is different from those observed during upward slurs. Here, the frequency of the opening of the lips is monotonically decreasing, with little or no decrease in amplitude of oscillation, as shown in the lower graph of Figure 7. It is not yet clear why the players are able to force their lips into making a smooth transition from a high resonant mode to a lower one, but less able to do so when moving from a low to high resonance.

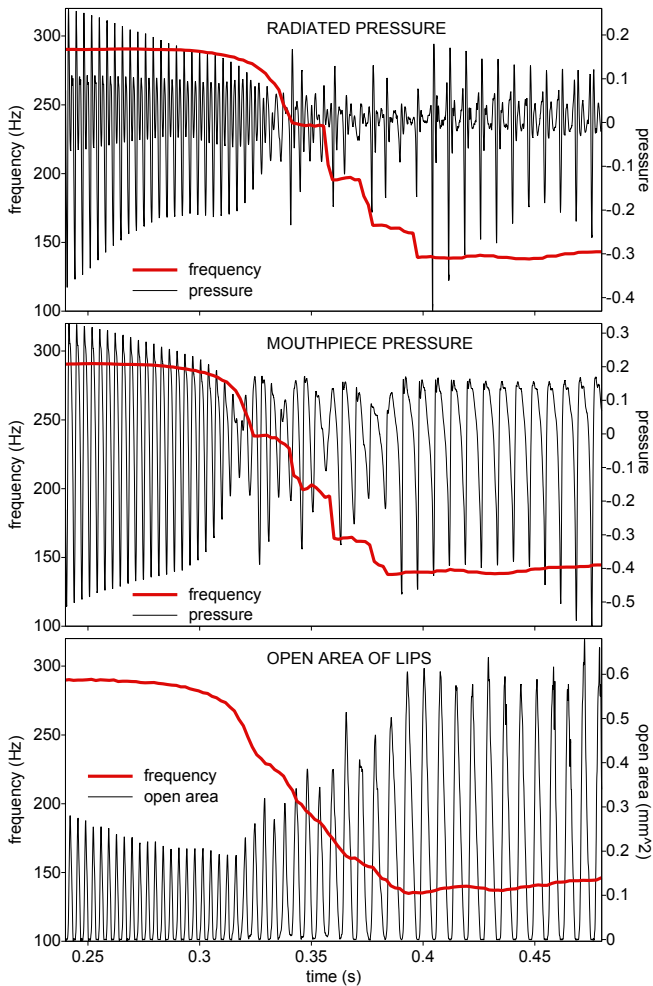


FIGURE 7 – Synchronised signals and instantaneous frequency for lip slurs from  $D_4$  to  $D_3$ , played by player B on a 4.42m D-horn.

Analysis of the pressure signals in the mouthpiece and at the bell exit, however, show three marked step changes in frequency between the initial and final notes. These correspond approximately to the pitches of the 5th, 6th and 7th resonant modes of the tube, although the measured values are consistently lower (by approximately 50 cents) than we might expect. Similarly, for tests carried out slurring from the 6th to the 3rd mode of the 3.26m instrument there were two intermediate step changes in frequency, also corresponding to those of the 4th and 5th modes, but approximately 50 cents lower.

The duration of these intermediate frequencies is approximately 0.01 sec, significantly less than the time needed to establish a co-operative coupling between the lips and the air column. It is interesting to hypothesise that these short duration resonances are ‘ringing’ effects induced by the frequency sweep of the lip oscillations and corresponding excitation at the input to the instrument.

## 4 Conclusions and perspectives

This exploration into the mechanics of brass players’ lips during slurred note transients has uncovered some interesting characteristics.

Slurring on a brass instrument requires the precise coordination of a number of different variables, under the direct control of the player as mentioned previously : most importantly, the correct changes in the pressure in the mouth, and size and tension of lip aperture must occur in order to move smoothly from one note to another. The amplitude and rate of change of these variables are not so exact as to imply only one correct approach to slurring, and indeed, it has been shown that, for upward slurs in particular, the player does have a certain degree of control over how the transition is made, while downward slurs showed much more continuity among the different players and instruments.

Some of the patterns that were observed for all instruments and players included the following :

- upward slurs generally occurred over a shorter time span than downward slurs.
- also, for upward slurs, the lip aperture decreases significantly before settling on the desired note, but for the downward slur, the lip aperture steadily increases until the lower frequency is sounded.
- during the downward slur, intermediate resonances were observed to ‘ring’ briefly as a result of the excitation sweep.

These differing characteristics were consistent for all measurements taken.

### 4.1 Further Work

Given that there is a significant difference in approach between players to performing an upward slur, it would be interesting, in future experiments, to explore how the player approaches slurs in different contexts. For example, the expressive romantic upward slur that appears in a Strauss horn concerto, compared with perhaps an upward slur from a Mozart horn concerto or Bach’s 1st Brandenburg concerto.

It would also be interesting to look at different models of instrument to see what effect small changes in the bore profile of brass instruments have on slurring transients. Gregor Widholm has carried out some interesting research into the influence of the position of the valves within the instrument tube length on the ease of slurring, focusing primarily on the difference between Vienna horns and the modern double horn [9][10]. Previous research has also examined the link between changes in bore profile and the timbre of an instrument but issues relating directly to the technique of slurring are still relatively unknown.

The role of the shape of the cavity of the mouth and movement of the brass player’s tongue might also be an interesting area to investigate. Brass instructors often talk about changing the shape of the mouth cavity from ‘aaah’ to ‘eeee’ when slurring upwards and vice versa.

The long term goal of the present work is to clarify the relationship between a player’s subjective musical judgment of a given brass instrument and the objectively measurable features of its construction and acoustical behaviour. The ease with which specific slurring techniques can be initiated and controlled is one of the factors likely to be considered by players when evaluating the ‘flexibility’ or ‘responsiveness’ of an instrument. Time-domain computer simulations will provide a va-

luable test bed on which to explore the influence of different aspects of a brass instrument's design on the nature of the transients in slurred transitions. A very promising approach which is well adapted to this problem is the Modal Resonator-Reed Interaction Simulation Code (Moreesc) developed by Fabrice Silva and colleagues at the Laboratoire de Mécanique et d'Acoustique (CNRS UPR 7051) in Marseille [11].

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