PROCEEDINGS of the
23rd International Congress on Acoustics
9 to 13 September 2019 in Aachen, Germany

The effect of fast trombone slide glissandi on the mechanics of artificial lips

D. M. CAMPBELL(1), A. LOPEZ-CARROMERO(2), J. A. KEMP (3)

(1)University of Edinburgh, United Kingdom, d.m.campbell@ed.ac.uk

(2)University of Edinburgh, United Kingdom, alopezc2@ed.ac.uk

(3)University of St. Andrews, United Kingdom, jk50@st-andrews.ac.uk

Abstract

The lips of a brass player can be modelled as a mechanical oscillator which couples with the acoustic resonances of the instrument to generate and sustain a musical note. On instruments like the modern orchestral trumpet, operation of a valve changes the length of the resonator without significantly altering the mean pressure of the air column. On a slide trombone, however, a glissando involves a telescopic change in the length of the resonator, resulting in localised changes in the mean pressure in the air column. The consequent low frequency fluctuations in mouthpiece pressure can disturb the equilibrium position of the lips, affecting their dynamic behaviour. This paper describes experimental studies in which an artificial mouth is used to investigate the infrasound mouthpiece pressure gradients generated by fast glissandi on a trombone, and their influence on the mechanics of the oscillating lips.

Keywords: Brass wind instruments, playing transients, lip dynamics

1 INTRODUCTION

Previous studies have shown that fast trombone slide movements, such as the ones performed by the player during glissando, introduce infrasound pressure (ISP) variations inside the instrument which are approximately proportional to the slide acceleration. The amplitude of the pressure fluctuations can reach 100 Pa inside the slide when the instrument is connected to a loudspeaker cavity [1, 2]. When the instrument is connected to a soft termination, such as the one present in the artificial mouth used in this experiment, infrasound pressures of around half this value have been observed [2].

These pressure fluctuations are transmitted through the instrument to the mouthpiece, where they induce very low frequency modulation of the position of equilibrium around which the lips oscillate when playing. To investigate whether this modulation exerts a measurable influence on the behaviour of the lips during fast glissandi, an artificial mouth connected to a King tenor trombone has been studied. The pressure across the lips is measured using two high pressure microphones, one in the mouth and another in the mouthpiece, and the lip opening is tracked using a light transmission setup consisting of an optical rail, lenses, a laser and a photodiode. The position of the slide against time is also tracked using a distance measuring laser.

The physical effects of ISP variations on the artificial lips are evaluated by performing fast inward and outward glissandi across different slide positions x, so that a comparison can be established with the playing behaviour measured with stationary slide at the same positions.

2 METHODOLOGY

The experiments were carried out in an acoustics laboratory in the James Clerk Maxwell building at the University of Edinburgh. The space has low reverberation but is not anechoic, since this characteristic was not needed in the present experiment. Figure 1 shows a general schematic including all the apparatus used in the setup.

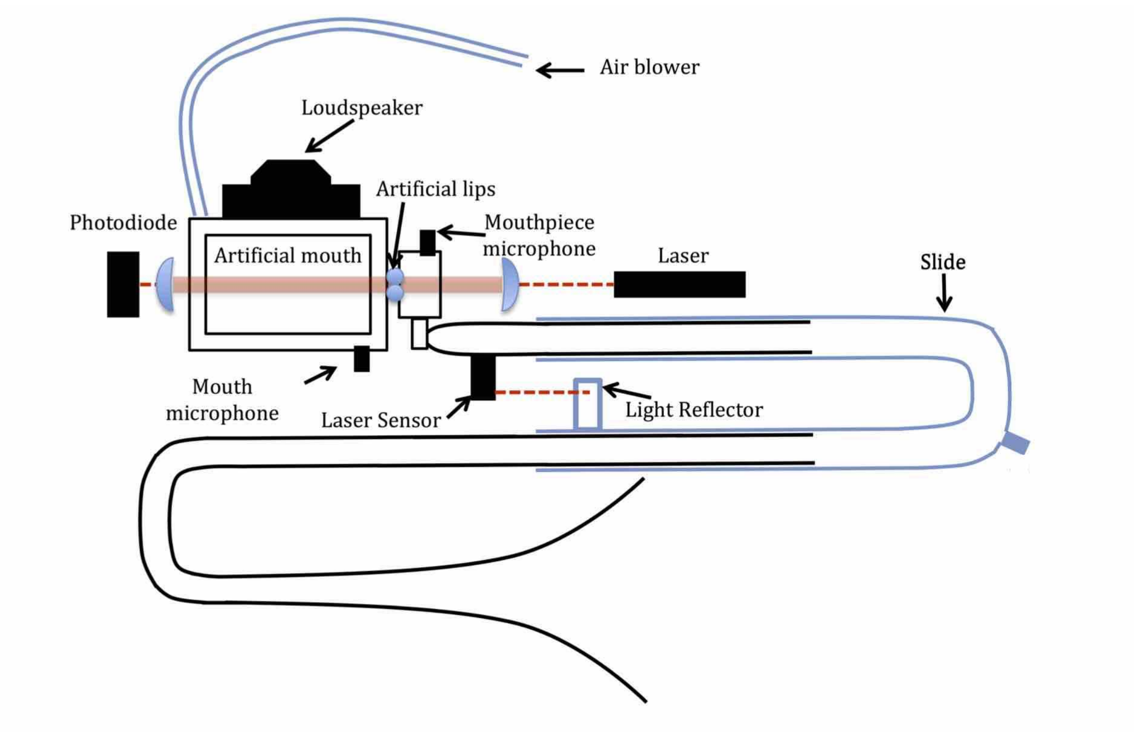

Figure 1. Schematic showing the light transmission setup, allowing the lip opening to be tracked when the slide undergoes a fast gesture. The blue section of the instrument indicates the slide, which moves in a direction perpendicular to the plane of the diagram [2],

2.1 Technical setup

The artificial mouth was mounted on an optical rail, together with a IIB COHERENT 638DG laser (with its beam parallel to the rail) a photodiode, two G.R.A.S. 1/4" high pressure microphones and a loudspeaker. The optical rail allowed an optimum alignment between all the devices. The laser beam was first filtered with a polariser to control the intensity of the light and prevent the saturation of the photodiode located behind the artificial mouth. The beam was then expanded via a divergent lens with a focal length of -8 mm and a diameter of 30 mm, until an area wide enough to illuminate the internal diameter of the mouthpiece was achieved. At this stage, the beam was made parallel using a convergent lens with its focus located at the position of the divergent lens, and limited using a circular shutter to ensure that the vertical dimension (parallel to the lips) remained constant during the oscillation. After reaching the artificial mouth, and crossing the oscillating lips, the beam was converged at the other side by another lens, of both focal distance and diameter 50 mm, on to the photometer's sensor. A photograph of this set up can be seen in Figure 2. The trombone was connected to the artificial mouth via a transparent mouthpiece, and clamped perpendicularly to the optical rail to minimise structural vibrations during the manipulation of the slide as shown on the left side of Figure 3. The artificial lips are water filled balloons, as shown on the right side of Figure 3, which can have their pressure modified by varying the difference in height between the water bottle to which they are connected and the mouthpiece against which they are compressed. Their correct handling requires a degree of expertise and familiarisation with the system, and there is variation in their behaviour depending on the water pressure. After thorough adjustment, an embouchure able to play a note close to the third resonance between the first and third positions of the trombone was achieved.

The position of the slide x was measured using a Baumer OADM 20I4471 laser sensor, powered via a custom

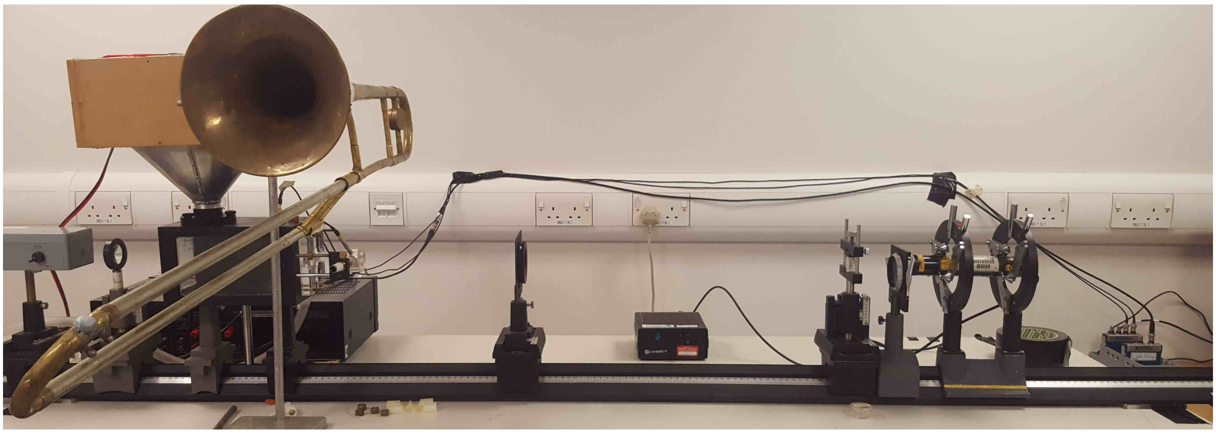

Figure 2. Optical setup used for the measurements.

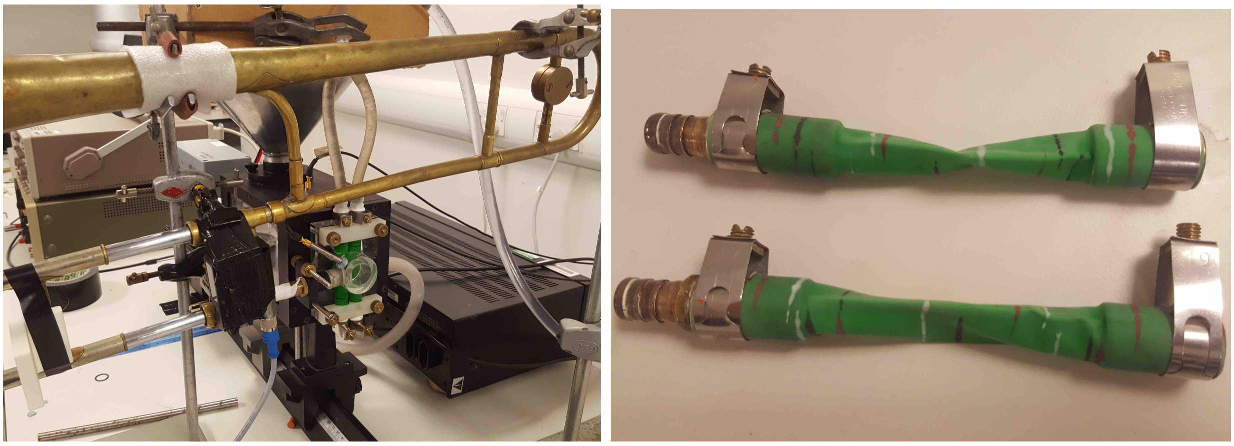

Figure 3. Left: artificial mouth clamped on the optical rail, on which the laser used to measure the slide displacement x is also visible. Right: deflated rubber tubes used as artificial lips before being connected to the elevated water bottle which ensures equal static pressures on both lips.

made supply box. The laser sensor was attached firmly to the mouthpiece end of the instrument and remained static during the whole process. The laser beam was intercepted by a small reflector attached to the mobile part of the slide, as can be seen in the left side of Figure 3

An air blower was used to create an excess pressure inside the artificial mouth. When the lips were correctly adjusted this overpressure in the mouth set the lips into motion, coupling with the instrument and playing a note.

All signals were acquired via code written in MATLAB using National Instruments C-Series digital modules mounted on a CompactDAQ Chassis connected to the desktop computer. The sampling frequency used was 51200 Hz. The transducers were calibrated during the post processing, using information from their technical specifications documentation. All signal processing was also coded using MATLAB.

2.2 Experimental protocol

2.2.1 Lip characterisation

In order to determine the physical characteristics of the lips, the mechanical response of an embouchure able to couple to the instrument and play it for slide extensions x varying between 0 and 0.45 m was measured.

The mechanical response is defined as the relationship between the opening height $\widetilde{H(f)}$ of the lips and the pressure $\widetilde{\Delta P(f)}$ acting across them, both given as a function of frequency f.

$$\widetilde{MR(f)} = \widetilde{H(f)} / \widetilde{\Delta P(f)} \tag{1}$$

This was achieved experimentally by driving the whole system acoustically (the mounted lips connected to the instrument) via the loudspeaker connected to the artificial mouth. The signal played by the loudspeaker in this case was a sine sweeping exponentially in time over a frequency range that varied from 2 Hz to 1 kHz in a time interval of 10 s. This measurement was repeated ten times and averaged using the median value of all the repetitions. The pressure acting upon the lips $\Delta P(t)$, was obtained as the difference between the pressure measured in the mouth $p_m(t)$ and in the mouthpiece $p_{mp}(t)$ in Pascals. The lip opening height was taken to be proportional to the voltage signal collected by the photodiode $H(t)$, and was not calibrated as only magnitude ratios are of interest here. These experimental magnitudes were transformed into the frequency domain via the Fourier transform:

$$\widetilde{H(f)} = \mathscr{F}(H(t)), \text{ and } \widetilde{\Delta P(f)} = \mathscr{F}(p_m(t) - p_{mp}(t)) \tag{2}$$

The artificial lips are a non-linear system whose behaviour depends on the equilibrium position imposed by the static overpressure in the mouth. This has been previously reported and studied in [6], and can be observed in the particular case under study in this article. A static overpressure in the mouth, just below the playing threshold, modifies the dynamic characteristics of the lips, which are pushed slightly outwards into the mouthpiece. Figure 4 shows the mechanical response of the artificial lips both for a static overpressure in the mouth (blue line) and no static overpressure (black dashed line).

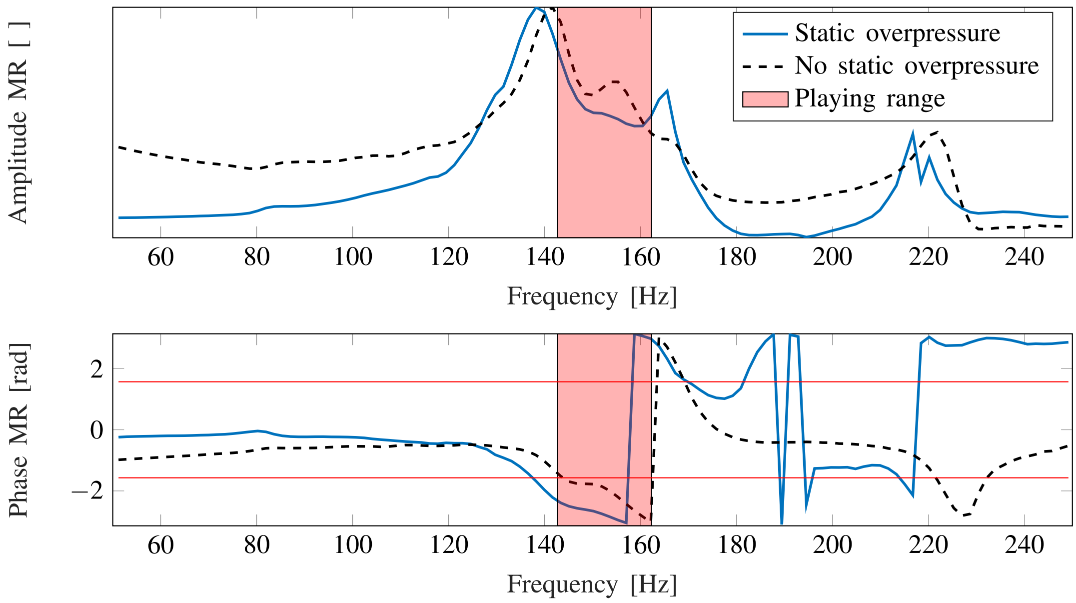

Figure 4. Mechanical response of the lips in a configuration able to play between first and third position of the slide in dimensionless magnitude (upper subplot) and phase (lower subplot).

2.2.2 Experimental protocol

The embouchure achieved in this experimental work was able to play a musical note close to the third resonance of the instrument for slide extensions between 0 m and 0.45 m. These lengths ensured that the Baumer OADM 20I4471 laser sensor remained inside its range for a reflector attached to the slide at 5 cm distance. It also ensured that the artificial lips would not stop buzzing at any time, playing fundamental frequencies that spanned between 143 Hz (for the longest slide extension) and 163 Hz (for the shortest one).

In a realistic musical context with a human player sounding the third regime of the instrument, this slide movement would correspond to a pitch interval of 4 semitones, from $F3$ (173 Hz) in first position (slide fully contracted) to $C\sharp 3$ (131 Hz) in fifth position (slide extended by around 0.4 m). The difference between the normally played pitch interval and the experimentally observed one is explained by the fact that a human player modifies the embouchure when operating the slide in order to match the resonances of the instrument with those of the lips. The adjustment of the artificial lips before playing sets a fixed embouchure, which is not deliberately changed during the glissando.

The position of equilibrium of the lips does however have an effect on the mechanical resonances, as shown by the comparison in Figure 4 between the lip response curves with and without the sub-threshold overpressure in the mouth. It is therefore a plausible hypothesis that a negative infrasound pressure in front of the lips, sucking them out from their normal equilibrium position, could create a transient modification of the mechanical resonance curve in similar in character to that caused by a static mouth overpressure, as represented by the blue line in Figure 4. In the absence of slide movement the curve would be expected to resemble more the mechanical response measured with no mouth overpressure (dashed black line in Figure 4).

The amplitude of the infrasound pressure generated during the playing experiments was estimated by low pass filtering $\Delta P(t)$ using a Hanning filter with a cutoff frequency of 10 Hz. The microphones used to determine $\Delta P(t)$ have been shown to operate consistently at infrasound frequencies, although their calibration is not specified by the manufacturer below 3.15 Hz [7].

The experimental protocol was designed to look for differences in the playing amplitude, pressure across the lips and lip opening height which can be correlated with changes in the slide velocity and therefore the ISP. Results were obtained from two different playing situations:

- a quasi-static slide position x which was either constant or varying very slowly;
- a rapidly changing slide position x during the playing of a fast glissando, either outward or inward.

This dataset was sorted as independent data points according to increasing slide position x. Three different data subsets were selected, based on the values of the slide velocity $\dot{x}$:

1. $-0.01\,\mathrm{m/s} < \dot{x} < +0.01\,\mathrm{m/s}$ (quasi-static);
2. $\dot{x} < -0.5\,\mathrm{m/s}$ (inward glissando);
3. $\dot{x} > +0.5\,\mathrm{m/s}$ (outward glissando).

3 RESULTS AND DISCUSSION

Figure 5 plots the variation of $\Delta P(t)$, lowpass filtered with a cutoff frequency of 10 Hz, as a function of the slide velocity $\dot{x}$ for several inward and outward glissando gestures. As expected, the ISP is predominantly positive for inward glissandi and negative for outward glissandi, athough there is a wide variation in the curves for different gestures. In interpreting this graph it should be borne in mind that the stationary endpoint of a glissando corresponds to $\dot{x} = 0$. The ISP values continue to fluctuate for a significant fraction of a second after the gesture has finished; the initial pressure swing generated by a glissando will be followed by a series of decaying swings of alternating polarity, all of which are superimposed at $\dot{x} = 0$.

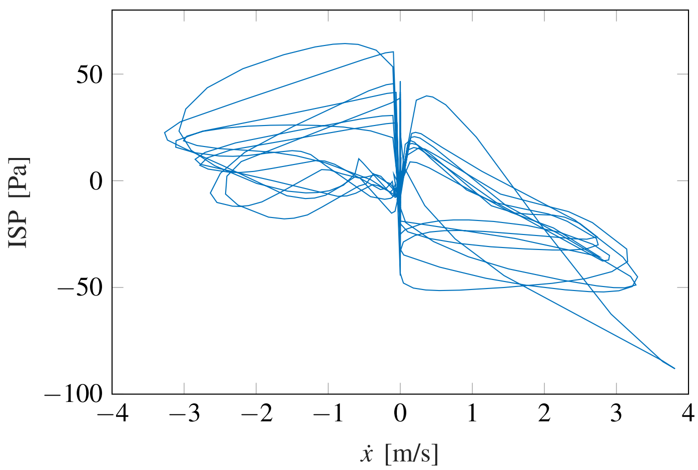

Figure 5. Infrasound pressure (ISP) as a function of slide velocity $\dot{x}$.

Figure 6 shows the recorded data, processed to allow comparison between the cases with static slide (left column), negative slide velocity (middle column) and positive slide velocity (right column). The first row of this Figure shows the RMS value of the acoustic pressure variation across the lips $\Delta P(t)$. This value was obtained using a time window of 1000 samples which included over three cycles of the signal for frequencies in the playing range, and a 50 % window overlap. The middle row displays the RMS value of the dimensionless lip opening H, responding to the acoustic pressure. The RMS was calculated in the same way as described above. The bottom row displays the infrasound pressure $\Delta P(t)$ low pass filtered by a Hanning filter at 10 Hz.

The results shown in the first column, for the stationary slide case, are in line with what is expected from the mechanical response characterisation presented in Figure 4. The resonance located around 140 Hz has a greater amplitude than the one just above 160 Hz, therefore the extended slide, which facilitates lower resonant frequencies, displays larger amplitudes in both the RMS values of ΔP and H. In the absence of slide motion there is no significant ISP.

It appears from the results presented in the middle and right column that fast slide gestures in either direction reduce the amplitudes of both the acoustic pressure and the lip opening at a given value of slide displacement x. In both negative and positive velocity cases, there are appreciable trends, albeit with different degrees of dispersion, suggesting that the artificial lips may be susceptible to infrasound pressures capable of altering the position of equilibrium around which they oscillate. However the interpretation of the results is complicated by the fact that the decay time of the infrasound pressure fluctuations is typically longer than the duration of a fast glissando gesture. The ISP force exerted on the lips for a given slide position x therefore depends on the past history of the gesture as well as the current value of $\dot{x}$. This hysteresis could help to explain the different shapes of the curves in Figure 6.

4 CONCLUSIONS AND FURTHER WORK

The acoustic behaviour of a trombone sounded by artificial lips, as measured by the RMS values of the pressure difference ΔP across the lips and the lip opening H, was found to depend on the direction of slide movement during fast glissandos. Infrasound fluctuations in ΔP with amplitudes ranging from +60 Pa to -90 Pa were measured during these gestures. Further experiments and physical modelling simulations will be necessary to establish whether there is a correlation between the infrasound pressure fluctuations and the changes observed in lip behaviour. It is expected that any effect of infrasound will be greatest for quiet playing, as the infrasound pressure amplitudes will then be a more significant fraction of the static excess mouth pressure.

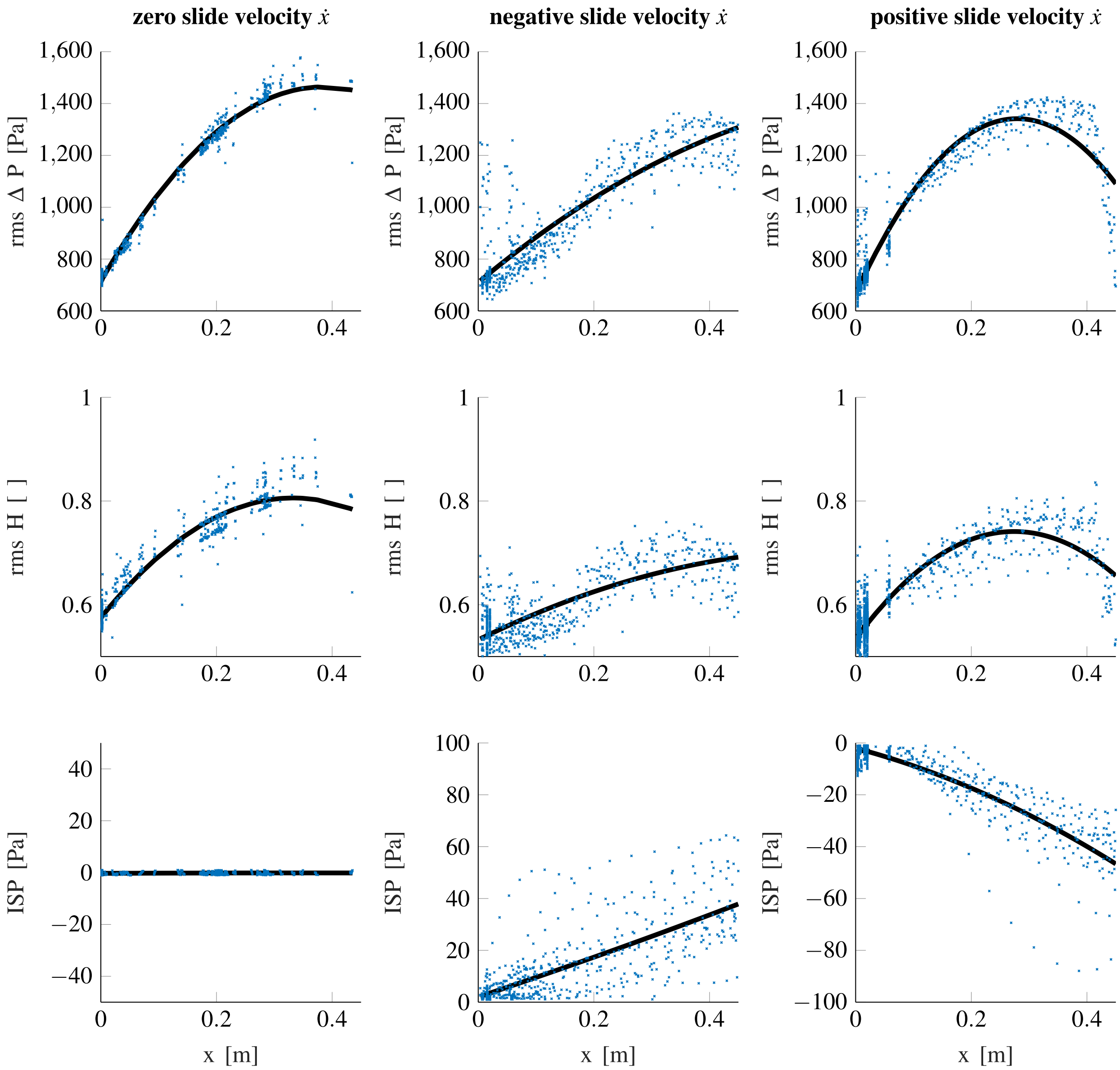

Figure 6. Analysis of three different stages of the mouth and trombone system, processed from data collected from numerous slide gestures during playing. Left column: slide velocity smaller than 0.01 m/s (quasi-static). Middle column: slide velocity less than than -0.5 m/s (inward glissando). Right column: slide velocity greater than +0.5 m/s (outward glissando). Top row: RMS acoustic pressure in Pa, measured across the lips. Middle row: adimensional RMS lip opening height. Bottom row: infrasound pressure (ISP).

ACKNOWLEDGEMENTS

The authors of this paper are thankful to Dr. Alan Woolley for assisting with instrumentation.

REFERENCES

[1] Kemp, J. A., López-Carromero, A., Woolley, A. and Campbell, D. M., Experimental investigation of Doppler shift and infrasound generation during wave propagation within the bore of the trombone during slide movement. Proceedings of the Third Vienna Talk on Music Acoustics, 9-14, 2015..

[2] López-Carromero, A., Kemp, J. A. and Campbell, D. M., Experimental investigations of the effects of fast slide movements in the trombone on the behaviour of an artificial mouth. Proceedings of the 24th International Symposium on Musical Acoustics, Montreal, CA, 2017.

[3] Richards, O. F., Investigation of the lip reed using computational modelling and experimental studies with an artificial mouth. PhD thesis, University of Edinburgh, 2003.

[4] Bromage, S., Visualisation of the lip motion of brass instrument players, and investigations of an artificial mouth as a tool for comparative studies of instruments. PhD thesis, University of Edinburgh, 2007.

[5] Newton, M. J, Campbell, M. and Gilbert, J., Mechanical response measurements of real and artificial brass players lips. J. Acoust. Soc. Am. 123: EL14-20, 2008.

[6] Neal, M. Study of the brass instrument lip reed mechanism using artificial lips and Lattice Boltzmann flow simulations. PhD thesis, University of Edinburgh, 2003.

[7] López-Carromero, A. Experimental investigation of acoustic characteristics of radiation and playing gestures for lip-excited musical instruments. PhD thesis, University of Edinburgh, 2018.