Proceedings of 20th International Symposium on Music Acoustics
(Associated Meeting of the International Congress on Acoustics)

25-31 August 2010, Sydney and Katoomba, Australia

Pitch Bending on Early Brass Instruments

L. Norman[1], J.P. Chick[2], S. Logie[3] and D.M. Campbell[3]

[1] School of Arts, Culture and Environment, University of Edinburgh, UK, lisa.norman@ed.ac.uk
[2] School of Engineering, University of Edinburgh, UK, john.chick@ed.ac.uk
[3] School of Physics, University of Edinburgh, UK, {shona.logie, dmc}@ed.ac.uk

PACS: 43.75.Fg, 43.75.Zz

ABSTRACT

Horn and trumpet writing in the first half of the 18th century often called on the player to sound certain potentially problematic natural resonances of their instrument. These are notes which do not fit easily on any known tempered tuning system. A well-designed brass instrument typically produces a series of open notes which approximate a harmonic series, including the characteristically ‘out of tune’ 7th, 11th and 13th resonant modes. There is much debate concerning the extent to which players attempted to ‘correct’ the tuning of these wayward notes, either through pitch bending due to embouchure manipulation, using hand technique, or not at all. By manipulating the embouchure, a skilled player can, to some extent at least, bend certain notes to more closely match those of a tempered scale. The ease with which this can be achieved depends on a number of factors, including the bore profile, which largely determines the frequencies and bandwidths of the resonances. Recently developed computational models have been used in conjunction with playing tests carried out on a range of early orchestral horns from the Edinburgh University Collection of Historic Musical Instruments to investigate the influencing factors which determine how easily these instruments can be played in tune.

INTRODUCTION

Perhaps the most fundamental aspect of the acoustics of a brass instrument is the creation of a bore profile designed to produce a set of harmonically related resonances. The harmonicity of this series is important as it allows for a strong coupling between the resonances of the air column within the instrument and the oscillation of the lip, also known as a cooperative regime of oscillation. Early horns and trumpets did not have valves (the invention of which extended the gamut of notes available to the player) and so seventeenth and eighteenth-century composers were restricted to using predominantly the natural resonances of the instrument. Most of the pitches fit well on a tempered scale but there are certain harmonics which do not, namely the 7th, 11th and 13th, and these modes have proved to be problematic to musicians today interested in performing on natural brass instruments (horns and trumpets without valves).

The fact that some of the resonant modes on the natural horn are better in tune with the tempered scale than others did not stop composers in the eighteenth century from including these slightly wayward notes in their compositions. The 11th mode for example is a natural resonance that composers frequently used, despite the fact that it falls somewhere in between two pitches. Horn and trumpet players were required to play both pitches, written either as an f♮ or an f♯, and thus, players would have somehow had to bend the pitch of the note up or down accordingly. The short excerpt in Figure 1 shows the second horn part for a piece of music written by the early eighteenth-century composer, Heinichen, in which both f♮ and f♯ are required to be played by the musician.

There are two possible options available to the horn player wishing to alter the pitch of a note slightly; one is to “bend” the note in tune with the lips and the other is to use the right hand in the bell of the instrument. For the purpose of this research have we focused on the potential for bending the pitch with embouchure control alone. “Lipping” the note is a difficult technique and it is more easily achieved on some instruments than on others, but the reason why this should be the case has not previously been explored in significant detail.

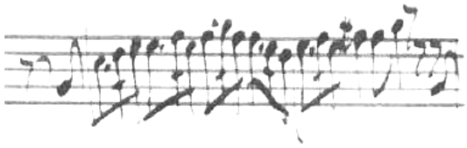


Figure 1: Example of lipping of music with f♮ and f♯

There has been some discussion among players interested in period performance, that early original brass instruments may be better suited to the demands of eighteenth-century repertoire than their modern counterparts, arguably because the series of resonant modes on these early horns and trumpets is not as harmonically aligned as on either modern instruments, or even copies of early eighteenth century instruments [1][2]. In a study exploring the acoustical properties of different trumpet mouthpieces, Poirson *et al.* suggested that slight inharmonicity might in fact be a desirable quality in a brass instrument [3]. From the point of view of pitch bending, misalignment in the series of resonant modes would result in weaker support from higher resonances and could thus, in theory, provide the player with greater flexibility of pitch. It is an interesting theory, and this paper investigates some of the features of horn acoustics which make it possible to bend the note in tune.

MEASUREMENTS

Playing Tests

Playing tests involving human players were carried out on a number of different early orchestral horns in order to explore the ease with which certain notes could be “lipped” up or down in pitch. The instruments used included five horns from the Edinburgh University Collection of Historic Musical Instruments (EUCHMI) by makers Hofmaster, Kretzschmann, Sandbach, Winkings and an anonymous horn. Figure 2 shows one of the Winkings horns from the EUCHMI collection. The dates of these instruments range from the mid eighteenth to the early nineteenth century. A modern copy of an early horn from around the same period was also included in the dataset. All horns were crooked in D as this was a common key for horn players of the eighteenth century to play in.

Figure 2: One of the instruments used in this study: Winkings orchestral horn from the Edinburgh University Collection of Historic Musical Instruments.

Players were asked to bend the pitch of the 4th resonance downward as far as they could before the note dropped to the 3rd resonance below. This test was to be played at a strong dynamic level of approximately *forte* and was repeated three times. The player was then asked to repeat the process, but in this case, attempting to bend the note upwards as far as it would go until the note jumped to the higher 5th resonance. There was no attempt made to aim for a specific pitch, only to test the extremes of the flexibility of the pitch on a particular resonance. The "lipping" potential of the 11th resonance was explored in the same way for all horns.

The radiated sound pressure was measured at the bell of the instrument, with the microphone positioned one bell diameter from the plane of the bell, on axis. All measurements were performed with hand out of the bell. In addition to the radiated sound, the mouthpiece pressure was recorded for the modern copy using a 106B PCB Piezotronics dynamic pressure transducer located in the throat of a specially modified mouthpiece.

Input Impedance

Acoustic input impedance curves were measured for all horns using the Brass Instrument Analysis System (BIAS) [4]. Two small microphones in the measuring head of the BIAS apparatus measure the sound pressure while a loudspeaker (also enclosed in the measuring head) emits a frequency sweep referred to as a chirp. The same mouthpiece (a commercially manufactured PHC 22) was used for all measurements. From the input impedance curves, information concerning the harmonicity of the resonances of the instrument, and the Q values of the peaks were calculated.

RESULTS AND DISCUSSION

Pitch

The pitch detection software *Praat* [5] was used to analyse the sound recordings and to explore the extent to which the player was able to bend the pitch of the notes. A mid eighteenth-century horn by the maker Hofmaster was found to be quite amenable to pitch bending. The upward pitch contour for the 11th mode, rising to the 12th can be seen in the bottom graph in Figure 3. Note that these horns are from different periods and have slightly differing nominal values of concert pitch.

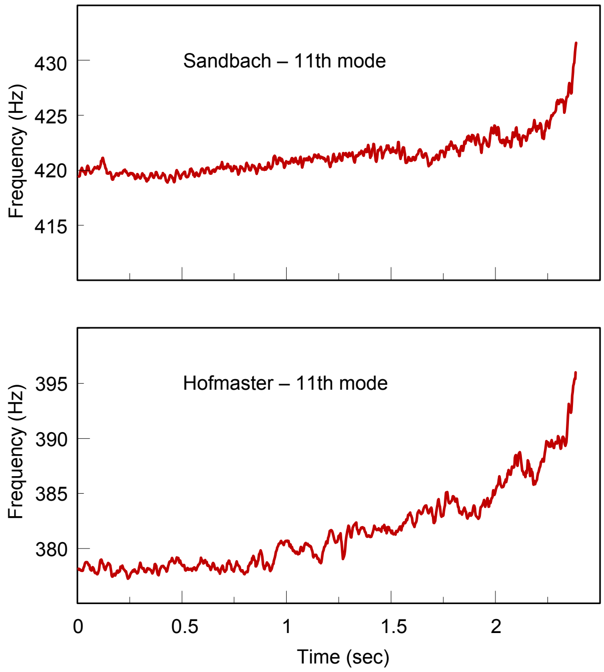


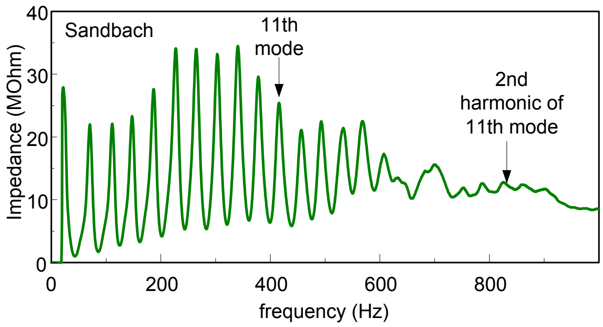
Figure 3: Pitch contour for Hofmaster and Sandbach horns. The player was instructed to bend the pitch of the 11th mode upwards as far as they were able.

In contrast to this, an instrument by the maker Sandbach from around the beginning of the nineteenth century proved to have a more difficult 11th mode to manipulate and a similar pitch contour for this instrument can be seen in the upper graph in Figure 3 for comparison. Analysis of downward lipping on both of these instruments revealed similar playing characteristics: the 11th mode on the Hofmaster proved more amenable to bending upwards than on the Sandbach. Also interesting to observe was that the intensity of the sound was more easily maintained for the Hofmaster horn as the pitch was bent away from the natural resonance than for the Sandbach instrument. In the latter case, the intensity became noticeably weaker as the pitch was forced away from the natural mode of resonance.

Input Impedance

In trying to understand what makes one instrument more amenable to embouchure pitch manipulation than another, it is interesting to examine the acoustic input impedance curves, which provide some information about the strength and positioning of the resonances of an instrument. The quality factor, or Q factor, of each peak can also be determined from the input impedance curve and is an indication of the bandwidth of a particular resonance. This is a useful factor to consider when examining pitch bending as it has been discovered that high values of Q, i.e. narrow peaks, make pitching notes on the horn more difficult because there is a smaller "target" frequency range to aim for [6]. On the other hand, one might deduce that a low Q factor could make "lipping" easier on the horn because there is a wider frequency range, but initial comparisons of the Q values of 11th resonant modes with player tests, have revealed that a trend was not immediately apparent. It seems likely however, that another aspect of the acoustics of the instrument is more influential: the location and strength of modes of resonance near higher harmonic frequencies particularly that of the second harmonic.

As discussed above, playing tests revealed that the Hofmaster horn has a more flexible 11th resonance than the Sandbach. The Q values of the 11th resonance for both instruments were found to be similar: Hofmaster ∼ 22.5 and Sandbach ∼ 22.3. Where the acoustics of the two instruments differ most significantly is in the region of the 2nd harmonic. The lower graph in Figure 4 shows the input impedance curve for the Hofmaster horn, and for comparison, the curve for the Sandbach instrument is shown in upper graph Figure 4.



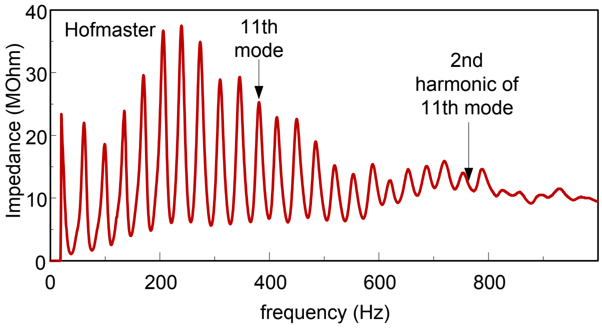


Figure 4: Input impedance curves for the Hofmaster and Sandbach horns.

The Hofmaster horn clearly has much stronger resonances in the region of the 2nd harmonic than the Sandbach. The positioning of these peaks is also of importance, as it would seem that these resonances play a potentially key role in supporting the oscillation of the lip as the player forces the frequency away from the natural resonance of the air column. The upper resonance peaks for the Hofmaster instrument happen to fall at frequencies which provide potential support to the fundamental during lipping, but for the Sandbach instrument there is very little potential for extra support because the peaks are so weak.

Spectral Frequency

Further evidence suggesting a link between the ease with which a note can be lipped in to tune and the influence of resonant peaks in the upper harmonic region can be seen by examining the spectral content of a tone during the lipping process. Figure 5 below shows an image of the varying spectral content, measured in the mouthpiece, of the 4th resonance of a horn in D as it lipped upwards. The vertical axes displays the frequency range from 0 to 2000 Hz. The bands correspond to the harmonics of the note D_3, where the darkest shade of grey indicates highest intensity and lighter shades of grey show lower intensity. Time is displayed on the horizontal axes from left to right with the far left of the image corresponding to the spectra of the note played normally (without lipping). As time increases, so too does the pitch. In this example the pitch varies by approximately half a semitone, rising from 148 Hz to 153 Hz.

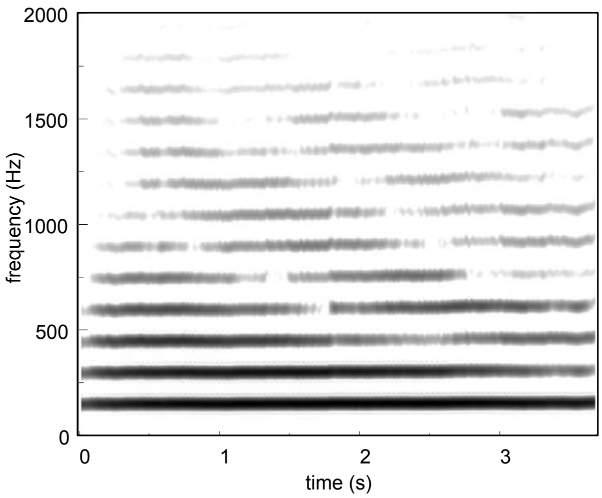


Figure 5: Spectral frequency of the 4th resonance of a 4.4m long horn in D (ie the note D_3) being lipped upwards.

Initial observation of the spectrogram shows that as the note is lipped upwards in pitch, the upper harmonic spectral content generally weakens. Players commented on a feeling of resistance which varied slightly as the pitch of the note was bent upwards. This not surprising given that the lips receive increasingly less support from the air column as the pitch gets further from the natural resonance of the instrument. What is particularly interesting about the graph in Figure 5 however, is that a number of diagonal bands (at approximately 45° angles) of weaker intensity are also apparent in the spectra. It is possible that these temporary harmonic weaknesses occur when there is very little support from higher modes of resonance in that particular region. This hypothesis is supported by the fact that the intensity of the higher harmonics, above 1000 Hz, varies more frequently than for example the fundamental or second harmonic which remain nearly constant throughout the pitch change. The fundamental frequency rises in pitch by about 5 Hz, meanwhile the frequency of the 6th harmonic varies by about 30 Hz.

The characteristic fluctuating spectral content is more pronounced in measurements of the mouthpiece pressure but can also be observed to some extent in the radiated sound. The waterfall plot in Figure 6 shows the 4th resonance being lipped upwards on a mid eighteenth-century horn by maker Hofmaster. Time is shown as increasing from front to the back of the graph and the frequency of the harmonics from left to right. The heights of the peaks are an indication of their strength.

As in the previous graph, a similar pattern can be observed among the lower harmonics, where they appear to drop in intensity in a seemingly orderly fashion; first the fifth, then fourth, third etc. At the point of maximum upward bend, where the player feels that the note is on the edge of jumping to the next highest resonance, the frequency spectra is characteristic in that the second harmonic is considerably weaker than those immediately higher.

At this point, the fundamental frequency has risen from 136 Hz to approximately 141 Hz which means that the for the second harmonic to provide potential support to the oscillation of the lips at this higher frequency, there would need to be a

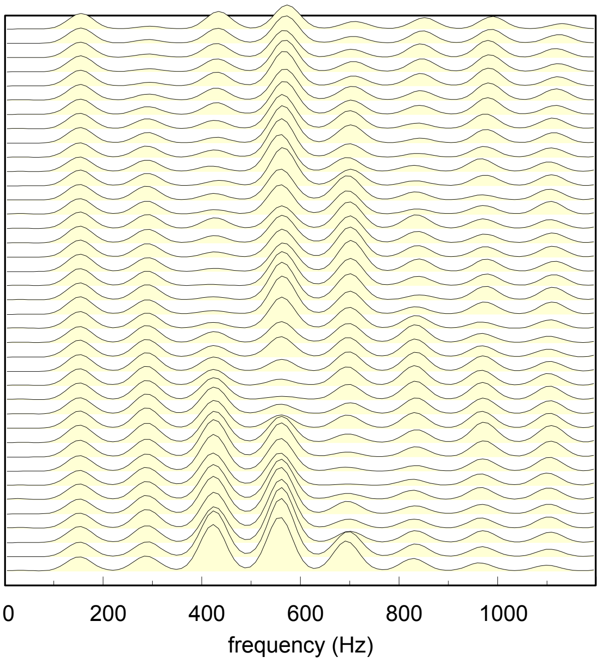


Figure 6: Waterfall plot of the 4th resonance of the Hofmaster horn crooked in D (ie the note D_3) being lipped upwards. Time(and f0 pitch) is shown in creasing from front to back.

peak in the region of 282 Hz. At this point on the impedance curve however, there are no strong resonances as this pitch lies close to the trough in between the eighth and ninth resonances. The timbre of the note changes quite significantly due to the varying harmonic spectral content of the note and can be heard generally as a brightening of tone quality.

It is interesting that the players mostly felt that bending the note downwards was easier than lipping it up, and observation of the frequency spectra for the downward pitch bends showed very different harmonic spectral patterns to those included above. The intensity of the harmonics did fluctuate slightly but there was no obvious systematic pattern like the diagonal lines shown in the previous graphs. Research carried out by Chick *et al* [7] concerning the difference between upward and downward lip slur transients also discovered that there was a significant difference between pitch increase and pitch decrease.

SUMMARY AND FURTHER WORK

The results, comparing the "bendability" of six different horns, revealed that some instruments were easier to manipulate than others. In the small sample of instruments examined, there appeared to be no obvious link between ease of lipping and the Q value when focussing on a specific note such as the 11th resonance. Instead, what seemed to influence the potential flexibility of the note more was the location of the peaks nearest the second harmonic. Where these peaks were strong and located at a position which would positively support the lipped fundamental as it was forced away from the centre of the note, the pitch could more easily be lipped than where there were either very weak resonant peaks or peaks positioned where there would be little positive support. Furthermore, concerning the notes which were easier to lip, the intensity of the note as the pitch changed generally remained more constant, and the player felt less resistance, than for the less flexible pitches.

Observation of pitch bending on lower modes of resonance such as the 4th mode, showed interesting fluctuations in the intensity of the higher harmonics. It seems likely that the resonances of the air column influence the strength of the harmonic content of the note to a certain extent.

This is one possible explanation, but it would also be interesting to explore the role that the shape and volume of the mouth cavity plays in lipping a note. Studies into the role of the vocal tract in didgeridoo playing have revealed that the player makes subconscious movements with the glottis to accentuate timbral variation [8] and it is possible that brass players might do a similar thing when trying to manipulate the pitch with their embouchure. The horn players involved in the current research described making quite significant changes to the shape of the cavity as they attempted to manipulate the pitch of the note.

ACKNOWLEDGEMENTS

The authors would like to thank the director of the Edinburgh University Collection of Historic Musical Instruments, Arnold Myers, for kindly allowing access to measure and carry out playing tests on a number of early orchestral horns.

REFERENCES

[1] D. Smithers, K. Wogram, and J. Bowsher. Playing the baroque trumpet. *Scientific American*, 254:108–115, April 1986.

[2] Arnold Fromme. Performance Technique on Brass Instruments During the Seventeenth Century. *Journal of Research in Music Education*, 20(3):329–343, 1972.

[3] Emilie Poirson, Jean-François Petiot, and Joël Gilbert. Study of the brightness of trumpet tones. *The Journal of the Acoustical Society of America*, 118(4):2656–2666, 2005.

[4] Brass Instrument Analysis System (BIAS). Institute für Wiener Klangstil, Vienna, `http://www.bias.at`.

[5] P. Boersma. Praat, a system for doing phonetics by computer. *Glot International*, 5(910):341–345, 2002.

[6] George R. Plitnik and Bruce A. Lawson. An investigation of correlations between geometry, acoustic variables, and psychoacoustic parameters for french horn mouthpieces. *The Journal of the Acoustical Society of America*, 106(2):1111–1125, 1999.

[7] J.P. Chick and S. Logie. Comparison of the mechanics of the brass players' lips during slurred note transients. *J. Acoust. Soc. Am.*, 125(4):2598–2598, May 2009. 157th ASA Meeting, Portland, OR.

[8] A. Tarnopolsky, N. Fletcher, L. Hollenberg, B. Lange, J. Smith, and J. Wolfe. Acoustics: The vocal tract and the sound of a didgeridoo. *Nature*, 436, 2005.