NOVEL DESIGNER PLASTIC TRUMPET BELLS FOR BRASS INSTRUMENTS: EXPERIMENTAL COMPARISONS

Dr. David Gibson

Birmingham City University
Faculty of Computing, Engineering and the Built Environment
Millennium Point, Curzon St, Birmingham, B4 7XG, United Kingdom
david.gibson@bcu.ac.uk

ABSTRACT: The application of ABS in the design of plastic trumpets has resulted in low cost solutions for new learners. However, there are no professional level plastic 'brass' instruments currently available. Previous work suggested that novel bells for professional applications may be designed for different genres of music. This may be achieved by eliminating or enhance particular harmonics by altering the thickness of the plastic bell, thus altering the impact of the vibrations to the sound column within it. This paper investigates experimentally how increased plastic bell thickness plays an important part in the timbre produced and the feasibility of applying them to professional brass trumpets. Results show that the timbre produced varies between instruments with the thicker bell producing harmonics closer to that of a brass instrument. A further comparison between a plastic and hybrid brass trumpet with an identical plastic bell indicates that the harmonic content is also similar; the bell producing a significant contribution to the timbre rather than the body of the instrument. This suggests that designer bells would be feasible for professional applications.

1. INTRODUCTION

The application of using plastic as a design material for student 'brass' instruments has been increasing over the last few years with the development of the pBone - 2011, pTrumpet - 2014, Tromba trumpet and cornet – 2014 as examples. However, there have been no developments for a professional level instrument even though it is now possible to obtain gold or silver lacquered bells that visually appear no different to brass counterparts. The issues of acceptance of such materials have been debated in the past. Musicians have blind tested trombone bells made of alternative thicknesses and materials balanced to 'feel' like traditional brass bells and could not tell the difference. When told the material their perceptions altered (Smith, 1986). Smith (1978) states that in other tests with trumpets by listeners and players they could only tell the difference between fibreglass and brass bells when the thickness between them was altered. It is accepted that the use of different materials does alter the sound spectrum due to material type, thickness and fabrication methods. There is also agreement that thinner (brass) bells alter the vibrations contained within them and accentuate the higher frequencies. However, not all agree that the material type significantly contributes to the tone but rather the thickness of the material (Smith 1978, Schilke nd, and Pyle 1997). Furthermore, Smith (1986) concludes that the bell thickness does not have a significant effect on the far field sound, only that in the near field for the player who in turn would alter the timbre produced.

More recent focus on the vibration of bells and their effect on tonality have shown that vibrations do cause significant changes to the sound spectrum which can also be detected by listeners in the far field (Moore *et al* 2005 and Kausel *et al* 2015). Kausal *et al* (2010) demonstrate theoretically that the radiated sound is affected by the vibrations of the instrument coupled to the internal sound field. They show that vibrations are most significant in the flare of the bell and not in the cylindrical pipes and that the primary effects are constrained to the first 15 cm of the bell section.

Further investigation by Kausel *et al* (2015) on axial vibrations of the bell conclude that damping the bell vibrations can contribute to impedance changes and thus the sound spectrum produced. Moore (2015) applied Kausel's model and verified through experimentation that the axial vibrations do affect the sound generated with elliptical vibrations less so.

As the axial vibrations have been shown to effect the sound spectrum the question of whether a plastic bell can be made to mimic the natural modes of a brass bell are investigated. Gibson (2016) simulated various thicknesses of plastic trumpet bells and concluded that to make the bell resonate similarly to a brass bell the thickness had to be increased beyond that of current commercial offerings.

This paper summarises the simulation work from the previous paper by Gibson and further investigates the effects of increasing bell thickness through experimentation and measurement of timbre in the near field.

2. EXPERIMENTAL METHODOLOGY

The initial investigation considered the concept of producing a plastic bell that can emulate a brass bell by study of the components that affect the axial air column within the bell of the instrument. The distinctive sound is a product of the interactions of the vibrations with the air column.

Using finite element analysis, the natural resonances of a trumpet bell made from brass and various thicknesses of plastic was analysed. The results are summarised in section 3.

The second part of the investigation focuses on timbre measurement of plastic and hybrid trumpets using plastic bells of various thicknesses based upon the simulations obtained.

2.1 EXPERIMENTAL MEASUREMENTS

The method applied to the testing of the bells uses a subjective approach with each being played in an acoustically treated room by the author (who has many years of experience in playing). Three plastic trumpets subjected to testing have bell thicknesses of 1.5, 2.0 and 2.5 mm.

A plastic mouthpiece (size - 3C) and notes F4, G4, C5 is used, played repeatedly for a period of 5 seconds. A plastic mouthpiece is used as this couples with the plastic instruments better than compared to the metal mouthpiece. Measurements are taken at different distances in the nearfield and again at the far field for comparison. A distance of 0.5 metres is chosen as the preferred nearfield position. They are recorded using a DPA4090 omni-directional microphone with maximally flat response into a Focusrite ISA828 preamplifier unit. This is fed into a Lynx Aurora16 LT-TB ADC recording at 24 bit, 48kHz. Tonality analysis is undertaken using MIRtoolbox using long term average spectrum (LTSA). Each recording used is truncated to remove any unwanted anomalies due to the start and end of the note.

A further experiment is undertaken to explore the differences between a plastic bodied trumpet and a metal bodied trumpet using the same bell as the plastic instrument. It is well known that the lead pipe has an influence on timbre but to what extent is unclear. Kasel informs us that cylindrical pipes should not influence the timbre therefore the lead pipe and bell would have the most impact. A professional Schilke B1L tuning bell trumpet is used allowing simple replacement of the bell. A mount for the plastic bell is fabricated using a 3D printer and the narrow end bored out to make an airtight fit at the union between trumpet and bell. This can be seen in Figure 1.

Figure 1: *plastic bell on tuning bell trumpet*

3. RESULTS AND DISCUSSION

The results of the simulations are summarised below and demonstrate that in order to produce a bell that exhibited similar traits to that of a brass bell the thickness had to be increased significantly.

The Bb trumpet produces standing waves at resonant frequencies that follow a harmonic sequence from F3sharp; 185Hz to C6; 1046.5 Hz. The deformations that occur within the harmonic sequence will have an effect on the behaviour of the wave that will give rise to the tone associated with the bell (although higher modes will also have some impact).

The simulation results showed that there is a correlation between the deformation amplitudes and frequency when increasing the thickness of the material. By thickening the ABS bell the mode frequencies for each increases whilst the deformation is reduced. The increase in thickness alters the rigidity of the bell therefore vibrations are further damped.

In order to emulate the brass bell it is desirable for the plastic bell deformations to occur at similar mode frequencies. Due to the nature of the plastic being a ‘softer’ material it is expected that the resonances will be lower. The simulations clearly demonstrate this with frequency values of less than half that of the brass bell (0.75 mm thickness) with an increase to approximately 60% at 3.00mm (Figure 2).

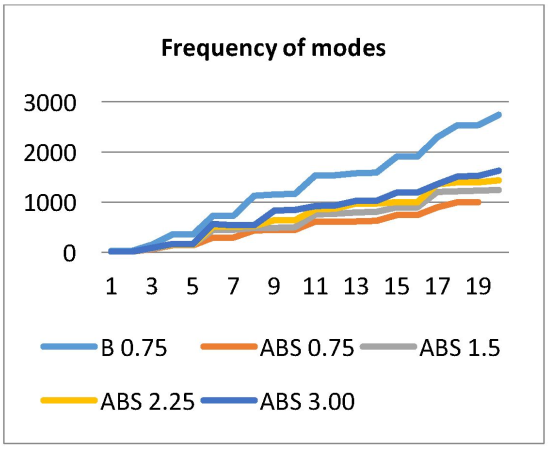

Figure 2: Mode frequencies (Hz)

Axial deformations are shown in Figure 3. Beyond mode 7 showed unpredictable behaviour as did the elliptical vibrations after mode 12 although again there was a tendency for the deformations to reduce. This is at the top range of the Bb trumpet and the influence this has will need further investigation.

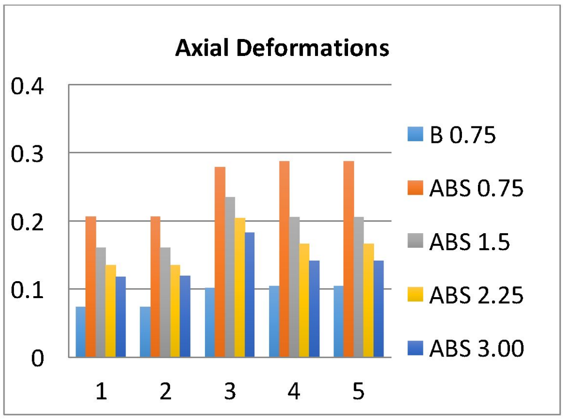

Figure 3: Axial deformations 26 Hz to 325 Hz

3.1 EXPERIMENTAL RESULTS

The harmonic content of the three trumpets are shown in Figures 4 to 8. The higher modes have not been included as the magnitude is small in comparison to the frequencies shown. It can be seen in Figure 4 that the trumpet with a 1.5 mm bell displays a higher magnitude content of the upper harmonics with only a slight rate of change between adjacent modes whereas the thickest bell the least.

In semantic terms for timbre the former manifests itself as a thinner sound which is perceived as more directional whereas the latter gives a fuller richer sound. This is expected due to the lower magnitudes and rates of change between the higher harmonics. The ear is most sensitive at this region and would pick up the subtle magnitude changes.

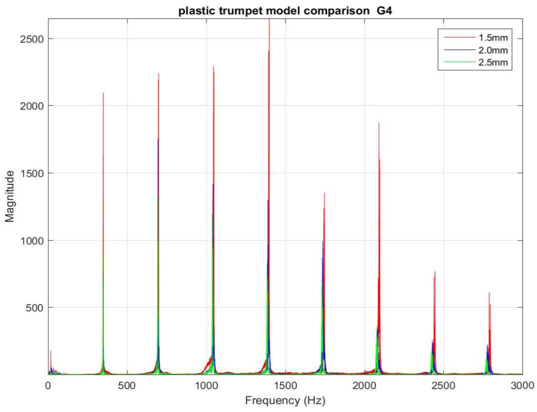

Figure 4: G4 harmonics – plastic trumpets

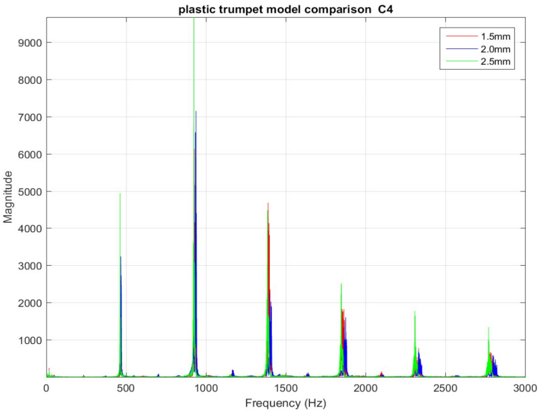

Figure 5: C5 harmonics – plastic trumpets

At the higher note of C5 (Figure 5) the rate of change can still be seen as the smallest between the modes for the thin belled trumpet. Again the richness of the 2.5 mm bell can be observed. Anecdotal comments from the recording engineers commented on the thinner trumpet saying it did not sound as 'real' as the thicker belled instrument. Other measurements produced similar results although not all were as conclusive as those shown. This may be explained by the subjective nature of the tests compared to that which would be conducted using artificial lips.

The second part of the experiment investigated the timbre of the pTrumpet compared to a hybrid Schilke B1L professional instrument using a pTrumpet bell.

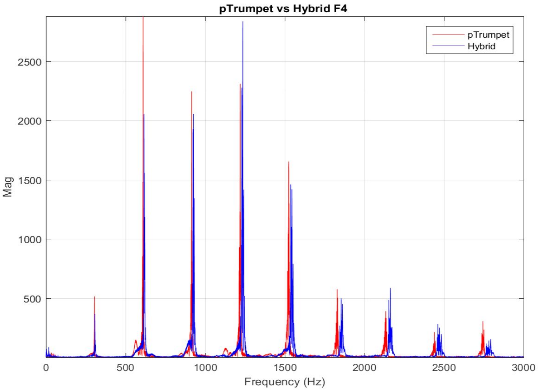

Figure 6: F4 harmonics – pTrumpet vs Hybrid

The graph shown in Figure 6 shows an interesting response in that there is a high degree of similarity between the pTrumpet and the hybrid trumpet at F4. However, there were subtle differences in timbre which is borne out by the different rates of change at the second and third modes and again between the third and fourth mode.

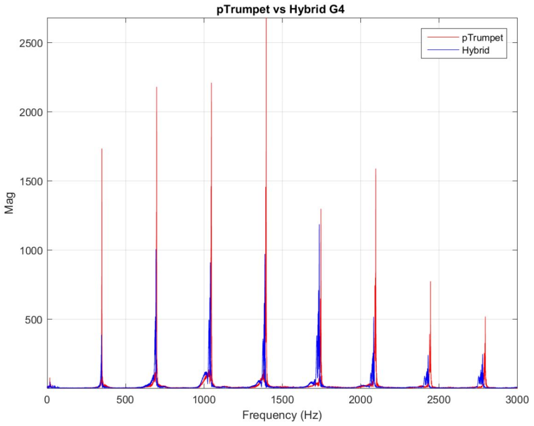

Figure 7: G4 harmonics – pTrumpet vs Hybrid

A similar pattern can be seen at G4 and C5 (Figures 7 and 8) although at higher notes beyond C5 there becomes a greater disparity between the changes. This indicates that other artefacts begin to feature such as changes in embrasure which cannot be kept constant as well as construction of the instruments influencing the vibrations of the air column within it, for example, bell braces.

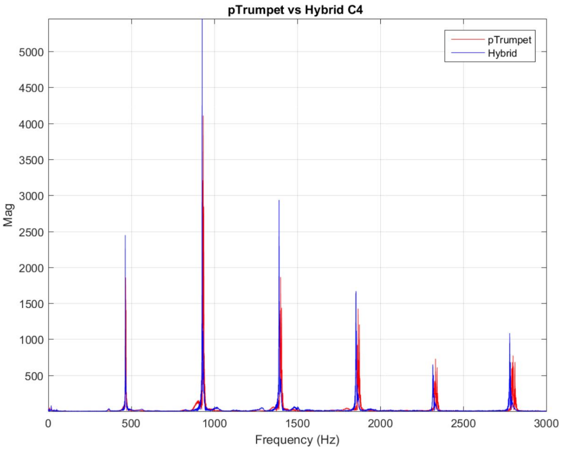

Figure 8: C5 harmonics – pTrumpet vs Hybrid

4. CONCLUSION

The discussion presented has highlighted the need to consider material thickness in the design of novel plastic bells for professional trumpets for different timbres. Thickness and material type influence the axial vibrations that in turn alter the timbre as stated by Kausel. The simulations presented show that the vibrations within the bell occur at similar nodes in the flare with reducing amplitudes to increased thickness of the material for lower modes. If an ABS bell is made thick enough then the vibrations begin to approach that of a thinner brass bell.

The experiments presented demonstrate that the timbre is altered as the bell thickness is increased. The results, although subjective, show indicatively that the thinner bell gives a less rich or 'brassy' sound compared to the fuller or broader sound of the thicker bell. Although the higher modes are more prevalent in the thinner bell it does not produce a 'bright' sounding instrument as the lower harmonics are not present to produce the richness of tone.

The application of a plastic bell on a brass bodied instrument demonstrates that it plays a significant part on the timbre whether on a plastic or metal body with similar timbres produced at the mid-range of the instrument.

Further work will require a thorough analysis of the bell thickness through modelling and simulations to estimate the optimum dimensions using more accurate model parameters. The choice of Young's modulus and density of ABS for different manufacturing will alter this thickness and will determine factors such as mass and fragility. Bells will need to be fabricated and timbre measured using less subjective experimental methods such as stimulation by artificial lips. Far field measurements will also determine performance (projection). Investigation of the repeatability of printing will also be necessary, an issue that has plagued manufacturers. Mass production using moulding techniques may facilitate this. This will result in a new low cost fabricated bell that may be used for professional applications where the musician can use a hybrid trumpet, one that may use brass or plastic bells as required.

5. ACKNOWLEDGEMENTS

I would like to thank Jay Stringer with his help with recording and Emilia Romagnani-Onida for her help with the plots.

6. REFERENCES

Gibson D., (2016) Novel Designer Plastic Trumpet Bells for Brass Instruments, *Proceedings of Electronic Visualisation and the Arts London 2016*, pp.10-14.

Kausel, W., Zietlow, D. W., and Moore, T., (2010) Influence of wall vibrations on the sound of brass wind instruments, *Journal of Acoustical Society of America*, vol. 128, pp.3161-3174.

Kausel, W., Chatziioannou, V., Moore, T., Gorrman, B. R., and Rokni, M., (2015) Axial vibrations of brass wind instrument bells and their acoustical influence: Theory and simulations, *Journal of Acoustical Society of America*, vol. 137, pp.3149-3162.

Moore, T., Shirley, E. T., Codrey, I. E.,and Daniels, A. E., (2005) The effects of bell vibrations on the sound of the modern trumpet, *Acta Acustica united with Acustica* vol. 91, pp.578-589.

Moore, T., Gorrman, B. R., Rokni, M., Kausel, W., and Chatziioannou, V., (2015) Axial vibrations of brass wind instrument bells and their acoustical influence: Experiments, *Journal of Acoustical Society of America*, vol. 138, pp.1233-1240.

Pyle, R. W., (1997) How brass instruments are built: Art, craft, perhaps even science, *Journal of Acoustical Society of America*, vol 101, 3056.

Schilke, R. O., http:/www.dallasmusic.org/schilke/Brass%20Clinic.html (retrieved 21 March 2016)

Smith, R. A., (1978) Recent developments in trumpet design, *International Trumpet Guild Journal* vol 3, pp1-8.

Smith, R. A., (1986) The effect of material in brass instruments; a review, *Proceedings of The Institute of Acoustics*, vol 8 Part 1, pp. 91-96.