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An Investigation into the Brassiness Potential of Wagner Tubas

Lisa Norman[1], Arnold Myers[1], Murray Campbell[2]

[1]School of Arts, Culture and Environment, University of Edinburgh, EH8 9DF Edinburgh, United Kingdom, {lisa.norman,a.myers}@ed.ac.uk
[2]School of Physics, University of Edinburgh, EH9 3JZ Edinburgh, United Kingdom, dmc@ph.ed.ac.uk

The Wagner tuba is a relatively new addition to the family of brass instruments and could be said to contain physical and acoustical characteristics of both the horn and the tuba. It has survived the test of time, as it successfully provided the addition of a noticeably different tonal colour to the already rich spectrum of brass timbres. One of the most characteristic aspects of a brass instrument's timbre is how quickly the tone becomes brassy with increasing dynamic level. This paper describes an investigation into the brassiness potential of Wagner tubas and related instruments. Tests involved measuring the rate of spectral enrichment during a crescendo, using a loudspeaker positioned at the input of the instrument as the excitation mechanism. The relationship between the input and the radiated sound pressure at the bell of the instrument is explored. The results from these experiments are compared with the values of the Brassiness Potential parameter derived from detailed measurements of the bore profiles of the instruments.

1 Introduction

As a topic for discussion concerning the brassiness potential of brass instruments, the Wagner tuba may perhaps seem to be an unusual choice; far from being described as brassy sounding, its timbre is often referred to as dark and solemn [1]. There are a number of other types of brass instrument whose tones could certainly be described as sounding brighter and brassier than that of the Wagner tuba, such as the trumpet or trombone. The human ear is capable of detecting subtle differences between similar types of brass instrument and one of the cues it uses to decipher the sound is a change in timbre with increasing dynamic level [2]. One note in isolation might not always be enough to be sure of the instrument type but in the context of a piece of music, the distinction is usually much clearer.

This change in timbre with increasing dynamic level indicates a change in the spectral content of the tone; at louder dynamics this can be observed as an increase in the strength of higher frequency components, thus generating a brighter sound. The rate at which this increase occurs varies from instrument to instrument and can be described as the rate of spectral enrichment, or as the brassiness potential.

The main factor which influences brassiness potential is the bore profile of an instrument [3]; however other variables such as the dimensions of the mouthpiece [4], the technique of the player [5], and properties of the construction material [6][7], have all been found to play a role. Trumpets are definitely on the more brassy end of the tonal spectrum and as a generalisation, their bore profiles have generally been found to have a larger proportion of narrow cylindrical tubing than their more mellow sounding counterparts, the cornets.

The acoustical implication associated with cylindrical tubing is that it provides a greater potential for the occurrence of non-linear behaviour in the air column of the instrument as a result of wave steepening. On the other hand, in brass instruments where there is a greater proportion of expanding tubing, as in the case of the cornet, wave steepening does not occur to the same extent because the energy from the travelling sound wave is distributed over an increasingly large area [8].

Wagner tubas are usually played by horn players and while the mouthpiece used is the same or similar to that of the horn, the bore profile of the rest of the instrument is noticeably different, being less cylindrical in shape than the horn and thus with a reduced potential for brassy playing. Similarities and differences between the two instruments will be explored further in this paper.

An alternative method for predicting brassy behaviour has been devised by Pyle and Myers and has been called the Brassiness Potential parameter [3]. The calculation is based on detailed bore profile measurements and as such, is a valuable way of gaining insight into the playing characteristics of certain historic instruments where acoustical experiments might be detrimental to their fragile state. A comparison is made between the results from the experimental data and the theoretical parameters.

2 Experimental procedure

In order to examine the rate of spectral enrichment with increasing dynamic level, the relationship between the initial sound pressure waveform at the entrance to the instrument and that of the resulting radiated sound was measured using the set-up shown in Figure 1.

Previous research in this area has involved the use of human players to provide the input crescendo [8], but in order to provide a more objective analysis for this study, the human player has been replaced by a loudspeaker.

The radiated sound from the bell of the instruments was measured using a Bruël and Kjaer microphone and the input sound from the loudspeaker signal was measured using a PCB microphone. All measurements were carried out in an anechoic chamber in order to record only direct sound radiation from the bell. The loudspeaker was set to emit a crescendo of a sinusoidal tone, frequency 1.5 kHz, over a period of approximately three seconds. The value of 1.5 kHz was chosen as a suitable frequency for two main reasons: first, it was higher than the predicted cut-off frequency of the instruments examined, thus ensuring that the sound was radiated straight out of the bell, rather than causing reflections, which lead to the formation of standing waves in the air column; second, the frequency was low enough that distortion of the waveform due to the excitation of higher mode resonances was kept to a minimum.

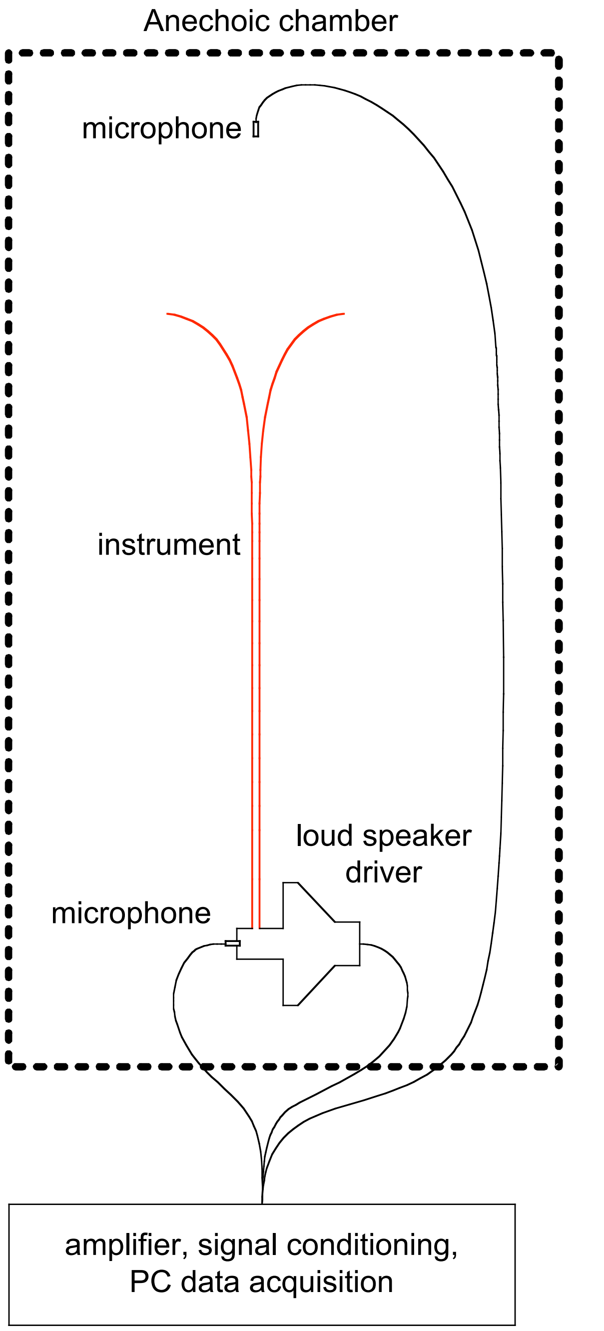

Figure 1: Experimental set up showing the positions of the microphones.

The spectral centroid for the radiated pressure signal was then plotted as a function of the rms pressure of the input signal and an example of a resulting 'brassiness' curve can be seen in Figure 2. Instruments with the least brassiness potential would appear on the graph as a nearly horizontal line, and as the potential for spectral enrichment increases, so too does the final value of the radiated spectral centroid value on the curve.

3 Results and discussion

3.1 Comparison of tenor and bass Wagner tubas

Figure 2 shows the spread in results from all of the Wagner tubas measured, including examples of both bass and tenor instruments. It would be expected that the longer bass tubas in 12-ft F have a greater potential for brassy behaviour than the shorter tenor tubas, given that they generally have a larger proportion of cylindrical tubing. This is apparent from the graph, although the relationship between the two groups could be described more accurately as existing on a brassiness potential spectrum.

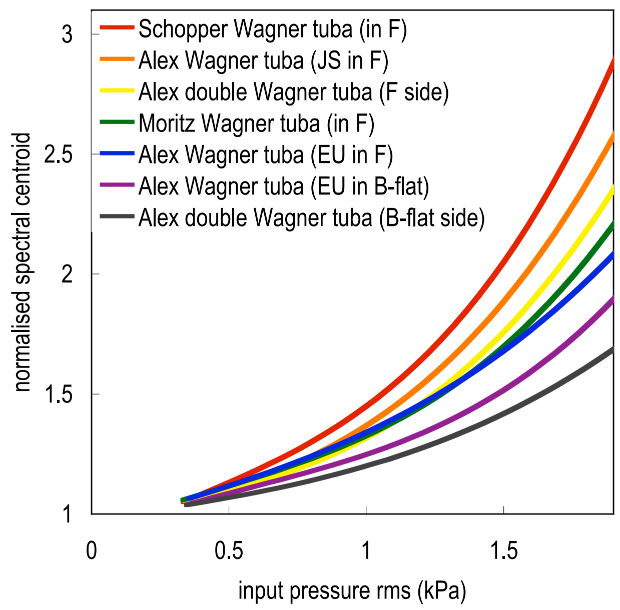

Figure 2: Brassiness curves showing the radiated spectral centroid as a function of the input pressure for both bass (12-ft F) and tenor (9-ft B-flat) Wagner tubas.

It is interesting to observe the variation between the two sides of the double Wagner tuba (grey and yellow lines). These two measurements were recorded on the same instrument, which has a thumb valve allowing for easy transition between the shorter 'B-flat side' and the longer 'F side', hence the name 'double' Wagner tuba. This relatively new model has come under some criticism concerning the assumption that a shared bore profile would merge the tonal qualities of the bass and tenor instruments. This data shows that, on the contrary, there appears to be a greater difference in spectral enrichment between the different sides of the double instrument than there is between the associated bass (blue line) and tenor (purple line) pair of Wagner tubas from the Edinburgh University Collection of Historic Instruments (identified in legend on graph with EU).

3.2 Comparison with other brass instruments

In order to further explore the identity of the Wagner tuba sound and brassiness potential, it was useful to include in the data set examples of other types of brass instrument. In the graph in Figure 3, three examples of Wagner tuba brassy curves (thick lines) have been plotted alongside the curves of a horn, a trombone, a cornophone and a euphonium (all thin lines).

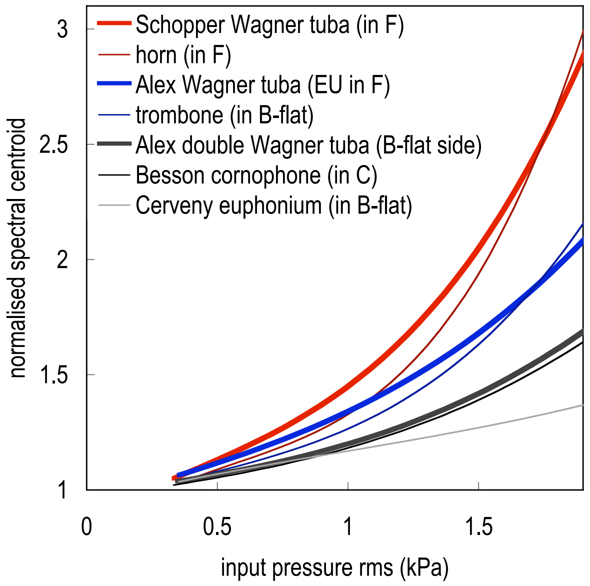

Figure 3: Comparison of brassiness curves showing the radiated spectral centroid as a function of the input pressure between selected Wagner tubas and other brass instruments.

At approximately 1.75 kPa, the curves of the horn and the Schopper Wagner tuba are shown to cross and the two curves have noticeably different contours; while the Wagner tuba becomes brassy earlier on in the crescendo, the horn appears to have a more sudden transition to a brassy timbre. In the graphs displayed, the input pressure is only shown up to approximately 2 kPa, but in reality a player is capable of producing an input pressure of as high as 3 kPa [8]. Given the shapes of the curves and the crossing of the lines, it is easy to imagine that the horn, played at its brassiest dynamic level, would sound substantially brighter than the Wagner tuba. This result is also consistent with the theory that the bore profile of the horn consists of a longer cylindrical section, allowing for greater non-linear behaviour in the air column.

A similar shape of curve can be seen in the example of the trombone, which crosses the curve of the bass Alexander Wagner tuba (EU), again at approximately 1.75 kPa. Of all the '9-ft B-flat' instruments measured, the trombone was the only example whose curve crossed over into the brassiness spectrum of the longer 12-ft instruments. Despite the shorter overall length of tubing, the trombone by its very nature has a substantial cylindrical section (through the slide) and this provides the potential for the build up of shockwaves in the air column, leading to greater brassiness at loud dynamic levels.

The cornophone is a little known brass instrument, which was popular for a short time around the end of the nineteenth century, particularly in France where it was often used as a substitute for the Wagner tuba. It is interesting therefore, and perhaps not surprising, that a comparison of its brassiness potential with that of the Wagner tuba reveals that they share very similar timbral characteristics in this area. This is evident from the graph in Figure 3, which shows very similar curves for a double Alexander Wagner tuba (B-flat side) and a Besson cornophone (in C). This similarity may also help to explain the fleeting nature of its popularity, because there was no demand for two such homogeneous voices in the palette of brass instrument timbres at the time.

Also included on the graph in Figure 3 is the brassiness curve for a Cerveny euphonium with the same length of tubing as that of the tenor Wagner tubas. This euphonium has the least amount of cylindrical tubing of all the instruments measured and as such it has limited potential for the production of a brassy timbre, even at the loudest dynamic levels.

3.3 Brassiness Potential Parameter

The Brassiness Potential parameter, B, was derived by Pyle and Myers as a way of predicting the spectral enrichment of different brass instruments, and it can be calculated based only on measurements of the bore profile of an instrument using the following equation [3]:

$$B = {z(L)}/{L_{ecl}} \qquad (1)$$

where B is the Brassiness Potential parameter and $z(L)$ is the equivalent cylindrical length – a hypothetical length of cylindrical tubing in which non-linear distortion of the waveform occurs to the same extent as it would in the actual instrument under observation. L_{ecl} is the equivalent cone length – a hypothetical cone length that would produce a harmonic series based on the nominal fundamental frequency of the instrument in question [9].

Table 1 shows the spread in results of Wagner tubas, ranked by highest value of parameter B. Also included in this list is the Besson cornophone in C, previously discussed in section 3.2 as sharing similar acoustical properties to the Wagner tuba. Results range from 0.37-0.44.

	L_{ecl} (m)	$z(L)$ (m)	B
Alex double Wagner tuba (F side)	3.849	1.673	0.44
Schopper Wagner tuba (in F)	3.923	1.649	0.42
Alex Wagner tuba (EU in F)	3.966	1.626	0.41
Besson cornophone (in C)	2.689	1.079	0.40
Moritz Wagner tuba (in F)	4.035	1.577	0.39
Alex Wagner tuba (EU in B-flat)	2.875	1.089	0.38
Alex double Wagner tuba (B-flat side)	2.955	1.101	0.37

Table 1: Equivalent cone length (L_{ecl}), maximum stretched coordinate value ($z(L)$) in (m), and Brassiness Parameter (B) for instruments with narrow mouthpiece receivers.

Previous research into the Brassiness Potential parameter has explored typical values of B for different types of brass instrument [3]. Horns for example have been found to have values of B in the range 0.45-0.60, and trombones in the range of 0.63-0.80. These results are consistent with those displayed on the graph in Figure 3 where the horn is shown to have a slightly brassier potential than the bass Wagner tubas, and the trombone is shown to be significantly brighter than the tenor Wagner tubas of similar length.

Euphoniums have been found to have values of B in the range of 0.37-0.47, comparable to those of the Wagner tubas (0.37-0.44). Although there are certainly acoustical similarities between these two groups of brass instruments, there is still an aspect of their tonal characteristic, which makes it possible to tell them apart. The main difference between the Wagner tubas and the euphonium is the different mouthpiece used; euphoniums generally require a larger mouthpiece with a wider shank than that of the Wagner tuba, which is normally smaller given that the mouthpiece receiver is narrower in diameter so that it can receive a horn-like mouthpiece.

3.4 Mouthpiece and timbre

Differently shaped mouthpieces have been found to play a role in influencing timbre; for example, the horn mouthpiece is shaped in such a way that the lower modes of resonance are strengthened, but in the case of the trumpet, the more cupped mouthpiece is designed to boost frequencies around the fifth, sixth and seventh modes of resonance.

Preliminary tests exploring the acoustical effects of three differently sized horn mouthpieces on the brassiness potential of the Wagner tubas, revealed that a small difference could be heard in the timbre of a very loud brassy sound. However, greater variation in the spectral content of the sound was apparent at medium and quiet dynamic levels. Further experimentation and research is required in this area in order to draw more substantive conclusions.

4 Conclusions and further work

When trying to identify the type of brass instrument based on timbre alone, the listener intuitively picks up on acoustical characteristics during both quiet and loud playing. How an instrument responds in terms of spectral enrichment during the playing of a crescendo is a key identifier. The spread in Wagner tuba data appeared at first viewing to be quite broad, but on closer inspection the shapes of the curves were all relatively similar when compared to that of other instruments such as the horn or trombone. In general, the production of a brassy edge to the tone quality of the Wagner tuba appeared to develop more gradually than on the horn and trombone where the transition was more sudden and more extreme.

The cornophone in C by Besson was the only instrument included in this data set to show a significant similarity with the curves of the Wagner tubas. This result was to be expected because analysis and comparison of their respective bore profiles showed similar congruence.

The Brassiness Potential parameter was found to be a useful tool for predicting spectral enrichment characteristics of different brass instruments; the predicted brassiness behaviour agreed to a large extent with the experimentally measured spectral enrichment curves.

The area in which there remains some ambiguity is the effect of the mouthpiece on potential brassiness. Further research is planned to look at the influence of the throat diameter and cup volume of a horn mouthpiece on the spectral enrichment of a tone.

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