GETTING TECHNICAL

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There is no such thing as a perfect instrument! Part 2

The first article in this series showed that (a) the air column contained in a brass instrument has a natural series of resonances which are ***not*** harmonically related and (b) the size, shape and frequency of these resonances is largely controlled by the shape of the instrument's bore. This explains why all instruments are different. As a consequence, there is no such thing as a perfect instrument, only the best one to suit each individual player. However, the note produced by the instrument and player contains true, exact harmonics, each harmonic being reinforced or weakened by the accuracy of its fit into the resonances (or slots) of the instrument.

Resonance Curve
The Instrument's Fingerprint

Let us now treat the instrument as a 'black box' and measure the output from the bell when a pure signal of varying frequency is put into the mouthpiece. We obtain something like the resonance curve shown in Figure 1. This is similar to the sound created when a player makes a *glissando* from low to high frequency without stopping or deviating!

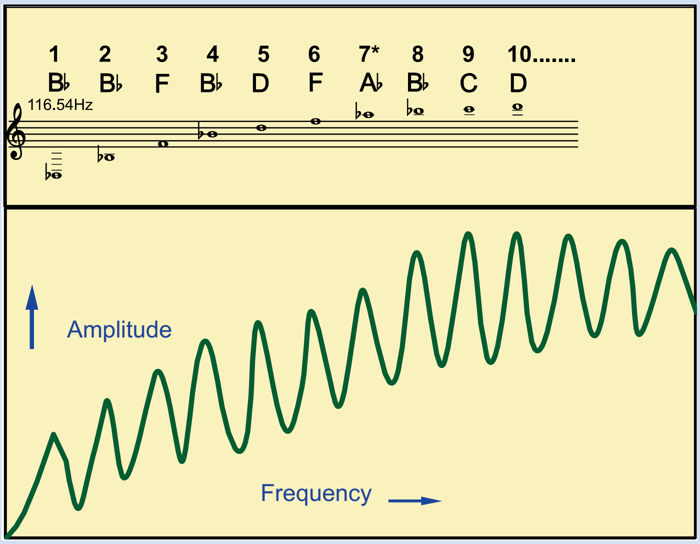

Fig 1. The impedance curve of a trumpet.

I have superimposed the note names which approximate to each of the peaks. This graph is similar to my 'Brick Wall' analogy when turned on its side, as described in the previous article. It represents the characteristics of that one unique instrument which we have measured and I believe that these data, if we could measure them accurately enough, contain most of the information needed to determine how the instrument behaves. For me, this is the unique *fingerprint* of the instrument.

The general characteristics of the open notes of a trumpet, bugle or tuba, for example, are as follows. Firstly, the pedal note (mode 1) is often flat and is useless on 3-valved instruments where the octave gap to the next note on resonance #2 cannot be closed. This is why 4-valved instruments were invented to breach the gap, especially on the large brass where pedal notes are frequently required and easier to play.

Secondly, the 7th resonance on most instruments is often too flat to be used in conventional music. One exception springs to mind, in the *Serenade for Tenor, Horn and Strings* by Benjamin Britten, where the french horn player is instructed to play on the 'natural harmonics (*sic*) of the instrument'. Fortunately a valved instrument gives the player alternative fingerings to replace this flat 7th.

Finally, the sixth resonance tends to be sharp and the fifth is usually flat.

We shall now investigate the fifth and its associated 10th a little further to illustrate just one of the compromises that the player and acoustician have to make between perfect intonation and uniform tone quality.

Playing Notes - The Clash of Harmonics

In the last article, we saw that the steady notes of a wind instrument consist of a fundamental and many (true) harmonics all exactly integrally related in frequency to the fundamental. The four diagrams in Figure 2 illustrate what happens when we choose to play two different notes.

If in Figure 2a, we superimpose a B-flat note (233 Hz) on the resonance pattern of numbered peaks, we see in this instance that all the harmonics represented by equally spaced vertical lines are well supported by the peaks of the resonances.

If in Figure 2b, we now add a D (587 Hz) to the same pattern, the fundamental lines up perfectly, but its second harmonic is sharp to the peak of the 10th resonance. So the 10th resonance of the instrument has to support the 5th harmonic of B-flat (1165 Hz) and the second harmonic of D (1175Hz), the difference being a quite noticeable 14% of a semitone (Figures 2c and 2d).

By choosing only two notes, we have demonstrated how imperfect all brass instruments are. Basically, there are not enough resonances in the instrument to support all the possible notes and their harmonics, and therefore some compromise between intonation and tone quality has to be made.

How Can The Designer Help?

There are several ways to make a compromise. Firstly, some manufacturers (probably by trial and error) flatten the 5th resonance and allow the note D to play flat, as shown in Figures 2c and 2d. Consequently the player has to 'lip-up' to correct this note, which they learn to do automatically, although the tone quality could be degraded.

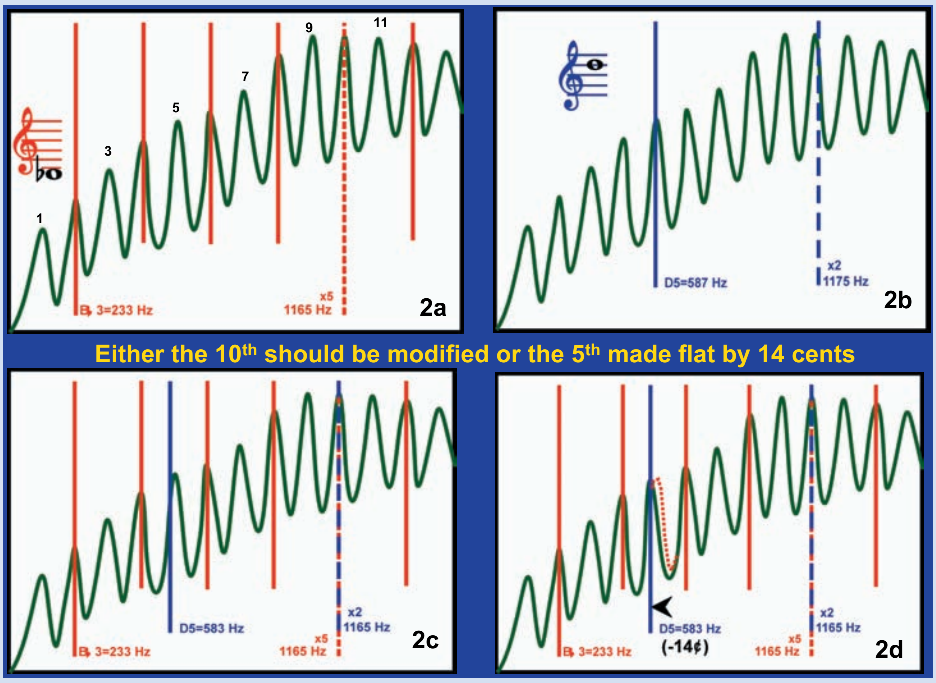

Fig 2. Superimposing the notes B-flat and D shows a conflict at the 10th.

Secondly, choosing a large bore instrument, which has wider resonances and therefore makes the accommodation easier, will help to give the player more flexibility when adjusting notes.

Finally, a method preferred by ourselves is to tune the 10th resonance to accommodate both harmonics for their mutual benefit by using a 'perturbation technique'.

Perturbation Technique

In a simple form, a perturbation technique was developed by David Blaikley in 1878 when, as works manager of Boosey & Hawkes, he had to improve the tuning of bugles as used by the Army. He made sample bugles out of *papier maché* and discovered that if he slightly modified the bore diameter (a perturbation) at the low and high pressure points (nodes and antinodes) of a particular note, he could change the pitch of that note, as shown in Figure 3. His improved bore profile was then made out of copper.

The Blaikley method might seem a straight forward procedure,

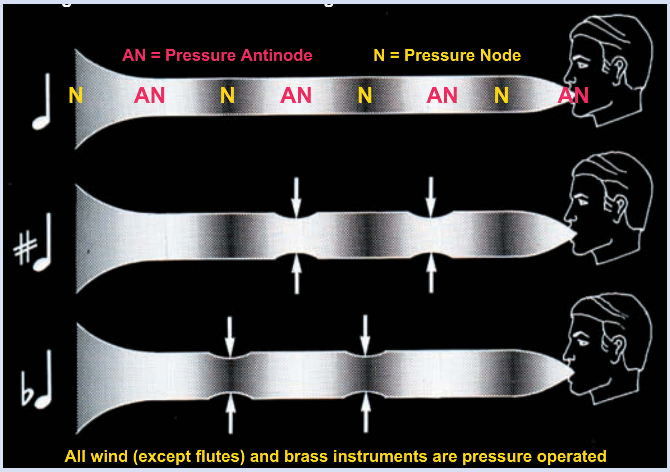

Fig 3. The effect of reducing the area at nodes and antinodes.

but I would not advocate it for the *DIY* enthusiasts amongst the readership of *The Brass Herald*! In reality, the problem of intonation correction is very complex as shown in Figure 4 by our measurements of pressure inside a trumpet for resonance modes 2 to 10. Note that, as already shown in the previous diagram, the *real* measured pressure is a maximum at the mouthpiece and zero at the bell. In between, there is a mass of

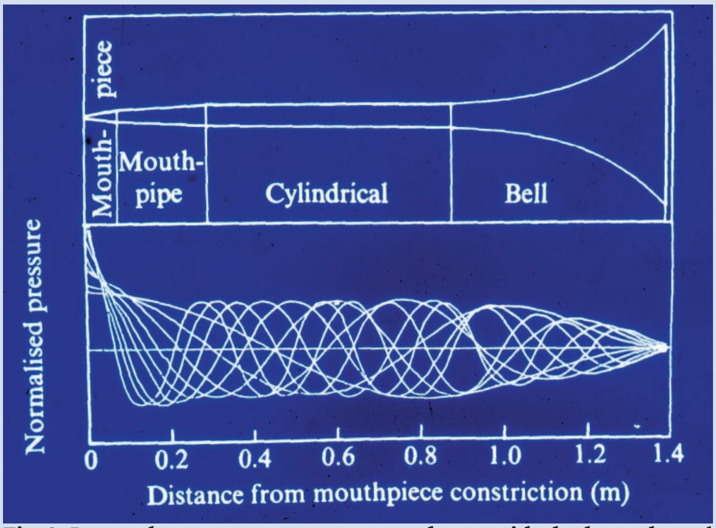

Fig 4. Internal pressure measurements shown with the bore shape.[1]

high and low pressure points making it impossible to find a position along the bore where only one mode would be affected by a small change in bore diameter. Imagine what the picture would be like if we tried to add the pressure curves of all the valve combinations!

It is clear that simple perturbations to the bore would affect many notes in different directions at the same time on even a simple bugle-type instrument.

Almost 100 years later, it became apparent to Geoffrey Daniell and myself (working at the University of Southampton) that the resonances in the air column of a tube behave in a similar way to the distinct energy levels of electrons flying around the nucleus of an atom. Using Perturbation Theory from Quantum Mechanics, we were able to set up a mathematical matrix which included each resonance or note. This allowed us to control the change required for each resonance e.g. *'to modify the 10th by 5% and set all the other resonances to zero*'. The computer generated output from this experiment was a modified bore shape. The cumulative effect of very small changes, each less than 0.2mm, over all or part of an instrument made the required change in intonation.

This discussion might be pedantic, but it explains why there is no such thing as a perfect instrument. In the next article, however, I will describe how I optimised modern design techniques to produce the Sovereign 928 Cornet, still a best selling instrument worldwide, 25 years later.

[1]Modified from: Smith R A & Daniell G J. Systematic approach to the correction of intonation in wind instruments. Nature, 262, No 5571, pp761-765, August 26, 1976.