GETTING TECHNICAL
Where is the Harmonic Series

Dr Richard Smith

Dr Richard Smith, designer and maker of the Smith-Watkins brand, has combined academic study with practical musicianship to tackle some of the myths surrounding brass instrument design. In this and future volumes of *The Brass Herald*, he will tackle some of these issues with the aim of helping players to understand their instruments better and to determine which attributes are the most important when choosing and playing their horns.

Anyone involved with brass instruments talks freely about the *harmonic series* in or on their instruments. Much of this is hearsay and misguided information passed down from teacher to pupil. Personally, I believe that the blame goes back centuries to the ancient philosophers, such as Pythagoras, who proposed that the overtones and modes of oscillation of a string or air column are *exactly* harmonically related. In contrast, in this first article, I lay out the facts as they are in *real life* to help you understand why instruments are *all* different. This gives the musician an infinite choice of instrument and the expert maker the knowledge and capability to design better instruments.

You might think that you get a *harmonic series* free with every brass instrument you buy. If this were true, the world would be a very boring place, with instruments playing identical notes, similar to the characterless sound of the early electronic pianos. Instead, with your purchase, you buy a *unique* series of resonances of the air column inside the instrument, largely defined by the shape of the tube and known to many professional players as *slots* or *grooves*. Unlike shopping at Marks & Spencer, once you have bought them you cannot make an exchange if they are not to your liking. The strength, position and shape of these grooves have been chosen by the manufacturer to give maximum sales of a particular instrument for the 'average' player. I know this from personal experience in designing the 928 Sovereign cornet for Boosey & Hawkes in 1984, a model which went on to sell in its thousands until the present day. That unique design procedure will be described in a future article.

Apart from practical music-making (on the side), my interest in the subject of instrument design was first sparked by a particular 'A' Level Physics practical test in which the end corrections of a vibrating air column had to be calculated. This clearly demonstrated to me that science in the 'natural' world is quite different to that described by the theoretician or basic physics syllabus. Even the air resonances in a perfect cylinder are not exact harmonics and furthermore, by modifying the tube from a perfect cylinder, they can be moved, resized and reshaped by a skilled designer. The effect of these changes is to alter the intonation, tone quality and response of one or more selected notes. This topic will be explored in the next article.

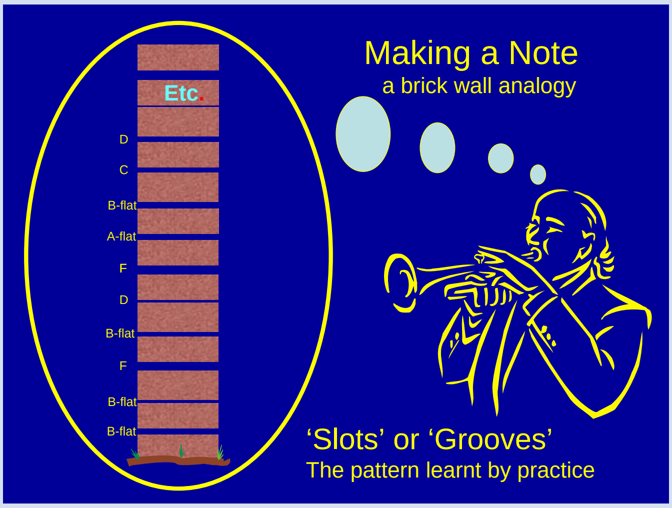

Figure 1. This diagram represents players' descriptions of the slots in which they aim their notes. The pattern of slots between the bricks is one learnt by practice and will vary from one instrument to another.

My Brick Wall Analogy

After 35 years of instrument measurement, I have developed the following overview of brass playing which allows for a logical understanding of the design and playing of brass instruments.

Most brass players imagine a set of 'slots' or 'grooves' in which they aim to place a note. Figure 1 represents an instrument using the analogy of a brick wall, without any mortar between the bricks. The gaps, which are irregular, are the 'slots' and the bricks, which also vary in thickness, are the parts where a note cannot be made. It is clear that a player has to learn the slot positions for the notes of their instrument through hours of practice and, given a new or replacement instrument, will need to re-learn the new set of slots. As for the bricks, how often do you see a player giving his instrument the accusatory look of *'did you do that?'* when a slot is missed and the note is split against a brick? Indeed, if we take the wall analogy to its extreme, every wall (in real life) and every brass instrument ever built is going to have its own characteristic qualities. This is why the most discerning player can select 'the best' instrument from a group of supposedly identical instruments of the same batch.

What about the Harmonics?

In playing a steady note, which must have exact harmonic content for it to exist, players need to find a slot, not just for the fundamental (the lowest harmonic which gives the note its name) but also for support of the many higher harmonics. If you want to play a note which has a fundamental frequency, for example a B-flat at 233Hz, its second harmonic will be exactly twice that value (466Hz), the third at (699Hz) and so on, to higher harmonics well over the 20^{th}!

Imagine the harmonics to be like the rigid, equally spaced prongs of a comb, which you are attempting to fit into the slots. Figure 2 shows the first 6 harmonics of B-flat based on a

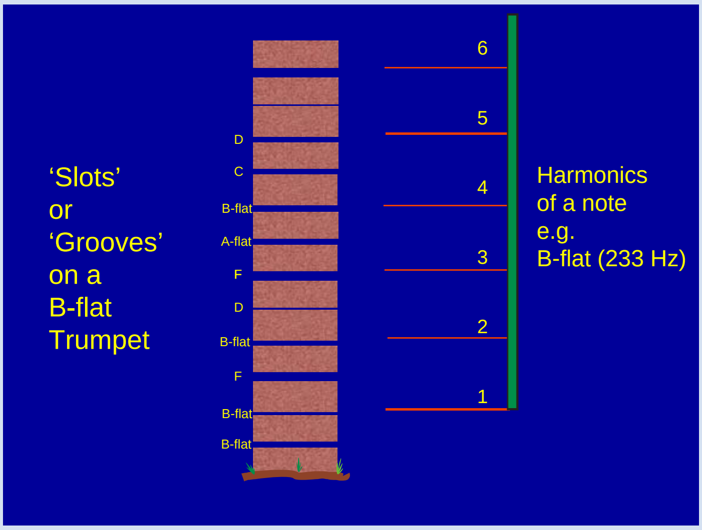

Figure 2. The note created by the player has true harmonic content and the player has to fit this into the non-harmonic series of slots of the instrument.

fundamental of about 233Hz. When this note is played, you unconsciously place the fundamental in the second slot up, the 2nd harmonic in the 4th slot, and so on. Whilst doing this, the skilled player will lip up and down slightly to gain the maximum output from the instrument whilst trying to maintain the pitch and best quality of sound, resulting in some sort of compromise as shown in Figure 3. The steady note produced depends not only on the one slot the player imagines but also on the support of many higher locations. Consequently the 'best sound' might actually be sharp or flat.

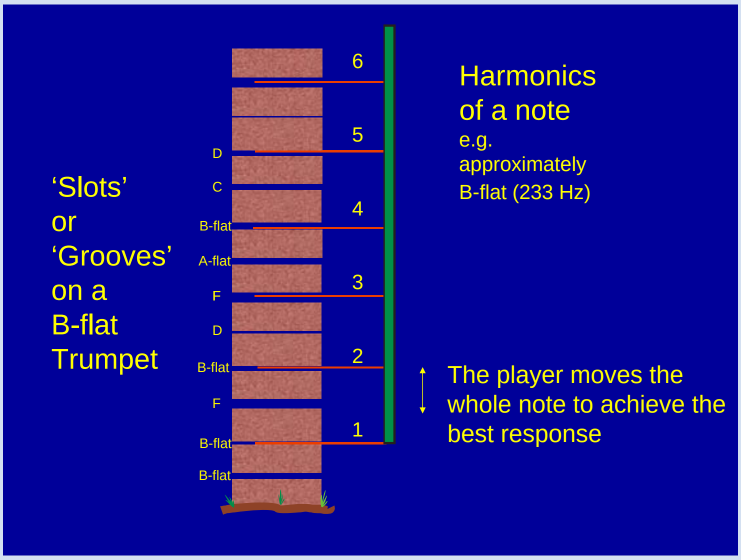

Figure 3. When the note is located in the slots, some of the harmonics will be reinforced or attenuated, thereby affecting the overall quality of sound.

Even this is a simplified view of note-making since in reality the slots are tapered, making the process far more critical in the way the harmonics of a note are reinforced or attenuated and thereby affecting the overall quality of sound.

After reading this, you might have already joined me in the conclusion that there is no such thing as a perfect instrument - but only the best one to suit you!

Effect of Bore Size

Student horns generally have relatively small bores and the slots are narrower, locking the player into the instrument's intonation. This also restricts the degree to which the player can 'swing' the note - which is probably a good idea for a beginner. It follows that, for these players, it is advisable to choose an instrument with the best intonation. Conversely, the more experienced player has better control of larger-bored instruments with their wider slots, giving the player greater flexibility to vary the pitch and to create a stronger and richer sound with additional reinforced harmonics.

In conclusion so far, although the overtones in a steady note are true harmonics, the series of slots which are the resonances of the air column inside the instrument are not harmonically related and are unique to each individual instrument. It is more appropriate to call the group of slots a Natural Series - it is pleasing to note that many players of the non-valved 'early' instruments refer to them as *natural trumpets* or horns. Similarities to the natural world are striking; the natural series of resonances defines the properties of the instrument. It is its fingerprint - almost like human DNA ….except, unfortunately for us designers and makers, clones are impossible!

The author:
Richard Smith gained his PhD in Musical Acoustics at the University of Southampton and was recently awarded an Honorary Fellowship in the College of Science and Engineering at the University of Edinburgh. He is Managing Director of Richard Smith (MI) Ltd, which designs and makes the Smith-Watkins trumpets, cornets, flugel horns and fanfare instruments - www.smithwatkins.com