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APPROACHES TO AN ACOUSTIC TAXONOMY OF BRASS MUSICAL INSTRUMENTS

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1. INTRODUCTION

Scholars of brass musical instruments and curators of museums holding collections of historic brasswind have sought to arrange their material by classification systems. Some (Hornbostel & Sachs 1914) and many general writers on musical instruments do not go beyond a division of instrument types into 'conical' and 'cylindrical': both concepts have intuitive meaning but remain incapable of satisfactory definition. Other writers (Carse 1939, Tarr 1984) have developed classifications taking into account bore size, mouthpiece profile, bell flare characteristics etc, but still without precise definition of terms. These broad-brush classifications distinguish satisfactorily between the types of instrument in use before the invention of the valve, but fail to give clear places to new types such as the cornet, the tuba, the saxhorn, and the bass trumpet.

2. HISTORICAL BACKGROUND

Throughout the 18th century and into the 19th, the trumpet and the horn were increasingly used in orchestral and band music. Despite the widespread use of hand-stopping in horn playing and the rarer use of slide trumpets or keyed trumpets, composers and arrangers were very restricted in the kind of music they could write for brass instruments. Up to four or five crooks had to be used for trumpets for the keys commonly used and ten or eleven for horns. Parts written for these instruments were closely related to the natural series of notes; if the music changed into a different key, time had to be allowed for the players to change crooks. These limitations prompted the invention of the valve (c. 1814), which had the effect of an instantaneous change of crook. It was soon realised that valves could be used not merely to change crook, but to play melodies and ensemble parts with great facility - more evenly than by handstopping a horn and faster than with the slide of a trombone or slide trumpet.

Not only did the invention of valves revolutionise horn and trumpet technique, but it also permitted the development of new kinds of brass instrument. The use of a slide in a trombone or in a trumpet necessitated a bore profile that included considerable lengths of cylindrical tubing. The use of fingerholes or keys for the cornett, serpent, keyed bugle and ophicleide was most satisfactory for instruments with an almost purely conical bore profile. The use of handstopping was only effective with instruments of the bore profile of the French horn - narrow at the mouthpipe, wide at the bell throat and pitched not too far from F (12ft tube length). With valves, however, makers had complete freedom to introduce designs with any bore profile that resulted in an instrument that was acceptably in tune with itself. Within a few years of the invention of the valve, instruments in various sizes and shapes were being produced which were the forerunners of the cornet, the tuba and other intermediate bore profile instruments such as the saxhorns.

3. HEYDE'S BORE CHARACTERIZATION

The greatest body of detailed and consistent measurements so far made of brasswind has been for the series of catalogues by Herbert Heyde of the museums in Eisenach, Leipzig, Halle and Frankfurt an der Oder. As well as the lengths of the various conical, cylindrical and flaring sections, he gives the bore measurements at certain points including:-

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d — the minimum diameter, usually a short distance in from the mouthpiece receiver

D — the bell diameter

D3 — the tube diameter in the bell at the depth of one bell diameter.

It is instructive to look at Heyde's measurements and proportions, to see how far they can help us characterise instruments. Heyde designates the relative lengths of the conical, cylindrical and flaring sections of an instrument the AV or *Anteilverhältnis*, and gives this as fractions whose sum is unity. The 1794 trombone in the Edinburgh University Collection of Historic Musical Instruments, for example, is seven-ninths cylindrical plus two-ninths 'hyperbolic'. This proportion is often cited as the principal distinction between a trombone and a trumpet. However, a simple plot of this ratio against nominal pitch for the trumpets and trombones described in Heyde's catalogues shows consistency among renaissance and baroque examples but reveals that both trumpets and trombones have evolved to contain less cylindrical tubing. What was a valid distinction between, say, an alto sackbut in Eb and a natural trumpet in Eb does not hold for valved instruments.

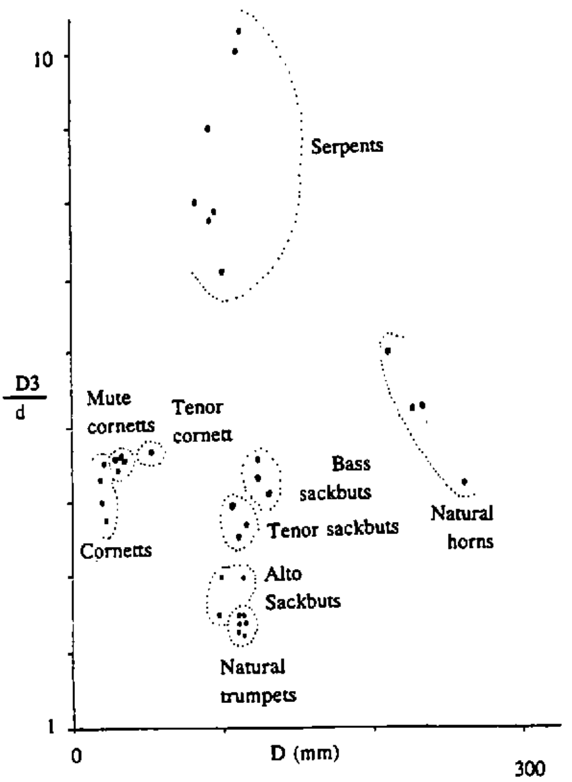

Figure 1: D3/d against D, natural and fingerhole instruments

Heyde has suggested that the ratio of D3 to d is particularly valuable. It is a measure of the increase in diameter over the tube length up to the start of the final flare. We have plotted this ratio against D for some different kinds of instrument. If we look at early brasswind, the different kinds occupy distinct areas (Fig. 1). If we look at instruments prior to the general adoption of valves, an altered pattern appears (Fig. 2). With later specimens (Fig. 3) we see the proliferation of bore profile design made possible by the invention of the valve. Although prior to the invention of valves, signalling instruments such as posthorns could be made with any viable bore profile, instruments for musical purposes were restricted to those with usable high registers (French horns and natural or keyed trumpets) those with slides (necessarily with much cylindrical tubing), horns that could be hand-stopped (long and with a pronounced bell-flare) or those playable in the lower harmonics with finger-holes or keys (conical throughout). Valved horns and trumpets are shown in Fig. 3, in positions close to those of their natural predecessors, together with the cornets, tenorhorns, tubas and other new instruments represented in the museums catalogued by Heyde.

However, we see that the wide-bore trombone, the design introduced by Sattler and adopted by Wagner, has moved some way from the old sackbut. The main orchestral instruments have changed considerably. At each point of change they have carried with them an established repertoire, and enough of their character for the new design to be recognised as being in the same class as the old. If, however, someone had invented the modern valved trumpet without the intermediate evolutionary steps, one feels it would hardly share the same name as the old natural trumpet. Fig. 3, of course, omits valved designs such as the ballad horn, the cornophone, the tenor cor and many others.

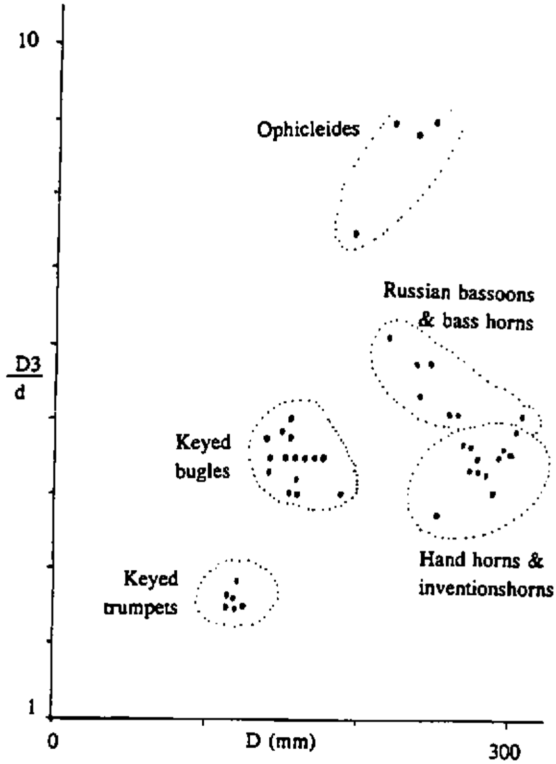

Figure 2: D3/d against D, keyed era instruments

4. TAXONOMIC PRINCIPLES

We require principles of division consistent with acoustical theory involving the minimum necessary number of parameters, which should relate to factors under the control of makers (e.g. properties of patterns and mandrels), to the audible character of the instruments (e.g. the radiation characteristics) and the feel to the player. We therefore seek some quantity that is constant for all sizes of the family of saxhorns, for instance, or for all trombones from soprano to contrabass. One would expect this quantity to remain constant, or at least to change slowly and continuously, when an instrument undergoes an evolutionary change. Although direct physical measurement should identify the maker's model, it may be that acoustically measured quantities will provide the key to consistent characterisation of instruments.

5. FACTORS AFFECTING BRASSWIND CHARACTER

As in other areas of musical acoustics, it is a delicate task to prioritise the many factors which can, in different circumstances, appear important to instrument makers, players and audiences. Some of these factors may be used to distinguish between good instruments and bad, but in attempting a rigorous taxonomy, it is a greater priority to distinguish, say, a bass trumpet from a valve trombone than to distinguish between a superb French horn and a poor one.

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The factors considered by various authors to affect the character of brasswinds are:-

1. Bore profile (which can be varied in one instrument by use of slides, valves or placing the hand in the bell)
2. The properties of a particular player's lips and vocal tract.
3. The profile of the mouthpiece
4. Wall thicknesses, particularly in the bell flare
5. Bore perturbations (e.g. water-keys, dents, valve misalignments)
6. Bends in the tubing
7. Temperature and humidity; thermal gradients
8. The flow of air through the instrument

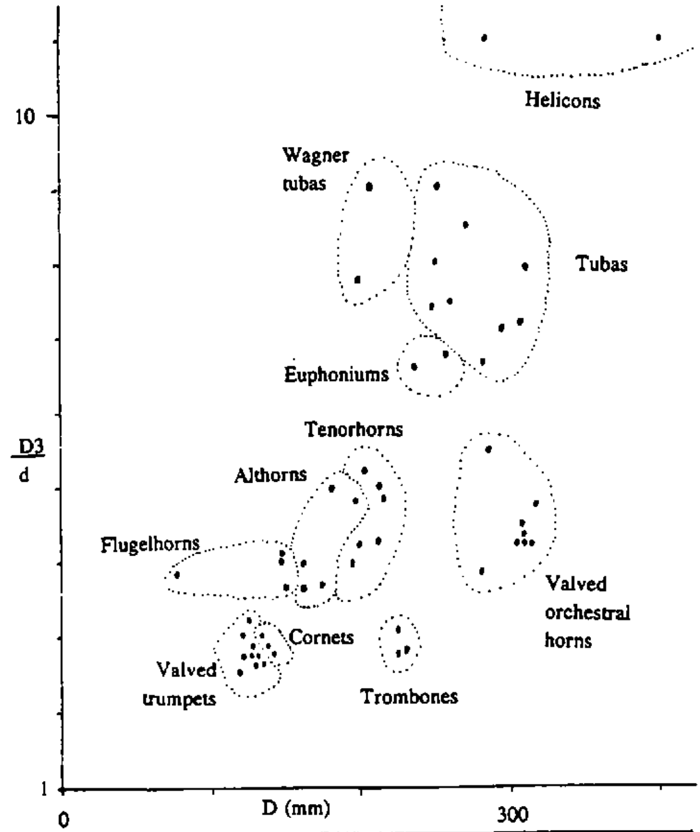

Figure 3: D3/d against D, valved era instruments

Several of these factors have been investigated in previous research and can be discounted as forming primary principles of division in a taxonomy. Pratt & Bowsher (1978) ranked the factors determining the perceived tone quality of trombones as (1) the instrument (2) the player and (3) the mouthpiece. The effect of wall thickness, particularly in the bell section of trombones has been investigated by Smith (1981) and is at most a second-order factor in determining tone quality. Although from an organological viewpoint the manner of folding, looping or coiling instruments may be significant, Keefe and Benade (1983) have shown that the effects of tube bends is small.

6. IMPEDANCE MEASUREMENTS ON TROMBONES

In order to test the hypothesis that the bore profile of the bell flare is of prime importance, we investigated the acoustic impedance of a considerable number of trombones of different sizes and models. This continues the work of one of us (Campbell 1987) and relates directly to work reported elsewhere (Pratt & Bowsher 1978, 1979), Caussé et al (1984). The trombone has been used with a wider variety of mouthpiece than other brass instruments, ranging from the shallow cup of the jazz era to the deep cone of the 19th century French trombone; this makes it particularly suitable for investigation. The experimental part of our work has consisted of input impedance measurements of trombones of various sizes, styles and periods ('sackbut' reproduction, baroque, 19th century and modern). The apparatus was that described by Campbell (1987), similarly calibrated. Peak envelopes were similarly derived. The instruments measured included:-

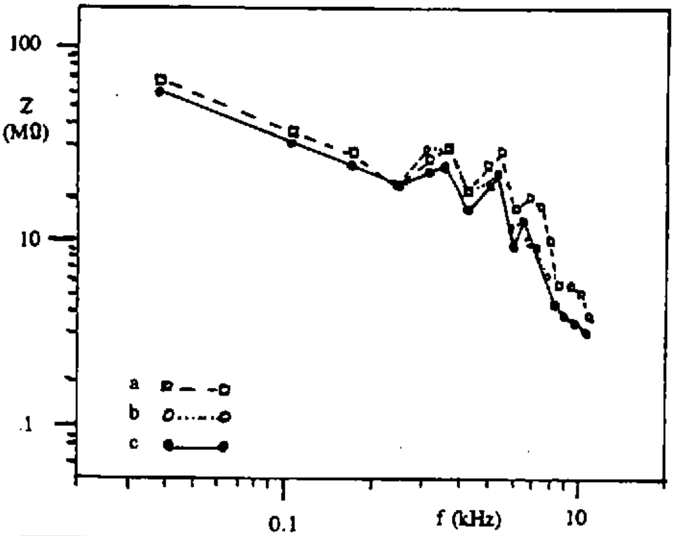

Figure 4: Peak envelopes of Courtois narrow-bore trombone with (a) Courtois deep cone mouthpiece, (b) Selmer 23D jazz mouthpiece and (c) Bach 6½AL mouthpiece of much greater volume than (a) or (b)

Alto sackbut in E♭ (Tomes) bore 11.0mm.
Alto trombone in E♭ (Besson, London, c 1940) bore 11.5mm.
Tenor sackbut in B♭ (Tomes) bore 12.0mm.
Tenor trombone in B♭ (Huschauer, Vienna, 1794) bore 10.8mm.
Tenor trombone in B♭ (Courtois, Paris, c 1880) bore 11.2 - 11.5mm.
Buccin trombone in B♭ (probably France, c 1840) bore 11.1 - 11.4mm.
Tenor trombone in B♭ (Boosey & Hawkes Imperial model) bore 12.4mm.
Tenor trombone in B♭ (Schopper, Leipzig, c 1920) bore 13.5mm.
Tenor trombone in B♭ (King 2B model) bore 12.2 - 12.5mm.
Tenor trombone in B♭ + F (King 3B model) bore 12.9mm.
Tenor trombone in B♭ (Conn 8H model) bore 14.0mm.
Bass sackbut in G (Tomes) bore 12.0mm.
Bass trombone in G (Higham, Manchester, c 1935) bore 12.0mm.
Bass trombone in G + D (Boosey & Hawkes wide bore model) bore 13.4mm.
Bass sackbut in E♭ - D (Meinl) bore 13.0mm.
Contrabass trombone in E♭ + B♭ (Germany, c 1925) bore 13.5mm.

7. DISCUSSION OF RESULTS

1. The input impedances were measured with each instrument equipped with an appropriate mouthpiece and in several cases with alternative mouthpieces. It was found that the peak envelope is only seriously disturbed if a mouthpiece of radically different volume is used. A deep conical traditional French mouthpiece (virtually a scaled-up French horn mouthpiece) gave a peak envelope differing little from that given by a shallow jazz era mouthpiece (Fig. 4). Campbell (1987) discussed the effect of using a reproduction sackbut mouthpiece of much smaller cup volume.

2. The tenor and bass sackbuts by Tomes are equipped with removable tapered lead pipes. The tapered lead

pipe is not an authentic feature of the renaissance sackbut, but this maker supplies them for present-day players who find the instruments speak more readily when the lead pipe tapers as does that of the modern trombone. It was found that the taper has the effect of levelling the peak envelope slightly, raising the peaks of modes 3-7 and lowering the peaks of modes 8-12 (Fig. 5).

3. Comparable instruments in different sizes (alto, tenor and bass) can have very similar peak envelope shape. Where there is less correspondence in model, the peak envelope for the lower pitch instrument can be close to that for the higher pitch instrument with its slide extended (see below).

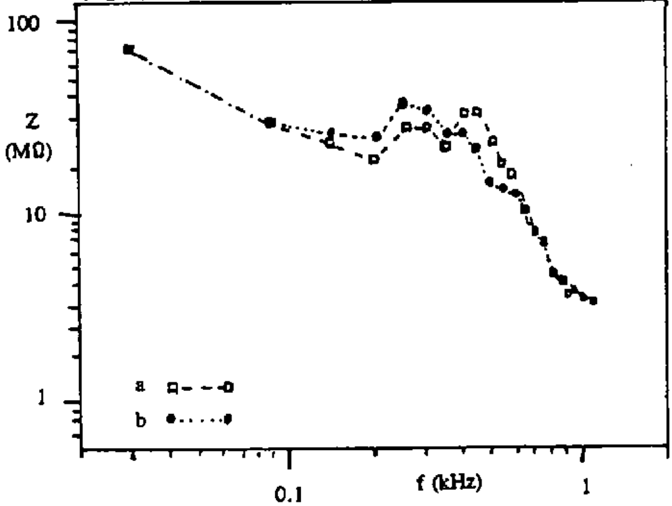

Figure 5: Peak envelope of Tomes G bass sackbut (a) without tapered leadpipe and (b) with tapered leadpipe

4. The effect of moving the slide on the trombone is more pronounced than the effects discussed above. A slide shift of 500mm, increasing the tube length by 1m, gives approximately the player's sixth position on a B♭ trombone (in practice, a trombonist varies the position from one note in sixth position to another). The introduction of so much extra cylindrical tubing into the instrument constitutes a drastic modification of bore profile, which has the effect of lowering the peaks of the first six to eight modes and raising the peaks of the higher modes; the use of the thumb valve lowering the overall pitch by a perfect fourth has a comparable effect (Fig. 6). This effect can be regarded as that of a formant at the resonant frequency of the mouthpiece; moving the slide lowers the frequencies of all the modes, the mouthpiece formant at constant frequency subsequently enhancing peaks of higher mode number. Also, the increase in the proportion of cylindrical tubing increases the frequency intervals between the lowest modes. This is not so noticeable to the player because of the accompanying enhancement of the higher mode peaks which can support co-operative regimes; for a trombone in sixth position, the lowest three tones should be regarded as 'privileged' notes.

5. The greatest and most irregular variations in peak envelope are found between trombones of different model, especially those of different bore size. The Tomes Eb alto sackbut has a similar envelope to that of the Besson alto trombone; the King 2B tenor trombone has a similar envelope to that of the King 3B model; the Tomes G bass sackbut has a similar envelope to that of the Higham G bass trombone. The main traditional schools of trombone design, however, show distinctive peak envelopes (Fig. 7).

8. PULSE REFLECTANCE TECHNIQUES

The extension of the pulse reflectance techniques for bore reconstruction already in use in the medical field (Marshall, 1990) to brass instruments is a potentially useful means of investigating brass instruments for the purposes of classification. Existing applications to musical instruments (Watson and Bowsher 1987) have been directed to other purposes. A particular advantage would be in establishing the bore profile of instruments with substantial portions of curved tubing without the difficulties of making large numbers of precise physical measurements of curved tube: a smaller number of direct physical measurements could be made and bore reconstruction techniques used for interpolation.

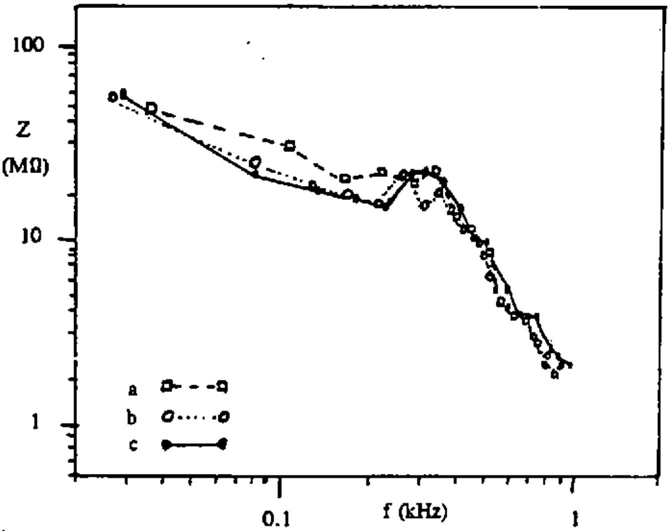

Figure 6: Peak envelope of King 3B trombone (a) slide in, (b) slide extended 500mm and (c) thumb valve used to put instrument into F

9. CONCLUSIONS

Investigations of the input impedances of a varied sample of trombones supports the hypothesis that the bore profile of the bell flare is the factor of greatest significance in characterizing brass instruments. Other features such as the presence of a tapered lead-pipe and the mouthpiece shape are second-order factors. The input impedance curve can act as a 'fingerprint' of instrument design, if like slide and valve positions are compared. The effect of extending the slide on the trombone is pronounced. Work is continuing into the establishment of suitable principles of division for classifying the whole family of brass instruments, based on parameters of the bore profile. These parameters include the constants associated with the best-matched Bessel horn (Pyle 1975, p.1312) and suitable quantities associated with the horn function (Amir et al, 1993).

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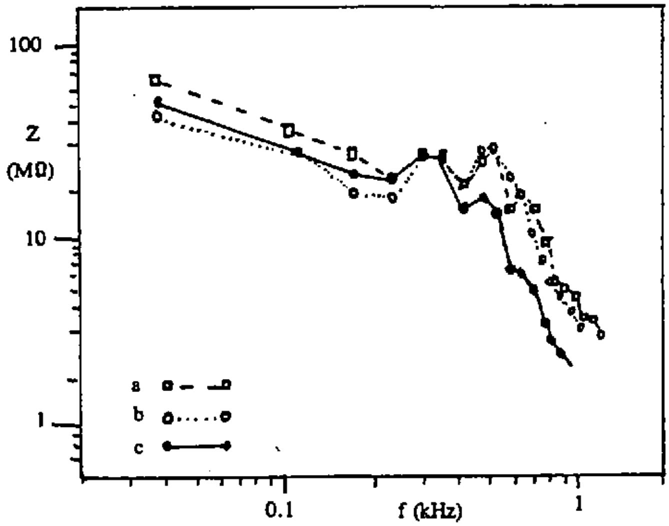

Figure 7: Peak envelopes of (a) Typical narrow-bore French trombone (Courtois), (b) typical Sattler model German trombone with medium bore and wide bell (Schopper) and (c) typical modern wide-bore orchestral trombone (Conn 8H)

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