BORE RECONSTRUCTION BY PULSE REFLECTOMETRY AND ITS POTENTIAL FOR THE TAXONOMY OF BRASS INSTRUMENTS

David Sharp, Arnold Myers, Raymond Parks and Murray Campbell

Department of Physics and Astronomy, University of Edinburgh, Edinburgh, UK.

SUMMARY

The character of a brass musical instrument is primarily dependent on its bore profile. Many historic brass instruments are so constructed that substantial parts of the air column are inaccessible to direct measurement. This paper discusses the factors involved and reports recent advances in the use of pulse reflectometry for bore reconstruction, in particular compensation for losses and allowance for multiple reflections. Measurements of historic musical instruments are presented and their significance evaluated.

TAXONOMIC OBJECTIVES

By a ‘brass instrument’ we mean a lip-vibrated aerophone consisting of a tube narrow in relation to its length, with or without a mechanism for changing the sounding length. Here we limit ourselves to unperforated tubes, i.e. instruments without finger-holes. The bore profiles which have proved to be viable for brass instruments have at one end a mouthpiece, which may be cupped or funnel-shaped, followed by the narrowest part of the windway, the ‘mouthpiece throat’. From the throat, the windway passes through the mouthpiece backbore, the mouthpipe or leadpipe, any tuning-slide or valves, finally coupling with the free air at the widest part of the tube, the bell. The area of cross-section in most cases increases monotonically; in some cases there is a localised narrowing (e.g. at slides and at valves, or due to some slight damage). The traditional bore cross-section is circular; where (rarely) a deliberately elliptical cross-section is introduced, or in the slight deformation at bends in the tube, the bore profile can for most purposes be considered to be equivalent to that of a cylindrical tube of the same cross-sectional area.

Few classification systems go beyond a division of brass instrument types into ‘conical’ and ‘cylindrical’: both concepts have intuitive meaning, but are not capable of rigorous definition. In order to approach an acoustically-based system of taxonomy, it is helpful to look separately at the beginning, middle, and the end of a brass instrument. The choice of a mouthpiece can affect the character of an instrument, though not completely determine it (Myers and Campbell 1993). The design of the bell flare is of critical importance in the sound radiation properties and in the relative intonation of the resonating modes (Benade and Jansson 1974; Jansson and Benade 1974). However, it does not appear that the mouthpiece and the bell flare even considered together can account for the more subtle distinctions between instrument types, or between earlier and later historical models of the same instrument type. It is therefore necessary to examine the complete bore of an instrument. A mouthpiece, where present, can be physically measured, as can the tapered mouthpiece receiver on the body of the instrument. The bell can also be physically measured, or at least enough of it to allow calculation of the horn function in the region of its peak value (in the case of flaring bells). Much of the sounding length of the instrument can, however, pose severe problems for direct physical measurement, particularly in instruments with many coils.

For the purposes of comparison between instruments, a coiled instrument can be treated as equivalent to a perfectly straight instrument with the same cross-sectional area at each point along a line drawn through the geometric centre of the bore, the ‘mid-line’. The effects of bends in the tubing of wind instruments were considered theoretically by Keefe and Benade (1983) and its practical implications for taxonomy considered by Myers and Parks (1995). The bends encountered in the great majority of actual instruments will give rise to second-order discrepancies only. Other factors which affect brasswind character, although important in performance, have to be regarded as being of second (or higher) order for taxonomic purposes. These include the properties of a particular player’s lips and vocal tract, wall thicknesses, bore perturbations (e.g. water-keys, dents, valve misalignments) temperature and humidity gradients in playing conditions, and unsteadiness in the flow of air through the instrument.

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 coiled 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. Pulse reflectometry is a non-invasive technique and hence is very useful in the measurement of instruments with a degree of inaccessibility.

In work carried out at the department of Physics at the University of Edinburgh, an electrical pulse (containing frequencies from 0-12 kHz) was produced, amplified and used to drive a loudspeaker. The resultant sound pressure pulse was passed along a source tube of diameter 9.6mm (of the same order of magnitude as the tubing of the narrower parts of brass musical instruments). A microphone, embedded partway along the tube, recorded the input pulse as it passed. A short time later, it recorded the reflections returning from the instrument under test, which (without its detachable mouthpiece) was coupled to the far end of the source tube.

For an ideal delta function sound pressure pulse, the reflections obtained from the instrument would be its input impulse response. However, the sound pressure pulse departs from a pure delta function in an arbitrary way, so to obtain the input impulse response, the reflections are deconvolved with the input pulse shape, using a transform size of 1024. The reflections occur at changes in impedance, such as at expansions or contractions of the instrument bore. A suitable algorithm allows the reflection coefficients arising from these impedance changes to be evaluated from the input impulse response. It is then a small step to calculate the changes in area along the bore and, assuming cylindrical symmetry, the changes in radius.

Watson and Bowsher (1978, 1988) applied the technique of pulse reflectometry to brass instruments, using the algorithm derived by Ware and Aki (1969) to reconstruct the bore profiles. However, although the Ware-Aki algorithm takes into account multiple reflections within the instrument, it does not consider attenuation of the signal along the length of the instrument. Hence, the accuracy of the bore profiles decreased with the length of the instrument (as attenuation became more significant). More recently, Amir, Rosenhouse and Shimony (1995, 1996) have developed an algorithm which compensates for the attenuation along the instrument, resulting in significantly more accurate reconstructions. We have used this algorithm to examine the bore profiles of brasswind from the Edinburgh University Collection of Historic Musical Instruments.

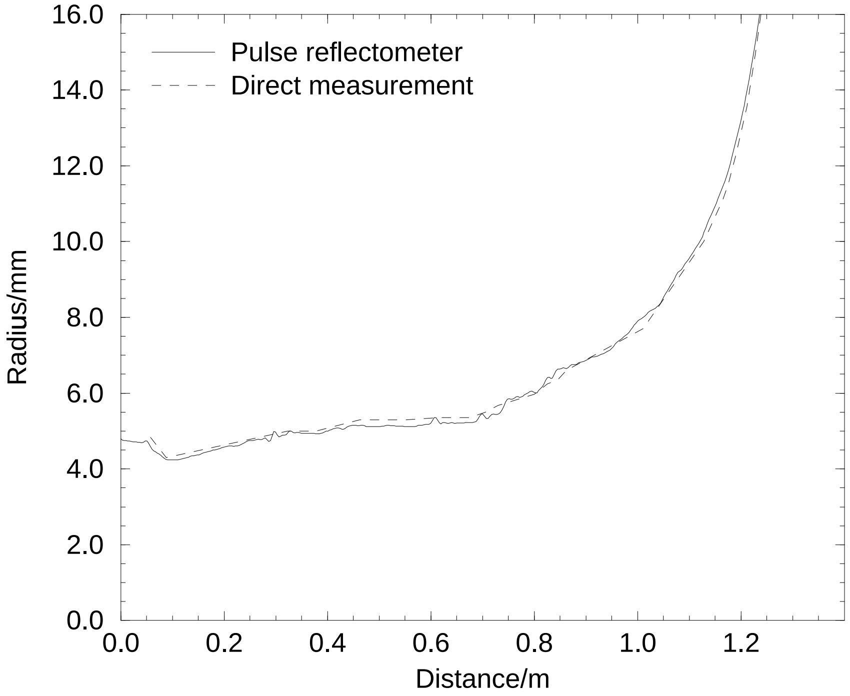

Figure 1: Bore profile of Rudall Carte cornet (EUCHMI 2988), no valves operated.

Fig. 1 shows the bore profile of a B♭ cornet by Rudall Carte (without mouthpiece) without any valves operated. The directly measured profile and the profile reconstructed from reflectance measurements are superimposed. The initial dip is the mouthpiece receiver taper, and does not represent part of the sounding bore when a mouthpiece is inserted. The small-scale fluctuations in the reconstructed bore are mostly accounted for by features such as waterkeys and small discontinuities at the ends of tuning slides and at the valves; no attempt was made to measure the cross-sectional area at these features.

In Fig. 2 we see the reconstructed profile of the same instrument with all three valves operated; there are more small-scale fluctuations in the central part of the bore where the windway passes in and out of the valves. When the measurements were first taken, the irregular (solid line) 'profile' was plotted, deviating substantially from the measured profile beyond the third valve. Close examination of the instrument showed a leak in the tubing of the third valve tuning-slide - a leak too small to be perceptible to a player of the instrument, but 'seen' by the pulse as an enlargement of the effective cross-section of the tube. With the leak sealed, a good agreement with the actual bore of the instrument was obtained (broken line). The question of musically inconsequential leaks having a disproportionate effect of the bore reconstruction is a potential problem. The bandwidth of the pulse spectrum utilised in reflectometry does not, of course, match the range of frequencies employed in musical use of the instrument. It is proposed to distinguish such small leaks by comparing the results obtained from 'tailored' pulses with differently shaped spectra.

Careful inspection of the central part of the bore in the previous figure indicates that the bore through the valves is not cylindrical, but expands gradually. This is indeed the case: the Rudall Carte cornet is the 'Patent Conical Bore' model with incremental bore cross-section in the windways through the pistons and

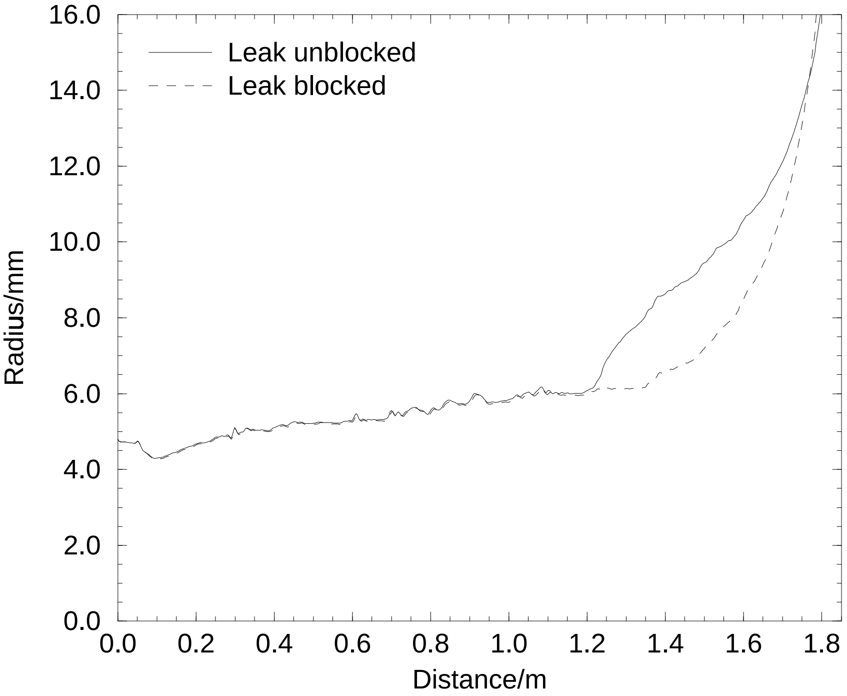

Figure 2: Bore profile of Rudall Carte cornet (EUCHMI 2988), all three valves operated.

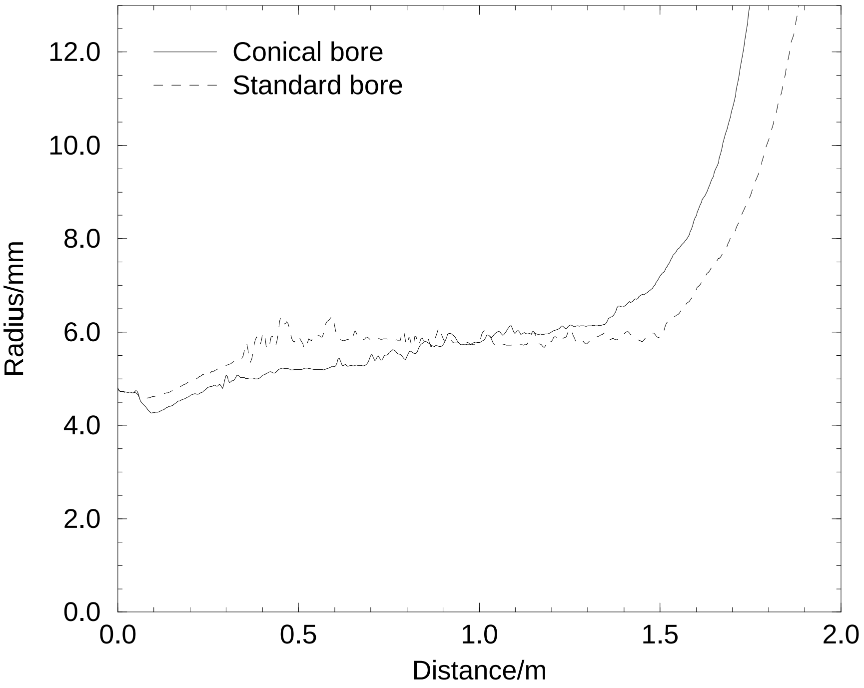

Figure 3: Bore profiles of Rudall Carte cornet (EUCHMI 2988) and Boosey cornet (EUCHMI 2704), all three valves operated.

in the tuning-slide bows. Fig 3 shows a comparison of the Rudall Carte ‘Conical Bore’ cornet with a standard cornet by Boosey which has the usual cylindrical profile. The Boosey cornet has at some time had its playing pitch lowered by extension of each leg of its tuning-slide; this accounts both for the greater overall length and for the two peaks around 0.5 metres.

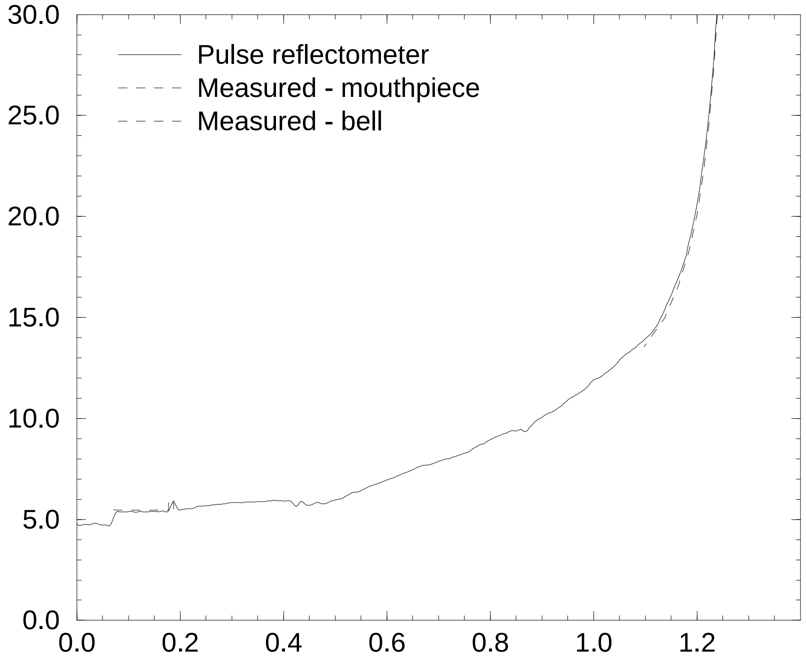

Figure 4: Bore profile of Honsuy bugle in C (EUCHMI 2343).

The method of pulse reflectance is of potential value for coiled tubes with bores inaccessible to direct measurement. Fig. 4 shows the successful reconstruction of a Spanish bugle. Only the mouthpipe (sliding for tuning purposes) and the bell flare could be reached for direct measurement.

CONCLUSIONS

For purposes of comparison of bore profile between instruments, bore reconstructions of the accuracy now possible with corrections for attenuation offer a useful tool for the taxonomist. The problems of measuring the mid-line in coils are avoided, since the use of sound waves in measurement ensures that the acoustically defined path is what is measured. The interpretation of the results for the great variety of instrument types is our next goal.

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