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INPUT IMPEDANCE MEASUREMENTS ON HISTORIC BRASS INSTRUMENTS

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ABSTRACT

Input impedance curves have been obtained for (a) a sackbut by Anton Schnitzer, dated 1594, and (b) a serpent by Haye, c.1820. These measurements are discussed and compared with similar curves for modern reproduction instruments.

INTRODUCTION

In recent years there has been a growth of interest in the performance of music on instruments appropriate to the period of composition. The search for authenticity has given rise to a flourishing industry in the reproduction of historic instruments, since the originals are frequently either too fragile or too valuable for regular concert use. It is therefore timely to consider the acoustically significant differences between historic instruments and their modern counterparts.

In some cases these differences are relatively subtle. The modern trombone closely resembles its sixteenth century predecessor, known in Britain as the sackbut. Nevertheless, a recent publication [1] lists ten manufacturers offering "authentic" reproduction sackbuts. An acoustical study of original and reproduction instruments may assist players and manufacturers by identifying features which distinguish the timbre and playing technique of the sixteenth century sackbut from that of the modern trombone.

In contrast to the sackbut, the serpent became extinct in the nineteenth century, and has no recognisable descendent in the modern orchestra. Parts written for it by composers such as Mendlessohn and Wagner are now played on tuba. Serpents are once again being manufactured and played; in this case an acoustical analysis can help to explain some of the particular problems of serpent technique.

EXPERIMENTAL METHOD

Measurement of input impedance has become a standard technique for the evaluation of brass instruments (i.e. instruments of the lip reed family) [2], [3], [4]. The apparatus used here (Fig. 1) is similar to that described by Backus [5]. The output from a sine generator feeds a horn loudspeaker driver. A microphone senses the pressure generated in a cavity mounted in front of the horn driver; the output of this microphone is used as a feedback signal, controlling the output of the sine generator so as to maintain the cavity pressure constant. In the present case the cavity pressure is 120 $\pm$ 0.5 dB SPL over the frequency range 20Hz - 5kHz. An annular capillary of length 69mm connects the cavity to a horizontal flange on which is mounted the mouthpiece of the instrument under test. On the assumption that the impedance of the capillary is independent of frequency, and much larger than the highest impedance to be measured, this system can be considered as a source of constant volume velocity. The pressure in the mouthpiece, measured by a second microphone, is then directly proportional to the input impedance

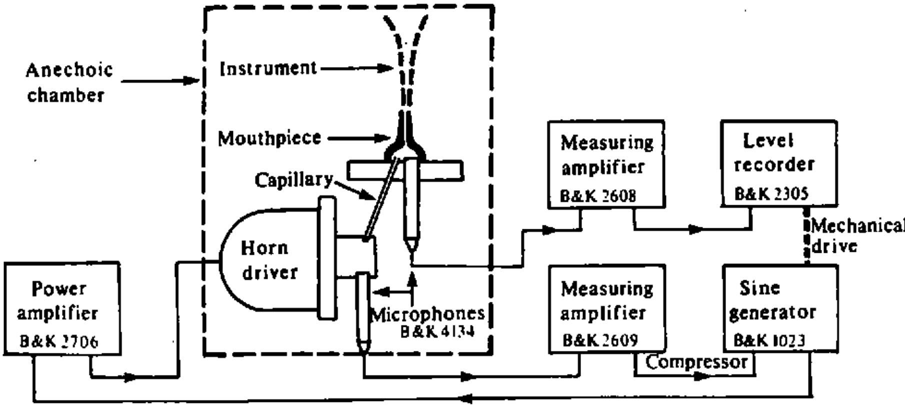


Fig. 1: Sketch of experimental apparatus.

at the entrance plane of the instrument.

To investigate the range of validity of the foregoing assumptions, and to calibrate the apparatus, two methods were adopted. In the first, several small cavities, with volumes ranging from 3.8×10^{-6} m^3 to 3.9×10^{-5} m^3, were mounted in turn on the flange. The impedance Z of a small volume V is known to be

$$|Z| = \frac{\rho c^2}{2 \pi f V}$$

where ρ is density of air, c the speed of sound and f the frequency. Thus by measuring the dependence of pressure on frequency for each volume, the volume flow rate and hence the capillary impedance Z_c can be derived. Consistent results were obtained from the different cavities, yielding a value of Z_c = 800 $\pm$ 50 MΩ.

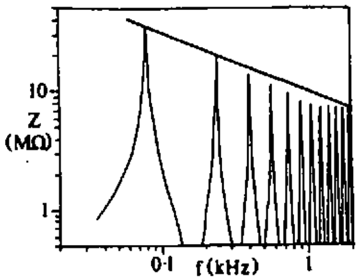


Fig. 2. Input impedance curve for open cylindrical tube with l = 1043mm, a = 12.7mm.

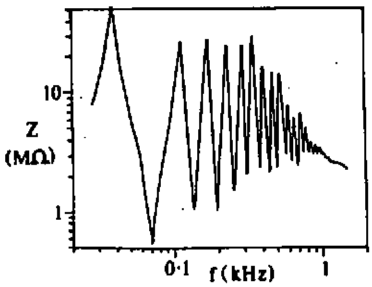
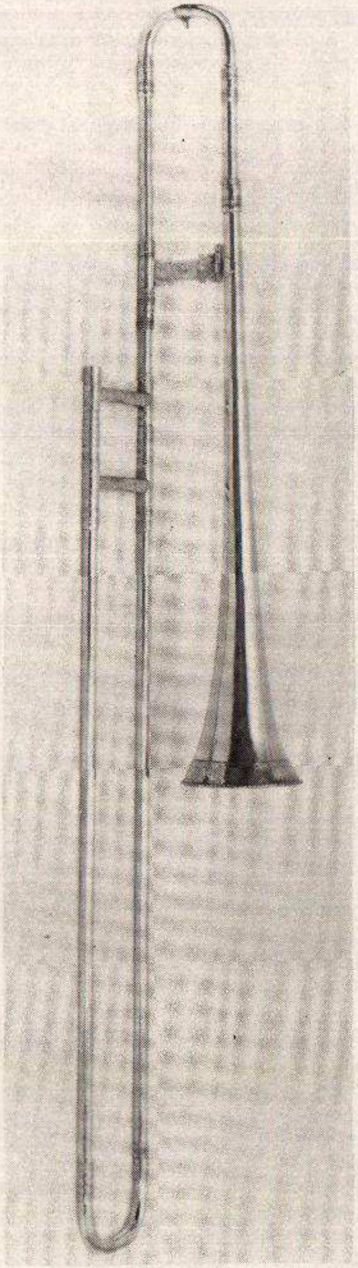


Fig. 3. Input impedance curve for King trombone.



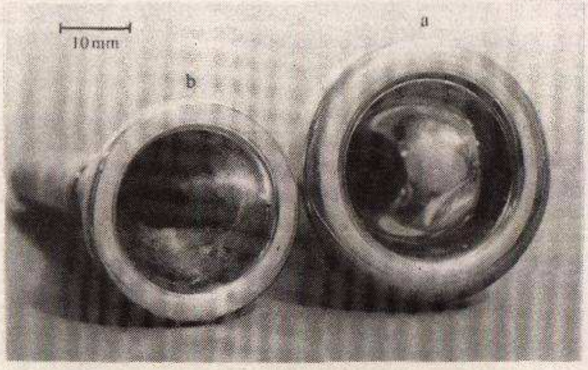


Fig. 4 (left): Sackbut by Anton Schnitzer.
Fig. 5 (above): (a) Denis Wick 6BS trombone mouthpiece. (b) Büchel reproduction of 1579 sackbut mouthpiece.

In the second calibration method, a cylindrical brass tube of radius a = 12.7mm and length 1.043m, open at the upper end, was mounted on the flange. Again, the impedance of this simple system can be calculated [5]. In Fig. 2 the measured input impedance curve is shown, together with a straight line joining the calculated maxima. The agreement is good below 300Hz and at 2kHz, but in the vicinity of 1kHz the measured maxima are about 2dB too low. This appears to arise from a frequency dependence of Z_c. Fig. 2 can be used to correct impedance values on other graphs in the paper, which are presented without modification.

SACKBUTS

Input impedance curves for many modern trombones of varying quality have been obtained, and a fairly typical example is shown in Fig. 3. The instrument in this case was a medium bored King tenor trombone, with a Wick 6BS mouthpiece.

The Edinburgh University Collection of Historic Musical Instruments has recently been fortunate in acquiring a tenor sackbut by Anton Schnitzer, dated 1594 (Fig. 4). The sackbut is in reasonable playing condition. The original mouthpiece has been lost, and is now replaced by a reproduction by Büchel of a mouthpiece dated 1579. Fig. 5 shows the modern Wick 6BS mouthpiece and the Büchel reproduction. An impedance curve measured with the Wick mouthpiece alone gave a mouthpiece resonance frequency of 492Hz; for the smaller volume Büchel mouthpiece the resonance frequency was found to be 620Hz.

Fig. 6. shows the input impedance curve for the Schnitzer sackbut with the Wick mouthpiece, while Fig. 7 shows the curve when the instrument is fitted to the Büchel mouthpiece. A useful way of comparing such curves is to sketch the peak envelopes, which are lines joining the impedance maxima [6]. From Fig. 8 it can be seen that, although the substitution of the smaller mouthpiece has little effect on the magnitude of the lowest impedance peaks, it raises the peaks above 500Hz by more than a factor of 2.

In Fig. 9 is shown an impedance curve for a modern reproduction of a sackbut by Christopher Monk. Fig. 10 gives the curve for a modern King tenor trombone with the bell cut back to a diameter of 100mm and re-rimmed. In both these curves it is noteworthy that the 20th mode still gives a distinguishable impedance peak, although for the modern trombone with its larger bell modes above the 16th are usually insignificant. The relatively abrupt termination of the smaller bells would be expected to raise the cut-off frequency; it is curious that the higher modes are less in evidence in the Schnitzer impedance curve.

The peak envelopes for the Schnitzer, the Monk and the "sawn-off" King are presented for comparison in Fig. 11. In each case the Büchel mouthpiece was used. The envelope for the King is very little different from that of the modern trombone, and is significantly highest over most of the playing range. The most striking difference between the Schnitzer and the Monk is the greater irregularity of the Schnitzer envelope.

A strong note on a brass instrument involves a co-operative regime of oscillation in which several modes of the air column interact with the lips [2]. A suitable mode- locked regime requires a set of impedance peaks with an almost harmonic frequency relationship. The deviation of mode frequencies from such a relationship can be usefully displayed in terms of the "effective cone length" L_e of the air column at each mode frequency [7]. L_e is defined by

$$L_e = \frac{nc}{2f_n}$$

and is the length of an ideal cone whose nth mode frequency is f_n.

Equivalent length curves are shown in Fig. 12 for (a) the Schnitzer sackbut, (b) the Monk reproduction and (c) the modified King trombone. The first mode is not shown, since in each case it is too low in frequency to affect the playing of the instrument. An equivalent cone length of 2943mm corresponds to an exact harmonic series with fundamental $B^{\flat}_1$ (f = 58.27Hz). The second and third modes of the Schnitzer sackbut (with Büchel mouthpiece) are nearly half a semitone too flat, while the effective length of the higher modes places them closer to $B^{\natural}_1$ than to $B^{\flat}_1$. This accords with playing experience on the instrument; the fourth natural note, written $B^{\flat}_3$, sounds as $B^{\natural}_3$. The second and third natural notes of the instrument (written $B^{\flat}_2$ and F_2) can also be played at this high pitch, although the co-operative regimes involved will not make

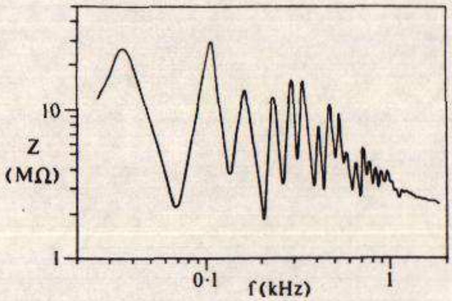


Fig. 6: Input impedance curve for Schnitzer sackbut with Wick mouthpiece.

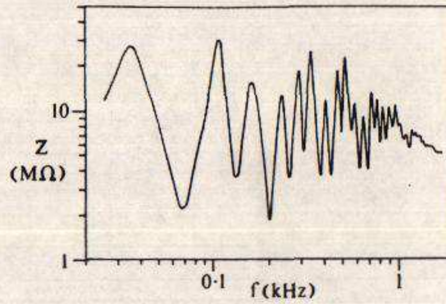


Fig. 7: As Fig. 6, but with Büchel mouthpiece.

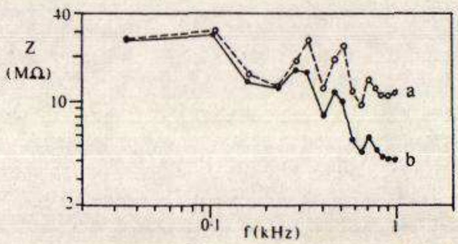


Fig. 8: Peak envelopes for Schnitzer sackbut with
(a) Büchel mouthpiece,
(b) Wick mouthpiece.

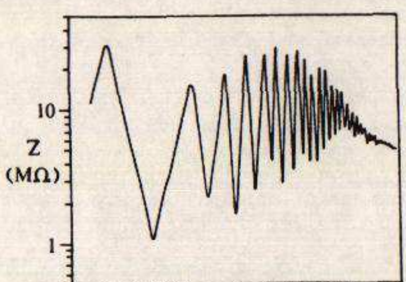


Fig. 9: Input impedance curve for Monk reproduction sackbut with Büchel mouthpiece.

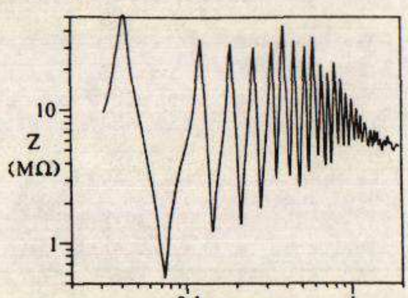


Fig. 10: Input impedance curve for King trombone with bell cut back, with Büchel mouthpiece.

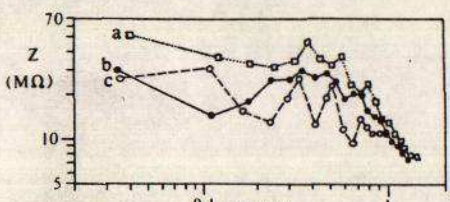


Fig. 11: Peak envelopes for
(a) modified King trombone,
(b) Monk reproduction
(c) Schnitzer sackbut, all with Büchel mouthpiece.

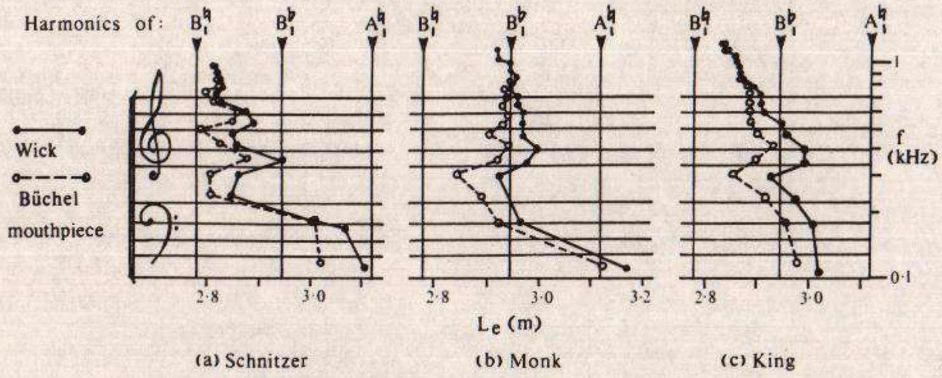


Fig. 12: Equivalent cone lengths of (a) Schnitzer sackbut, (b) Monk reproduction (c) modified King trombone.

use of the second and third impedance peaks. These notes will have the quality of "privileged notes" [8], since the fundamental gets no direct reinforcement from the impedance curve.

A similar character is evident in the Monk sackbut (Fig. 12 (b)), although in this case the pitch is closer to B♭ and the third mode frequency is not significantly flat. On the modified King trombone, the reduction in length has sharpened the high modes, while the second and third modes are relatively well in tune.

One other striking difference between the Schnitzer impedance curve and that for the modern trombone is that the impedance peaks are much broader in the case of the early sackbut. A similar broadening, though less marked, is evident in the curve for the Monk reproduction sackbut. Smithers et al [9] have recently pointed out that the resonances of original baroque trumpets are also of characteristically low Q, and consider this to be an important influence on the intonation and timbre of the instrument.

SERPENTS

The serpent is an instrument with a cup mouthpiece and an approximately conical bore (Fig. 13). Six finger holes are provided; in later instruments several keys permit additional holes to be opened. With all holes closed the fundamental pitch is C_2 or $B^{\flat}_1$.

The playing technique of the serpent thus combines features of the trombone and the saxophone. The greatest problem in playing the serpent is the

Fig. 13: Serpent by Haye (c. 1820)

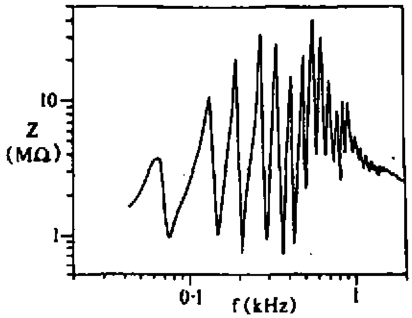


Fig. 14: Input impedance curve for Haye serpent, all holes closed.

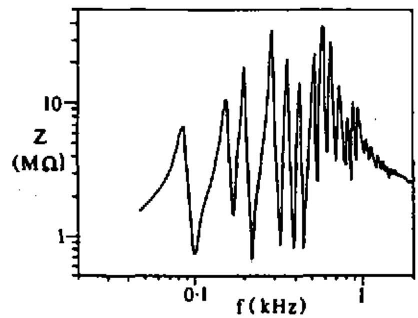


Fig. 15: As Fig. 14, but lowest finger hole open.

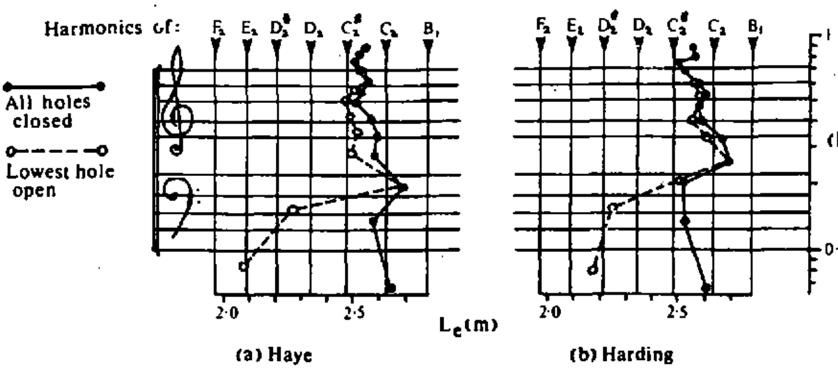


Fig. 16: Equivalent cone lengths for Haye and Harding serpents, showing effect of opening lowest finger hole.

difference in quality between notes obtained with all holes closed and those obtained when one or more of the finger holes are opened. The closed notes are strong and well-centred. On the other hand, once a finger hole has been opened the pitch can be varied over an octave by adjusting the lips. An excellent musical ear and good lip control are therefore essential if the instrument is to be played in tune.

The acoustical reason for this discrepancy is clear from a comparison of Figs. 14 and 15, which show input impedance curves measured for a typical English wooden serpent made by Haye in about 1820. In Fig. 14 all holes are closed (to play C_2), whereas in Fig. 15 the lowest hole is opened (to play D_2). The corresponding equivalent length curves are displayed in Fig. 16 (a). With all holes closed, the lowest six modes give a reasonably close approximation to a harmonic series based on C_2. Opening the lowest hole raises the first mode much too far; the second mode is about 50 cents too sharp for a harmonic series based on D_2, while the higher modes are relatively little affected. A similar pattern is obtained from a modern fibreglass reproduction serpent by

Harding (Fig. 16 (b)).

Since the hole must be closed by the finger, its diameter is limited to about 10mm. However, the bore diameter at the lowest open hole is ~ 100mm. Such a small hole has a very low cut-off frequency; above the second mode frequency waves propagate along the whole length of the instrument whether or not the hole is opened. The almost harmonic relationship between the mode frequencies is therefore disrupted, and a strong co-operative regime cannot be obtained.

REFERENCES

[1] H G Fischer, 'The Renaissance Sackbut and its Use Today'. New York: Metropolitan Museum of Art (1984).

[2] A H Benade, 'The physics of brasses'. Scientific American, July issue, 24-35 (1973).

[3] S J Elliott, J M Bowsher and P Watkinson, 'Input and transfer response of brass wind instruments'. J.A.S.A., Vol. 72, 1747-1760 (1982).

[4] R Caussé, J Kergomard and X Lurton. 'Input impedance of brass musical instruments'. J.A.S.A., Vol. 75, 241-254 (1984).

[5] J Backus, 'Input impedance curves for the reed woodwind instruments'. J.A.S.A., Vol. 56, 1266-1279 (1974).

[6] X Lurton, 'Étude analytique de l'impédance d'entrée des instruments à embouchure'. Acustica, Vol. 49, 142-151 (1981).

[7] R W Pyle, Jnr., 'Effective length of horns'. J.A.S.A., Vol. 57, 1309-1317 (1975).

[8] H Bouasse, 'Instruments a vent'. Paris: Libraire Delagrave (1929).

[9] D Smithers, K Wogram and J Bowsher, 'Playing the Baroque trumpet'. Scientific American, April issue, 104-111 (1986).

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