Proceedings of The Institute of Acoustics

THE BOEHM FLUTE - SOME IMPERFECTIONS AND POTENTIALS FOR REDESIGN

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ABSTRACT

Resonance measurements on a Boehm flute show how the headjoint taper compensates for the effects of changes in lip cover. Comparative tests are described using a parallel headjoint and a smooth bore flute. Blown spectra indicate the relevance to flute performance.

BOEHM'S FLUTE

The flute as we know it today was patented by Theobald Boehm in 1846. Boehm's new design represented a radical change from the existing baroque flute. This had a body with a conical bore, tapered down towards the end, with a cylindrical headjoint. The holes were small and covered by the fingers, except that later versions had one or more keys, used primarily for trills and ornaments. The new Boehm flute, on the other hand, had a cylindrical bore and tapered headjoint, with much larger tone holes covered by pads.

Although the Boehm flute has a body made from a cylindrical tube, the geometry inside is complex due to the fact that each of the flat pads closes on to a tone hole chimney fixed to the main tube. This factor, together with the complications of the end corrections make it difficult to calculate the precise positions of the tone holes. Much of Boehm's efforts in designing his new flute were directed towards the determination of the best hole positions. He did this by blowing a headjoint attached to tubes of different length, made up from sets of short tubes which could be connected together.

After extensive experiments, Boehm found that it was impossible to bring the full range of the instrument into tune; this problem he partially solved by introducing a taper into the headjoint. Without the taper the high register notes always blew flat. The shape of his taper is generally described as being parabolic and in his book (Boehm 1964) the coordinates are given in a "schema". In reality the shape bears little resemblance to an actual parabola.

The Boehm flute also had a number of other radically new features. The most striking was the sophisticated mechanism developed for opening and closing the holes in the correct combinations, and tailored to the anatomical structure of the human hand. This was arranged to give the scale of C major as the keys were raised in turn, in contrast to the baroque flute which was firmly pitched in the key of D. Boehm also pioneered the use of new construction materials and experimented with the bore diameter, finally settling on 19 mm as representing the best compromise over the full range. A larger bore creates difficulties in the high register, whilst a narrower bore stifles the low notes.

The concert flute of today has not in fact evolved in a smooth progression of developments throughout the ages. Rather it has undergone radical changes in design at different periods; the most dramatic of these was due to Boehm. Since his original patent only minor improvements have been incorporated. It is not inconceivable that a new generation of flutes could now emerge, taking advantage of some of the modern manufacturing materials and scientific design techniques. In this paper we examine some of the acoustical features of the Boehm flute and explore possibilities for improvements.

EXPERIMENTAL FACILITY

A facility for acoustic measurements on resonating tubes i.e. flutes etc., has been made by converting a small room into an anechoic chanber by lining the walls with foam. This was maintained at a constant temperature of 19° Centigrade. The flute under test is held vertically and excited by a miniature loudspeaker (Knowles 2850), driven by a sine wave oscillator. Resonances are detected with a subminiature microphone (Knowles BL 1785) as the oscillator is scanned through a range of frequencies.

Two different arrangments have been used for the tests described in this paper. When comparing the different headjoint tapers we were primarily concerned with the frequencies of resonance modes. In this case both the loudspeaker probe and the microphone probe were inserted through the embouchure hole with their tips a few millimetres apart (Fig. 1, M1, S1). The microphone was mounted using Luer hypodermic fittings and could very simply be disconnected from the standard heavy gauge (2mm) needle, which acted as the probe. The loudspeaker was similarly attached to a 2mm Luer fitting needle of 5cm in length. This arrangement is shown in Fig. 2. It has the advantage that no permanent attachments are made to the headjoint so that a number of different design can easily be interchanged. When investigating the standing wave patterns throughout the flute the loudspeaker was inserted into the cork, again using a standard 2mm needle, to allow quantitative comparisons of pressure amplitudes to be made. A microphone, about 14mm x 5.5 mm Ø (Fig. 3), was mounted at the end of a long stainless steel tube (500 x 2mm). Dimensions were kept as small as possible, although inevitably the device will have some effect on the overall response of the resonating system. The position of the measuring tip was traversed through the flute using a mechanism synchronised to the graph plotter drive, so that sound pressure could be measured as a function of position (Fig. 1, M2, S2).

HEADJOINT TAPER

The reason why Boehm found that a taper in the headjoint was necessary in order to bring the flute into tune was explained by Coltman (1966). He observed that when playing notes in the high register the flautist's lips projected further over the embouchure hole. This increase in "lip cover", effectively introduces a constriction at a pressure node which causes a drop in pitch. Similarly in the low register the lip cover is less, resulting in a rise in pitch. A taper in the headjoint, on the other hand, causes an "octave stretching" effect which compensates for the changing lip cover.

Lip cover is intimately related to the direction in which the player directs the airstream and its relationship to flute design and playing technique is far from clearly understood. Before embarking on detailed resonance experiments we decided to film a professional flautist in the laboratory and analyse his lip movements. The results of these tests will not be described here but the findings were in general agreement with those of Coltman. It is not completely clear however to what extent changes in lip cover are desirable in playing technique. Could they be reduced and the tone quality improved if the flute were redesigned?

We describe here the results of resonance tests using both a headjoint with the standard Boehm taper and a headjoint with a parallel bore. Making headjoints with varying tapers is a difficult task, which makes it inpractical to test a large number of shapes. Eric Lucey has devised a technique which overcomes this. Instead of tapering the outer wall, a central insert is placed within a parallel headjoint and designed so that it gives the equivalent reduction in area at each location along the tube. Central inserts can be made quite easily in a wide range of shapes. Fig. 4 compares a Boehm headjoint with a parallel headjoint, together with a Boehm equivalent tapered insert.

Tests were carried out with the Boehm headjoint, the parallel headjoint and the Boehm equivalent to identify the frequencies of the different resonance modes. All of the tests used a standard Yamaha closed hole flute, the headjoint slide being adjusted at the outset of each experiment so that the note A4 was tuned to 440 Hz. Keys for appropriate notes were held down using spring clips. Resonances for the first six modes were identified by scanning the loudspeaker signal through the frequency range and noting where the microphone output reached peaks.

Figs. 5 and 6 are the resonance values of the first six normal modes for the notes C4 and A4 respectively. Each graph gives for comparison the values for Boehm, parallel, and Boehm equivalent headjoints. The ordinate gives the deviations from the true harmonics of the fundamental. The second mode frequencies for the note A4 can be related directly to the blown note A5, since the fingerings in the first and second octave are the same. Fingerings for the notes C4 and C5, however, are different, so the second mode frequencies for the note fingered C4 can not be related directly to the blown note C5.

Notice firstly that there is a close correlation between the Boehm and Boehm equivalent headjoint, confirming our expectation that a central insert can be used to replace an external taper in resonance tests. Comparing the Boehm with the parallel headjoint, it is seen that in the former case the second and third resonances for the note A4 are decidely sharp, which is not the case with the parallel taper. This confirms Coltman's view that the Boehm taper gives an "octave stretching" effect which counteracts the "octave contraction" caused by the changing lip cover.

SMOOTH BORE CONCEPT

Having gained some knowledge of how the headjoint taper affects the resonances, we proceeded to examine an entirely new concept in design developed by Eric Lucey. This is called the "smooth bore flute". As the name implies, the bore of this instrument is completely smooth inside when the pads are closed; this is achieved by eliminating the tone hole chimneys. The original idea of the smooth bore sought to reduce energy losses and strengthen the sound. It must be said that it is not entirely obvious that the smooth bore will in fact reduce losses. Considerable loss is due to streaming in the vicinity of the open holes and this will probably be increased by the elimination of the tone hole chinmeys (Keefe, 1983). On the other hand this latter effect is likely to be less significant in the lowest part of the register, where the flute is weakest.

Two smooth bore flutes have been constructed, with differing designs. These are shown in Fig. 7. The flute on the left has been made from a cylindrical tube using curved pads. The flute on the right has a bore shape which is flattened on one side. This lacks symmetry but has the advantage that flat pads can be used. In all the tests described it is the cylindrical model which has been used.

Fig. 8 shows resonance curves for the smooth bore flute using a parallel headjoint, for comparison with Figs. 5 and 6. The same two notes have been fingered. Notice the similarity with the curves for the Boehm headjoint. It appears that with the smooth bore body it may not be necessary to have a taper.

Minor adjustments to the tuning of resonances can be made by introducing small bore variations in the body as well as the headjoint. In order to be able to predict the effect of a given constriction or expansion, it is necessary to know the details of the standing wave patterns. With this in mind, standing wave patterns have been measured along the length of the smooth bore flute using the parallel headjoint. These are shown in Figs. 9 (a and b) for the first seven modes of the notes fingered C4 and A4 respectively. Smith and Daniels (1976) have recorded similar results for the trumpet. Having measured the exact positions of nodes and antinodes they predicted the effect of a specified bore variation by applying a simple adaptation of the Rayleigh formula (Rayleigh, 1894). It is hoped that this procedure can be adapted to the flute, although the end conditions are considerably more complicated than in the case of the trumpet. From Fig. 9 (b) it can be seen that the lowest mode waves do not progress past the end of the closed tube section whereas the high frequencies penetrate right into the open hole region. The dip in pressure at the embouchure hole is also to be noted. Clearly the embouchure end of the flute can not be treated as a simple pressure node.

SOME BLOWN SPECTRA

So far we have primarily discussed static resonance tests. The question then arises as to how these relate to actual flute performance. First of all it should be said that no artificial lip cover has been introduced in the experiments so far described. However, we have shown that the effect of lip cover shifts all resonance frequencies proportionately either up or down. When the flute is actually blown the strength of a particular harmonic depends on how closely its frequency corresponds with a resonance.

Figs. 10 to 13 show spectra of the sound when the instruments are blown. Fig.s 10 to 12 are for a standard flute body, comparing Boehm (Fig. 10), parallel (Fig. 11) and Boehm equivalent headjoints (Fig. 12). Notice that the Boehm and Boehm equivalent headjoints give very similar spectra whereas the parallel headjoint shows severe attenuation of all the upper harmonics. This fits with our assessment of the resonance curves. Fig. 13 is for the smooth bore flute with parallel headjoint. In this case the upper harmonics are again strong and there is a reasonable correlation with Fig. 10 for the standard Boehm flute.

These results give us some encouragement that resonance measurements may be correlated to flute performance. The pitfalls that can be encountered in the interpretation of spectral measurements from blown notes must however be recognised and great caution applied in using these measurements for quantitative comparisons.

THE WAY FORWARD

Before we can proceed further it will be necessary for us to determine accurately the hole positions required for the smooth bore flute. Several practical problems of construction still need to be overcome before an instrument can be produced which can be used in performance by a professional flautist. Only then will we be able to fully assess the merits of the different designs.

ACKNOWLEDGEMENTS

The authors would like to thank Boosey and Hawkes for supplying flute tubing and parts; Knowles Ltd., for supplying subminiature microphones; B&K Manchester, particularly Barry Heald, for use of their spectrum analyser and professional help.

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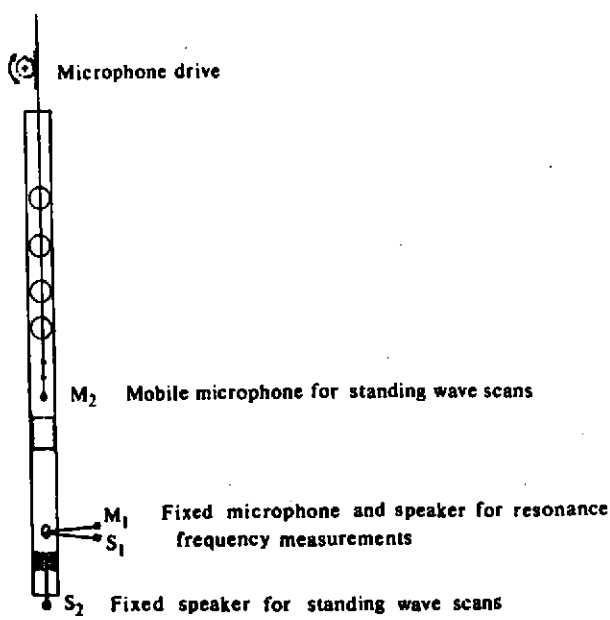


Fig. 1. Flute mounted vertically on optical bench (not shown).

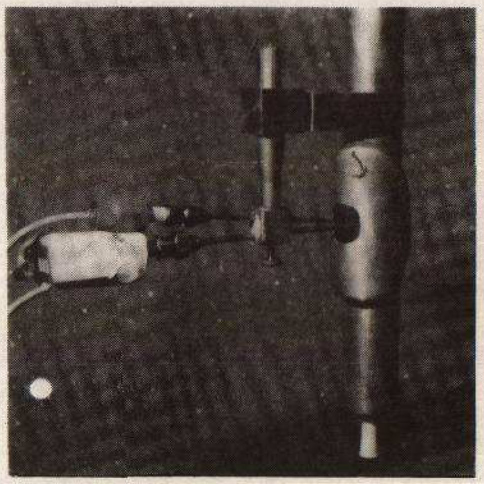


Fig. 2. Microphone and speaker probes for resonance frequency measurements.

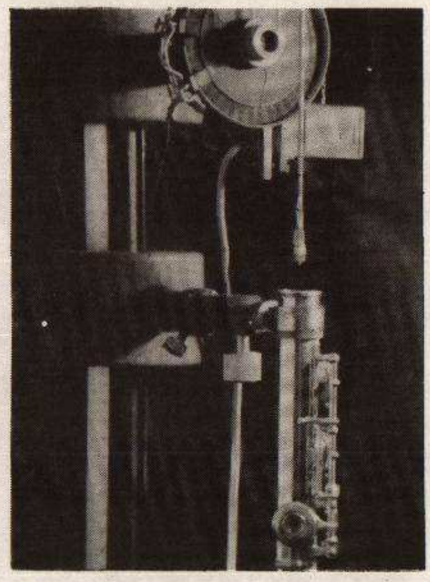


Fig. 3. Scanning microphone retracted from flute.

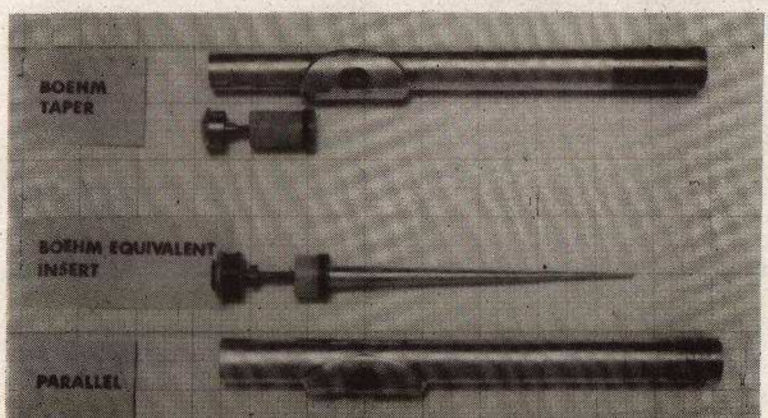


Fig. 4. Conventional and experimental headjoints.

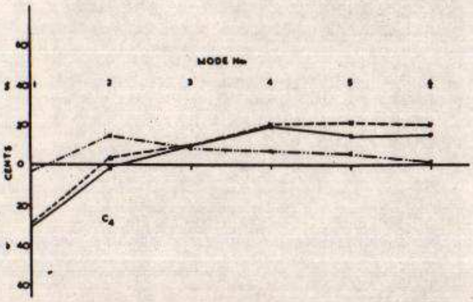


Fig. 5. Resonance frequencies of first six modes of flute clipped to play C_4. ——— Boehm headjoint, ----- Boehm equivalent headjoint, —··—··— parallel headjoint.

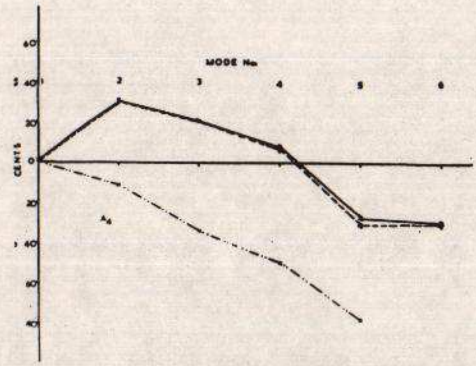
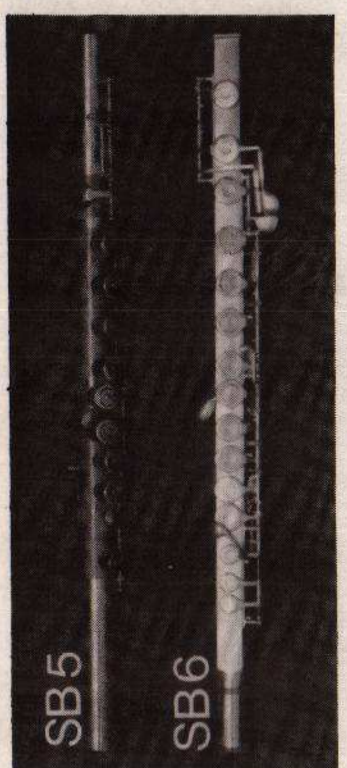


Fig. 6. As for Fig. 5, but clipped to play A_4.



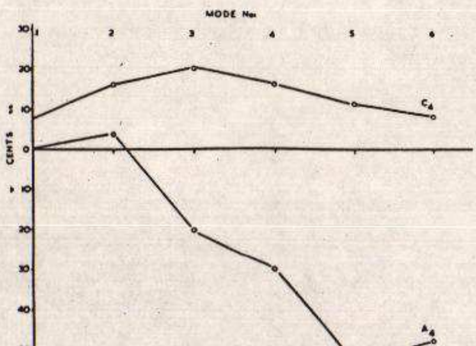


Fig. 7 (left). Two experimental smooth bore flutes.

Fig. 8 (above). Resonance frequencies for first six modes of smooth bore flute SB5 with parallel headjoint, clipped to play C_4 and A_4.

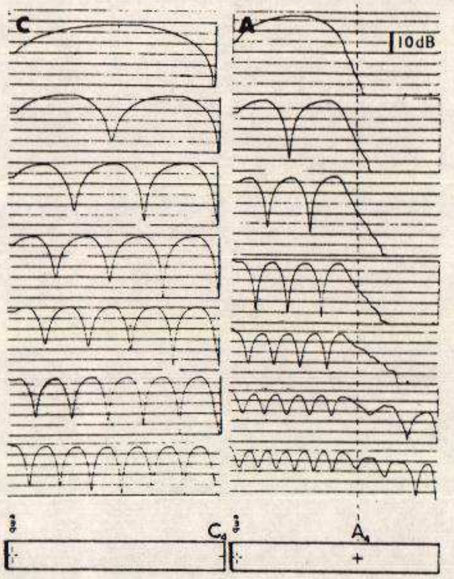


Fig.9. Standing wave patterns in SB5 with parallel headjoint, clipped for C_4 and A_4.

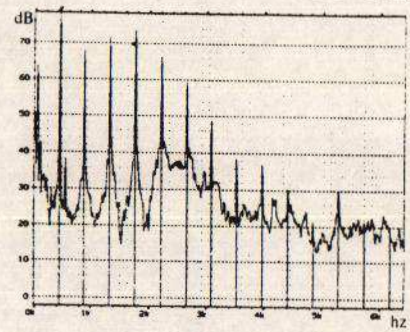


Fig.10. Spectrum of A_4 blown by E.C.A.L. on standard flute with Boehm headjoint.

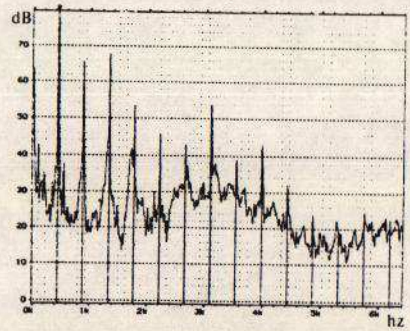


Fig.11. As 10, but with parallel headjoint.

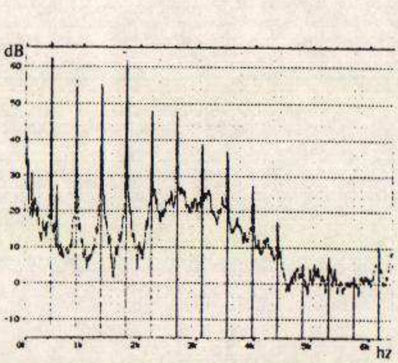


Fig.12. As 10, but with Boehm equivalent headjoint.

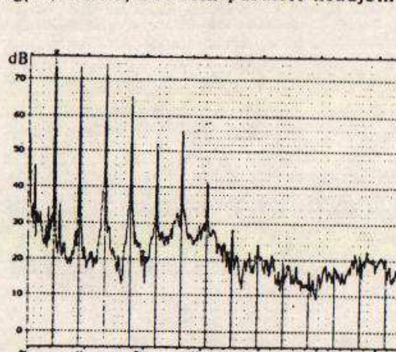


Fig.13. As 10, but smooth bore flute SB5 with parallel headjoint.