The Effects of Design on the Tone and Response of Clarinet Mouthpieces

Edward Pillinger

A thesis submitted in partial fulfilment of the requirements of London Guildhall University for the degree of Doctor of Philosophy

London Guildhall University

September 2000

BRITISH THESIS SERVICE

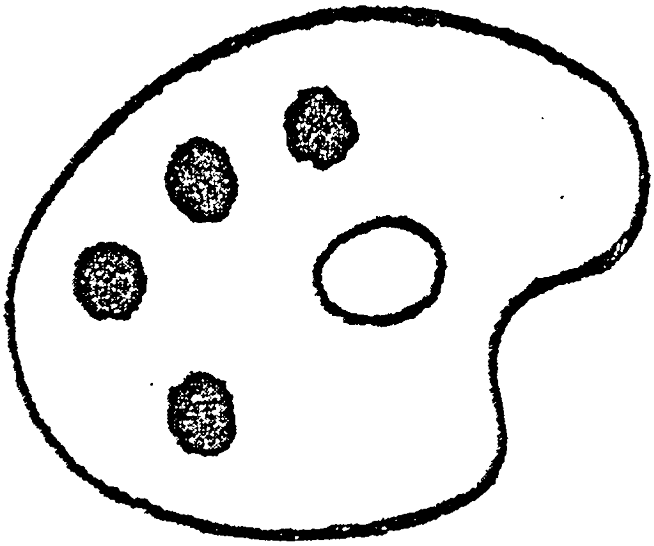
DX218699

Awarding Body : LondonMetropolitanCity

Thesis By : PILLINGER Edward

Thesis Title : THE EFFECTS OF DESIGN ON THE TONE AND RESPONSE OF CLARINET MOUTHPIECES

Numerous Originals in Colour



Abstract

PC-based sound analysis was used to measure timbral changes brought about by small incremental modifications to the internal and external dimensions of clarinet mouthpieces. Methods were developed for use with the software data acquisition and analysis programmes to cope with the non-linear behavioural aspects of the mouthpiece. In addition, the research investigated and evaluated conventional and new methods of displaying the sound spectra; this new, visual method resulted in a quick way of simplifying and clarifying the data, leading to efficient comparison of the effects and trends caused by design modification. Professional clarinettists and a controllable artificial embouchure were used in the procedures for gathering sound data, with an expert listening panel enlisted for comparative listening tests. The excellent tone produced by the artificial embouchure suggested that the effect on timbre from vocal tract resonance was minimal, and that tone was controlled by a player's subtle adjustment to lip pressure, lip position and variation of air pressure alone. Baffle angle and shape, together with the slipway under the reed, were shown to play an important role in balancing brightness in a way hitherto not clearly understood, whilst the lay profile, arguably influencing the tone and response more than any other parameter, was found to have a direct relationship with the reed's natural curvature during vibration. A large bore mouthpiece in conjunction with a small bore, French style instrument equipped with a shorter (and sometimes smaller bore) barrel, was found to increase vibrancy in many set-ups and to shift the spectrum of sound closer to Germanic tone. The influence exerted by different materials on tone was also considered, with special emphasis on the development of new resins. These polymers, which could be cast and machined, enabled the testing of materials with widely differing properties of density, hardness and flexural qualities. The research demonstrated that the nature of the material used in the manufacture of a clarinet mouthpiece becomes increasingly significant once all other parameters approach optimum configuration.

Information contained within the research will enable a more informed choice in the selection of lay profiles to be made by both players and makers, and aid in the design of new mouthpieces where both traditional and new features might be combined, thereby offering a broader range of playing properties.

Objectives of this Research

It is widely recognised that each parameter of a clarinet mouthpiece influences the tone and response of the instrument in a unique way. The aim of this research is to ascertain how quantifiable changes made to the lay, tone chamber, bore and various other areas affect the quality of tone, responsiveness and articulation of a clarinet. The results will be of benefit in the development of new mouthpiece designs and assist in solving problems associated with a clarinet's poor or inadequate performance.

Dedicated to Suzanne

who made it all possible

Contents

Illustrations

Figures

Photographs

Graphs

Graph

Acknowledgements

I am indebted to many people who have helped me during the course of this work, and those who continue to encourage me in the designing and making of both clarinet and saxophone mouthpieces. In particular, I should like to thank the following players who gave of their time so generously, and, without a word of complaint, allowed me to record them playing tediously boring scales over and over again, Richard Addison, Nick Bucknall, Tony Coe, Alan Hacker, Hale Hambleton, Ian Herbert, Tony Lamb, Tony Pay, Andrew Roberts, Nick Rodwell and Bernie Stanton.

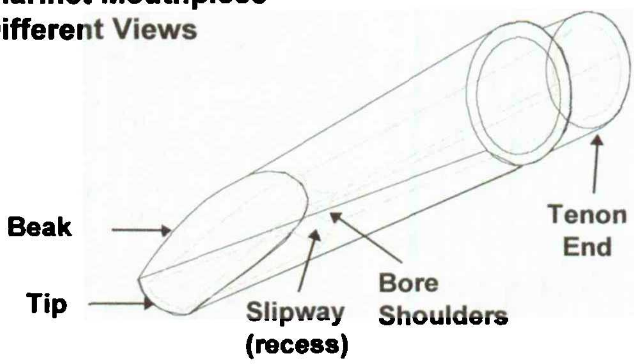
I am grateful to the retailers, Jack Dawkes and John Myatt who lent me large numbers of mouthpieces, and to the manufacturers, Paul Kinzelman, Ernst Schreiber, Guntrum Wolf, the Wurlitzer Company, Hans and Jürgen Zinner and Dave James who shared their knowledge so freely with me.

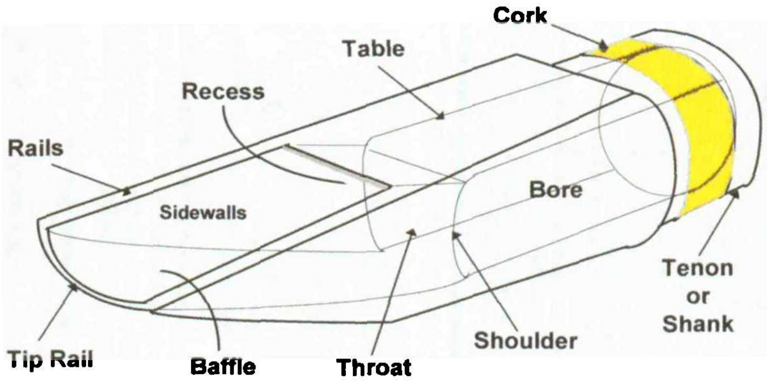
Thanks to all at the London Guildhall University, in particular, Lewis Jones for his enthusiastic and thoughtful supervision, also Sam Verik for help and advice with computer programmes and the construction of electronic circuits which worked.

Special thanks to Sir Nicholas Shackleton and Professor John Playfair for allowing me access to large numbers of mouthpieces, and for helping me with their
knowledge and unfailing enthusiasm.

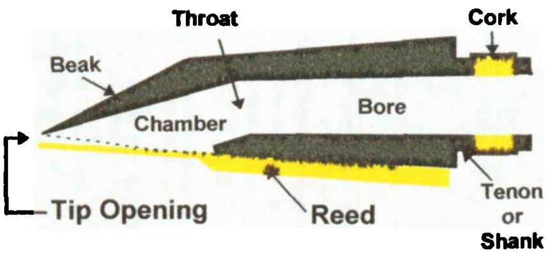
Fig.1

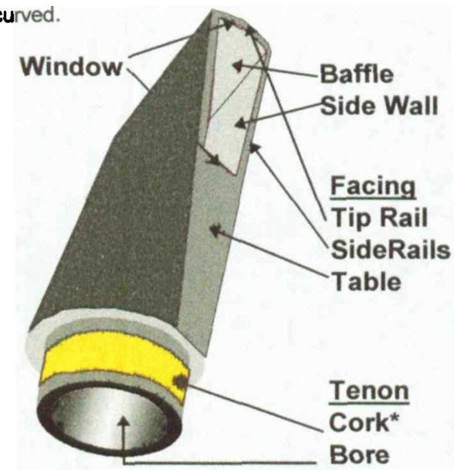
Clarinet Mouthpiece Different Views





Typical Modern French Bb Mouthpiece Dimensions (approx.)
Overall Length: 89mm
Outside Taper: 3^{0}-3.5^{0}, 28.5mm diameter at connection with the barrel
Baffle to Bore Angle: 20^{0} Bore: length 55mm, Conical, 0.6^{0} taper, 14mm-15mm
Chamber Wall Angle: Slight A-Frame or Parallel
Tenon: 22mm x 17mm
Facing: Tip Opening, 1.00-1.25mm. Length,18-25mm. Usually curved.





*Occasionally, waxed thread is used in place of cork. In early English clarinets, the mouthpiece and barrel were made in one piece; this is rarely to be found nowadays. An airtight fit between mouthpiece and barrel is essential to avoid squeaks and poor performance of the setup, but an over- tight fit can cause compression at the tenon end and consequent alteration to the mouthpiece bore perturbation. All of these variations can alter playing properties.

Glossary of Terms

A-Frame, the shape of the throat region or aperture into the top of the mouthpiece bore, as outlined by the side walls, recess and baffle configuration and viewed from the tenon end (/ \).
Baffle, the surface area directly opposite the reed, continuing into the top of the bore and forming one side of the tone chamber or slot. Sometimes known as the ramp or slipway but not to be confused with the recess under the table.
Beak, the bevelled section of the mouthpiece upon which the upper teeth rest.
Bore shoulder, the top end of the bore where it meets the tone chamber. Normally a rounded contour.
Bore, lower, lower half of the internal section of the bore extending into the tenon.
Bore, the internal section of the mouthpiece below the tone chamber and throat, can be tapered (conical) or parallel (cylindrical).
Bore, upper, upper half of the bore.
Chops, alternative term for side walls, so-called because of the shape.
Cork, thin material glued around the tenon in a wide groove to secure the mouthpiece in the clarinet barrel and form an air-tight seal.
Facing, the surface to which the reed is attached. Incorporates a flat section (table) and a gradual opening towards the tip of the mouthpiece which allows the reed to vibrate.
Lay (profile), same as facing.
Lay length, the distance from the point at which the lay begins and the outer extremity of the tip rail.
Ligature, device to hold the reed securely to the mouthpiece. Made from metal, string, leather or other material.
Parallel bore, cylindrical bore found in Boosey and Hawkes 1010 clarinet mouthpieces.
Recess, in this thesis, the region at the lower end of the slot or window directly beneath the table.
Side rails, the upper portion of the facing, either side of the window and crowned by the tip rail.
Side walls, the upright or slightly inclined sides of the tone chamber or slot, sometimes known as the chops.
Slipway, in this thesis, same as recess.
Slot, otherwise known as the tone chamber. The cavity beneath the window, enclosed by the side walls, baffle and reed surface.
Table, flat portion of the facing against which the butt of the reed is clamped or tied. Sometimes slightly concave to avoid the reed lifting or distorting under pressure from the ligature.
Tapered bore, conical bore, part of the clarinet's overall perturbation.
Tenon or shank, lower end of the mouthpiece, designed to fit securely in the clarinet barrel.
Throat, the section between the tone chamber and the bore, sometimes called the aperture into the bore.
Tip opening, gap between the reed at rest and the mouthpiece tip rail.
Tip rail, the thin curved rail at the top edge of the mouthpiece forming the upper cross section of the facing.
Tone chamber, see slot.
U-Frame, similar to A-Frame, but here the shape formed is straight sided (|_|).
Window, the open section under the top end of the reed.

Clarinet terminology

All clarinets referred to are in B flat unless otherwise specified. The written and fingered notes for a clarinet in Bb sound one tone lower than indicated, that is to say, the note fingered C_4 on the instrument will produce Bb_3 (233Hz and not 261Hz).

'Throat' notes (written G_4 - Bb_4 sounding F_4 - Ab_4) are low register notes which emanate from the tone-holes and the speaker pipe (register tube) on the upper part of the top joint. Throat notes should not be confused with the 'throat' region inside the mouthpiece (aperture).

'Bell' notes emanate from the lower end of the instrument known as the bell; these notes are low E_3 and middle register B_4.
The quality of the tone from both throat and bell notes is crucial to clarinettists.

A 'set-up' indicates a specific reed, mouthpiece and clarinet combination.

References to 'the feel' of a set-up are made throughout the text; this rather vague and subjective term is used by clarinettists to describe their physical and musical reactions to the response of a specific set-up.

Graphs

Not all the graphs are calibrated in both axes, but scales are included where it has been felt necessary. Most of the graphs are not in the frequency domain but are line graphs of the average amplitude of the harmonics of one or all registers (as in a Long Term Average Harmonic Spectrum). This way, the results of more than one set-up could be displayed on a single graph without the confusion that would arise from the use of a bar graph. Unless otherwise stated therefore, in the graphs of spectrum analysis the x-axis is a harmonic series and the y-axis the amplitude expressed in millivolts (linear) or decibels (logarithmic). The y-axis values are mostly arbitrary. Where accurate comparisons are necessary (as in repeat experiments) the same relative scaling is used throughout. The use of millivolts rather than decibels is a personal preference, as, although the logarithmic scale does make it easier to locate component activity of a very small order of magnitude, it also makes it more difficult to recognise differences in playing properties, particularly in the middle range of harmonics.

LTAS and LTAHS Spectral Graphs

Long Term Average Spectra (LTAS) are spectral graphs which are plotted in the frequency domain. The data is captured several times, the results are then averaged and presented as one trace. It is a commonly used technique amongst acousticians. A similar system is employed in the present research whereby many or all the notes on an instrument are analysed and only the resulting amplitudes of the harmonic series averaged so that a composite picture of the general tone quality of the instrument set-up may become apparent. In the text this is called Long Term Average Harmonic Spectrum (LTAHS).

1

Introduction

Undertaken from the standpoint of a performer/maker, this work complements previous research [Benade,1985, Kruger,1997 and Wehner,1961] by using sound analysis to measure timbral changes brought about by modifications to mouthpieces. Tests also involved clarinettists, a controllable artificial embouchure and listening panels. In the initial stages, differences in timbre alone were examined, and consideration given as to how these differences might best be described and quantified. Finding a method of using the analysis systems to reveal subtle timbral differences and the so-called 'feel-good factor' in an instrument set-up is difficult; repeat test results often contained substantial harmonic inconsistencies. The non-linearity of the reed and player, and possible flaws in the data acquisition methods were the most likely cause. Methods of manipulating analysis data were eventually devised and these provided a satisfactory solution to most of the problems.

The 'golden age' of the clarinet is widely regarded as belonging to the second half of the 19th and the early part of the 20th century. It was around the middle of the 19th century that the French Boehm clarinet emerged with its efficient new key-system of rings and levers, and by this time the German Oehler system had also attained much of its complexity.[1]

At the same time as these developments were taking place, the mouthpiece also underwent changes. The tone chamber dimensions of the earlier, classical mouthpieces tended to have been smaller and the facings had been designed for use with narrow reeds; these dimensions were now enlarged and began to resemble more closely the designs with which we are familiar today. The practice of making the mouthpiece and barrel in one piece, as in the very first (Denner) clarinets and early English instruments, was also abandoned in favour of the more practical, short length mouthpiece, with a tenon and separate tuning barrel. But these developments were not universally adopted: the

[1] For a comprehensive history of the instrument see 'The Clarinet' by Geoffrey Rendall, W. W. Norton,1971.or 'The Clarinet' by Oskar Kroll, B.T. Batsford Ltd. London, 1968.

German clarinettist Mühlfeld for whom Brahms wrote the two clarinet sonatas was still using a small chambered mouthpiece with a narrow reed on his Ottensteiner clarinets in the 1890s, whilst Buffet, only a few years later, were making mouthpieces very similar to those in use today (Shackleton collection).[2] Contemporary German and Viennese style clarinets still use mouthpieces incorporating features more associated with older designs, often attaching reeds to the mouthpiece with string rather than the more usual clamping with a metal ligature.

As with all performers, clarinettists from the 'golden age' would have wished to produce the most beautiful tone possible, by using the best available equipment. French and Belgian made Boehm system instruments produced around the turn of the century and in the early decades were well regarded and widely used in England.[3] In common with all Boehm system instruments they did encourage a lighter, brighter and more vocal tone, but archive recordings of players using these instruments, even taking into account inadequacies of reproduction, often exhibit a mellowness and resonance more often associated with the traditional 'German' style.[4] These players invariably used mouthpieces incorporating different internal shaping from those in common use today, often in combination with closer lay profiles. As a result, it is difficult for contemporary clarinettists using a modern Boehm clarinet set-up (i.e. a Boehm system clarinet combined with a modern mouthpiece) to emulate older styles or to produce a more Germanic timbre.[5]

Alan Hacker's work over many years demonstrated how the tone of a clarinet could be changed and the range of colours increased simply by attention to the mouthpiece. This often entailed renovating old mouthpieces or modifying new ones and the use of as large a bore mouthpiece as possible on a French style, small bore instrument. This practice was adopted by several leading players in the 1960s, including Jack McCaw in the Philharmonia Orchestra and, more recently, Nick Rodwell when he was co-principal with the London Symphony Orchestra.

---

[2] The mouthpieces in the Shackleton collection also have relatively high baffles, yet an example of a similar wooden Buffet mouthpiece from the same period, belonging to Professor John Playfair, has a large bore, a large tone chamber and a deep baffle.
[3] e.g. Albert and Martell
[4] It is interesting to note that despite the advantages of the Boehm system clarinet, many English players in the first half of the 20th century were reluctant to abandon their simple system instruments (closely related to the German system), considering their tone to be superior.
[5] But not impossible, as demonstrated by players such as Alan Hacker, Nick Bucknall and Tony Pay.

Modern mouthpieces can generally be differentiated in the following ways:

French Boehm Clarinet Mouthpiece

- Fat, smooth-bodied mouthpiece (approximately 28.5mm diameter at the widest section where it meets the barrel). Reed normally attached to the facing using a metal ligature (rubber, leather and fabric ligatures also possible).
- Bore size and other internal dimensions designed to suit the intonation characteristics of the instrument, although most modern instruments tuned to work with a conical bore mouthpiece (bore length 55mm, diameter 13.9mm at the top of the bore and 14.9mm at the tenon end, equating to a bore with approximately a 0.6 degree taper).
- Tone chamber incorporating a straight or slightly concave baffle.
- Side walls parallel or sloping away very slightly from under the lay side rails.
- Facing (lay) generally medium length (18-20mm) curved, and with a tip opening of around 1.20mm to suit lighter reeds.

German clarinet mouthpieces

- Body usually more slender with a series of grooves around the circumference of the middle section below the beak to facilitate binding of the reed to the facing.
- Bore size to suit the tuning characteristics of the instrument, but usually more tapered than the French style (<0.9 degrees) and generally not smaller than 13.5mm at the top of the bore and 15mm at the tenon end.
- Tone chamber invariably incorporating sloping side walls (A-frame). Baffle angle rarely more than 20 degrees to the centre line of the bore but commonly slightly concave in both planes.
- Facing designed for thicker, narrower reeds. Opening between 0.8mm - 0.9mm at the tip with the take-off point (length) up to 25mm from the tip rail. A flatter, rather than a curved profile. Presently a move towards more open lays with tip openings of 1.00mm or greater.

Viennese

In many respects, Viennese mouthpieces share German characteristics, with the facing adapted for slightly wider reeds. Traditionally, the Viennese facing was long and close, with a tip opening of 0.6mm common. However, measurements taken of '00' facings which would have been expected to conform to these dimensions were found to be considerably more open at nearer to 0.8mm. It is uncertain whether this was a fault in the manufacturing process or a deliberate application.

These three types of mouthpiece are quite distinctive. Broadly speaking, the German tone is the darkest of the three; the Viennese, similar but lighter; the French, the brightest but most vocal. But everyone's perception of tone is different and good players will be capable of a wide range of timbre within each style. The situation in Germany has altered greatly in the past years with players moving to French Boehm instruments, combining these with more open lay mouthpieces and softer reeds.

All references to 'German' tone in the text imply clarinet sound with a predominantly dark quality, setting it apart from the French style.

The two Boehm clarinets used throughout the research were a Buffet R13 c.1970 and a Louis c.1920. The Buffet was chosen because internationally it is the most popular model to be used by professionals and therefore the most representative of modern instruments. The Louis was used because it was an excellent example of a clarinet made at the end of the 'golden age'.

THE PARAMETERS UNDER INVESTIGATION

The effects of modifications and incremental alterations to the following parameters were investigated:

Bore

- Diameter
- Taper
- Length

Tone-chamber

- Baffle angle & shape
- Side-wall angles
- Area on the baffle below the tip rail

Recess
The angle & thickness of the recess under the table

Volume
The effects on timbre and intonation of variation in internal volume were considered

Aperture or throat
Aperture into the bore from the bottom of the tone-chamber

Lay profiles
Tip opening, length and curve

Wall and body thickness

Materials

- Density
- Hardness
- Flexural qualities

In addition, a wide range of new and old German and French facings were examined. As work progressed, there was an increasing awareness of the importance of the tip rail and side rail thickness and overall dimensions of the window under the reed.[6]

A large number of commercial mouthpieces was measured and tested to assess the current situation. The quality and performance of these were found to be inconsistent. A disappointing lack of variety in design was also revealed, particularly with regard to

---

[6] Although a systematic investigation of the side rail thickness was not included, it is on a list of priorities for inclusion in further research.

mouthpieces for French style instruments. The differences that did exist were mostly to be found in the lay profile, tip rail thickness with some variation in the configuration of the aperture.[7]

The importance of the mouthpiece in tone production, ease of response and compatibility with reeds is paramount. The primary aim of this research however was not to find the definitive mouthpiece design but rather to discover the reasons for changes in timbre and thereby evaluate the nature of 'good tone and response', irrespective of style of playing. It was hoped that a greater understanding of the behaviour of the three interacting areas of the mouthpiece and an ability to manipulate them would enable makers to design mouthpieces whose tone and response could be tailored to suit individual specifications or particular instruments. It might also be possible to alter the character of an instrument more easily than is presently the case, allowing a French clarinet to assume a more Germanic quality and vice versa. It has often been suggested by players and conductors that an ability to quickly and easily modify the sound of their instruments to suit different styles of music could be advantageous. There are some clarinettists and bassoonists in orchestras who change their instruments for this purpose. The musical implications of this are considerable and were judged beyond the scope of the present research, but the nature of the differences in tone between different schools of playing was researched in some detail.

Mouthpiece makers and manufacturers use designs that are traditionally considered as suited to a particular school of playing. French, English and American schools use Boehm system clarinets, German and Viennese schools use both Oehler system and Boehm hybrids such as the Schmidt Reform Boehm clarinet. The dimensions of the mouthpieces for these instruments are largely the result of empirical work. Makers of the 18th, 19th and early 20th century always produced mouthpieces to accompany their clarinets. Account was taken of the instrument's bore size and its intonation characteristics before finalising the mouthpiece dimensions. In some instances this continues to be the case,[8] but many modern clarinet manufacturers now buy their mouthpieces from specialist makers. Buffet supply their instruments with mouthpieces which are stamped with the Buffet name and logo, but, until recently, these were made in Germany by the Ernst Schreiber company. Contemporary handmade instruments are also rarely supplied with their own

---

[7] Refer to chapter 4, p 33
[8] Yamaha, Selmer and Wurlitzer

mouthpieces. Frank Hammerschmidt who hand-makes clarinets obtains most of his mouthpieces from Viotto, and Guntrum Wolf, who copies antique clarinets, enlists the help of specialist manufacturer Hans Zinner to provide the mouthpieces. This is not exclusively a recent development; in the recent past, Boosey & Hawkes imported and modified French Chédeville mouthpieces for their top of the range 1010 and 926 instruments, and in the 1920s and 30s, Louis clarinets were mainly supplied with mouthpieces made by George Howarth.[9]

Most of today's professional players will have a favourite mouthpiece or collection of mouthpieces that they will expect to be able to use with almost any instrument. Clarinet manufacturers are aware that, irrespective of the quality of the mouthpieces supplied with their instruments, most players will want to use their own existing mouthpiece, or, if they do want to change mouthpiece, will choose from the large number available from specialist makers. But whilst there is no shortage of mouthpiece manufacturers, many of whom offer an apparently wide range of models, the majority of mouthpieces offer very similar playing characteristics and, as such, little choice to clarinettists. Manufacturing methods such as injection moulding may have placed some constraints on design, but a lack of awareness of the possibilities and the conservatism of many modern clarinettists is also perhaps partly to blame. The increasing emphasis on virtuosity, sometimes at the expense of tone, and the trend towards a more homogeneous, 'international' sound amongst orchestras have also played their part.

Although player/maker based, the present research did not rely on empirical work or subjective analysis. A systematic approach ensured repeatability of all procedures, and the listening tests established 'listening criteria' which posed many questions regarding the accepted norms of good sound and good clarinet tone in particular. A thorough investigation was conducted into the new, affordable, computer-based analysis technologies now available, with two of these hardware/software systems being used extensively throughout the research. Knowledge of these systems should be of particular benefit to musical instrument makers needing an uncomplicated, cost effective method of analysing the sound of their instruments.

---

[9] No criticism is implied in these observations, simply an intention to assess the situation as it now exits.

The results of the research will also help players to make a more informed choice from the large number of commercial mouthpieces currently available, or to work with specialists to adjust tone more successfully. The research initiated much debate, and not a little controversy, as to the precise role of a player's embouchure and oral cavity in tone production.

A clarinettist's ability to perform expressively relies to a large extent upon the tone and response of his instrument. A poor mouthpiece will have a catastrophic effect on the playing properties of the clarinet, detracting not only from the quality and range of tone colour but also diminishing the dynamic range and clarity of articulation. Conversely, a mouthpiece which encourages a rich tonal palette, a wide dynamic range and clean articulation will allow a player access to a greater resource of colour and attack and hence a freedom of expression and interpretation.

2

Review of previous research

Part of the present research, in which sound analysis was used to measure timbral changes brought about by modifications to mouthpieces, complemented previous work undertaken by Benade, Krüger and Wehner. Reference to other research is made throughout the thesis, but in this chapter I discuss work which is of particular relevance to my own investigations.

Little investigation has been carried out into the complex nature of the mouthpiece since the 1960s. Most scientific research concerning the clarinet has dealt with its basic acoustic properties [Ghosh, 1937, Backus, 1961 & 1967, Nederveen, 1969 and Benade]. Whilst these researchers accepted the importance of the mouthpiece, their work did not focus specifically on this area but dealt rather with air column resonance frequencies, reed vibrations, intonation and bore perturbation.

Two publications by Walter Leroy Wehner dealt with the effect of the design of the mouthpiece on playing properties. 'The Effect Of Interior Shape And Size Of Clarinet Mouthpieces On Intonation And Tone Quality, University of Kansas, Ed.D., 1961' was a doctoral thesis; an edited version re-appeared under the same title two years later, in the *Journal of Research in Music Education*, [Vol 11 No 2, 1963, p.131-136].[1]

Wehner's use of a Stroboconn and tape loops for analysis was typical of work carried out in the early 1960s. The effects of various bore sizes and tapers on intonation (well known to experienced technicians) were examined, and the effect on timbre of altering the angle of the baffle and therefore the depth of the mouthpiece tone chamber, was considered. Differences in the number and the strength of upper components in the tone when using varying depths of chamber were found and this was discernible in the Stroboconn traces. However, a listening panel was unable to detect a significant change in sonority. This was curious, since for decades jazz players had brightened the tone of their clarinets and

[1] The magazine version was primarily aimed at clarinettists and teachers needing help in solving the intonation problems suffered by inexperienced players.

saxophones by pressing pea-sized pieces of chewing gum onto the centre of the baffle in order to raise the contour and thereby reduce the depth and volume of the chamber. (Blu-Tak, or a more permanent epoxy resin or fibreglass is often used nowadays. Small 'slips' of self adhesive plastic material are also available from an American manufacturer for the same purpose). I demonstrated this technique at a seminar at the London Guildhall University in June 1996 by sticking a small piece of Blu-Tak to the baffle of a clarinet mouthpiece, and there was unanimous agreement that the effect on the sound was dramatic. The difference in tone was also clearly displayed in a significantly altered spectral graph.[2]

Wehner's original thesis was more detailed than his article in the Music Education journal. The thesis described two clarinets used for testing; both were stated as typical but not named. The mouthpiece starting dimensions were given, but the make was not revealed. It was also chosen for being apparently 'typical' (to America?). The thesis contained copious amounts of well organised data. Unfortunately, testing had been confined to the analysis of live playing alone, and only one lay profile, described as medium French, was used for all tests, the role of the lay being outside the scope of the research. But, as all players know, the lay profile has an enormous influence over the ability to control and vary timbre. The lay also dictates the thickness and strength of reed that can be used, influences how easy or difficult the instrument is to blow and how responsive the whole set-up feels. The reed thickness, lay profile and feedback to the player from this sensitive area undoubtedly have a profound effect on the quality of tone.

Consideration was not given to the effects of air pressure, temperature and humidity, or to the type and strength of reed used, all of which can have a significant effect on intonation and timbre. Temperature in particular has a marked effect on pitch. But perhaps the most serious omission was that consideration had not been given to the possible effects of the interaction of bore, lay and chamber, and how the alteration to one parameter may exaggerate or cancel out the effect of either or both of the other two. The methods used were also virtually impossible to repeat or verify.[3] Nonetheless, there was useful

---

[2] See appendix E, p 241, for a detailed description of this technique.

[3] The importance of repeatability became apparent to me during my own work: if it were not possible to repeat an experiment with fully controlled parameters, then a method incorporating averaging techniques or statistical trends had to be used.

knowledge and data to be found in both of Wehner's pieces of work, especially if one's primary interest were in French style clarinets destined for the American market.

Since conducting the seminar which included the Blu-Tak test, Virginia Benade, wife of the late Arthur Benade, has given me copies of his rough seminar notes. These include details of some of his experimental work with clarinet and saxophone mouthpieces. In one of these papers [Benade, A.H. 1974], Benade states that the shape and height of the baffle has little effect on tone, concluding that 'high and low baffle shape is hardly influential more than 1mm from the mouthpiece tip on a Bb clarinet - the story is nearly all told in the first ½ mm!'. I am in complete accord over the importance of the tip rail area, but cannot agree with his assertion that the baffle does not play a significant role in shaping tone colour and influencing response properties. However, in an earlier paper of Benade's, concerning the timbre of wind instruments [Benade, A.H. 1970] he clearly states that '.....the sound spectrum is made up of waves which have revisited the reed many times in their reflected travels up and down the air column. It can be shown that under these conditions the strength of the partials is determined to a large extent by the bore *and the mouthpiece shape...*' (my italics).

It was clear that something was preventing differences from being detected by the listening panel in the American experiments. It may be that, in common with much clarinet research in the U.S.A., the instrument and mouthpiece used were limited to the arguably narrower sound spectrum of a small bore French clarinet and a typical 'middle road' mouthpiece. This mouthpiece would be characterised by a relatively shallow tone chamber, flat baffle and parallel side walls with a taper down to a small rectangular entry to the bore (U-Frame). This design forms a bocal (constriction) similar to a saxophone or an oboe, and is in contrast to German style mouthpieces or even pre-war English examples. In these mouthpieces the side walls slant outwards from the rails of the lay profile (A-Frame) allowing the baffle to remain the same width all the way from the tip to the point where it meets the bore, virtually dispensing with a bocal. The brighter toned French design, encouraged by the bocal, is by far the most widely used style of mouthpiece in the USA. Unfortunately, research confined to this kind of mouthpiece may only benefit small bore French clarinets.

Apart from the fact that the breadth of colour is rather limited with this set-up, the main reason that differences were perhaps difficult to observe was because the tests were conducted using only live players who may have compensated for any changes to the design by altering the way in which they blew the instrument. This would have made any results unreliable. The experiments also failed to include alterations to side wall angles or to examine the effect of the many kinds of longitudinal and lateral curves or troughs that can be machined into the baffle, along with a change in angle.

Wehner's research focused on the modern French/American set-up. More recent research by Walter Krüger considered German and French schools of playing. Both studies sought to discover which mouthpiece dimensions would give playing properties that both players and listeners alike would agree gave the 'best' overall sound. Krüger's study also drew attention to the notorious conservatism rife amongst musicians with regard to timbre, and noted their prejudice towards certain materials used in the manufacture of mouthpieces.

Walter Krüger [Krüger, 1997] investigated the possibility of improving a badly tuned instrument through alterations to the mouthpiece and barrel. His aim was different from mine. Whilst intonation was an important aspect and a concern throughout my work, it was not central to it.[4] Krüger's study laid as much emphasis on the effect that small dimensional changes to the design of mouthpieces had on tone and response as they had on intonation, and in that respect it came closest in nature to my work, although his approach was simpler. His results were based upon players' graded assessments of changes in tone quality brought about by relatively minor alterations made to a small number of mouthpieces. Spectral analysis was employed to support the impressions of the professional clarinettists in the group taking part. Unfortunately, certain crucial areas of the mouthpiece were ignored in this study, but as this kind of work is extremely difficult to conduct in an absolutely rigorous scientific manner, Krüger's decision to limit the scope of the experiments and finally to opt for the analysis methods employed was understandable. As a way of achieving rapid but easily comprehensible results, I found this to be a satisfactory procedure; I also found that I agreed with most of the conclusions drawn from the results of the experiments and found his approach sympathetic.

Krüger's methods were not controversial. The professional players were asked to assess the characteristics of mouthpieces where the dimensions were found to give playing properties that agreed with accepted knowledge based on empiricism. e.g. higher baffles

---

[4] Some instrumentalists have suggested that perhaps too much emphasis has been placed on designing and adjusting a clarinet to play in tune, at the expense of tone.

encouraging brighter tone. This reaffirmed the status quo, rather than discovering something entirely new that might affect mouthpiece design in an interesting way.

Krüger's experiments used a number of mouthpieces which had been made as identical as possible, but with each mouthpiece incorporating one small alteration to its internal dimensions. At the outset of my own research, I began in a similar way, but found this to have serious pitfalls. The mouthpieces for Krüger's experiments were made by the Ernst Schreiber company, using computer controlled machines. I know from first hand knowledge that this firm can produce consistently accurate mouthpieces. However, we cannot know for certain that, in spite of their supposed accuracy, the mouthpieces actually shared the same playing properties. My own and other clarinettists' experience of supposedly identical mouthpieces is that they can perform in a far from identical manner. This is also the case with 'identical' instruments. Therefore, to rely on their consistency for the purposes of scientific study may have been a little unrealistic. There were other differences in his approach but, more crucially, some omissions, which Krüger acknowledged.

Reflections on Krüger's research and comparison with the present research

- Krüger's players chose their own reed from a single batch for all the experiments. The tests were quite lengthy and a reed might easily have deteriorated before the tests were completed. For this reason, one of the players insisted on using 3 different reeds. Reeds are non-linear in their behaviour, and make a considerable difference to the playing properties of a set-up.

  EP - experimented with specially coated reeds to try and maintain the reed quality over longer periods, or when using an ordinary reed, tried to complete the experiment as quickly as possible, before the reed changed its properties.
- Krüger's baffle tests were based on different heights, incorporating a step and ledge, rather than reworking a smooth transition into the back bore of the mouthpiece.[5]

  EP - changes to the baffle height were accompanied by a smooth taper to the mouthpiece bore in order to achieve a more realistic shape.

---

[5] This design works well for jazz style saxophone mouthpieces but does not suit the clarinet. Similarly, sidewalls tapering smoothly into the top of the backbore, thereby removing any bocal where the tone chamber meets the bore of the mouthpiece, work well in a saxophone but not in a clarinet.

- Krüger's experiments omitted to include the effect of the design of the recess under the table at the base of the reed window.

  EP - included this area.

- Krüger's research did not take tip rail thickness into account, although there was concern over the side rail thickness. The area just below the tip is widely thought to influence response [Benade Seminar notes etc.] but this was also omitted.

  EP - the area immediately below the tip was included in the present research.

- Krüger's research did not investigate the effect on tone of enlarging the bore, although mention was made of the possibility of improvements (mostly to intonation) by enlarging the upper bore in either the mouthpiece, the barrel or both.

  EP - included experiments to determine the effect of bore size on timbre.

- Krüger did not examine lays and their effect on tone nor, more crucially, was the onset transient investigated. Perhaps this was considered outside the scope of the work. However, Krüger did discuss the performance of open and close lays and explained how wide lays need lighter (softer) reeds which can swing into action rapidly (accelerate quickly) and at greater speed, whereas the closer, narrower lays can begin to operate with a lower acceleration and velocity than is possible with a thicker (harder) reed. From this it follows that the open lay, demanding higher pressure thereby inducing greater acceleration of the movement of the reed at the tip, will snap shut more easily, producing a near square wave and therefore a fuller spectrum more readily than a narrow one. It is also worth considering that a wider opening will require a softer reed in order to be able to use lip/jaw pressure to bend the reed around the lay so as to reduce the tip opening to a point where the Bernoulli effect can commence. This shortens the effective length of the lay with a resulting change to both timbre and response in addition to those brought about by increased forces. The closer lay is already nearer to a Bernoulli conducive opening, so requires less lip and jaw pressure and therefore shortens less whilst being played.

  EP - included investigations into the effects of different facings on tone and response.

- All of Krüger's results were based on players' perceptions, with limited backup in the form of hard data.

EP - used a combination of data acquisition and players' response to set-ups to assess tone quality.

Enormous prejudice against mouthpieces made from acrylic was observed by Krüger in his research, with these mouthpieces scoring 0 on a 0 to 5 scale where 0 = poor, 5 = excellent. This was strange, as a number of respected German clarinettists use mouthpieces made from acrylic. Acrylic (methyl methacrylate) is, arguably, a superior material to ebonite, being mechanically more stable, strong and safe, but having a similar density. Mouthpieces made from acrylic have similar playing properties to those made from ebonite and many players in the UK actually prefer the tone of acrylic mouthpieces. In blind tests of my own, I found that professional players were often unable to distinguish between the two. I was surprised at the outright dismissal of this material by the German players and as a result, somewhat uneasy as to the lack of bias in their appraisal in other areas of the procedure. Nonetheless, the opinions of excellent players cannot be disregarded. Krüger also expressed his disappointment, feeling it to be the result of outright prejudice and conservatism. Reaching similar conclusions to myself concerning the important role of mouthpiece material, he pointed out that the vibrating reed exerted considerable forces on the mouthpiece, particularly at the tip. The energy transfer would almost certainly be different between different materials and would affect damping of the vibrations. In addition, the differing flexural modulus of the materials would influence the nature of the oscillation and in turn affect the shape of the primary spectrum at the point of excitation. This highlighted the importance of the choice of material to be used in the making of mouthpieces.

In Krüger's experiments the results of the marks awarded by the players in assessing the playing properties of each set-up were displayed in a ray chart. Given the limited range of simple experiments carried out by Krüger and his team, the method worked well.

Krüger's results in brief:

(based on assessments made by the eight professional clarinettists)

1. The effect of side rail width was minimal. Thicker rails diminished the dynamic range because, as blowing pressure increased, the Bernoulli forces became greater, causing the reed to shut off earlier resulting in more upper harmonics (a richer spectrum). With thicker rails therefore, a bright timbre might become apparent at a lower volume.

2. Increase in tone chamber volume, either by lowering the baffle angle, making the baffle more concave or widening the side walls [chops] resulted in a warmer, fatter sound. It was not clear whether or not there was a limit to these modifications or if optimum dimensions were achievable.
3. Raising the baffle by a mere 1mm (presumably from the control mouthpiece baffle angle) was perceived to cause an overly bright and brilliant tone. As the baffle was raised further, responsiveness was reduced even further and the intonation in the upper register (3rd mode) became sharp and unmanageable. Players were found to be extremely sensitive to reduction in tone chamber volume.
4. Parallel side walls (U-frame) were found to be inferior to outward sloping walls (A-frame). This was perhaps not surprising given that German mouthpieces normally have steeply sloping walls (A-frame). In the UK, France and the USA, the U-frame configuration would almost certainly be preferred.
5. A concave tone chamber baffle gave good playing characteristics according to the eight German players. This shape increased volume and reduced richness in upper harmonics.[6]

It is worth noting that in the context of Krüger's work, 'richer' tone ('obertonreicher') means timbre with a greater proliferation of upper harmonics and partials, i.e. more like a square wave. The German players taking part in Krüger's experiments all preferred mouthpieces which he described as *poorer* ('obertonärmer') in their tonal output, i.e. producing a tone with less upper harmonics. This is typical of the German School of playing, but it is, rather confusingly, usually described by clarinettists as being 'rich'. This sound is also associated with the timbre produced by a mouthpiece with a large deep chamber, which again is lacking in certain overtones. Less upper harmonics result in a warmer, darker and more mellow sound, and to most clarinettists this is described as 'rich'.

Where a design has encouraged this tone colour, the higher upper harmonics have been attenuated, sometimes removed altogether, and there is a lowering of the cut-off frequency. Usually there is also some reduction in the strength of the remaining higher harmonics, but the net effect on the ear is that, with the disappearance of the very high

[6] Views in the American, English and French schools vary on the subject of baffle shape. Straight baffles have been popular for most of the latter half of this century. However, there is now a move away from the straight flat baffle towards the more concave, older *Chédeville* design, characteristic of the first half of the twentieth century. Care needs to taken when selecting a mouthpiece for its baffle design, since an over-deep and concave shape can make *some* clarinets sound 'tubby' or woolly and unfocused.

partials, many of which may have been inharmonic, the balance of amplitudes between the fundamental and the remaining harmonics are more evenly distributed. The ear can focus more easily on the 3rd, 5th 7th and 9th harmonics as they have acquired greater prominence. These middle components now sound as though they are the upper ones (explaining why some musicians thought that the design had increased upper harmonics) but the overall effect is that the tone has become smoother, darker, mellower, more rounded, less harsh or less bright or whichever way one wishes to describe it. All the players taking part in Krüger's experiments considered that the best tone was achieved when less harmonically complex tone was being produced, either by way of a deeper baffle, more chamber volume, or with a close lay. Another interesting observation of Krüger's was that a narrow reed slot (the distance between the side rails) and relatively thick side rails (max. 0.6mm) encouraged the generation of components in the upper portion of the spectrum, i.e. a richer and more complex tone through increased Bernoulli effect. This is of course the more usual German set-up and, to some extent might be desirable to counter-balance the attenuation of upper components brought about by greater tone chamber volume and/or baffle shape and angle.

In Krüger's experiments, the players found that a mouthpiece with a large amount of metal filler was found to give the best tone and overall response. This mouthpiece was presumably of the same design as the control which was considered very good by all the participants in the tests. Surprisingly little attention was paid to this result, which was strange, as clarinettists either believe that the mouthpiece material has little or no effect on tone and response, or that ebonite is the only acceptable material for a good quality mouthpiece. I encountered a similar response from players when I made some mouthpieces incorporating a large proportion of bronze powder in the polymer. These mouthpieces performed exceptionally well, several professional players remarking on their excellent tonal qualities. One of these clarinettists now plays on one of these mouthpieces on a regular basis.

Conclusions and differences in approach

Where Krüger's research and mine overlapped, we reached similar conclusions. However, by including the use of spectral graphs, my aim was to focus in more detail on how small changes in design could influence the wave form. The random and chaotic nature of the spectral graph of individual notes on the clarinet required me to develop different analysis systems to show how the spectrum of harmonics changed when relatively small incremental changes were made to dimensions and shapes within the mouthpiece.

I included the lay profile dimensions and the density and hardness of materials in my experiments.

I examined the different regions of the mouthpiece to ascertain how they interact. By defining the specific areas which benefit the playing properties of the mouthpiece the development of new designs incorporating these features is now possible, and aspects which are detrimental to the tone and response avoided. It is also possible to design mouthpieces to more specific specifications with regard to timbre, articulation and intonation.

3

Clarinet Tone and Response

One of the most crucial aspects of the initial survey in which the mouthpieces were assessed using the artificial embouchure, was the identification of the criteria to be used in their assessment. If the main issue were to be the tone, then should assessment of this be made by a listening panel or by reference to a spectral graph? If a listening panel were to be used, should this be made up of professional players, musicians, lay people or a mixture of all three? Subjectivity would surely be a problem here and opinion might vary between generations. Would players from one school disagree with those from other schools, or would taste vary within the same style of playing? Would it ultimately be possible to agree on what constituted 'good tone'?

Many professional players visited the workshop. Most were from the French Boehm school of playing but there were also two who used Schmidt Reform and Oehler system instruments . Each player produced an individual sound, if only subtly different one from the other but they all had very definite ideas concerning 'good' clarinet tone. It was curious to note however, that two very different players would express admiration for the tone of another player who differed in tone again from either of them. A possible explanation for this may be the complex way in which players hear their own tone production, with the added complication of the sound transmitted through the beak of the mouthpiece to the inner ear via the teeth, jaws and cranium.

Clarinettists have to deal with the problem posed by the fact that different acoustics and distance can have a marked effect on tone. The celebrated player Reginald Kell was renowned for his sublime tone when heard in concert, yet players sitting next to him observed that the tone was curiously buzzy. Here we have a situation where the important portion of the spectrum, that which constitutes 'good tone', was able to project, whilst the buzz was left behind. The buzz which formed this part of the complex wave did not radiate well, and therefore presented no problem in performance. The question this then poses, is whether the components that created the 'buzz' might be beneficial for the radiation of good sound. We do know that Kell used a relatively short length lay with a narrow tip opening (approx. 0.95mm x 16mm). Krüger's hypothesis [Krüger, 1997] states that this set-up encourages clipping from a low dynamic level (closure of the reed against the tip rail and the early formation of a square wave), resulting in a tone quality which is rich in uneven harmonics even at a moderately low sound level. Kell used soft reeds which would have encouraged this tendency further and perhaps explain the buzz heard in close proximity; the reed beating against the tip rail of the mouthpiece.

Most players nowadays form an embouchure with their top front teeth resting on the top (beak) of the mouthpiece and the lower lip folded over the bottom front teeth to create a cushion for the reed, the older practice of the double lip technique used by their double reed colleagues, having been largely abandoned.[1] Many players also stick a rubber patch onto the top portion of the beak to cushion the teeth from the hard surface of the mouthpiece. This is thought to have the additional benefit of helping to reduce internal resonance produced by the transfer of energy from the mouthpiece to the inner ear by way of the teeth and bones in the head, and as a result, give a truer picture of the sound being produced. Unfortunately, the sound heard by the player will always be different from that heard by the listener, even if the listener is only a few feet away. A distance of at least a metre is necessary to receive anything like a balanced mix of the predominantly upper frequencies radiating from the bell and the strong fundamental and lower harmonics emanating from the tone holes. In electronic terms, the clarinet bell behaves much like a high pass filter and the tone-holes a low pass filter.

The many hours spent listening to steady state clarinet tone during the course of the research, caused me to question the nature of sound and to realise the importance of comparing my own perception of timbre with that of others. It was for this reason that listening panels were enlisted and the judgement of individual musicians sought as often as possible, particularly during the assessment of the effect of a large bore mouthpiece on the Howarth clarinets.

Subjective Preferences in Clarinet Tone

The possibility of establishing a norm of clarinet timbre that would be agreed upon as representing 'good tone' to a majority of players and listeners alike was put to the test in a seminar at the London Guildhall University. Students, staff and public attending were a cross section of people involved in the music world, including players, researchers and makers. I conducted an experiment whereby the audience was asked to listen to contrasting excerpts from the Mozart Clarinet Concerto[2] played by several leading British

[1] e.g. Reginald Kell used this technique.
[2] Opening section of the 2nd movement bars 1-8 and opening section of 3rd movement bars 1-8

and foreign soloists. There were several clarinettists in the audience so I was intrigued to discover which tone and articulation would be appreciated by them, since clarinettists are notoriously influenced by fashion and often have preconceived ideas and sometimes a degree of prejudice. Many of those present were also familiar with evaluating the sound produced from various musical instruments, so it would be of interest to see how clarinet tone would be perceived by this cross section of specialists, students and academics.

The players and recordings had been chosen such that a range of styles would be represented, including modern English, old English, modern German, Viennese (modern, Oehler system basset clarinet), modern French (English player) and an authentic performance on a boxwood basset clarinet. We discussed the different ways in which tone could be described, in particular the nomenclature commonly used by musicians. I provided a long list of words often used to describe tone (timbre) and response (articulation) and the audience was invited to add any others they thought useful. The list began very simply with the following, but grew extensively.

<u>Timbre</u>	<u>Articulation</u>
Dark\Light	Fast\Slow
Mellow\Harsh	Crisp\Fuzzy
Smooth\Rough	Strident\Delicate
etc.	etc.

Members of the audience were given a simple form to complete. The excerpts were then played without divulging the names of the players. After each example the audience was asked to fill the appropriate box with a word or phrase they thought best described the performance and then to give a mark out of ten.

Test 1
Mozart Clarinet Concerto K.622 Opening of the slow movement

	Tone	Response	Mark (10)
ex.1	smooth	sluggish	6
ex.2			
ex.3			
etc.			

Test 2
Mozart Clarinet Concerto K.622 3rd movement excerpt (fast articulation)

	Tone	Response	Mark (10)
ex.1	shallow but colourful	prompt-nice attack	8
ex.2			
ex.3			
etc.			

The papers were collected, the identity of the performers revealed and the results discussed. For the purposes of this document, the players in the experiments shall remain anonymous and only the instruments and styles of playing revealed. All the clarinettists present were intrigued and somewhat surprised by the results.

The highest marks and the most complimentary remarks given for tone and response were awarded to an authentic performance on a period boxwood basset clarinet. The instrument was the extended version with an extra four semitones down to the fundamental C_3. It was interesting that an instrument made from boxwood should have been preferred, and not one made from African black hardwood, Grenadilla, that is commonly considered as being the only material suitable for the manufacture of high quality clarinets. There are a number of clarinettists who believe that performances of the Mozart clarinet concerto will become impossible once the supply of this endangered species is exhausted. However, Mozart's exposure to the instrument was entirely limited to clarinets made from boxwood, grenadilla not being available at that time. The Guildhall experiment proved that, even to the educated listener, a clarinet made from boxwood can sound as good as one made from grenadilla and that many people cannot tell one from the other.

There was much discussion after this experiment. One of the clarinettists in the audience was shocked to have given a very poor assessment of a player he much admired. It was interesting too, to note that once the identities of the players were known, and the quality of the recordings taken into account (one, a rather bright recording from the 1930s, another a dull recording from the late 60s) opinions began to shift. The most generous assessment remained with the boxwood basset clarinet but the modern German and the Viennese modern basset clarinet versions were reassessed as being much better than had initially been felt (the quality of the recording in the case of the German performance was lacking in clarity) and the modern English was considered less good than at first hearing. The reasons for the shift were not altogether clear, but it seemed that subtleties in the playing became more important, as did depth of tone and clarity of attack. Allowances were also made for recording quality.

The audience response was later analysed in more detail, comparing the lists of words used to describe each player compiled from the questionnaires handed in.

If we take the first example which was the opening melody from the slow movement of the concerto, we have the following lists for each player:-

Slow Movement Melody

Player 1 (1930s English)

Tone	Response
edgy	smooth
reedy	satisfactory
stolid	
rough	
sour	
austere	**Mark: 52%(Overall)**
plain	(Both examples, tone & response)
piercing	
strident	
thin (x2)	

Player 2 (modern English)

Tone	Response
smooth (x2)	smooth (x3)
woolly (x2)	
flat	
clean	
pure	
dull	**Mark: 68%**
creamy (x3)	

Player 3 (modern English, French clarinet)

Tone	Response
sour	distinct
ringing (x2)	uneven
plangent	
clean	
woody	
thin	
hard (x2)	
dense	**Mark: 61%**
heavy	
sharp (x2)	
metallic	

Player 4 (Viennese, basset clarinet)

Tone	Response
natural	
fizzy	
complex	
good	
creamy	
sharp	
breathy	
hard	**Mark: 71%**
sour	

Player 5 (German)

Tone	Response
stodgy	heavy
dark	
watery	
clean	
creamy (x2)	
distant	
dirty	
compact	**Mark: 53%**
soft	
woolly	
warm	

Period Instrument (boxwood basset)

Tone	Response
natural	
flutey	
rich (x2)	
gritty	
lively	
reedy	
colourful	
crisp	**Mark: 75%**
clean	
nasal	

3rd Movement Fast Section

Player 2 (modern English)

Tone	Response
wooden	sluggish
even	good
woody	clean
heavy	
solid	
woody	
pure	

Player 3 (modern English, French clarinet)

Tone	Response
reedy	heavy
strident	striking
shallow	clean
rough	edged
bright	
harsh	
squawky	

Player 4 (Viennese basset clarinet)

Tone	Response
lively	good
rounded	breathy
light	fuzzy
breathy (x2)	even
smooth (x2)	uninteresting

Player 5 (German)

Tone	Response
creamy	clean
smooth	good
flutey	fuzzy
woody	good
distant (x2)	heavy
dirty	heavy
watery	

Player 6 (period boxwood basset)

Tone	Response
reedy	bubbly
smooth	good
light	prompt
flutey	nice
thin	clean
colourful (x2)	
lively (x2)	
shallow	

Marks for the tone and response in both examples were added together then averaged, weighted and turned into a percentage for easier comparison. Bracketed numbers e.g. (x2) indicate the number of times a word was used to describe the sound.

Not all the forms returned had an entry for every test, which is why some of the lists are short. The outright favourite was the period boxwood basset, achieving 75%. This was a fine recording and, in addition to the qualities of tone and response being considered, the performance was musical and well shaped. Curiously, the marks awarded to the other players did not seem to accord as well with the comments. Player 2 (modern English) scored a high 68%. From the comments attributed to this performance one might conclude that popular taste in clarinet playing favours a rather bland, colourless style of playing, yet this recording was beaten by the period boxwood instrument whose lively character, tone colour and articulation could not have been more different.

Only the slow movement was available as an example for the first player, so the marks were doubled here in order to make a fair comparison with the others. This player was a highly respected and famous clarinettist, one of the most recorded players of all time, yet it seemed that no-one could find a kind word for this performance. The style and interpretation of classical music has changed a great deal since then and this may have had an influence. Other than that, the comments were surprisingly consistent with just an occasional contradiction, and gave a fair account of the quality of the playing.

Further discussion following the experiment revealed some antipathy towards the modern English playing whose total marks put it in second place. The general consensus of opinion seemed to be that the German and Viennese playing both merited high acclaim, but that the period boxwood performance remained the firm favourite.

Conclusions of the Listening Tests

The information obtained was interesting, if not altogether conclusive. It demonstrated the difficulties inherent in describing sound, but showed nevertheless that a consensus can be arrived at. The awarding of marks was more problematic. The marks did not give a fair assessment of the order of merit of the middle group of players, and did not accord with the opinions expressed in discussion.

These tests did show the effect a player's own prejudice and conservatism can have on his judgement, particularly if there is prior knowledge of the set-up, the player or the style under consideration. This had worrying implications with regard to the effectiveness of professional clarinettists on a panel to judge tone and response. This had also been a problem for Krüger[3] in his research.

---

[3] See Chapter 2, p 15

Tone Quality in Spectral Graphs

Roland Synthesised Clarinet Tone

During a recording session in which I was playing, I was asked to listen to a pre-recorded synthesised clarinet playing a melodic line over an orchestral accompaniment. My brief was to play this line again so that it could be recorded live and substituted for the synthesised version. The quality of the artificial sound was so impressive that I requested a sample for analysis. The sound had been generated by a Roland keyboard synthesiser and was either a sampled sound, a totally synthesised sound or a combination of both. In order to compare the timbre of this synthesised tone with real clarinet tone I made a live DAT recording of the entire scale of the clarinet. The notes, complete with onset transient, were then transferred to the computer to enable me to carry out a more thorough investigation and wave analysis using FFTs.

It was noticeable that the onset transients of the Roland synthesised tone were faster in the low register than the fastest transients measured in live playing during the experiments with different lay profiles. Live transients were usually approximately twice the length of the synthesised sound. The middle register was similar in both the live and the synthesised sound.

Low C(Bb)	62ms to full amplitude
Middle register G(F)	52ms
High register E(D)	32ms

Fastest for live playing:

Low register	70ms - 250ms
Middle register	34ms

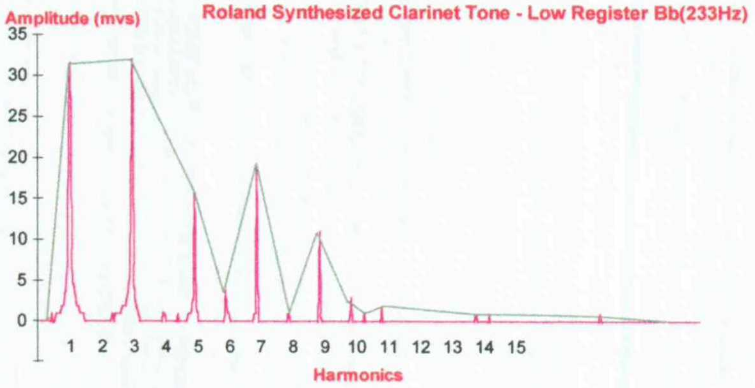
Transient lengths can be much longer in live playing, especially in the low register where an attack transient can be around 150ms before a steady state regime is established. The short transient length throughout the synthesised sound would explain the crisp articulation, but also probably contributed to it being easily recognised as artificial, articulation in live playing rarely being as consistent throughout the range of the instrument. The main criticism of this sound was that it was unnaturally clean and lacked the inflections and imperfections of the live player.

Reverberation had been added to the synthesised version at the recording session. The steady state tone was less impressive without this treatment but was still warm and fruity.

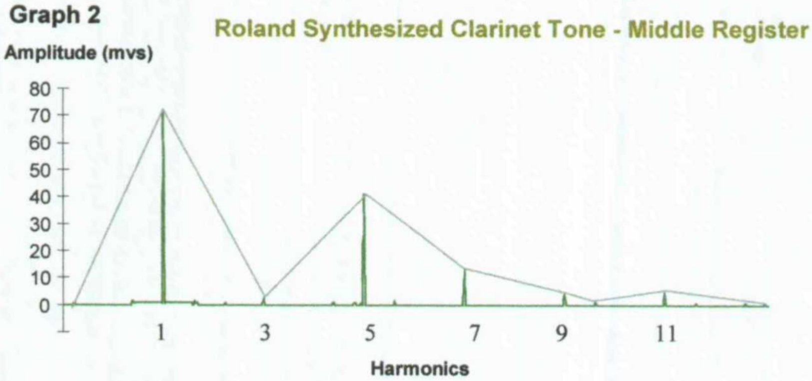
Analysis Set-up (Graphs 1 - 3)

Sample direct to computer hard drive from Roland synthesiser via floppy disk
Sample looped in SoundForge software
Spectrum analysis with Pico ADC 100 and Picoscope software (0 - 5kHz band)
Sampling rate better than 40kHz

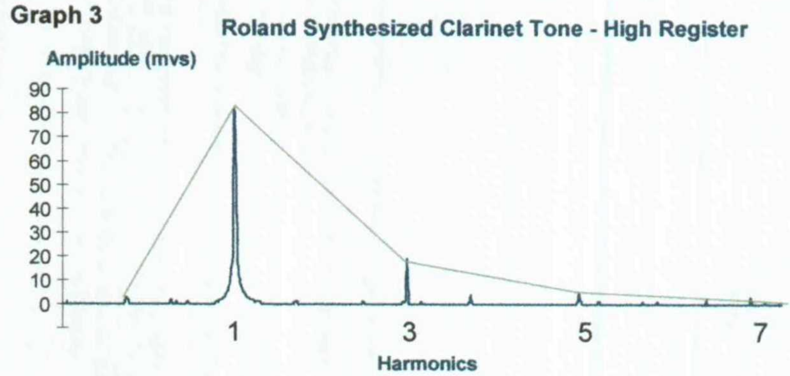
Graph 1



Graph 2



Graph 3



The first noticeable characteristic of each of the graphs is the low cut-off frequency in all modes. The absence of high frequency activity helps to explain the mellowness of the sound. This low cut-off and lack of very high frequency components is a feature of many spectral graphs of German clarinet tone. However, in the low register spectrum, the 3rd harmonic is particularly powerful, with strong 5th, 7th, and 9th components. In Germanic tone, the middle and upper harmonics are usually less prominent in relation to the fundamental, and decrease in amplitude in a stepwise manner. The Roland tone did not really sound Germanic, but rather a full bodied French, American or pre-war English. The tone might have been better balanced if the 3rd harmonic had been a little weaker, although this may have resulted in less vibrancy with the tone sounding less authentic and more like an organ stop. The formant, indicated by the grey line forming an envelope around the spectrum, is a text book shape, except for the peak at the 3rd harmonic. The fact that the spectra alter significantly in the 2nd and 3rd registers suggests that the sound was based on sampled live playing with filtering and signal conditioning applied.

Mouthpiece Survey

In the mouthpiece survey, a Vandoren B45• was used as a control to check the set-up for each of the tests and to ensure that the reeds consistently produced good tone and dynamic range. Vandoren consider this mouthpiece to be one of their best and it is used widely by professionals and amateurs alike. It was therefore adopted as both control and benchmark when comparing the playing properties of other makes and models. The spectra resulting from an analysis of the recordings were also compared to the control and this was of benefit when comparing the harmonic content and formant shapes of all the mouthpieces. This analysis was instrumental in identifying which part of the spectrum would benefit from attenuation or reinforcement, but the discovery as to which region of the mouthpiece affected which part of the harmonic structure was not made until later in the research.

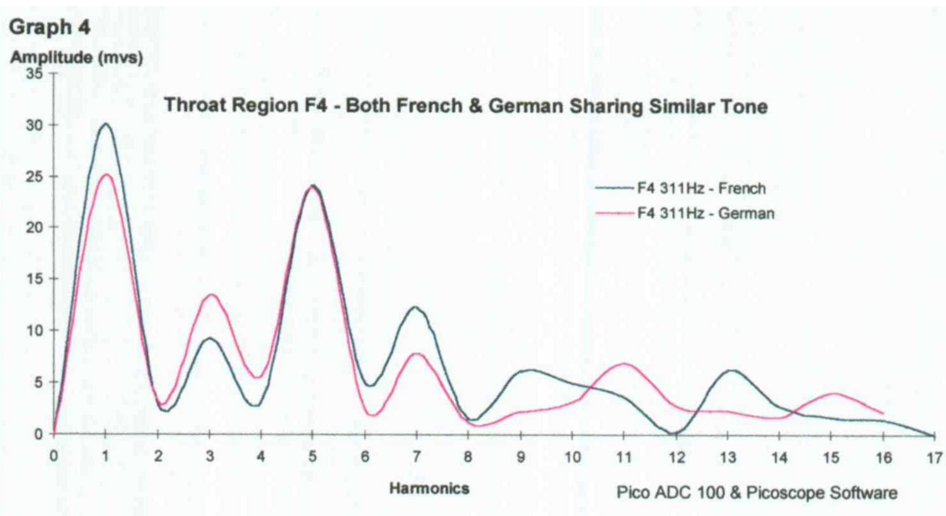
Comparison Of Basic German & French Tone

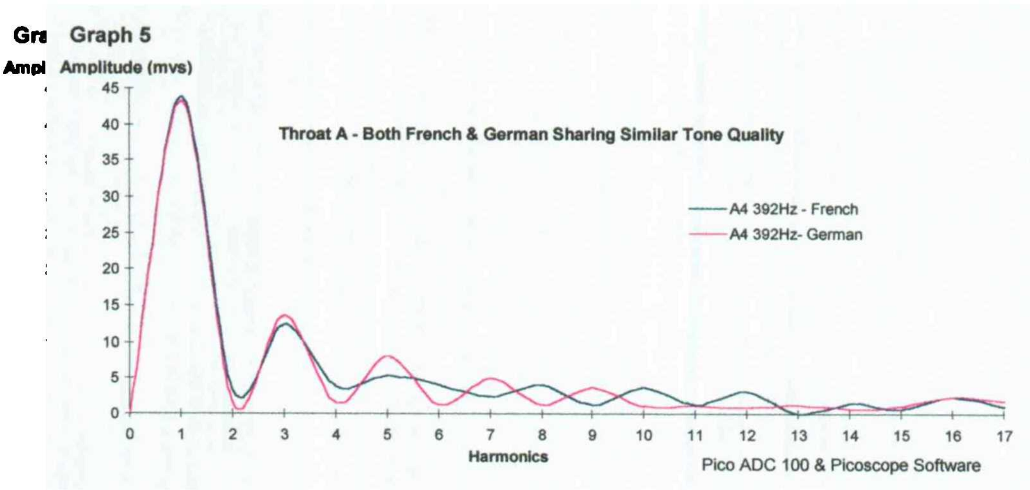
In the listening tests the preferred clarinet was a boxwood instrument. This is interesting, in that this is a material commonly used in classical clarinets, not modern ones. However the instrument is in many respects a forerunner of the German Oehler system instrument (although the lower half right hand tone hole venting is closer to the Boehm) and in the tests it was also found that one of the players much admired was a Viennese clarinettist using a modern Oehler system basset clarinet. Clearly in these tests, tone associated with the German or Viennese sound was preferred. But many players feel that there are positive aspects of both Boehm and Oehler clarinets and that a combination of the vocal qualities of a good French instrument and the dark resonance of a German one would result in the ideal instrument. Attempts have been made to achieve just this combination, with varying degrees of success, the Schmidt Reform Boehm clarinet being one good example.

It was hoped that, as one of the eventual benefits of this research, similar modification to the tone may be made more easily, through alteration to the design of the mouthpiece. To this end, it was first necessary to identify the specific differences between French and German clarinet tone. If these could be quantified and the precise effects of design on the tone understood, then modifications to designs could be attempted to see if it might be possible to effect a gradual tonal transition from one style to the other.

In order to quantify the difference between the French and German timbres, the spectral analysis (FFTs) of a typical French set-up were compared to the spectral analysis produced by a fine quality German set-up. Nick Bucknall, who has been playing German System instruments for many years, recorded a complete scale through all three registers, on his Oehler system instrument (an Uebel modified by Ludwig Warschewski in the 1930s). This maker, not well known outside Germany and Sweden, is widely respected by German players. The mouthpiece was by Hans Zinner with a lay by Berger, and German faced reeds were used (narrower and thicker). The French set-up was played by myself, using a Buffet R13 clarinet with a Vandoren B45• mouthpiece and a French reed. Both recordings were made direct to disk in the same acoustic, with the players in identical positions and at the same distance from the microphone(1.5m). Allowances for variation in dynamic level were necessary. However, the fact that the strength of the fundamentals was similar in all the results, with one or two FFTs almost identical, indicated that the recording set-up and dynamic level of the playing was within acceptable limits and that the results would be of significance.

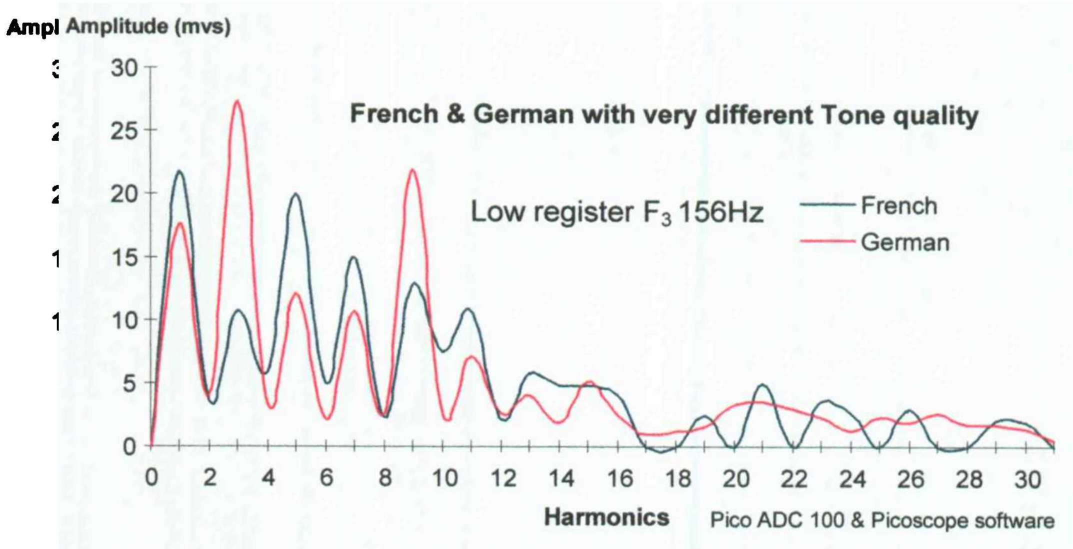
The results of the graphs showed distinct differences between the two instruments, apart from the throat A and F which were curiously similar.





It may be that the similarity owed more to the tone-hole size and undercut affecting the cut-off frequency than the overall differences in design between both instruments' bore, tone-hole pattern, mouthpiece and reed.

Graph 6



The formants changed as the notes progressed up through the registers, and were different in each clarinet. The formants were distinct resonant frequencies or a composite amplitude shape of the harmonics induced by the design of clarinet and mouthpiece combined. Later in the research it became possible to achieve the same formant shape by alteration to the mouthpiece alone.

Reviewing this experiment at a later date, I began by listening to the two recordings and was struck by how similar the tone was between the two set-ups, despite the fact that the spectral graphs had shown clear differences. This probably stemmed from the fact that my own notion of clarinet sound veers towards the Germanic and this influences my choice of reed and the way I blow the instrument. It was encouraging that the analysis could differentiate between subtle differences in tone colour.

In July 1998, the Swiss clarinettist Hans Rudolf Stalder gave a master class at the Royal Academy of Music. Stalder used a French Prestige Buffet R13 clarinet and a French Vandoren B40 mouthpiece, but he produced a light German tone. I discussed this with him and he explained that, in his opinion, a player has a concept of the sound that he wishes to produce in his head, and that, with skill, it is possible to produce this on almost any set-up. He went on to say that in the Tonehalle Orchestra in Zurich, one of the two principal clarinettists uses a Boehm instrument and the other an Oehler, yet they play together in the orchestra without any difficulty. Their concept of tone is similar and their playing compatible.

My own set-up, although not perfect, achieves a fair mix of tonal characteristics from both German and French schools. The clarinet is by Louis, an instrument after the Martell maker but manufactured in Chelsea, London in the early twenties, and a mouthpiece of an old English style but with some modifications.

In the experiment to compare French and German tone, I did not use the Louis set-up, as this would have been atypical. Yet, even with the more usual French Boehm Buffet used, the differences heard in the recordings were less pronounced than expected. It was clear from listening to the two recordings, and from Herr Stalder's comments regarding the Swiss players, that the timbres from the two schools of playing could be made similar when desired. This belied the belief of some of the craftsmen at Wurlitzer[4], who were adamantly opposed to the idea that tone could be modified in the ways just described, asserting that this would be an impossibility.

Certainly there are other properties possessed by an instrument that will contribute to the overall impression on the player and listener, such as the way in which the notes begin and end, the smoothness of the legato and also the way in which the instrument projects. The recordings suggested strong similarities between the instruments in all these areas. However, when the results were computed as a Long Term Average Harmonic Spectrum,[5] clear differences were observed and these accorded with the commonly held views of French and German timbres.

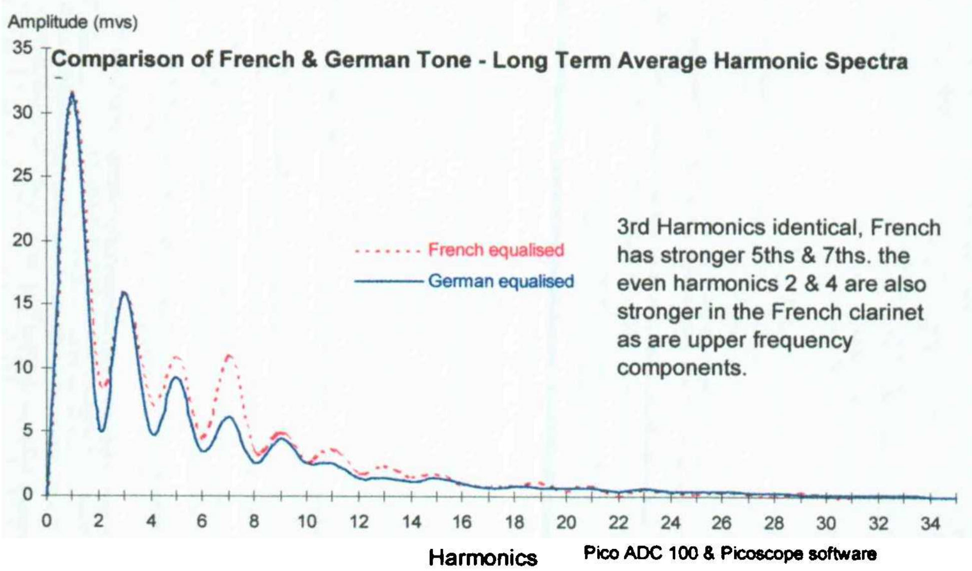
---

[4] See appendix B, p 216, 'Visit to manufacturers'
[5] See Chapter 8, p 112, for an explanation of LTAHS

The following graph shows the German sound to have been darker or mellower overall, with lower power 5th and 7th harmonics and a slightly earlier (lower) cut-off frequency, whilst the French instrument displays stronger 5th, 9th, 11th, 13th and very prominent 7th harmonics. The French spectrum would undoubtedly be described as 'richer' by Krüger (more complex) but would be termed 'brighter' by most players outside Germany. The graph also demonstrated the reasons for the timbres in the recordings sounding similar.

Graph of LTAHS Comparison:-

Graph 7



Pico ADC 100 & Picoscope software

4

Survey of Mouthpiece Types

The programme of mouthpiece research began with a survey of commercial mouthpieces currently available to players.

List Of Mouthpieces Tested In The Initial Survey

Vandoren
B45• (Control)
B46, 5RV, 5RVLyre, 111, B44, 116, V13, B40
Buffet (Schreiber)
Selmer (C85 115, C85 120)
Denman
Hyte
Morgan
Portnoy (BP2, BP3)
Pomerico Glass
Meyer (No. 4)
Louis (c.1930)
Nagamatsu (.90-27G)
Yamaha (4C & 6C)
Runyon
Zinner (418, 421, 518)

Accurate measurements of the internal and external dimensions of numerous mouthpieces were taken, using various specifically made gauges.[1] Precise measurements of the lay profiles were made using a special device.[2] The mouthpieces were played using an artificial embouchure,[3] DAT recordings made and the tone analysed using PC oscilloscopes and spectrum analysers.

The following data was amassed:-

- 53 Mouthpiece drawings.
- 90 Lay profiles measured and stored in a database
- 65 Spectral graphs of the steady state tone of mouthpieces currently available

---

[1] See chapter 8, p 72
[2] See chapter 8, p 72
[3] See chapters on artificial embouchure, p 52 and recording methods, p 72

Data was also compiled on the effects of pressure, temperature and humidity, also on reed strength and quality. This information was recorded in both conventional and tristimulus formats.[4]

The criteria for assessing the quality of tone and response at this stage were simple. These were:-

a) ease of blowing, using reeds that responded well with the control mouthpiece[5]
b) full tone with good dynamic range at a given air pressure and lip position
c) clear response in all three registers

Recordings were made and analysed to examine the tone produced by many professional players, including those using German style instruments. This work exerted some influence over the assessment criteria for the performance of the artificial embouchure and commercial mouthpieces.

Using the artificial embouchure, it was clear when a mouthpiece worked well by the immediate and satisfyingly robust sound produced. Use of the artificial embouchure ensured that all the operating parameters remained the same throughout the testing (air pressure, temperature, humidity, lip position and pressure). Plastic coated reeds were used in order to combat the drying effects of the artificial embouchure and to ensure longevity. Only four reeds were used during the entire testing period and these were still in good playing condition on completion of the survey. Of these, one was a little hard when used with the control mouthpiece, and one slightly soft. This was in order to accommodate the needs of different lay profiles.

Graphs resulting from the analysis enabled differentiation between the properties of the mouthpieces. Analysis of the tone produced line and bar graphs with characteristic shapes which varied according to the timbral qualities of each mouthpiece. When the data was used to construct tristimulus graphs, the values of the ratios placed similar sounding mouthpieces in close proximity, confirming the belief that these mouthpieces shared a similar balance of middle and upper harmonics. That the mouthpieces were found to be grouped in this way lent credence to the testing methods and assessment. However, these procedures did not highlight subtle differences between the better performing

---

[4] See chapter 8, p 108-109, tristimulus graphing methods.
[5] Vandoren B45•

mouthpieces in the way that became possible later in the programme, using long term spectral averaging and pressure transfer functions.

At this stage, the results suggested that the timbre of all the mouthpieces was similar and that the better mouthpieces may have to be further assessed using a narrower band of quantifiable values. However, the criteria to be used for assessing 'quality' were yet to be defined and these are discussed in Chapter 3.

During the survey, analysis showed that the better sounding mouthpieces, that is, those that produced a full tone, a wide dynamic range and that were easy to set up and play in the artificial embouchure, had a low (1^{st}) register pattern of harmonics with an extended range, and orderly, descending amplitudes. As expected, the harmonics were mostly *odd*, but occasionally, *even* components were present. These mouthpieces also displayed an increase in components in the middle (2^{nd}) register and sometimes even in the high (3^{rd}) register. This additional colour was almost certainly the result of the presence of additional partials. These components were not harmonics as they were not exact integer multiples of the fundamental. These partials were also present in the tone of professional players who produced particularly expressive timbre in the middle and upper registers.

During the course of these experiments it became apparent that one of the fortunate consequences of the work might ultimately be the ability to identify and therefore reproduce consistently in new mouthpieces, the characteristics which gave this additional quality to the tone. This quality, of which much is spoken later, came to be known as the 'feel-good factor'. Was this 'added value' the result of the presence of a precise harmonic (or partial) with absolute power in relation to the other components, or could additional quality be provided by the combined (averaged) effect of a number of components in the correct region, as suggested by tristimulus methods? Having identified which components were involved, it would be necessary to discover whether it was one single, or a combination of several properties that were involved in providing the 'feel-good factor'. Testing procedures were refined and improved during the course of the work, helping to explain the causes of this extra activity in the 2^{nd} and 3^{rd} registers.

It was hoped that the initial survey would reveal what extremes of tone and response could be expected from a clarinet mouthpiece, and which, of the many commercial mouthpieces available, achieved this. It was also hoped that an alternative mouthpiece would be found for use as a control later in the research. In the event, the need for a control mouthpiece became unnecessary as a result of the systems and methods that eventually evolved.

The fifty-three examples tested gave an overall view of mouthpieces currently commercially available. Most of these shared a similar design. This design was not, in fact, a modern one in the true sense of the word. Sir Nick Shackleton owns a set (Bb, A and C) of cocus wood instruments made by Buffet at the turn of the century. Included with these are six beautiful, handmade cocus wood mouthpieces, presumably made specifically for the instruments by Buffet. When measured, it was found that the dimensions of the mouthpieces were virtually identical to many present day examples, including the depth of the baffle. The only real difference was in the lay profiles which, although warped to some extent, were all much closer.[6] The fact that this design is the one favoured by the present clarinet fraternity is understandable as it does produce a bright and clear tone with good intonation.

It is interesting to note that, at the same time as Buffet were producing this design of mouthpiece, clarinets were also commonly being supplied with mouthpieces of quite a different design, often characterised by wide angled side walls, large volume tone chamber, concave baffle and sometimes a large bore (conical or parallel). These mouthpieces, made for both small and large bore Boehm and simple system clarinets,[7] continued to be produced up until the 1940s.[8]

This contrasts with the conformity of mouthpiece design prevalent today. Pre-war mouthpieces incorporating one, or a combination of the above characteristics offer a wider range of timbre and response than is possible with present day mouthpieces, but they are not always suitable for use with modern Boehm clarinets. These mouthpieces were designed to complement instruments whose tone was lively and responsive and to suit the instrument's intonation characteristics. The present day pursuit for perfect intonation and even tone has resulted in instruments that can often sound thin, bland and dull. To counteract this and to satisfy the demand for ever louder playing, particularly by orchestral players, it is understandable that many contemporary mouthpiece makers

---

[6] John Playfair has a cocus wood Buffet mouthpiece from the same period which has a larger bore and deeper, concave baffle. This mouthpiece has very good playing properties.
[7] A similar instrument to the Oehler clarinet, but with less complex key-work
[8] e.g. Boosey & Co., G and J Howarth.

should adopt the present design, usually incorporating an open lay, since it is one way to imbue many modern instruments with clarity, vibrancy and projection.
The Vandoren range of mouthpieces is probably considered the standard by which many players of Boehm system instruments judge other mouthpieces, and most professional players own at least one. The reason for this is Vandoren's consistency of quality, availability, price and reliability. Their tone is also invariably acceptable in all musical situations. However, French style mouthpieces made by the German Company, Zinner,[9] in conjunction with the typical and popular Buffet clarinet used in the tests, were above average in performance, offering a wider dynamic range and a more centred tone. The Zinner mouthpieces were consistently well made and had lay profiles which permitted the use of many reeds. These qualities are appreciated by many producers and suppliers who use them as 'blanks'.

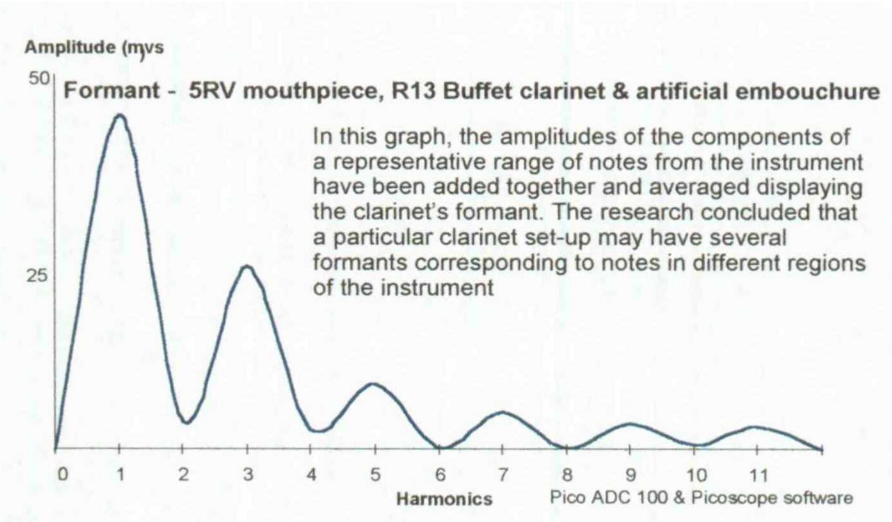
All the mouthpieces tested in the survey were intended for use with modern French, Boehm small bore instruments. The design of most of the mouthpieces was characterised by a small conical bore, straight, high baffle, parallel side walls and an open lay profile. There were some notable exceptions however, and these were; German style mouthpieces, German versions of French style mouthpieces and some older designs, including English. Apart from a few inexpensive examples made from a light plastic, and the Buffet (German made) mouthpieces that were made from acrylic, all the other mouthpieces tested were made from ebonite (hard rubber with the basic ingredients of latex, sulphur and carbon). There was some variation in the density and hardness of the ebonite used. Some mouthpieces had obviously been made from rod ebonite using the traditional method of boring and turning on a lathe, then filing and polishing. This was apparent by the slight inconsistencies which are not present in mass moulded examples. Other mouthpieces showed signs of compression moulding or casting, at least in the initial stages of manufacture. The small extrusions and extensions left on the rough blanks in order to assist in the subsequent machining could be seen clearly in Vandoren's publicity material. It is difficult to injection mould with an ebonite mix because the material needs to be compressed and heated for several minutes for the cross linking of the polymer to take place. The only way to mould and cast mouthpieces successfully in ebonite is by using a slower compression moulding technique. In spite of repeated requests, manufacturers understandably refused to divulge their ebonite formula.

---

[9] Zinner are little known to players outside Germany, but supply 'blanks' to many mouthpiece makers and suppliers, particularly in the USA

Vandoren's ebonite recipe results in a hard and durable mouthpiece. In blind tests, many experienced players maintained that, although the sound produced from these mouthpieces was acceptable and projected well, the tone was somewhat hard, and lacking in colour. When live playing was analysed, the tone from these mouthpieces often showed an uncharacteristic mid to upper harmonic peak in the spectrum of harmonics (the formant). However, a Vandoren 5RV mouthpiece which was tested in the artificial embouchure and whose tone was very acceptable did not produce this peak, probably because this mouthpiece had a much closer lay.[10] The spectral graph of the tone produced by the 5RV is typical of a mouthpiece with a smooth rounded tone. A leading London orchestral player said that, whilst he accepted the deficiencies of timbre with some Vandoren mouthpieces, their tone did cut through thick orchestral texture, Since the Vandoren designs are similar in most respects to the other mouthpieces tested, there had to be another reason for the timbral difference. The remaining factor was the material, and this suggested that the density, hardness and other mechanical properties of the mouthpiece material had a significant effect on tone and response.

5RV Mouthpiece, R13 Clarinet, Artificial Embouchure (Amplitude scale arbitrary)
Graph 8



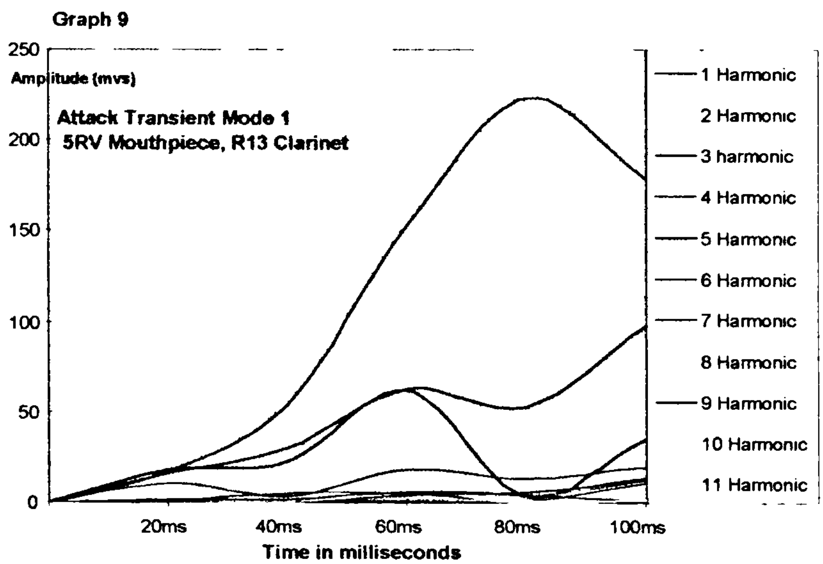
[10] See chapter 12, p 186, experiment 5 on the effects of lay profiles

Onset (Attack) Transient

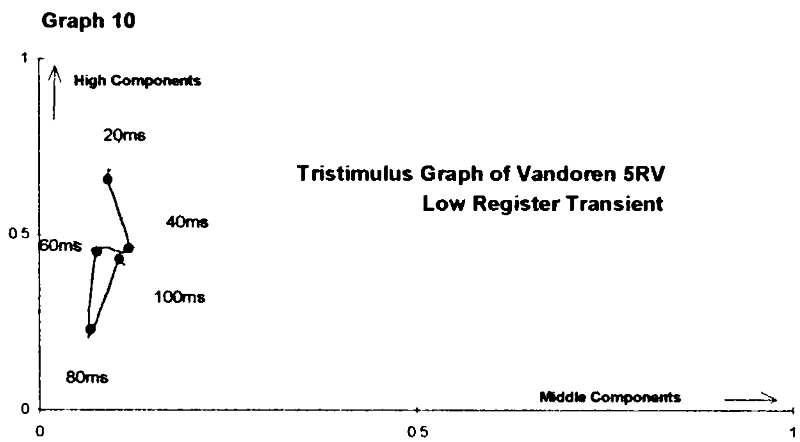
The following two graphs show the erratic, non-linear behaviour of the build-up of the harmonic components at the start of a note. There are advantages in both methods of plotting graphs. The first plots the progress of each harmonic separately so that the evolution of each individual component can be observed, whilst the tristimulus graph accumulates the data in a way that shows how the tone evolves (tonal bias) at different points in time from the onset and also provides a 'footprint' that can easily be compared with other graphs.

Harmonics Plotted Separately

(Analysis using VirtualWaves software)



The same data expressed as a tristimulus graph



The tests were carried out using an artificial embouchure in combination with a widely used Buffet R13 Bb clarinet, with the popular B45• Vandoren mouthpiece used as a control. A simple series of notes covering the three registers was used for testing each mouthpiece. The same lip position and blowing pressure were maintained for each test and the same plastic covered reed used for as many of the mouthpieces as possible. Some mouthpieces required a different strength reed in order to accommodate the lay profile, and in these cases the reed was chosen to match as closely as possible the 'feel' and quality of the other set-ups. Although great pains were taken to try and achieve equality here, the necessity to change reeds was unfortunate and did have implications for the reliability of evidence substantiating the differences between mouthpieces. Reed non-linearity is extremely difficult to circumnavigate other than using extensive averaging of the results from the use of many different reeds on each mouthpiece.

At this stage in the research, DAT recordings were made of the tests for later analysis and comparison. A detailed description of the artificial embouchure and the testing procedures can be found in the chapter on 'Methods'. The conclusions arrived at concerning the playing properties of the mouthpieces in the survey were somewhat subjective and were based on my own opinions and those of other players and musicians. Detailed drawings were made of all the mouthpieces and the dimensions were filed in a database.

A great deal of time was spent conducting the experiments whose results were ultimately rather straightforward. Apart from the mouthpieces that performed particularly badly (little or no dynamic range and thin or harsh tone, usually as a result of a poor lay profile), the others sounded much alike and somewhat mediocre (some dynamic range and warmth of tone) with good tone from the Zinners, Vandoren 5RV and B45•. This was in the early stages of the research and the intention was now to apply some of the analysis techniques such as LTAHS (Long Term Average Harmonic Spectra) to further differentiate between the various makes by highlighting the difference in the average spectral envelope and the formant(s) encouraged by the small differences in their design. This was carried out at a much later stage and a representative selection of the results is displayed in the following LTAHS graphs. A narrow bandwidth was employed in these early experiments (0-3kHz) resulting in a lack of very high frequency data for the analysis. A ceiling of 5kHz-10kHz was later found to give much clearer results. Nevertheless, the graphs show interesting differences in the spectra of harmonics in mouthpieces with distinct characteristics.

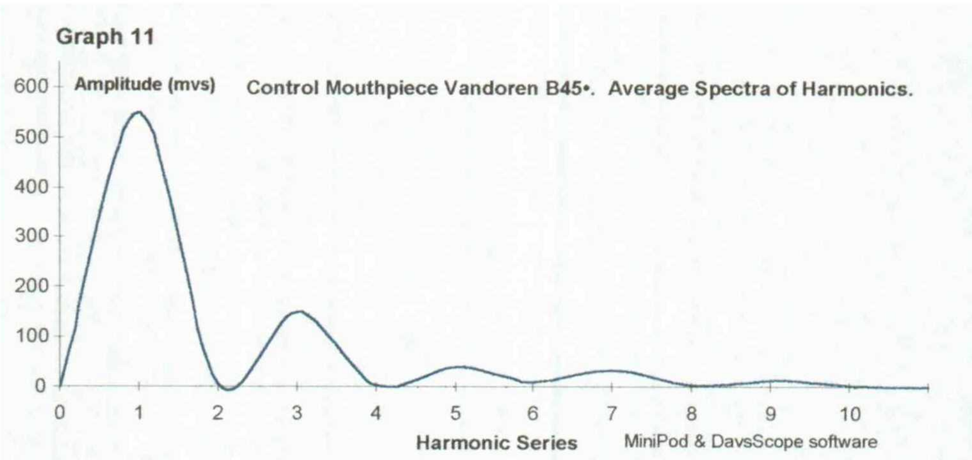
Survey Of Commercially Available Mouthpieces

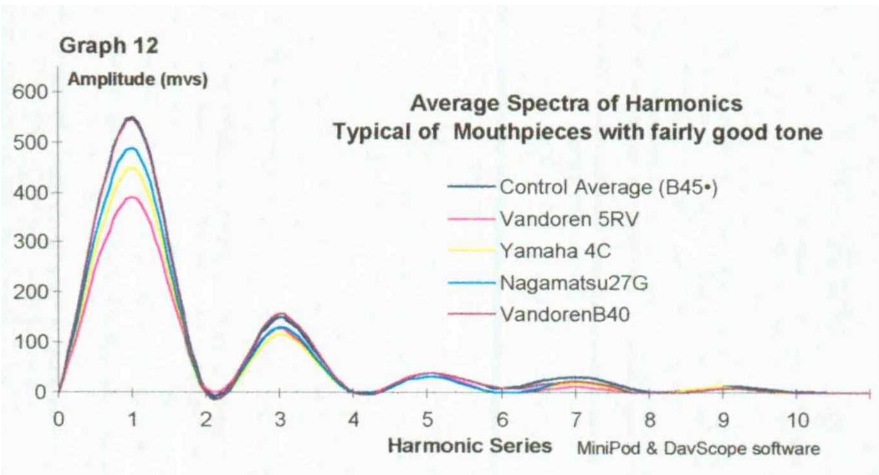
Long Term Average Harmonic Spectra (LTAHS)

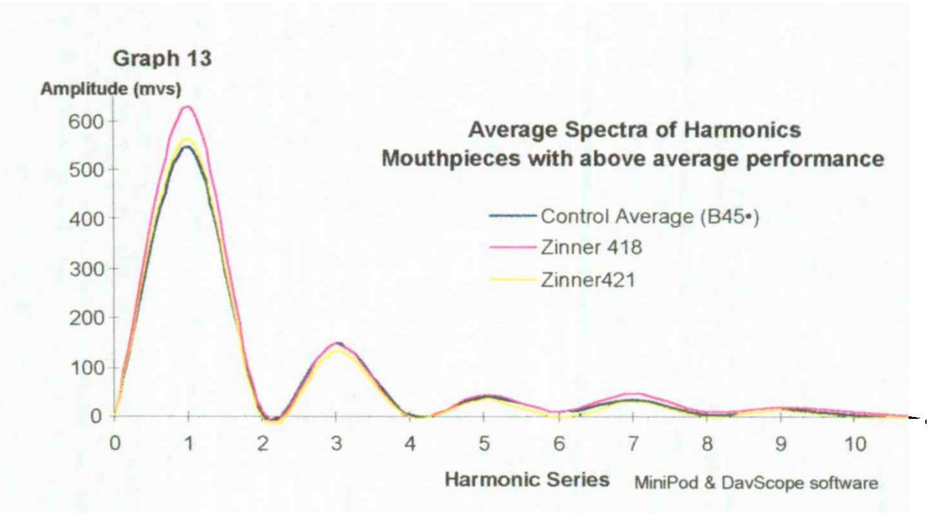
Equipment:

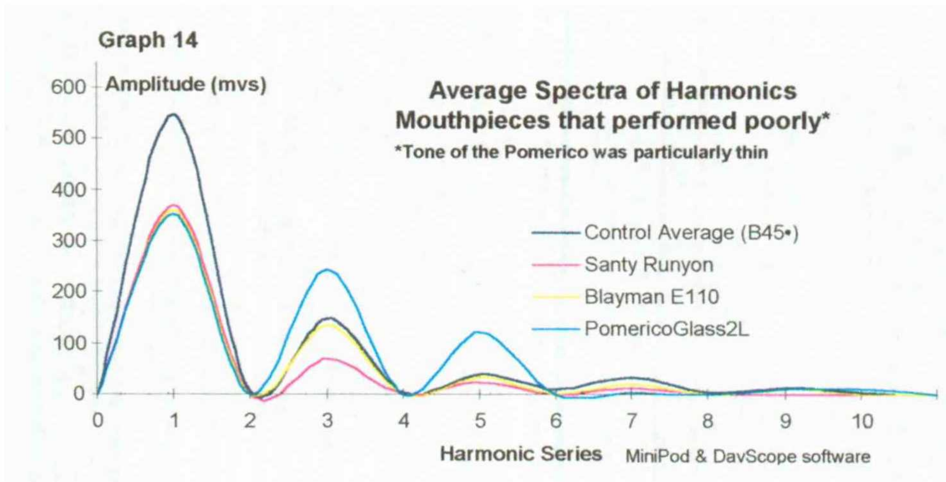
MiniPod 402 AD converter for PC. Sampling rate 30kHz. Bandwidth 3kHz
DavScope software
Fostex microphone positioned at 1 metre from the sound source in soundproof chamber
Artificial Embouchure
Air pressure - 14 inches water (monitored by manometer)
Buffet R13 clarinet

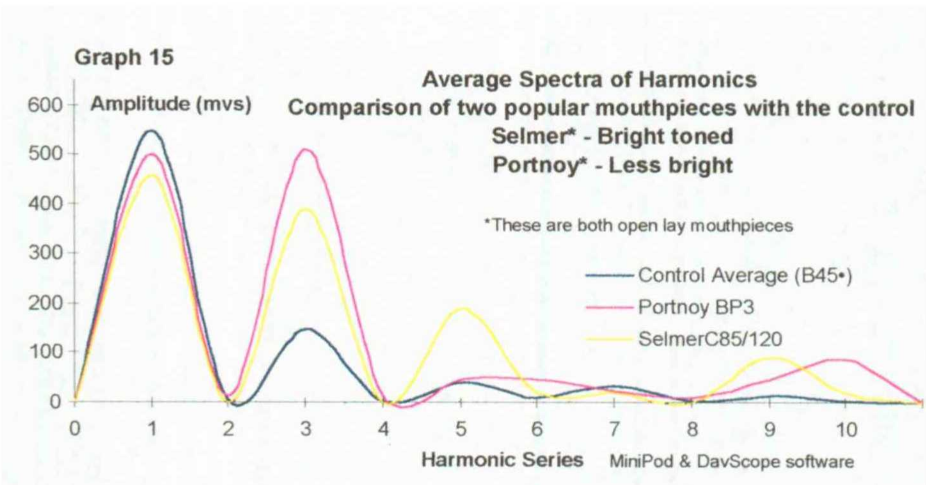
Resolution on the graphs appears poor because these are not frequency spectra but are graphs of the averaged amplitudes of each harmonic. It was hoped that this method of displaying the results, including the use of rounded line formats, would be more sympathetic to the visualisation of the sound from each set-up and therefore easier to make comparisons.



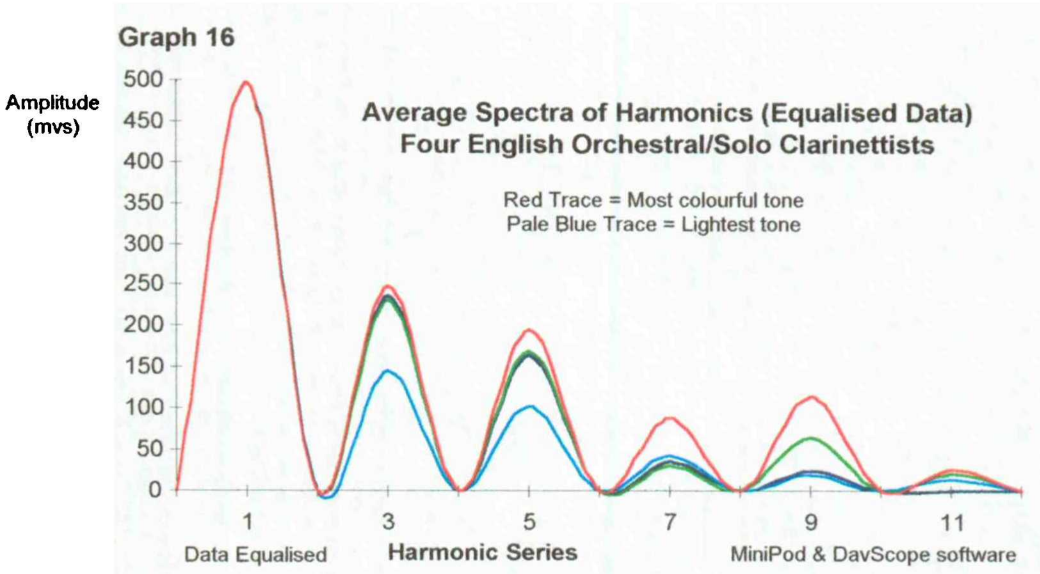



Graph 13
Amplitude (mvs)
Average Spectra of Harmonics
Mouthpieces with above average performance
Control Average (B45•)
Zinner 418
Zinner421
Harmonic Series
MiniPod & DavScope software


Graph 14
Amplitude (mvs)
Average Spectra of Harmonics
Mouthpieces that performed poorly*
*Tone of the Pomerico was particularly thin
Control Average (B45•)
Santy Runyon
Blayman E110
PomericoGlass2L
Harmonic Series
MiniPod & DavScope software


Graph 15
Amplitude (mvs)
Average Spectra of Harmonics
Comparison of two popular mouthpieces with the control
Selmer* - Bright toned
Portnoy* - Less bright
*These are both open lay mouthpieces
Control Average (B45•)
Portnoy BP3
SelmerC85/120
Harmonic Series
MiniPod & DavScope software

At the same time as conducting this survey, the tone of a number of professional players was recorded and analysed using the same recording equipment and method of data acquisition. This was to verify that the artificial embouchure was producing lifelike tone and also to observe the kind of spectrum live playing offered when analysed with this equipment. The same notes were used as in the mouthpiece tests.



Names are not applied to the traces as this is not a definitive assessment of each clarinettist's performance. The players were all using different mouthpiece/clarinet combinations, although the clarinets were all Boehm system: two instruments were French, one German and one English (large bore). Two of the players used relatively close lays and the other two quite open. The analysis revealed a marked difference between the palest and the most vivid tone colour. More crucially for the purposes of the research it also demonstrated that the artificial embouchure did produce lifelike tone and spectral graphs indistinguishable from live playing.

Manufacturing

The survey showed that manufacturing techniques have an effect on design and quality, and may be an obstacle to innovation and development. Moulding methods are used by several manufacturers,[11] as this process enables the inexpensive and rapid production of mouthpieces of reasonable quality. However, the set-up cost for injection moulding is extremely high and discourages changes in design and even the simplest of modifications.

Whilst trials of the commercial mouthpieces were being conducted, the wind instrument supplier WindCraft asked if I would assess for them the consistency between a number of early version Yamaha 6C mouthpieces made for Yamaha by an outside company, and a new batch of the same model now made by Yamaha themselves. The internal and external dimensions, along with the facings of all the mouthpieces were measured and playing properties were tested using the artificial embouchure. The internal and external dimensions of both batches were identical. The facings of the new version were consistent, but the earlier mouthpieces showed considerable variation. Despite these inconsistencies, the earlier versions performed better in the artificial embouchure, being more responsive and having a bigger dynamic range. The method of computing and machining the lay profile of the new versions may have been the problem.[12]

I also tested several Vandoren B40s for John Myatt and these were consistent in every respect.

The least consistent in performance were found to be the inexpensive Babbit moulded plastic variety. The bores, tone chambers and external dimensions were consistently accurate, but the lay profiles were rarely the same, some of these so uneven as to render the mouthpieces unplayable. This company supplies higher quality ebonite blanks to many makers in America and elsewhere.

---

[11] Yamaha, Schreiber and Babbit.

[12] The lay consists of two or more curves of different gradients which form the profile from the take-off point to the tip. The last 5 - 8mm is often virtually flat. The lay may be accurately applied to a mouthpiece using a computer controlled device (milling machine) but if the curve is calculated mathematically rather than following points plotted according to a profile known to respond well, any flat regions will be turned into curves. Although the set-up may function, it may not respond well. It was not known which method had been used with these mouthpieces.

Manufacturers who use some of the more traditional methods of boring and filing, are able to produce a wider range of designs, as demonstrated by the Japanese maker Nagamatsu and the American producer Morgan.

Visits were made to several European manufactures including Zinner, Hammerschmidt, Schreiber and Wurlitzer to compare manufacturing procedures and see to what extent research and development was influencing their designs, if at all. A report on this visit can be found in the appendices.[13] The French company Vandoren prohibits visits to their factory in the South of France. Wurlitzer were also reluctant, since, following a visit to their factory, a large and well known Far Eastern company had copied their German system clarinets and were now selling these in Germany and Austria. They agreed to a visit once suitable affidavits were sent from the university.

Conclusions

The first part of the research was successfully completed and knowledge was gained regarding both the mouthpiece and blowing techniques. Much of this was work of an original nature. Equipment was developed or adapted to suit the nature of the experiments and various forms of analysis were investigated. There was widespread contact with manufacturers, retailers, materials suppliers and data acquisition companies. Awareness of the research spread amongst the clarinet fraternity, both by word of mouth and as a result of an article written for John Myatt's magazine,[14] prompting some stimulating debate. Implications drawn from the excellent functioning of the artificial embouchure aroused a good deal of controversy as this suggested that the mouth and other parts of the oral tract may have little, if any, influence on the timbre of the instrument.

---

[13] See Appendix B

[14] 'The Design & Acoustics of Clarinet Mouthpieces' by Edward Pillinger, John Myatt Catalogue, 1997-98

5

Clarinet Playing
Physical & Technical Requirements

The skills required by a clarinettist to produce 'good' tone and articulation. Also, other, more specialised techniques demonstrating the wide range of tone and effects of which the instrument is capable.

For the benefit of those who are unfamiliar with the way in which the clarinet functions, and before giving a description of the artificial embouchure and assessing its performance, it may be useful to explain the techniques required in the production of sound and a description of some of the more specialised ways of playing.

For any sound to radiate from a clarinet, a standing wave in the air column within the tube of the instrument must be produced. To achieve this, the air column must first be excited at the mouthpiece end, and the resulting primary wave maintained as a regime of oscillations. This is not easy, as every beginner knows. The excitation is effected by the action of an air driven vibrating reed clamped to the mouthpiece facing.

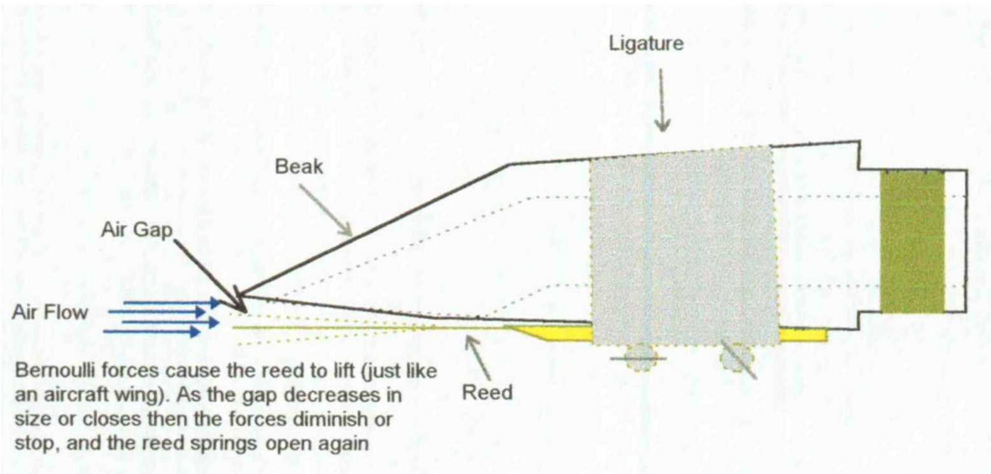
The clarinet is positioned and held in the mouth by a careful configuration of upper and lower lip muscles and the upper and lower jaw; this is known as the embouchure. The embouchure is formed around the mouthpiece and reed (a thin piece of cane), and air from the lungs is forced, under pressure (4" to 30" water) through a small gap between the reed and the facing of the mouthpiece. The reed is held in place by means of a ligature or string (this is widely used with early instruments and still favoured by many players of the German Oehler system). The air passing through this narrow gap causes Bernoulli forces to act on the reed, lifting it up against the tip and side rails which form the perimeter of the mouthpiece window. In normal playing, the reed vibrates hundreds of times a second, vibrating, in fact, at the frequency of the note being played.

To understand the action of the reed when it is vibrating, we must consider a single oscillation.

During the course of a single oscillation, the gap between the reed and the mouthpiece facing through which the air is passing, becomes smaller, and, when playing at a dynamic level above moderately loudly, will snap shut during the middle of each cycle. This has the effect of lessening the air flow or shutting it off completely, so that the forces either diminish or stop altogether. The natural spring in the cane now has greater strength than the Bernoulli forces and causes the reed to open again. If the air pressure and flow are maintained, the process can begin again, cycling as a continuous regime of oscillation - more simply described as the reed vibrating.

On the inside of the mouthpiece a stream of little 'puffs' of energy emerge at a frequency governed mostly by the length of the instrument's resonating tube. This primary excitation in turn excites the air column, sending a wave along the tube: this wave is reflected back at the open end and this continuum constitutes what is termed a standing wave. Surplus energy from the wave radiates from the bell, tone holes or both, as a steady state tone according to configuration (fingering) for the pitch required. The reed will continue in this way until it is stopped, either by the tongue or by interruption or cessation of the air supply.

Fig. 2 Cutaway drawing of the mouthpiece with the reed attached



The production of good clarinet tone requires considerable skill. A steady stream of air must be introduced into the mouthpiece at sufficient pressure so as to enable the reed to vibrate as described above. The reed must be acoustically dampened by being cushioned against the lower lip thus preventing squeaks and encouraging the production of what has become to be accepted as pure clarinet tone. The clarinettist is also expected to be able to offer a wide dynamic range, articulate clearly (tongue) and produce a variety of timbres.

If the reed is positioned badly within the embouchure, or the air supply is unstable and not well supported by the diaphragm, the tone will be poor, articulation will lack clarity and squeaking will occur, or indeed there may be no sound at all!

In clarinet playing, two kinds of embouchure are possible, single lip or double lip. In a single lip embouchure, the top teeth rest on the beak of the mouthpiece while the reed is cushioned by the lower lip folded inwards over the bottom teeth (Fig.4). This is the more commonly used embouchure as it facilitates easier control of the reed. A double lip embouchure demands that both the upper and lower teeth are covered by the lips which are folded inwards so that neither the mouthpiece beak nor the reed can come into contact with the teeth (Fig.5). This technique is essential when playing double reed instruments and is occasionally used by clarinet players who double on the oboe or bassoon. It is also used when a fluid, unrestricted tone is called for as it can help to prevent excessive squeezing and damping of the reed, thereby assisting in the production of a warmer and more rounded tone. Some players, prone to excessive biting on the mouthpiece and producing a stifled tone as a result, use the double lip technique as a way of forcing themselves into a more relaxed mode of blowing.

Fig. 3

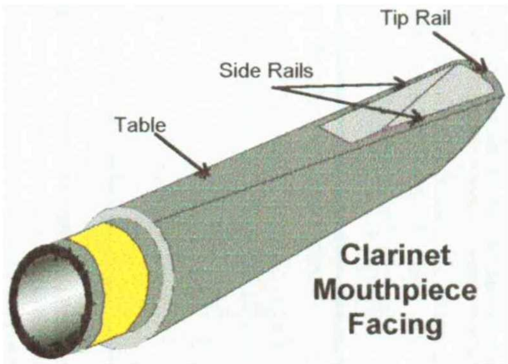


Fig.4

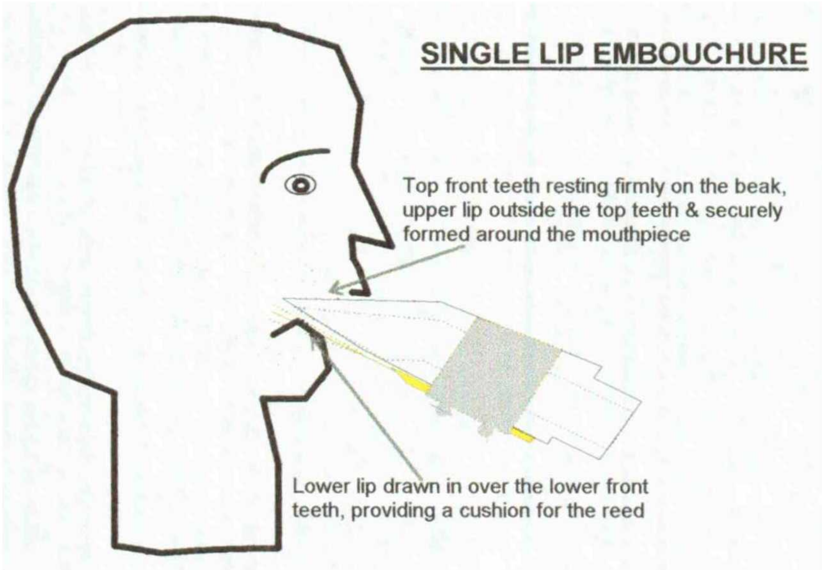
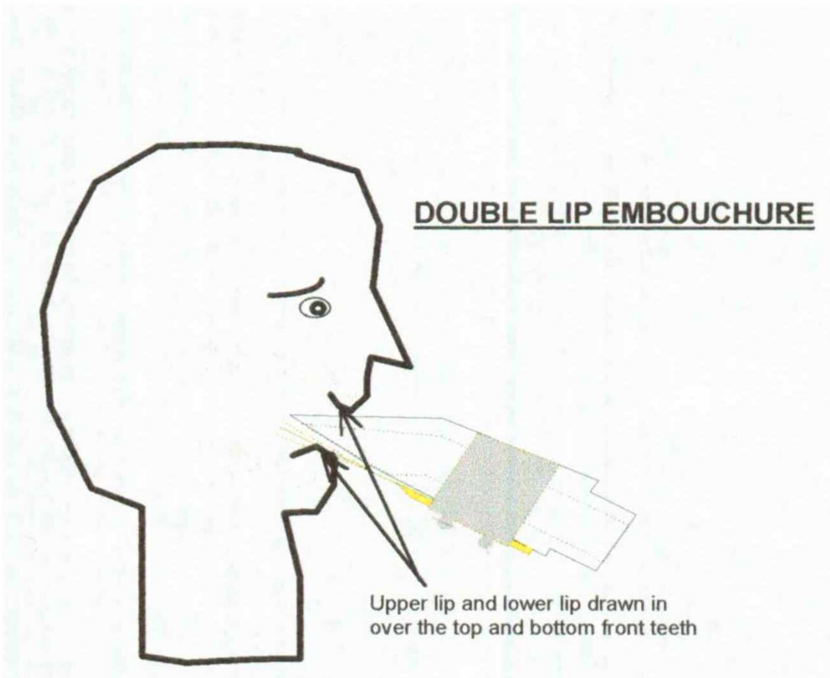

SINGLE LIP EMBOUCHURE
Top front teeth resting firmly on the beak, upper lip outside the top teeth & securely formed around the mouthpiece
Lower lip drawn in over the lower front teeth, providing a cushion for the reed

Fig.5


DOUBLE LIP EMBOUCHURE
Upper lip and lower lip drawn in over the top and bottom front teeth

Special Blowing Techniques

Legato
Vibrato (lip)
Vibrato (diaphragm)
Sotto voce
Flutter tongue
Double tongue
Triple tongue
Slap tongue
Glissando
Portamento
Staccato
Embouchure induced multiphonics
Singspiel,
Circular Breathing

The list of special and extraordinary techniques possible on a clarinet is quite extensive. Many of the effects and specialised playing techniques require years of practice to acquire and perfect. There follows a brief description of some of these techniques.

Legato

Smooth and sustained playing where the tongue is only used at the beginning of a phrase after which the breath pressure is maintained without interruption while the player moves from one note to another.

Vibrato (lip, lip/jaw)

Moderately fast to rapid periodic movement of the lower lip in contact with the reed. This vibrato is achieved by a slight backwards and forwards motion of the lower lip, sometimes aided by the lower jaw. A very similar style of vibrato can also be produced by a periodic pressure change on the supported (cushioned) portion of the reed; this is brought about by a very small up and down movement of the lower lip and jaw. The speed of the vibrato can be varied according to taste and musical demands. This kind of vibrato has a smoothing effect on the tone and can mask intonation problems.

Vibrato (diaphragm)

In this type of vibrato, the embouchure is held in a static position and vibrato is achieved by periodic changes in breath pressure controlled from the diaphragm. The speed of the vibrato can be very slow to very fast. Previous generations of French players and the jazz saxophonist Sidney Bechet used a very fast vibrato; many players now describe this technique as 'Bechet' vibrato; the effect is quite mechanical.

Sotto voce

Literally 'half voice'. A veiled, pale tone produced by blowing very gently with low but well supported breath pressure. To further improve this evocative, sensual and expressive tone, the lips are sometimes moved nearer to the tip of the reed and mouthpiece so that very little contact is made with the reed. The tone is actually depleted in harmonic content with a strong fundamental but only the first few harmonics present to any degree. In fact, the regime of oscillation when playing sotto voce produces a virtual sine wave since the reed fails to 'clip' and excite a full complement of middle and upper (odd) harmonics. Brahms includes sotto voce indications in his clarinet music.

Flutter tongue

A technique demanded in much 20th century music from Strauss, Schönberg and Webern onwards. The player is required to flutter the tongue as in rolling the sound 'r' whilst continuing to blow and maintain a good embouchure. The rapid periodic movement of the tongue disturbs the smooth flow of the air stream in a rather mechanical way but produces an exciting, jagged tone, almost a buzz, that sounds as though the note were being tongued very quickly.

Double tongue

Perhaps not as successful when used on a clarinet as on the flute or recorder. Instead of articulating by using single strokes of the tongue on the reed (Ta, Ta, Ta), the action of the tongue is separated by a throat induced 'Ke'. So that a rhythmic Ta-Ke, Ta-Ke, Ta-Ke is performed. This can be maintained at high speed with practise, and can facilitate the rapid articulation of fast passages of music. The sounds Ta and Ke are used here to try and explain how the effect is achieved, players and teachers may use different sounds (Da-Ge). The same movement of the tongue is necessary in making the sound 'Ta' as when the tongue moves on and off the underside of the reed tip in the production of a clean and crisp attack. The Ke sound is produced by closing the throat and then abruptly forcing air through, commonly known as a glottal stop.

Triple tongue

Similar to double tonguing except that Ta-Ke is replaced with Ta-Ke-De. The technique might better suit fast passages with triplet or sextuplet figures. Both techniques require a great deal of practice.

Slap tongue

This is a particularly violent form of articulation whereby a larger area of the tongue than is used normally, 'slaps' the upper portion of the reed. The sound produced is distinguished by a note whose transient begins with a thud/click combination. This technique works better on larger instruments such as the bass clarinet or saxophone.

Glissando

As the term implies, a sliding of the pitch up or down over different sized intervals. One of the most famous examples of this technique is the opening clarinet solo in Gershwin's Rhapsody In Blue, where the slide is upwards over nearly one octave in the middle register. This again is a tricky technique to master. Although easiest to achieve in the middle and upper registers, it can, to a lesser degree, be used between notes in the lower register. The effect is produced by a combination of variation in breath pressure, lip pressure and the additional aid of sliding finger work. To play a downward gliss, the lower lip is slackened slightly (this feels as though the bottom jaw is being lowered) while breath pressure is also reduced but kept strong enough to maintain the sound. If the interval is large, then the use of fingers may be necessary, slowly covering tone holes to assist the operation. The descent of the pitch is constantly monitored by the player and the required adjustments made in each area to correct any bumps in the smooth fall of the note. The reverse is required for an upward glissando.

Portamento

Here the notes are detached just slightly, by means of a gentle tongued articulation, usually described by teachers as tonguing with a 'De' sound. The tongue moves on and off the reed as in normal articulation, but the contact with the reed is very brief. The note is held for almost its whole duration, with the tongue brushing or stroking the reed lightly and briefly while breath pressure remains constant.

Staccato - short, half length notes

Here the notes are separated as cleanly and crisply as possible, and, although breath pressure is again maintained throughout, the tongue remains in contact with the reed for as long as possible so that the notes are only half their normal length with silences in between.

Embouchure induced multiphonics

Commonly known as 'chords' by clarinet and sax players. But these are not chords in the sense that one understands a chord on a keyboard or string instrument where several notes are played together. A wind instrument multiphonic is a complex wave where some of the harmonics or partials sound independently. In normal playing the role of these harmonics is to colour the note, their different pitch usually only being detectable to the trained ear. Multiphonics can be quite a surprise to the unsuspecting listener, the pitches forming strange and sometimes wonderful 'chords'. Although the effects can sometimes be produced simply by the use of a special fingering, it is usually necessary to nurse the sounds from the instrument by careful manipulation of lip position, lip pressure and air pressure. Using this technique, it is possible to make conventionally fingered notes crack, especially in the lower register. Many teachers describe the acquisition of this technique as being akin to controlling a squeak! Multiphonics are used widely in contemporary music. They are also used by many jazz and rock saxophonists who find that a multiphonic is often a desirable bi-product when trying to hit a very high altissimo note .

Singspiel

This is a technique whereby the player sings or hums whilst simultaneously blowing the instrument. The vocal sound wave passes through the mouthpiece and reed aperture and combines with the wave being produced by the vibration of the reed. This often causes some distortion (inharmonicity) unless the sung or hummed sound is in unison or concordant with the note being played. Singspiele has a similar sound to multiphonics, although its two voices can be heard quite distinctly; this is in contrast to a multiphonic, where several voices can be heard. Some sound energy also radiates via the head.

Circular Breathing

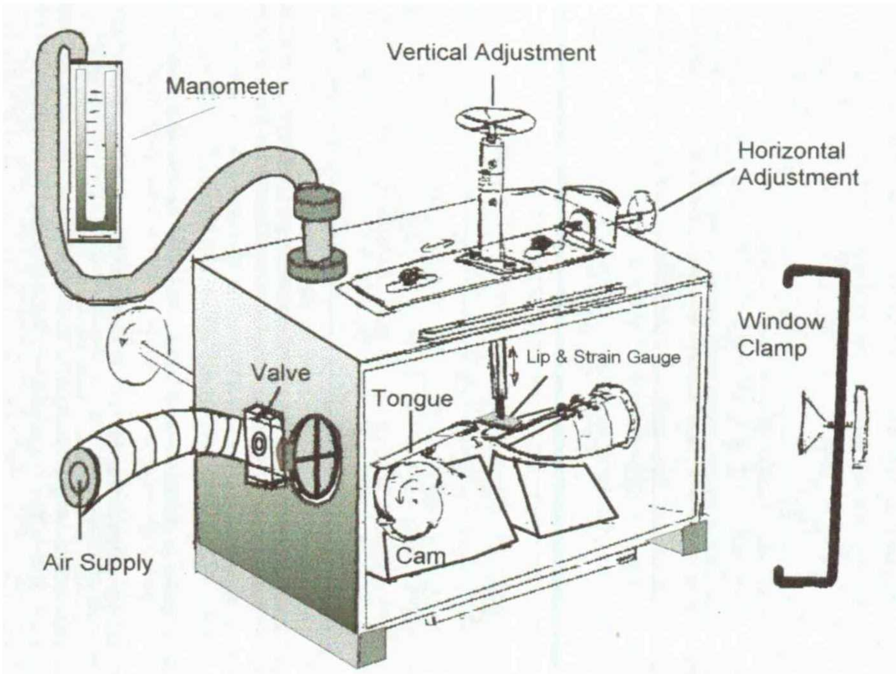
The technique whereby a continuous, uninterrupted flow of notes can be played over very long time spans. The instrument is blown normally, but the cheeks are filled with air and used as a reservoir, not unlike bagpipes. The cheeks are squeezed by the cheek muscles to maintain air pressure while simultaneously drawing a fresh supply of air into the lungs via the nose with the result that there is no interruption in sound.

PERFORMANCE OF THE ARTIFICIAL EMBOUCHURE

The artificial embouchure performed extraordinarily well and could be set up to perform most of the techniques described above. Steady state tone of high quality was easily achieved and the set-up was quite easily reset for experiments requiring repeatability. **Legato playing** presented no difficulties, nor did simple tonguing, although more subtle tonguing was probably beyond the equipment's capabilities. **Flutter tonguing** might have been possible had an electric motor been attached to the tonguing device, but this was not attempted. **Glissando** did present some problems but could nonetheless be produced to some degree with skilful co-ordination of the controls. A good **Sotto voce** was achievable when similar adjustments were made to lip pressure, position and air pressure as are made in live playing. It was not considered necessary to introduce singing or humming into the artificial embouchure as it was felt that the technique of **Singspiel** was beyond the remit of the present research. It would be possible to examine the effects of the introduction of a vocal-like sound on the internal and external spectra of the instrument by inserting a transducer in the form of an externally driven microphone or loudspeaker into the cavity or the air supply line of the artificial embouchure. The artificial embouchure achieved the best **Circular breathing** ever witnessed.

6
The Construction of an Artificial Embouchure to Blow Clarinets Mechanically

Fig.6 Artificial Embouchure



At the outset of the research, it was clear that, in order to analyse the sound from clarinet mouthpieces effectively, there would need to be a mechanical means of blowing them, as this would be the only way to ensure that identical conditions were maintained throughout the numerous experiments. Various ways of designing and making a blowing chamber were considered and experiments were carried out to discover which materials and equipment would produce the best results. The eventual piece of equipment (the artificial embouchure) performed very well and, with a little modification would also be suitable for the testing of saxophone mouthpieces and, with the addition of a second lip, double reeds. The construction procedures are described as follows, including, for the benefit of future researchers, mistakes that were made.

The initial ideas were inspired by the diagram of the apparatus used by John Backus for his experiments into the vibrations of the clarinet reed and air column [Backus,1961]. His equipment allowed him to view and measure the opening and closing (oscillation) of the reed at the tip of the mouthpiece via a photomultiplier tube. The light source was located at the bell-end of the instrument and the light was directed along the tube to the mouthpiece. Backus' interest however, was in steady state tones sounding at different dynamic levels and did not include the study of articulation (the attack transient). The present research required the observation of steady state tones and transients.

The onset transient or attack transient is an important element in the formation of a note, and the ability of a mouthpiece to assist in this area is crucial. Crispness of attack (the speed with which the set-up responds to the influx of air) is an important measure of the quality of a mouthpiece, so the system needed an artificial means of articulating the sound; this was provided by a mechanical tongue.

Construction

The blowing chamber was a simple box 200mm x110mm x110mm, made from 12mm plywood . When determining the size, account was taken of the space that would be needed for the tonguing mechanism and for ease of removal and replacement of the mouthpieces. Plywood was used for five of the sides, with the remaining large side recessed to allow for the positioning of a removable 6mm clear perspex window. After assembly, glue was run along all the internal edges and corners to minimise leakage. In order to seal the window, a gasket was made by running liquid silicone rubber around the recess, covering it lightly with PTFE tape and then gently fitting the perspex in place to form a good mating surface. Once the rubber had dried, the perspex was removed and the PTFE tape peeled off, leaving a perfectly fitting seal. The window was fitted with two small knobs to facilitate removal. A 'G' shaped clamp, complete with a central adjusting screw, was made to hold the window firmly in place by locating it behind a top and bottom rail screwed along the edge of the wood (see diagram). A large hole was made in the right hand wall (viewed from the front) to accommodate the mouthpiece and barrel sections of the clarinet. The hole was lined with a short length of rubber tubing, tight enough to hold the instrument securely around the barrel and form an airtight seal, but allowing a degree of adjustment

Air Pressure Regulation

The air supply could have been introduced at any convenient point, but it was decided to place the entry on the wall to the left of the window and directly in front of the tonguing device. It had been envisaged that the air supply in the University woodwind workshop would be used to power the artificial embouchure. The pressure of this air supply was very high, so, in order to be able to reduce this, a central heating radiator valve was incorporated into the side of the box connecting the supply to the chamber. In the event, due to the fluctuation in its pressure, the University supply was not used, a centrifugal compressor from a cylinder vacuum cleaner proving to be more reliable, stable and easily regulated by means of an electronic vari-speed. Unfortunately, the vari-speed produced interference in the recordings and, for fine adjustment of the air pressure, had eventually to be abandoned in favour of a mechanical valve.

Monitoring

The air pressure within the chamber needed to be monitored at all times, so a connection was needed for a manometer. Tank connectors, fittings and an inexpensive manometer, capable of reading 24 inches of water, were bought from a plumbing suppliers. The connection for the manometer was situated on the top of the box, towards the back left hand corner, out of the way of the lip pressure mechanism.

Barrel, rubber seal & wooden supports

Internationally, the most popular clarinet in use is the Buffet R13 (*Buffet Crampon & Cie*). It seemed logical therefore to choose this instrument for use in the survey. This is a French instrument with a smallish mean bore size of 14.6mm, and most of the mouthpieces to be analysed in the survey would be expected to work satisfactorily in conjunction with this clarinet.

The barrel of the instrument was removed and a new one made in ebonite, the outside shape adapted to enable it to fit securely into the opening in the artificial embouchure. The length and internal dimensions of this new barrel were the same as the original but the outside was shaped to incorporate a slight taper, increasing from the mouthpiece end to the connection with the top joint. The hole in the artificial embouchure, designed to take the barrel and mouthpiece, was lined with a piece of 40mm car radiator hose to act as a reducer and seal. The hole had been machined smaller in diameter than the hose (39mm) to ensure a tight fit. The clarinet was pushed into the chamber through the hole, with the barrel and mouthpiece inserted to a point where the reed was directly under the artificial lip (approx.10mm from the tip of the mouthpiece). As an additional means of horizontal adjustment to the moveable lip, the barrel could be moved slightly in and out of the chamber with the aid of a little rubber lubricant. Wooden chocks were made to support the clarinet at the bell-end and under the mouthpiece inside the chamber.

Artificial Lip

This proved to be the most complex part of the equipment as it needed to be able to move in the vertical and horizontal planes without disturbing the contact of the lip material unduly. It was also important to be able to make fine adjustments from outside the box which itself had to remain airtight. The best position for the adjustment of any mechanism was going to be from the top of the box, meaning that the mouthpiece had to be located with the reed facing upwards inside the artificial embouchure (as though playing the instrument standing on your head!). To facilitate horizontal and vertical movement, two brass plates were placed, one on top of another, on the top of the box. The lower plate was bolted to the box and the upper plate was able to slide over it. The vertical adjusting mechanism screw was located inside a barrel fixed to the top plate, with the lip plate attached to the end of a 4mm square section bar that could be drawn up or down through a rectangular slot in both plates. To enable horizontal movement, the stationary lower plate was given a screw adjuster at the side which passed through a tapped lobe on the top plate. The sliding upper plate was held in place by spring loaded screws which passed through slots in the top plate holding the two plates firmly together but allowing approximately 12mm of horizontal movement. The square bar had a 4mm x 0·75mm thread machined along the inside so that fine adjustment to pressure on the reed could be made by turning a screw at the top of the tap-like column inside which the bar travelled up and down. The lower plate incorporated a rectangular slot, allowing the whole assembly to travel backwards and forwards the 12mm distance allowed by the locating screws.

Tonguing Device

As the aim of the research also included the evaluation of the onset transient, it was imperative to be able to stop and start the reed's regime of oscillation in a manner as close to normal tonguing as possible. After careful examination of the way in which *most* clarinettists tongue, a system was devised for the rapid release of a 15mm wide, thin, springy brass tongue from a position that pressed on the top few millimetres of the tip of the reed, by means of a four quadrant cam. This ratchet flicked the tail-end of the brass strip causing the tip to move rapidly on and off the reed. A small patch of very thin polystyrene foam was glued to the end of the tongue where it came into contact with the reed, and the speed of release was achieved by means of a spring pulling the other end firmly down onto the cam. The cam was operated from outside the box by a knob attached to the end of a steel rod which passed into the centre of the cam through an externally threaded brass tube. This system worked very efficiently and there was no need to alter the tension of the spring although this was easy to do if necessary. As with the lip mechanism, air tight seals were achieved by the use of small rubber 'O' rings.

Air Supply Requirements

Clarinets require a relatively high level of breath pressure to operate over the wide dynamic range of the instrument. Tests using a tube from a manometer inserted into the mouth whilst simultaneously playing the instrument, show that a range of pressure from 4 inches (") for a pianissimo (ppp) dynamic to, in excess of 20" for a fortissimo (fff) are required. This is in contrast to a recorder which only requires approximately 4" for the loudest dynamic. An air supply capable of quite high and stable pressure was going to be necessary to drive the artificial embouchure.

Compressor, Varispeed, Silencer & Insulation

A vacuum cleaner compressor rated at 350 watts was found to be perfectly adequate in producing the pressure required to blow the clarinet; the problem was more one of reducing the power. This was achieved by inserting an electronic varispeed in the circuit (available from vacuum cleaner repairers). This, in conjunction with the air valve meant that any pressure from 0 inches to more than 24 inches could be attained and maintained indefinitely. Motor noise was intrusive and I was also concerned by the possibility of noise from the air travelling through the piping reaching the reed and combining with any sound produced by the artificial embouchure. Exterior motor noise was eliminated by abandoning the cleaner casing, building a more solid box to house the compressor and putting the whole apparatus inside a second, larger, padded wooden box. John Evling at LGU kindly constructed a silencer to place in the air line, close to the artificial embouchure to reduce air noise or any other mechanical noise travelling along the tubing from the motor.

I have since refined the system by using a quieter motor, more efficient compressor and locating the whole unit further from the artificial embouchure.

Initial Results

Reed Problems

In order to combat the drying effect of the air from the compressor, plastic coated reeds were used. These reeds were adequate, but did present problems. They are also not widely used by instrumentalists other than jazz players, people allergic to cane and those who object to the admittedly prohibitive cost of natural reeds. These plastic coated reeds did not dry out in the air stream, but nor did they produce the finest tone (although many players were agreeably surprised by the quality of the sound). The harder strength plastic coated reeds came closest in response to good quality natural reeds.

Experiments were conducted using oiled reeds to see if this might help them withstand the rigours of the artificial embouchure and prolong their useful life. Reeds were wiped with olive oil, the aim being to both imitate the essential wetting process necessary for the activation of a natural reed and limit the absorption of the water which eventually destroys it; this was not very successful.

To try and accommodate the use of ordinary reeds, the temperature was raised and the humidity increased to match that of human breath. This was achieved using an in-line humidifier which is described later in the text.

The extraordinary performance of the artificial embouchure brought into question the role of the oral tract in tone production. This is discussed in detail in the chapter 'Vocal Tract Resonance'.

Intonation

Apart from a little flatness, intonation was good. This was surprising, given that the air temperature averaged 23°C, with humidity around 30%, considerably lower than a player's breath temperature which would be 30°C and above, with over 90% humidity. The flatness was corrected by exerting more downward lip pressure on the reed. It was also gratifying to find that the artificial embouchure played very easily in all three registers. There was some lack of focus in the third register but this was rectified by using slightly less lip pressure. This was puzzling, tradition dictating that more pressure is normally required in the upper register. A possible explanation for this was the high blowing pressure and strong lip pressure being used.

Players' Reaction to the Artificial Embouchure

All the clarinettists who have come into contact with the artificial embouchure have been impressed by its performance, declaring the tone to be lifelike and of good quality. This was particularly impressive when one considers that the sound of the steady state tone was static, with no hint of the vibrato, shaping of the note or adjustment of the timbre that a player would instinctively apply. In electronic terms this would equate to an application of signal conditioning. But, important though the issue of tone was, the mouthpiece's ability to respond well in terms of dynamic range and speed of attack was also crucial and the artificial embouchure was a powerful aid in this area.

The artificial embouchure was used extensively in the initial work with a methodology gradually being developed and refined. It became increasingly clear when its use would be beneficial and when not. Where different set-ups were to be tested and compared it was vital that playing conditions remain constant, with temperature, humidity, blowing pressure, lip pressure and position all being maintained, and this was only possible using the device. It was also possible to measure accurately and consistently the efficiency of a mouthpiece in terms of dynamics, its richness in terms of harmonic content and, using the artificial tongue, the speed of attack (onset transient).

The resulting data was displayed as spectral graphs which showed the component content of the mouthpieces' tone quality and the speed with which notes would reach their steady state regime of oscillation, i.e. speed of attack or articulation. The graphs showed clearly the differences in performance between the mouthpieces, but these differences were not necessarily reflected in an appreciation of the sound and response by the listening panel, players and listeners perceiving tone and response in widely different ways as demonstrated in chapter 3. Later, very minor alterations made to the mouthpieces were found to result in dramatic changes to tone and response; the tone assumed more vibrancy and offered a wider dynamic range, and reeds responded particularly well, allowing superb articulation. This was sometimes brought about by a very small change in the design, perhaps just a few microns removed from a certain portion of a lay profile.

Comparison between live playing and the artificial embouchure

Experiments were conducted to compare the performance of the artificial embouchure with live playing. The bell note, E_3 was played, first by a live player, then by the artificial embouchure which had been filled with blocks of wood to reduce its volume and make it similar in volume to a human mouth cavity, and finally by the artificial embouchure empty. The wave data from the three recordings was then analysed and the differences between the three were found to be minimal. The embouchure in its empty state, however, bore the closest resemblance to live playing.

On a second occasion, the tests were repeated several times and the results averaged. This time, comparisons were made between the box empty, then packed with foam rubber instead of wood. Averaged results showed no significant difference between the box in its empty state, or packed with either material. These results suggested that neither shape, size nor texture of the mouth had any effect on timbre. For many clarinettists this was an unpopular conclusion, but it has yet to be proved otherwise.

Temperature Tests, Humidity Tests, Inline Humidifier, Lip Pressure Sensor

In the interests of simplicity, the possible effect of changes in temperature and humidity on the results had been omitted. The survey of commercial mouthpieces had been carried out in the stable environment of the research lab at the LGU where both the temperature and the humidity of the air driving the artificial embouchure had been constant. Repeatability tests associated with the Howarth Clarinet were completed in my workshop at home where the temperature was also stable. The mouthpieces were all being examined under unnaturally stable conditions which did not mirror the circumstances which might be encountered in a normal playing situation. The search for subtle changes in the harmonic spectrum was now to be undertaken and it was important to discover how much, if at all, the timbre was affected by alterations in temperature or humidity. In order to test this, a method was devised whereby humidity could be introduced into the air stream and the temperature raised.

Inline Humidifier

Woodwind instruments rise in pitch rapidly as they warm up. This rise in pitch is caused by an increase in the velocity of sound as a result of warm air from the lungs filling the interior of the tube and heating the walls of the instrument. The speed of sound always increases with a rise in temperature. The increase in velocity equates to approximately 1% for each 5^0C rise in temperature. Although this does not sound very much, a 10^0C rise and 2% increase in velocity produces a rise in pitch of roughly a third of a semitone, a 6% rise in pitch being equal to one semitone. This is a common problem when playing on a cold day. Instruments do not warm-up uniformly, so it is important to play an instrument for a short time prior to commencing any tests or evaluation, particularly if intonation is to be evaluated.

Velocity of sound (c) in air at 20^0C (room temperature - Benade) 345 m/s
Increase in velocity in air at 30^0 C 345 x 102% = 352 m/s

Example for a clarinet:-

C3(Bb_3), 233Hz, corresponds to a quarter wavelength of approximately 37cms (0.37m) when calculated at room temperature. This is the approximate effective length from the tip of the mouthpiece to the low register Bb tone-hole situated at the top of the lower joint.

Using the formula for calculating wavelengths and frequencies in cylindrical tubes.

$f_0 = c \div 4L$ where f_0 is the playing frequency (Hz), c is the speed of sound and L is the effective length.

With an instrument warmed up to 30^0 C, the effective length would correspond to a playing frequency of:

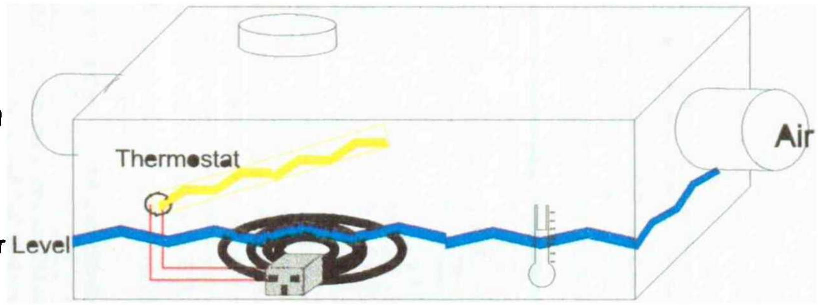
$$f_0 = \frac{352}{0.37 \times 4} = 238\text{Hz}$$

A rise in pitch of 5Hz (approx. 2.2%)

The expansion of the instrument's material is negligible and can be omitted from the calculations.

From these calculations it could be seen that temperature had a powerful influence on pitch, but its influence on the spectrum of harmonics was unknown. Sound travels faster in water than air, so it was feared that the water content of the air supply may exert a further influence on the tone and pitch. It was necessary to verify this, hence the construction of the inline humidifier which both warmed the air and introduced moisture.

Fig.7 Inline Heater & Humidifier



The device was very simple. A sealed, rugged plastic box in ABS, 500mm x 200mm x 200mm was fitted with a 2kw immersion heating element near the bottom and an adjustable thermostat above it. A hole with a tightly fitting plug was made in the top surface of the box through which water could be poured. A spy-glass was fitted half-way up the side of the box to ensure that the element was always covered with water. 32mm diameter pipe connectors were fitted to each of the opposite small sides of the box above the water line for the air input and output. The air was heated and humidified as it passed over the hot water. The whole system was connected to the air line close to the artificial embouchure to minimise condensation in the pipework.

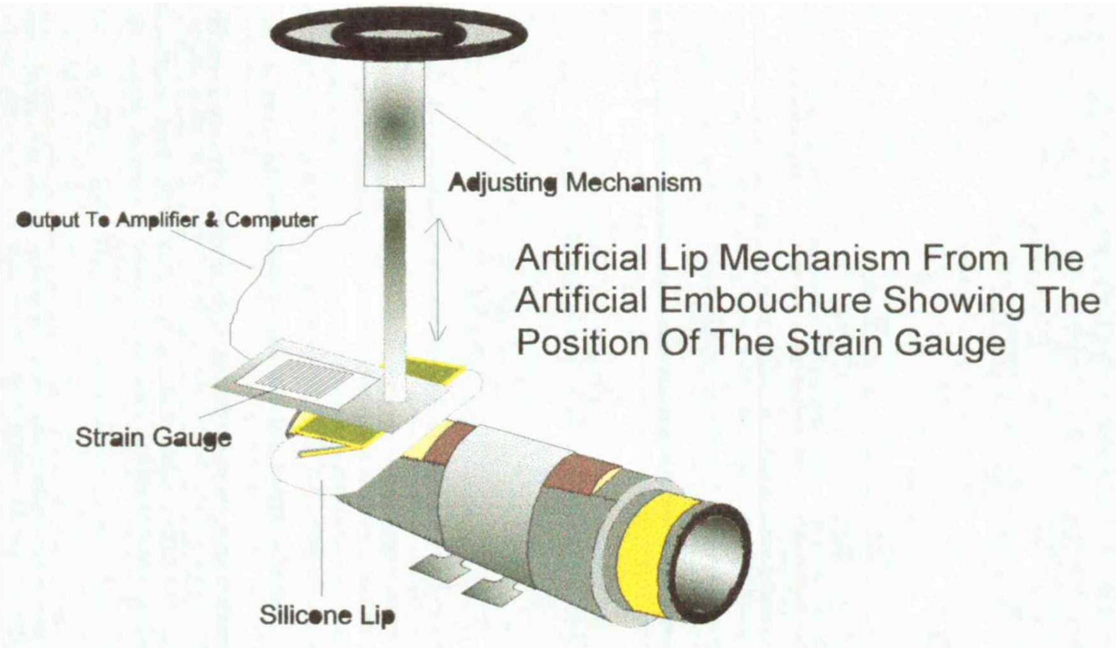
The device worked well and it was possible to regulate the temperature and humidity quite accurately. Use of the humidifier also made possible the use of ordinary reeds. There were drawbacks however. In order to maintain the very high humidity found inside a clarinet when being played, it was necessary to set the inline humidifier to produce correspondingly high levels of moisture. This caused problems in the artificial embouchure which filled with steam. The reed and mouthpiece became waterlogged, producing worrying gurgling noises. Fortunately, the outcome of this experiment was still positive, as it was found that, although the increase in temperature did raise the pitch, and the increase in humidity did enable the use of normal reeds for a short period, the effect on the structure of the harmonic spectrum from both interventions was negligible.

An additional concern was how to ensure consistency and accuracy when setting the downward pressure on the reed each time the mouthpiece was replaced in the device. The solution lay in incorporating a strain gauge into the artificial lip adjusting mechanism. A small, single element strain gauge was obtained from *Radio Spares,* along with a special, highly sensitive strain gauge amplifier. After some experimentation as to its location, the gauge was eventually found to work satisfactorily when attached to the brass plate supporting the silicone 'lip'. A strain gauge works by reacting to change in the stress of the material to which it is attached, by means of a minute variation in the resistance in its element. The gauge was connected to the strain gauge amplifier which converted and amplified this change into a varying voltage. The amplifier was in turn connected to the *Pico ADC 100* operating in volt meter mode. Pressure on the reed resulted in a voltage output from the strain gauge amplifier being displayed on the *Pico* meter, and each time the mouthpiece was relocated in the artificial embouchure the screw at the top of the lip mechanism could be adjusted to give the same voltage read-out for each test. The *Pico ADC 100* allowed for calibration of the voltage received, so, if the variation in downward pressure was measured, then this information could be used to calibrate the volt-meter. This pressure on the reed was measured using a specially adapted spring balance. The maximum weight exerted on a medium strength reed before the tip closed, was found to be in the region of 20 lbs per square inch - quite high. This could not be assumed to be the case for all players and all set-ups, since the measurement is dependent upon how much lip is in contact with the reed and will vary between players, but it did give an indication of the forces involved.

It was perfectly satisfactory to use the voltage measurements alone to set the lip pressure. However, it soon became evident that the same result could be obtained by using the naked ear alone, listening acutely and using the lip pressure screw to make fine adjustments to the pitch and focus of the tone.

The use of the gauge became unnecessary and was abandoned. The installation of the gauge had been worthwhile nonetheless, as it confirmed the accuracy and consistency of the original methods. If the Pico ADC 100 was switched to measure frequency then the gauge could also be used to determine the frequency of the reed vibration if so wished.

Fig.8



The effect of changes in air pressure on timbre

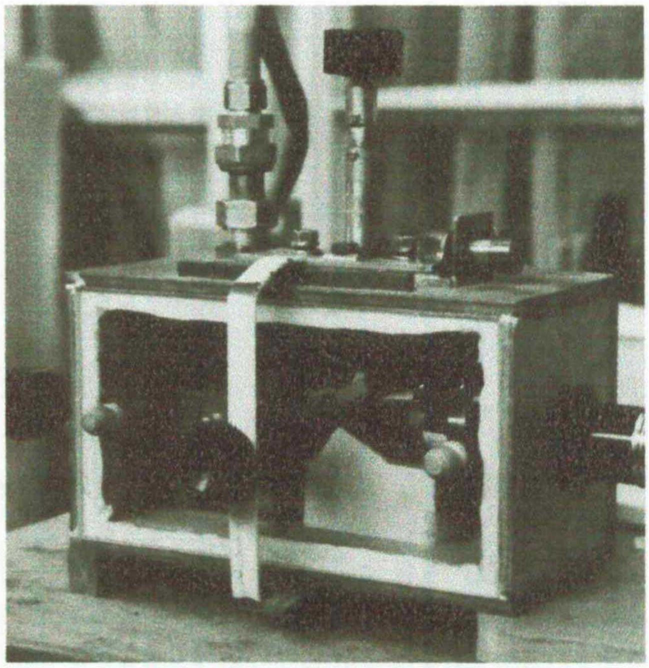
An earlier experiment with the oscilloscope showed that the balance of harmonics changed considerably at different pressure levels. It seemed that the richest tone colour was not necessarily being produced at the loudest level. Also, discussions with Nick Shackleton had raised the question as to whether or not it was wise to test at high air pressure levels. It became clear that there was a need to look at the way timbre changes and develops as air pressure and possibly air flow increases, to see if there was an optimum or ideal pressure level to adopt when analysing tone, especially when using the artificial embouchure.

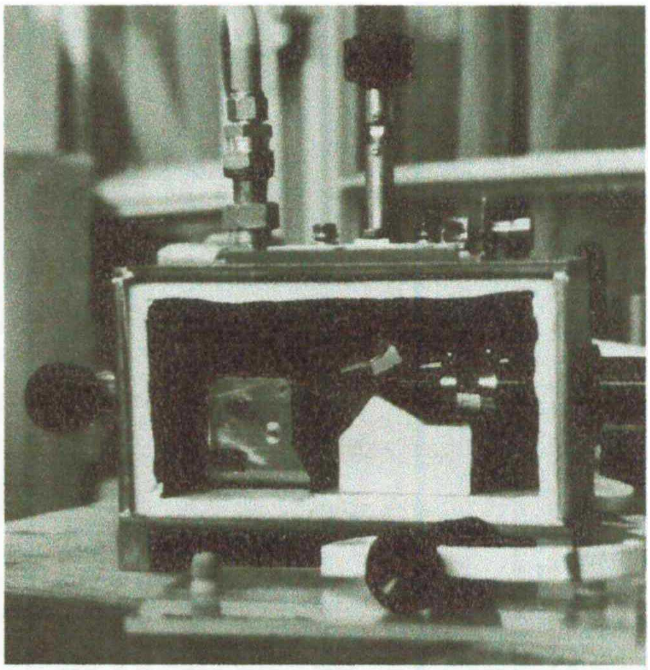
Most players test clarinets and mouthpieces at a moderately loud dynamic level (mf) where the tone is usually at its kindest. Testing would usually include the extremes of loud and quiet as well. It was decided to learn what air pressure a player would use to produce a moderately loud sound. To do this, I put the tube from the manometer into my mouth along with the mouthpiece (no mean feat) and attempted a mf tone on different notes over the whole range of the instrument but especially in the middle register where one would hope that the tone of a good instrument set-up would be particularly sweet. The result remained consistently in the region of 8"-10". I went on to see what pressure was needed for a pianissimo tone and then that required to produce a powerful fortissimo(*ff*). The sound began to disappear at or just below 4", and *ff* required 15" to 20" of pressure, with little increase in dynamic level above this. I had previously tested everything at 14" but now realise that this was unnecessarily high. The reason for adopting such a high pressure level had been because of a concern over signal to noise ratios and the desire to obtain all three registers easily. Some of the mouthpieces did not like being played in the high register unless the air pressure was high. Once the necessary technique had been mastered and it was established that the artificial embouchure could manage a *ppp* dynamic, experiments were initiated to analyse the sound through a range of dynamics from very quiet to very loud.

Extremes of dynamic

It was interesting to note that both the artificial embouchure and normal playing required the same degree of manipulation to air and lip pressure to achieve very loud or extremely quiet tone production; the quieter the sound, the lower the air pressure and the greater the downward lip pressure on the reed to maintain periodic oscillation. This took some practice to achieve, as the air pressure valve and the lip pressure screw had to be simultaneously sensitively adjusted. As with normal playing, the pitch rises as the dynamic drops.

The artificial embouchure in use.





7

Vocal Tract Resonance

It is a commonly held belief that any change made to the shape of the mouth, throat or nasal cavity, has a profound effect on the tone and projection of an instrument.[1] Clarinet teachers have long urged their pupils to "open the throat", "lift the head" or even, somewhat obscurely, to "imagine the enlargement of the sinuses", but it is has never been altogether clear as to how these parts of the body might resonate or cause a resonance that would affect clarinet tone under normal playing conditions. Clinch et al [Clinch et al. 1982] presented X-ray photographs of the vocal tract which were used to explain how a player's physiognomy influences tone. Although a powerful case was made in this paper, my own findings from experiments using the artificial embouchure belie their conclusions and demonstrate that inherent physical characteristics exert little influence over the tone. Any timbral properties attributed to vocal tract shape or alteration of the mouth and contour of the air column prior to reaching the reed are the result of highly skilled and sensitive adjustment of lip pressure on the reed, in conjunction with carefully controlled air pressure. Even the subtlest change to the position of the lip on the reed will alter the amount of damping of the reed's vibration and result in a change to the components of the primary wave. Any perceived change in a clarinet student's tone as a result of the teacher's request to "open the back of the throat and imagine a dark, rich sound" is almost certainly due to a subtle change in breath and lip pressure, and possibly lip position.

It is certainly true that dramatic special effects can be achieved by altering the embouchure or by breath control. Rolling the tongue behind the reed whilst making an 'rrr' sound produces the effect known as flutter-tonguing, a commonly used technique in much 20th century music. It is also possible to sing, hum or growl along with the tone. These sounds, in combination with the vibration of the reed, produce strange and eerie distortions of the tone or vocally induced multiphonics. Multiphonic chords can also be produced using a combination of special fingering, and subtle control of lip pressure on the reed, thereby de-stabilising the note. In this way, several individual harmonics within

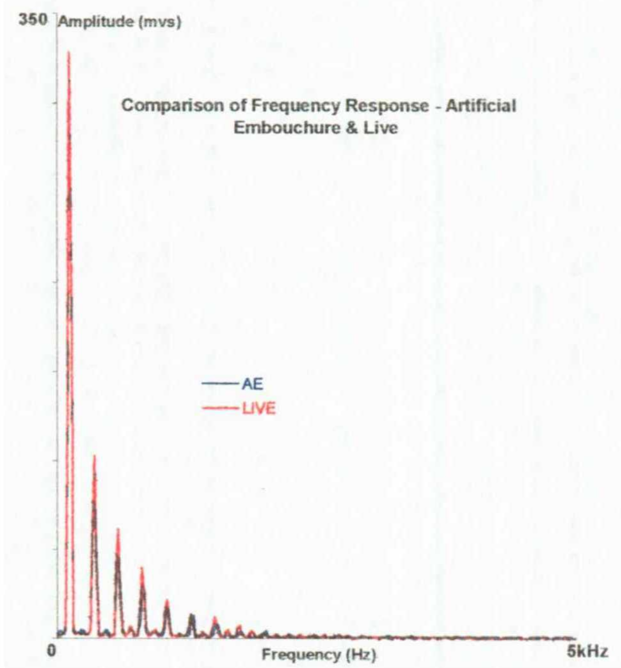
---

[1] see bibliography Clinch et al. 1982

the tone can be made to sound at a similar or louder amplitude than the fundamental; instead of simply colouring the tone, these components stand out as distinct notes in their own right, a multi-note chord being heard. These special techniques exert powerful influences over the tone, producing an unusual balance of harmonics and distortion of the sound.[2] Two distinct forms of vibrato are also possible; either by using a controlled, pulsating air column from the diaphragm and lungs (amplitude variation), or by periodic movement of the lower lip and jaw (pitch variation).[3]

Despite the obvious physical differences, the artificial embouchure, when equipped with a reasonable mouthpiece and attached to a clarinet (or a length of correctly dimensioned tube), sounded like a competently played instrument. The facility with which the timbre could be controlled by lip and air pressure alone was also astonishing. One distinguished player and teacher at a London Music College actually remarked that he wished that some of his students could sound as good. This was, hopefully, an exaggeration, but it is certainly true that the average listener was not able to distinguish between the sound produced by the artificial embouchure and that of a live player. The following graph shows the almost identical spectra of the same note, played live, and using the artificial embouchure.

Graph 17



---

[2] See chapter 5, p 43, *Special Blowing Techniques*.
[3] See chapter 5, p 47, *Vibrato*

If the shape of the vocal tract was so crucial to tone, individuality, and the correct functioning of the clarinet, then this device, with its hard, angular mouthchamber, ten times the volume of the average human mouth, connected to ten metres of large bore pipe with valves, bends and constrictions, should have sounded very different from a live player. In fact it was surprising that it sounded like a clarinet at all. The hard rectangular wooden box that formed the mouth cavity had a volume of 1800ccs and was powered by a compressor 10 metres away, the air travelling along a 32mm diameter pipe. This, in contrast to a volume of around 100ccs for the average human mouth, with a wind pipe of less than half a metre. The only physical similarities were to be found in the way the silicone rubber artificial lip and adjusting mechanism cushioned and dampened the reed, and the way in which the tonguing device released the reed, simulating a tongued attack. Once correctly set, all three registers were attainable without any further alteration to lip position, lip pressure or air pressure, only a slight adjustment being necessary in order to aid intonation and maintain dynamic level, as in live playing. All the subtleties possible in clarinet playing were also achievable using the artificial embouchure; sotto voce (half voice), very loud to very quiet tones, multiphonics, even a glissando down from a middle register top C could be achieved with practice.

The artificial embouchure required similar air pressure as that used in live playing, and to verify this, the following experiment was performed. I squeezed a section of 13mm rubber pipe between my lips alongside the mouthpiece and blew the clarinet through a range of dynamics, from pp to ff. The pipe was attached to a manometer which measured air pressure in inches or centimetres of water. Pianissimo playing was achieved using only 4" of water (similar pressure would result in forte in a recorder) whilst a fortissimo demanded more than 20" of water. A well rounded mezzo-forte tone with a complete spectrum of harmonics was achieved in both live playing and with the artificial embouchure, using between 10" and 14" of water.

The thick rubber tube did not distort the tone, although practice and care were needed to overcome the awkwardness of the set-up and to prevent air escaping from the lips. The fact that the presence of the rubber tube in my mouth did not appear to affect the tone prompted me to try a further test, playing the clarinet with a small rubber ball in my mouth. Here again, there was no detectable change in timbre.

In order to verify that the artificial embouchure itself was not affecting the tone, as described earlier, the chamber was alternately filled with wooden blocks and then sponge rubber, simulating a dramatic alteration to vocal tract shape. The same good tone was produced, with no change to the spectrum, suggesting that there was little or no interference from the alteration to the shape, texture and capacity of the internal parameters, thereby begging the question as to why there should be any difference in the human body. Clinch et al. had suggested that change to the vocal tract shape was a necessary aid to the production of notes in different registers, yet the artificial embouchure managed to achieve this without any alteration to the shape or size of any part of the apparatus.

The question as to whether vocal tract resonance exerts any influence over the tone and response of a clarinet or any other reed driven instruments continues to be a vexed one. Most instrumentalists insist that its influence is profound and that it is this which distinguishes one player from another. Their reluctance to relinquish this belief is understandable if it is felt that the uniqueness of their tone is dependent upon their physical make up.

Backus [Backus,1985] concluded that the influence of the vocal tract was negligible, but C.J.Nederveen [Nederveen, 1998 p.133] seemed to keep an open mind, stating that '....in the normal way of operating...."other" resonance in the vocal tract (mouth), the reed or the tube wall may be involved. They can be coupled to the excitation or to the air column vibrations and have a positive or a negative contribution. Their effects may be inaudible to the listener while still helping or hindering the player, an aspect which indirectly can be detected by the listener'. It would appear that even in the scientific world, those who believe that vocal tract resonance does have an effect on tone, risk appearing like the unscientific musician desperately wishing to prove their case. However, it was interesting that in conversation with Nederveen in the summer of 1998, he told me that he now agreed with the bulk of my findings.

Vocal tract resonance certainly exist, so much is proven. Also, that they alter with playing frequency. But the magnitude of influence, if any, is doubtful. The proof of their influence is said to be demonstrated by X-rays [Clinch et al. 1982] where an alteration in the shape of the tract can be seen to coincide with changes in tone quality. This is not convincing, as it cannot be proved that the change is not the result of connective tissue, muscles, tendons etc. moving to accommodate the alteration to lip and jaw position necessary to maintain the intonation or adjust the quality of the note.

Evidence, even when sophisticated equipment has been employed (Clinch), can be shown to be inconclusive. The paper 'The Importance of Vocal tract Resonance in Clarinet and Saxophone Performance, a Preliminary Account', [Clinch et al 1982], purports to show how vocal tract resonance influences sound. Here we are told that certain vocal tract shapes formed by the larynx and tongue will improve the tone and aid the production of certain notes. Yet it is quite possible to sustain a note on the clarinet or sax with no alteration to its intensity or timbre whilst at the same time moving the tongue to different positions in the mouth, or bending the neck backwards or forward to an acute angle, puffing one or both cheeks out or playing with a large object inside the mouth, situations where one would expect significant timbral change.

It is maintained that strong vocal tract resonance can be heard by wearing ear defenders whilst playing a wind instrument. A great deal of sound is certainly heard to be resonating inside the head when doing this, and I was all but convinced about the magnitude and source of this internal resonance until one day, whilst having a shower, my ears filled with soap and water. I was suddenly aware of the incredible noise produced by the water spraying onto the top of my head; this sounded as if it were being produced inside my head. In fact, the sound was reaching the inner ear by penetrating the cranium. This caused me to re-think the ear defender test and to question whether much of the sound that I had believed to be created by the excitation of the reed working within the vocal tract had actually been a combination of externally radiated sounds from the instrument penetrating the bones of the head, in addition to the sound that was being transferred from the top of the mouthpiece through the teeth and so into the inner ear.

In order to ascertain the nature of vocal tract resonance I carried out experiments using a probe microphone placed inside the mouthpiece and inside the mouth.[4] A thin probe microphone was inserted through a hole drilled into the mouthpiece near the pressure antinode, 25mm from the tip. When the instrument was played, measurements of the internal spectrum were recorded. The microphone was then removed from the mouthpiece, the hole plugged, and the probe slipped between the lips at the side of the mouthpiece finally being positioned just in front of the vibrating reed. The same notes were played, and again measurements recorded. The spectra produced by the two experiments were very different from one another in both amplitude and content.

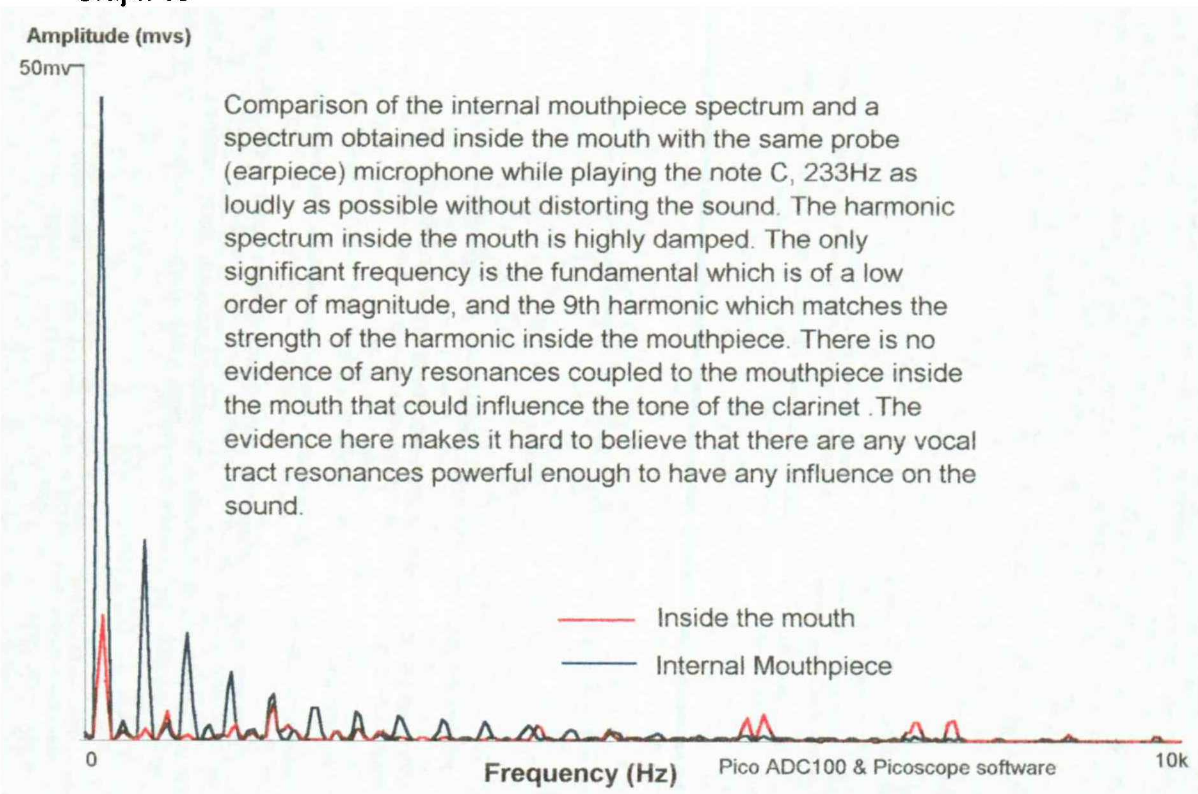
---

[4] See chapter 8, p 87-95

The spectrum inside the mouth consisted of few components other than a fundamental and small magnitude 3rd and 5th harmonics; the magnitude of the whole wave was 30 to 40dB below the power of the standing wave measured inside the mouthpiece. The vocal tract had no outlet for the energy associated with this internal (body) standing wave, there being no tone holes or bell, it was therefore impossible to measure the output from it, or to calculate a pressure transfer function to estimate the energy that may be escaping into the instrument or interfering with reed vibration. It is possible that, in this situation, the vocal tract was actually absorbing sound into the surrounding soft tissue, rather like an infinite baffle or labyrinth loudspeaker.

Comparison of Internal Mouthpiece and Vocal Tract Spectra

Graph 18



8

Data Acquisition and Analysis

Sound Field Tests

The effect of microphone placement on the spectral graph

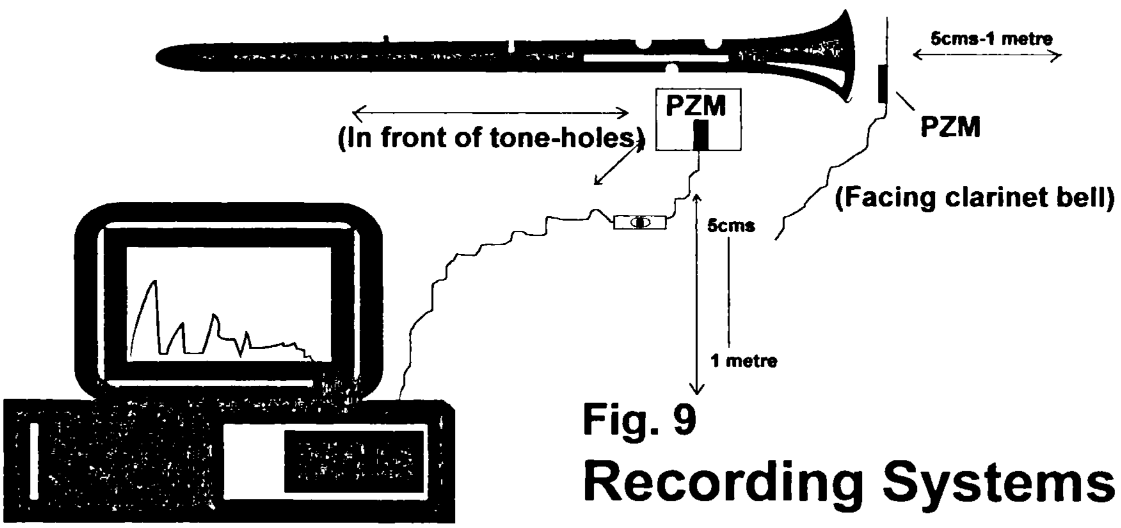
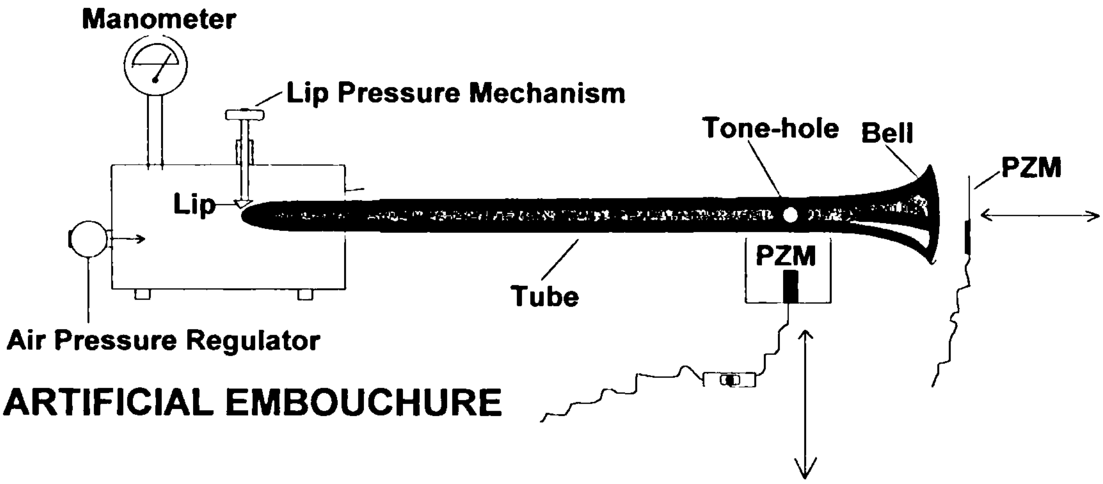


Fig. 9

Recording Systems



Equipment

Pressure Zone Microphones (Two)

Artificial embouchure

Clarinet length tube (66cm) with typical bell and a tone-hole bored on the bottom taper near bell to give F_3 156Hz (correct position)

Small bore mouthpiece, lay 1.10 x 18, No.3 reed

Compressor (blowing pressure 12")

Pico ADC 100 & software analysis

SoundForge direct to disc recording software

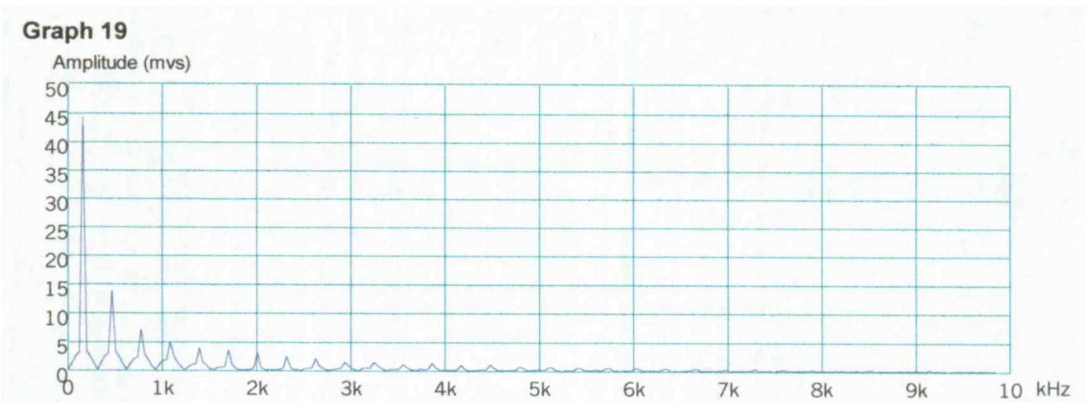
Aim

To demonstrate the effect different microphone placing has on spectral graphs and to determine the optimum position for recording when trying to ascertain changes to the spectrum brought about by alterations to the dimensions of the mouthpiece.

Microphones

There was an early change from using Fostex microphones to using PZMs (Pressure Zone Microphones, Realistic 33-1090A manufactured by Crown) as these gave a clearer, more realistic sound. These mikes reproduce upper frequency components more faithfully and are less affected by location. A full description of this type of microphone follows later.

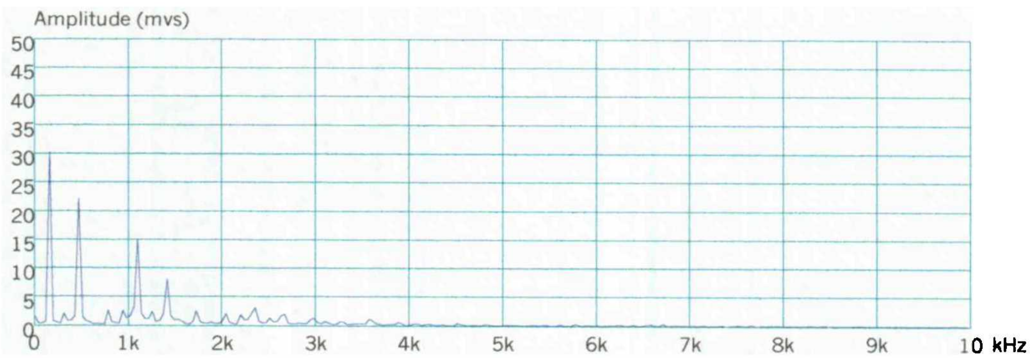
Test 1a **PZM mike @ 5cms from the tone-hole. Low register F_3**



Frequency (Hz) Pico ADC 100 PicoScope Software

Test 1b **PZM mike @ 25cms from tone-hole**

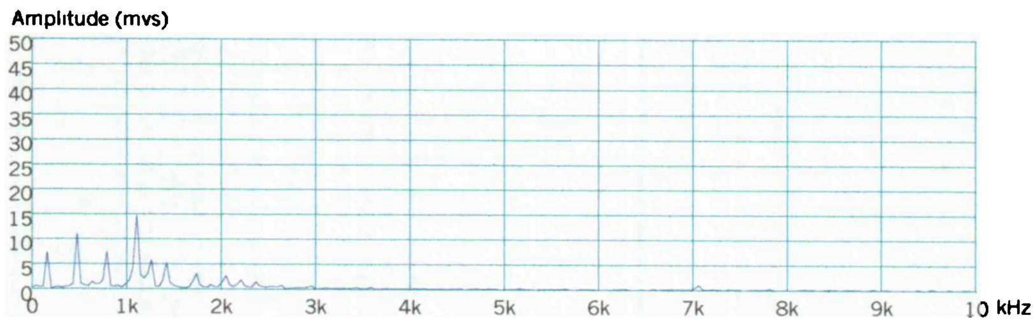
Graph 20



Frequency (Hz) Pico ADC 100 & PicoScope Software

Test 1c **Mike @ 1 metre from the tone-hole**

Graph 21

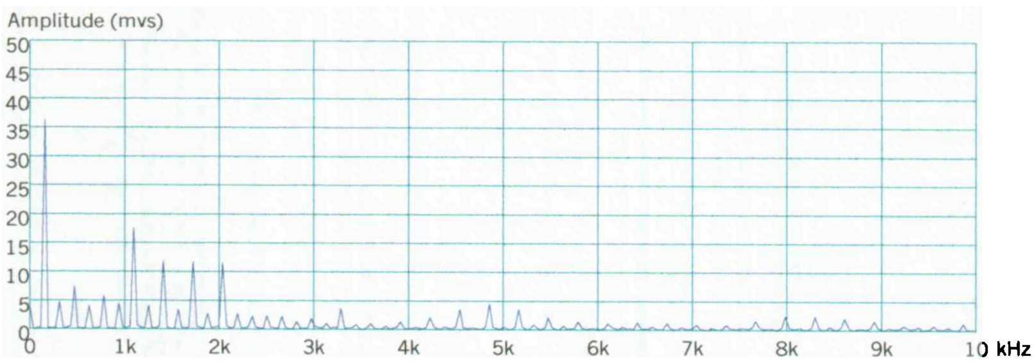


Frequency (Hz)

Microphone directly in front of the bell

Test 1d **PZM @ 5cms from the bell**

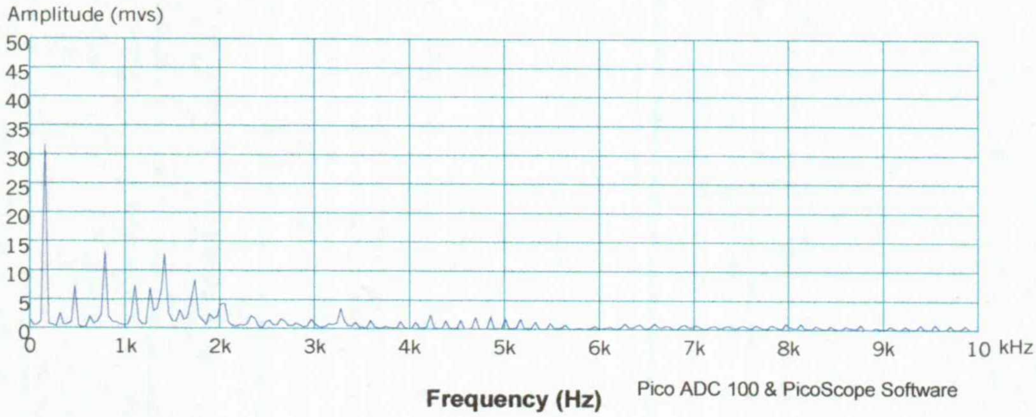
Graph 22



Frequency (Hz) Pico ADC 100 &PicoScope Software

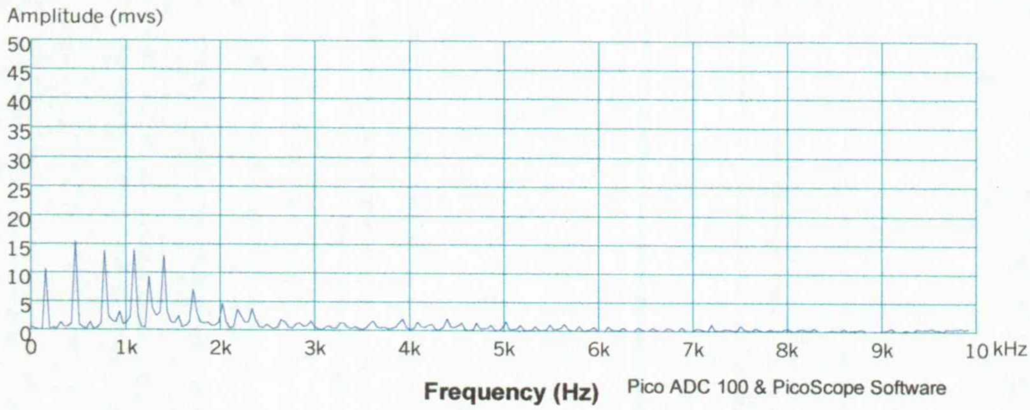
Test 1e **PZM @ 25cms from the bell**

Graph 23



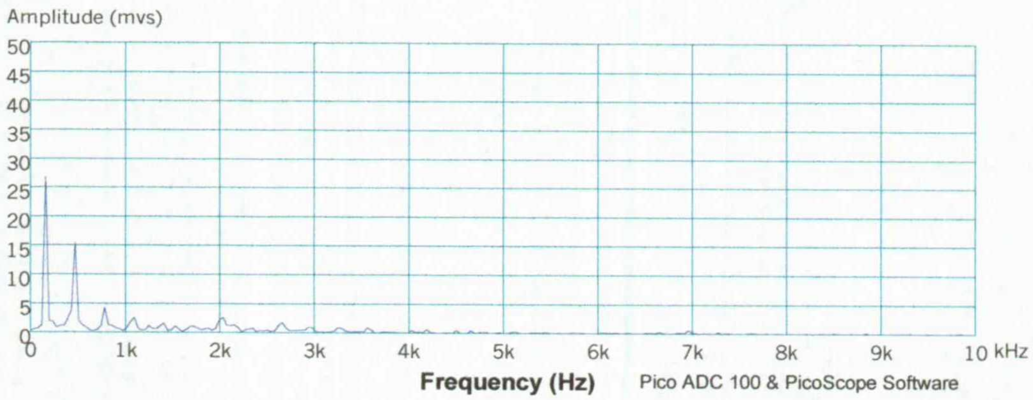
Test 1f **PZM @ 50cms from the bell**

Graph 24



Test 1g **PZM @ 1 metre from the bell**

Graph 25



Results

As predicted, the number of components and the energies associated with them varied considerably depending on whether the mike was placed in front of the tone-hole or below the bell. These findings supported Benade's theory, that a fairly complete harmonic spectrum can be obtained close to a tone-hole.

Test 1a, Graph 19 PZM @ 5cm from the tone-hole

This position gives a typical text book spectral graph i.e. a strong fundamental with all other harmonic magnitudes in uniform downward steps.

Cut-off frequency 3kHz

Ripples up to 5kHz

Test 1b, Graph 20 PZM @ 25cms from the tone-hole

Still a reasonable slope to the graph but the fundamental has weakened. The 3rd harmonic appears stronger, the 5th has almost disappeared whilst the 9th and 11th are both stronger.

Cut-off frequency 3kHz

Slight ripples to 4kHz

Test 1c, Graph 21 PZM @ 1 metre from the tone-hole

A complete reversal of the harmonic amplitudes here.

Cut-off frequency 2kHz (A confusing graph)

Test 1d, Graph 22 PZM @ 5cms from the Bell

The fundamental is strong, followed by a long array of odd and even components.

Harmonics 7,9,11 and 13 are very strong and, interestingly, lie between 1k and 2k where the formant might be exerting some influence. There are other quite strong components between 4k to 6k and 8k to 9k.

Cut-off frequency c.6kHZ

Ripples 8k-9kHz

Test 1e, Graph 23 **PZM @ 25cms from the bell**

Again, a good fundamental and 3rd harmonic. The 7th and 9th are good but all others are becoming weaker.

Cut-off frequency 6kHz

Ripples 4kHz-6kHz

Test 1f, Graph 24 **PZM @ 50cms from the bell**

Complete reversal of the amplitudes of the harmonics. The fundamental appears weaker than the 3rd, 5th, 7th and 9th harmonic.

Cut-off frequency 2.5kHz

Test 1g, Graph 25 **PZM @ 1 metre from the bell**

A return of a good strength fundamental and 3rd harmonic, but absence of upper components.

Cut-off frequency 2.5kHz

Conclusions

The resulting graphs show how recording at the mouth of the bell captures many more upper frequency components together with a good fundamental, than using the position close to the tone-holes. However, the fundamental begins to weaken from a position 25cm away (on a direct line) as phasing conflicts take place. The cut-off frequency appears to fall gradually as the mike is moved backwards, indicating that the upper partials are radiating less efficiently. By the time the mike is 1 metre from the bell, the fundamental has begun to regain strength, with a strong 3rd harmonic, but little upper harmonic presence at all. Good graphs are obtained close to the tone-hole but some upper frequency energy is lost here due to the hole's behaviour as a simple low-pass filter. The hugely varying amplitudes of the components experienced as the microphones change position must be caused by the increasing influence of the room acoustic, by way of reflections bringing about reinforcement, damping, and cancellations. Phasing differences cause harmonic amplitudes to fluctuate wildly and bring about the disappearance of some components altogether. However, for this particular low note, any position in the room beyond 1 metre gives similar uncharacteristic spectral graphs and is almost certainly due to the hole position on the large lower taper used to tune a Boehm clarinet.

Regardless of the positioning of the microphones, the sound on the playbacks was consistently life-like, yet marked differences manifested themselves in the graphs. This was somewhat unhelpful in the decision making process as to the optimum placing for the mouthpiece experiments! It was possible that any position below the bell should be avoided, since, when the tone-holes further up the instrument come into use, so the effect of the bell changes and some of its filtering functions are transferred to the tone-hole lattice below the note being played.

Although some upper frequency components are lost when miking close to a hole, this position does give a broad band of components with a reasonably high cut-off frequency and this has the advantage of eliminating reflections and other room acoustic problems. This also presents a clear, regular graph from which to begin the work of detecting change in harmonic structure brought about by changes in design. There appears to be no advantage in going any closer than 5cm, as there is little or no change to the spectral graph. Additionally, if the microphone is set too close, the note's ability to speak is affected. The 25cm position may be better when recording and analysing the instrument as a whole, in that a clear, ordered, step-like progression is still present, but with stronger 3^{rd} and 7^{th} harmonics. Going beyond this distance seems to create havoc with the spectral graphs of notes in the low register of the clarinet, reflections, damping and reinforcements causing the graphs to differ widely in some cases.

The experiments were confined to low F_3, a note on the bottom flare of the clarinet. Although this note usually has a robust, solid tone on a fine clarinet, uncharacteristic spectral graphs are obtained when it is recorded under normal conditions (microphone a short distance from the instrument). Reliable spectral graphs can be obtained when recording close to the low F tone-hole, but experiments were needed to discover if this would be the case for the rest of the instrument. The research continued with simple tests to discover more about the way in which microphones record sound radiating from a clarinet.

Clarinet Sound Radiation

The experiments with the artificial embouchure used a clarinet length tube with a 15mm bore. A typical bell (Buffet) was fitted to the end and a tone hole drilled to produce low F_3 (156Hz). The tube also incorporated the usual outward taper in the lower end of the bottom joint, continuing into the bell. The following work was designed to assess the effect on spectral graphs of a microphone's proximity to the tone-holes over the whole four octave range of the instrument. The distances from sound source to microphone were being investigated to determine a measurement where a reasonably strong fundamental could be obtained in relation to all the other harmonics and partials, since, as will be shown later, the internal spectra always have more powerful fundamentals than any other component. The 'close to tone-hole' set-up also gives a sturdy fundamental for each note, therefore external spectra that have middle and upper harmonics stronger than the fundamental are almost certainly being seriously influenced by reinforcements and cancellations brought about by the room acoustic. Erratic graphs may well be the result of the microphone being in the wrong position. Finding the optimum position for the mike at around 1.5 metres (the closest the instrument is likely to be listened to in a concert or teaching situation) where stable, consistent and logical spectra can be obtained, is reliable for comparison of clarinet tone. The set-up has to be adhered to consistently if meaningful data is to be obtained from a series of related experiments.

These suggestions for mike positions are not intended to be taken as definitive placements for general recording however, as experience in the recording studio has shown that pop, jazz and rock engineers usually favour as close a microphone placement as key noise will allow, whilst classical engineers use microphones positioned at some distance from the instrument, often several metres.

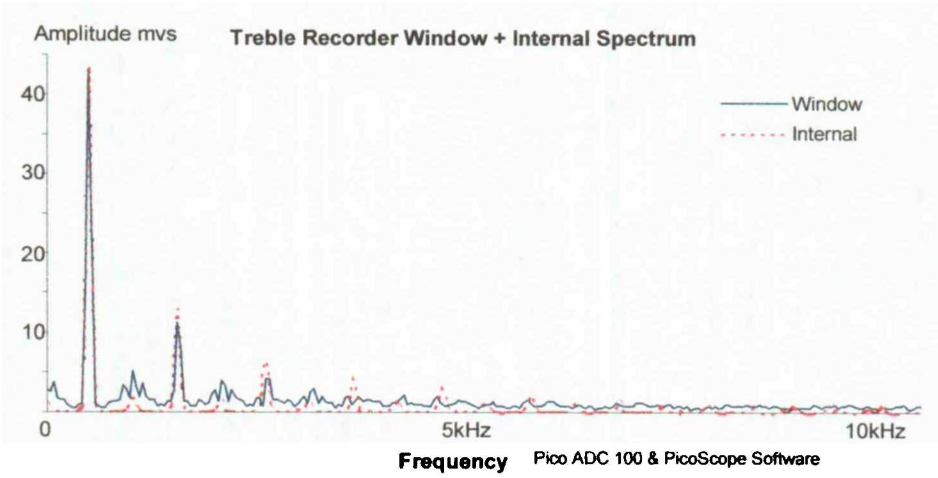
At this stage in the research it was difficult to state with any certainty, which method would give spectral graphs that gave the most faithful representation of the clarinet's tone.

John Martin [Martin, John. 1994] has produced a valuable thesis on the differing patterns of radiation of harmonics emanating from the recorder when microphones are placed at varying distances from the sound source. He encountered the same problems as myself and considered various solutions. The recorder has three point sources which can be investigated: the window (the opening where the air jet passes out of the windway and strikes the sharp edge 'lip'), the tone-holes and the pipe-end. Bearing in mind the problems associated with microphone positions, Martin decided to take measurements with the microphone close to the window, believing that this would reduce the effects of radiation from open holes, the open end and room reflections, making the task of taking measurements relatively easy. The enthusiasm for opting to record at the window is understandable, but there is a danger that the spectrum obtained here is going to be similar to an internal spectrum and therefore at variance with the external spectrum found at a tone-hole, pipe end or a combination of the two. Martin found that the graphs obtained from a range of recorders of different design were, not surprisingly, very similar, and he put this down to the fact that they all belonged to the same family and were, after all, all recorders. This could also be said to be true of clarinets whose unique sound is easily recognisable, but where the difference between individual instruments may be less obvious. Martin did discover certain resonance peaks present in one instrument yet lacking in another and found that this agreed with his perception of timbral differences between the instruments when listening to them.

The following graphs (Nos. 25 - 27) were obtained in an experiment to compare the recorder spectra taken from the three point sources and the internal spectrum. The internal measurements were obtained with a probe microphone positioned just behind the lip at the top of the bore. Each graph compares the window spectrum with each of the other three.

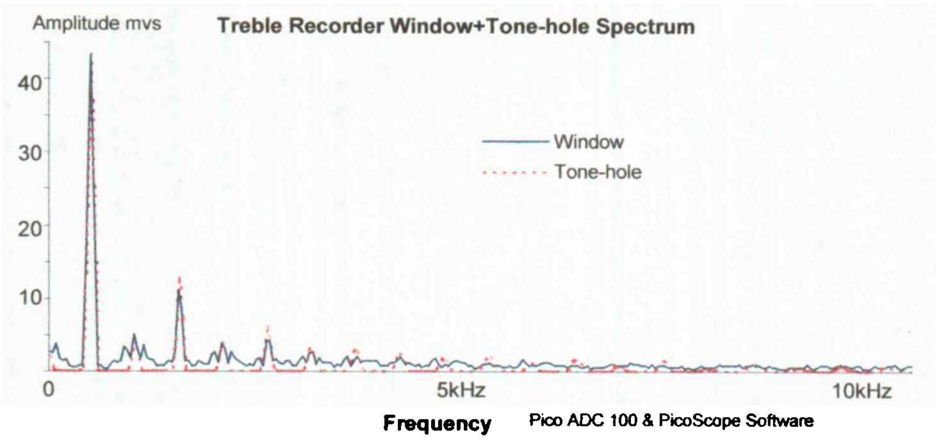
Test 2a

Graph 26



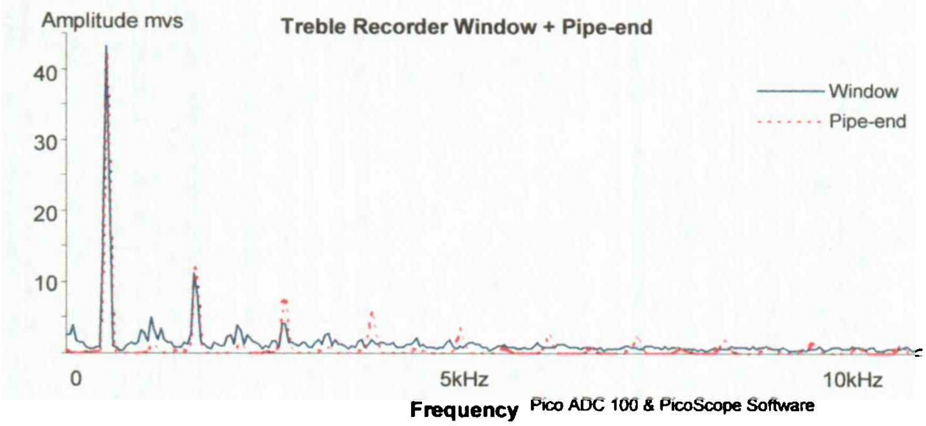
Test 2b

Graph 27



Test 2c

Graph 28



These results suggest that there was more harmonic activity in this recorder than would have been assumed had the data from the window alone been considered.

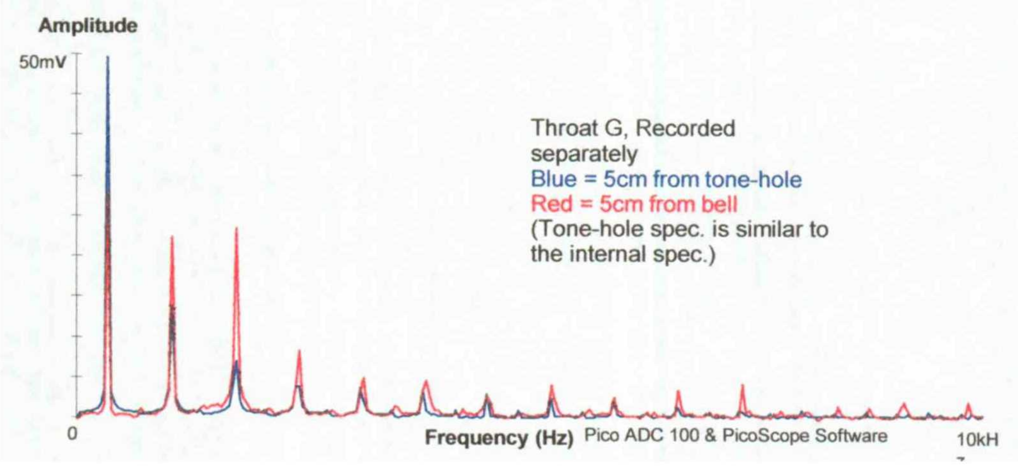
Much can be learnt from the internal spectra, but this may be more to do with the functioning of the primary region of excitation at the head (all wind instruments) than the eventual sound emanating from the instrument, transformed by the bore and the tone holes. The differences in the resonance peaks in the recorder spectra were possibly brought about by the design of each individual windway and 'lip' (different in each example) rather than by the overall design of the instrument.

The subject of the internal spectrum is covered in more detail later in this chapter.

Unlike the recorder which has three source points which radiate sound, the clarinet has only two, the tone-holes and the bell. The recorder is fortunate in having the window option for recording, since, although not without problems, it offers the opportunity to record from a single, stationary point and gives a spectrum that shares similar attributes with the internal spectrum. But for the purposes of this research we are interested not only in the harmonic components which radiate more efficiently in one direction or another, but also in the contrasting spectrums observed close to each sound source. It follows that, if sound components radiate in more than one direction, then a method of capturing this radiated sound should be found. It would be reasonable to suppose that the two-point source of radiation from the clarinet may make this easier. Unfortunately, recording close to the tone-holes would necessitate moving the mike for every single note. This leaves the bell. We now know that a higher proportion of upper frequency components emerge from the bell than from the tone-holes. The following graphs show the results of experiments to see if the output from both sources could be combined to give a complete and reliable spectrum. The results from the artificial embouchure with the tube vented to produce low F_3 156Hz show that if the mikes are positioned close to the two source points and the gain from the mike at the bell end is increased proportionally, there is a serious effect on the spectral graph. Phase differences reduce the apparent energy in the fundamental and 3rd harmonic whilst reinforcing some of the middle band harmonics and increasing the upper frequency components. Moving the bell microphone back approximately 35cms reduces the phasing problem associated with the fundamental and 3rd harmonic whilst retaining the upper frequency activity. Moving the bell microphone a further short distance has a destabilising effect on the combined spectrum as phasing differences have re-established themselves and changed the apparent output.

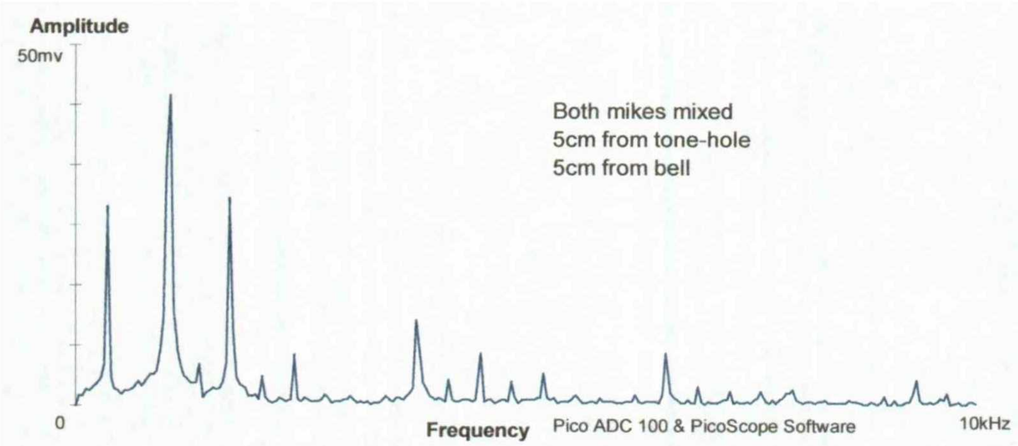
Test 2d

Graph 29



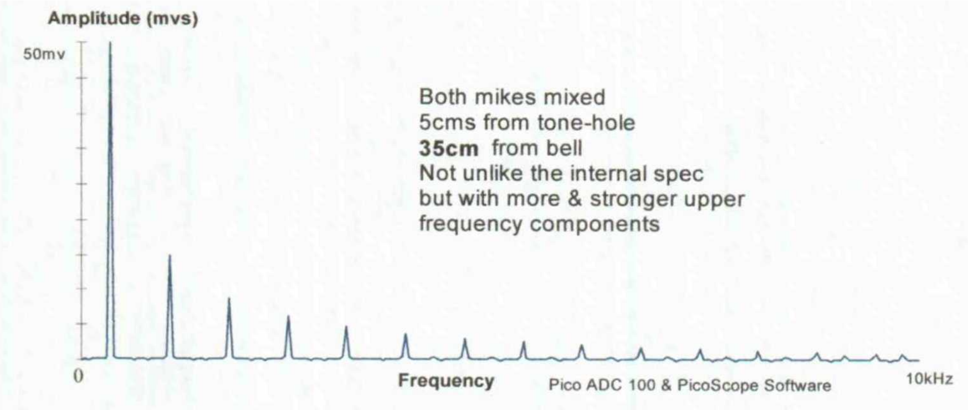
Test 2e

Graph 30



Test 2f

Graph 31



Conclusion

1. Combined, close miking gives a similar result to recording at the bell alone.
2. Microphone 35cm from the tone-hole gives similar spectrum to bell alone.
3. Microphone 35cm from the bell rim gives a similar spectrum to 'close to tone-hole' alone but with increased upper frequency activity.
4. Microphone 1m from the bell or 1m from the tone-hole is poor, beyond 1.5m is much improved.

These results place a serious question mark over the viability of using a 1m recording distance for work aimed at analysing the structure of the sound. Also, as phase problems are different for each wavelength, employing two microphones in the vicinity of the instrument would appear to over-complicate recording techniques. However, multi-miking should not be dismissed because, as shown below, it is helpful in producing stable results at distances over 1.5m from the instrument.

Overall microphone response was now investigated, substituting the length of tube with the R13 Buffet clarinet.

Equipment

Buffet R13 clarinet, small bore mouthpiece (lay 1.10mm x 20mm) & No.3 reed
Pico ADC100 + software (real-time spectrum analyser).

Results

Low register

E_3 Little effect between 5cms and 1 metre (this is a bell note anyway).

F_3 Problems recording at the bell end. Best fundamental 5cms from tone-hole.

G_3 Best fundamental at <u>less</u> than 5cms. Mike at bell shows strong 7th harmonic. Harmonics 3-13 strong at 1 metre. This can be a problematic note on a Boehm clarinet due to inadequate venting of the hole. Some players have resorted to drilling an additional hole which opens alongside this one to improve projection and tone of the note (double venting). German clarinets have this feature as a matter of course.

A & Bb^3 Less directional than previous notes but best at 10 - 20cms.

C^3-Bb^4 Best fundamental at over 1 metre.

Middle register

Effects on the 2nd register might suggest that it is best to avoid all bell microphone positions for all notes except bell-note B^4. The bell amplifies the 3rd and 5th harmonics in most cases. Best placement is between 20cms-50cms from the tone-holes in this register. The bell often has the effect of damping the fundamental, in other words, of behaving like a high-pass filter.

High register

Again, the bell acted like a high-pass filter whilst also amplifying the 3rd harmonic in most instances. Positioning the microphone closely in front of the clarinet produced very good results with characteristic graph shapes. In this register there was little difference moving back to 1 metre because, as one would expect, the higher the fundamental and all other components, the smaller the damping or reinforcing effect of the room acoustic. The 3rd register wave components radiated with little interference.

During these experiments using two microphones, I stumbled on an interesting situation when switching off the mike next to the tone-holes. Using the PZM alone 70mms from the bell mouth, I found that it was possible to obtain relatively strong fundamentals over the whole range of the instrument, with a broad band of upper frequency components (allowing for the occasional poor quality note that spoke less easily). This position avoided many of the problems caused by phasing which had been experienced in some of the previous set-ups and may prove to be a worthwhile option when using the artificial embouchure as the instrument is held in a fixed position allowing the mike to be placed accurately. The common practice of adding fingers of both the left and right hand to improve the quality of throat notes G#, A and Bb produced a marked increase in upper frequency components and a realigning of some middle band harmonics (3,5,7 & 9). Since these upper frequencies radiate efficiently from the bell, perhaps this microphone location should be considered seriously as one of the best places to record the instrument. Measurements at the tone-hole might be best reserved for investigation and analysis of tone-hole features such as undercutting, sizing and venting.

This research, using the artificial embouchure, Buffet clarinet and microphones has raised many questions as to the optimum mike placements. At the outset of my research I had placed the microphone at 1m distance and I had become increasingly disturbed by the resulting spectral graphs which were very confused, particularly when change in timbre could clearly be heard and sensed (as in the simple 'adding of fingers' experiment, the technique players use to add resonance to the throat notes). The PZM mike experiments showed that when using the closer set-up (70mm from the bell), marked changes to the spectral graphs could clearly be detected when subtle changes were made to breath pressure, lip pressure and position or change of fingering. Surprisingly, this was with the mike in a position where I had least expected to detect changes.

Internal Mouthpiece Spectrum

In addition to the methods of recording and analysing the clarinet's external spectrum, it was useful to be able to look at the 'internal spectrum' of the instrument. By this is meant the sound generated inside the mouthpiece by the oscillation of the reed and coupled to the standing wave in the bore. To do this, a means of penetrating the inside of the bore was required that would not disturb the instrument's natural regime of oscillation. Benade describes an excellent system for achieving this, using a probe microphone. The equipment set-up for this type of measurement can be found in the joint paper by Benade and Larson [Benade,1985]. It was with reference to this paper that I set about making experimental probe microphones to insert directly into the mouthpiece. Benade and Larsen used a 52mm length of hypodermic tubing which had an internal diameter of 0.58mm, coupled to a 1000Ω dynamic earpiece. This was connected to a tape recorder via a multiple-RC equaliser/attenuator, adjusted so as to ensure that the upper partials were kept well above the tape recorder noise. The probe tube was introduced into the mouthpiece through a small screw adapter which could be blanked off when the probe mike was not required. The hole for the adapter needed to be at a sufficient distance from the tip of the mouthpiece to avoid reed noise in the tone-chamber and not hinder the forming of a correct embouchure outside but had also to be above the end of the true bore of the instrument to avoid coinciding with the pressure node.

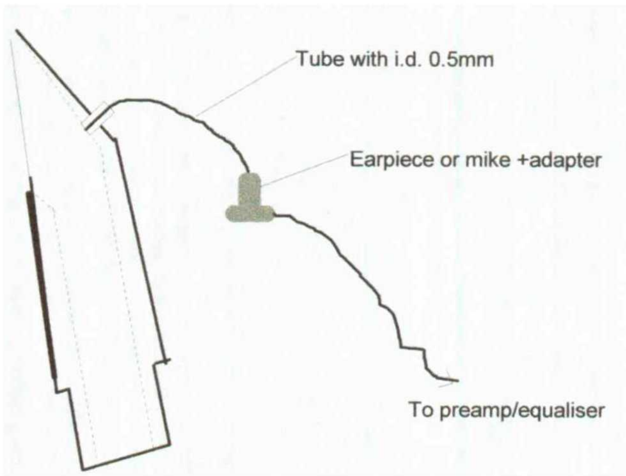
There was some difficulty in obtaining a dynamic earpiece with an impedance as high as the one used by Benade and Larsen. It was certainly important that the musical impedance of the set-up be very high so that no perturbation effects could be detected by the player or affect the overall performance. This musical impedance was achieved by using a short length of very small diameter tubing (0.5mm) as the probe part of the transducer (earpiece). I experimented using various earpieces and microphones offering different electrical impedance and found very little difference in the results.

The first step was to choose a mouthpiece and gather together pieces of tubing and various sizes of plastic rod to make the components of the probe; these included a small electret microphone and a high impedance crystal earpiece. A 5mm hole was drilled into the centre of the baffle 25mms from the tip, as suggested by Benade and Larsen, and this was tapped with a 6mm x 1.0mm thread (M6). An adapter was made from black nylon rod to screw into the hole. The adapter was first drilled with a 0.5mm hole. Several different diameter tubes were tried throughout the experiments but the best results were eventually obtained from a 50mm length of electrical wire that became a 0.5mm diameter tube once the inner wire was removed. The larger sizes of plastic rod were used to machine adapter/holders for the microphones or earpieces. Although the electret mike appeared to be doing its job and produced a respectable looking spectrum, the amplitudes of the frequencies seemed to be frozen at one level. The measurements were either full on or decidedly OFF! In addition, the recorded sound from the system was appalling. There was obviously a mismatch here. This was also the case, although to a lesser extent, with the crystal earpiece. The amplitudes from the earpiece did vary according to sound pressure levels, but this too transmitted poor sound. It was therefore obviously unsatisfactory to base assumptions about the sound structure of the internal spectrum on such a poor transducer. The problem with the electret microphone lay with the fact that it relied on pressure differences rather than a travelling wave, and this set-up presented the microphone with either high pressure/low flow, or no pressure at all.

A dynamic transducer was the only type likely to work properly. Several types were obtained, including a small 8Ω dynamic earpiece, a small 600Ω microphone insert and a high impedance crystal microphone insert. Adapters were made for each, so that a comparative study could be made.

Fig.10

Probe Microphone



The equipment list was as follows:

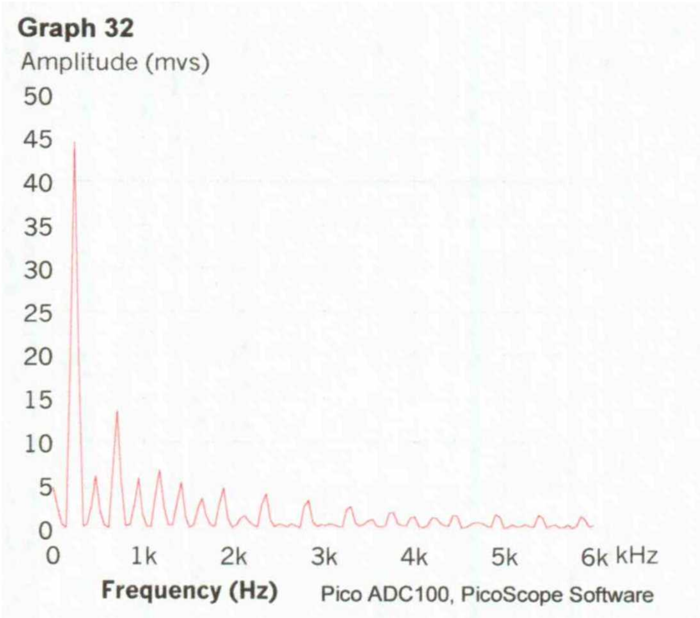
1. Louis clarinet and Louis mouthpiece with slightly oversize bore. Lay 1.10 x 20
2. Tube and adapters
3. Microphone amplifier/equaliser, Omega Electronics EQ-2S, 34dB gain(flat), Output impedance 5kW, Input impedance 50kW
4. Dynamic 8W earpiece, dynamic 600W mike insert and crystal mike insert (Maplin)
5. Realistic 4 channel mixer
6. ADC 100 A/D converter + Picoscope software, pentium computer

Test 3

The following graphs show the results of playing the same note, C_3(Bb) 233Hz, and using each transducer in turn to gather the data. The graphs are surprisingly similar when bearing in mind the distortion from the crystal earpiece. The explanation for this lies in the fact that the averaging facility within the Pico software eliminates the effects of noise from the data and shows how important and useful this feature can be. Nevertheless, the use of the crystal earpiece was ruled out. The dynamic earpiece worked very well and responded accurately to sound pressure changes. It also had the advantage of being light and inexpensive. The only drawback with this device was its small output which necessitated the use of a preamplifier. The larger dynamic microphone insert produced almost identical spectral results but had an output which was more than 10dB higher, making an extra pre-amp unnecessary. This meant that the whole system afforded a better signal to noise ratio of around 75dB.

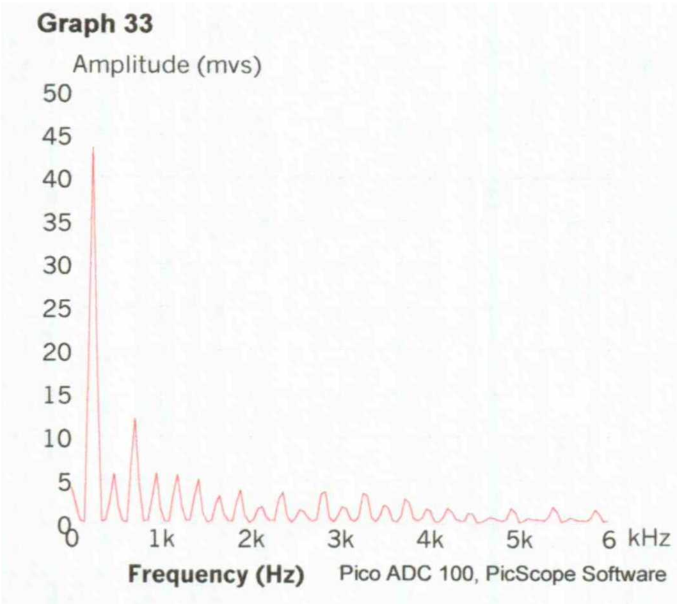
Benade's graphs exhibit a noise threshold of -50dB. I measured my system's noise threshold to be consistently below -60dB, even when pre-amplifiers and soundcard settings were at maximum gain, this ensured that the upper partials were well above any system noise.

Test 3a



Louis Clarinet, crystal earpiece, internal spectrum, Hamming, averaging, 233Hz (mv)

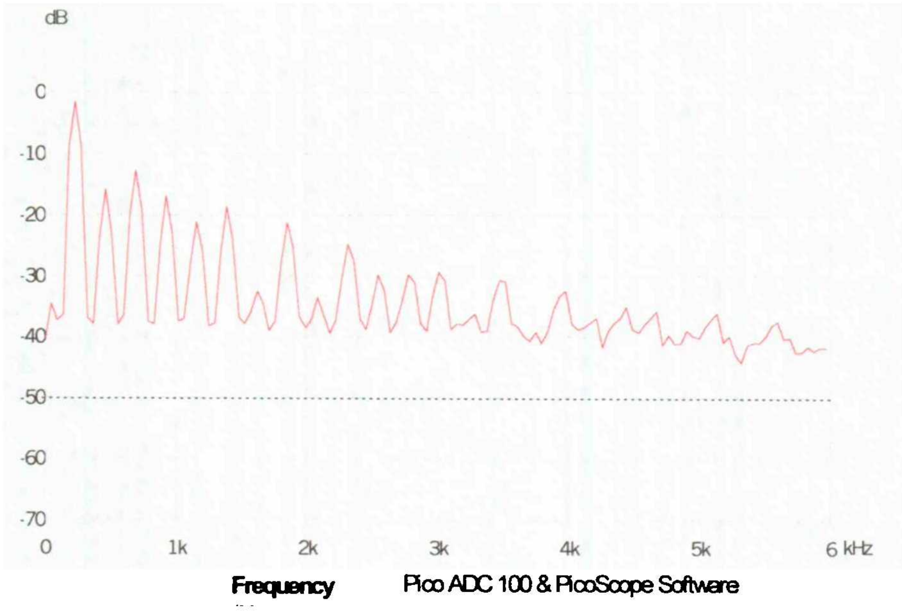
Test 3b



Louis clarinet, dynamic earpiece, internal spectrum, Hamming, averaging, 233Hz (mv)

Test 3c

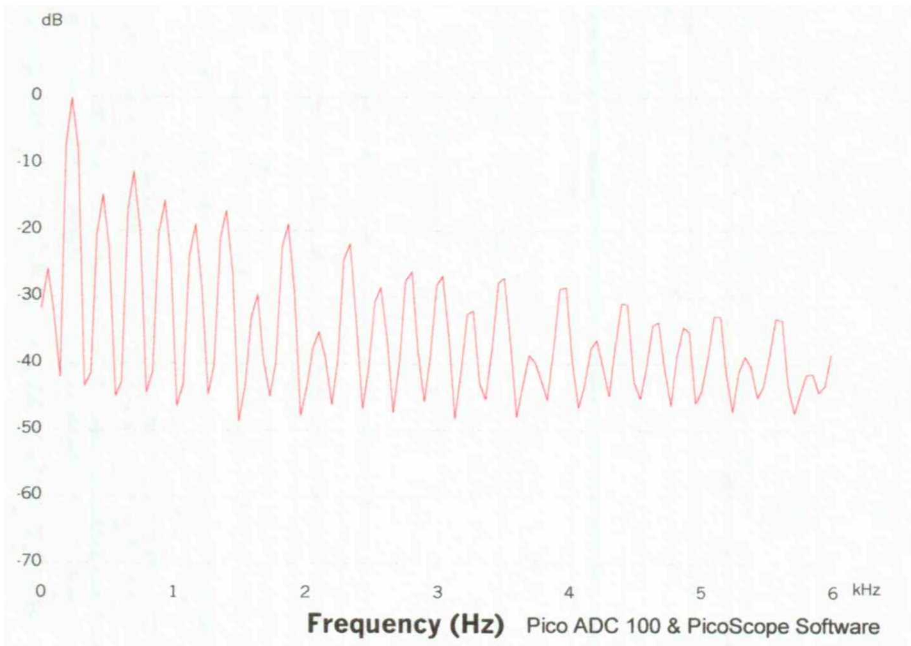
Graph 34



Louis Clarinet, Crystal earpiece, Hamming, Averaged, (dB)

Test 3d

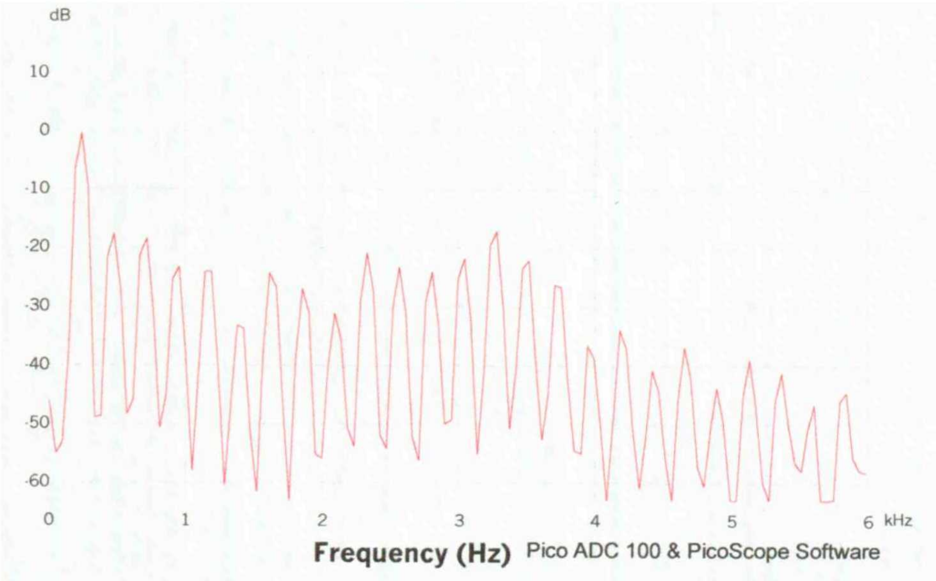
Graph 35



Louis Clarinet, Crystal earpiece, Hamming, Averaged, (dB)

Test 3e

Graph 36



Louis Clarinet, Dynamic earpiece, Hamming, Averaged, (dB)

As can be seen, the first two graphs (G31 and G32) use a y-axis calibrated to a millivolt scale and the subsequent graphs a logarithmic (dB) scale. It is a matter of taste as to which method is used to display data. A third option could be to convert values into percentages, where the harmonics and partials are expressed as a percentage of the power of the fundamental. Ultimately, it is for the researcher to decide which is the easiest to interpret. In 'real-time' analysis where the FFTs are being calculated fast enough for the graph to be an instant reflection of the sound as it is being performed, it is often clearer to see changes occurring in the millivolt or percentage mode. However, the dB scale is more akin to the way in which the ear hears the sound and, in addition, it usually enables a check to be made on the noise level existing in the system. I used averaging throughout. This is a good practice when looking at steady state tones since it ensures the elimination of rogue results and diminishes the effect from noise. The choice of 'windowing', Hamming, Blackman, Rectangular etc., is, again, a matter of preference. Rectangular windowing tends to be good for precise frequency measurement, whereas Blackman reduces the sidelobe effect. If the equipment allows for different forms of windowing then it is a good idea to double-check results in several of the options. In practice, I found little difference between them, hopefully indicating safe and precise data acquisition. Rectangular and Hamming usually results in clear, sharp peaks in the Pico software.

Initial observations of the internal spectrum

The internal spectrum of a clarinet is very different from the external spectrum. However, variation in the internal spectra between instruments is very small, but the results from my own experiments using two different makes of instrument (Buffet and Louis) show that differences are detectable. The similarity, as demonstrated in these tests is perhaps not altogether surprising since the same mouthpiece and reed were used in conjunction with clarinets sharing approximately the same bore size and similar overall dimensions. Nonetheless, the differences which do undoubtedly exist between different makes of Boehm system clarinets can be quite subtle and are to do with small variations in bore perturbation, tone-hole dimensions, tone-hole undercut and minor changes to the hole placements. Other factors such as wall thickness which dictates the tone-hole chimney height, size and position of the speaker pipe and even the degree of polish on the bore, will all contribute to an instrument which has a totally different feel and playing properties. An extreme example of this can be demonstrated by attaching a clarinet mouthpiece to a soprano saxophone. This does not make the sax sound like a clarinet. It does not sound very good, but it does still sound like a saxophone. It is the instrument's unique design which transforms the internal spectrum into the external spectrum. Benade describes measuring the internal spectra of two contrasting clarinets and obtaining the same results from both [Benade, 1985]. Repeating the experiment some years later using the same instruments, he obtained almost identical results. This is remarkable since the reeds would have been totally different if nothing else, and it demonstrates the consistency of clarinet sound production. Benade was not implying that his instruments sound the same to the player or listener, simply that the internally generated tone was almost identical at the outset. The internal spectra obtained in my own work closely matched Benade's (up to 3kHz) but showed variations between the two clarinets in the very high upper harmonics and partials. Benade often quotes a relatively low cut-off frequency for notes on the clarinet of 2kHz - 3kHz and sometimes even lower. Analysis does show a sharp drop in the power of components in this region and this is especially clear when viewed in a graph with a dB scale. If activity above this notion of cut-off is ignored, then all internal clarinet spectra will look alike. Clearly a mouthpiece can alter the playing properties of a clarinet by changing the tone and dynamic response and this change must surely be reflected in the internal spectra.

In my experiments, the internal spectra were extremely stable and remained consistent. The probe mike data displayed on a dB scale shows the marked downward fall in amplitude of the frequencies from 2k - 3k where Benade suggests clarinet cut-off frequency often occurs. Upper frequency activity can be seen above this, but in the main is 50-60dB below the magnitude of the fundamental and very quiet indeed. Although the magnitude of these components is small, I believe that they can have a significant influence on the timbre. When comparing differences between spectra resulting from different clarinet set-ups, a linear millivolt scale for the amplitude of the harmonics can be easier to interpret. The marked, downward step in the logarithmic scale is less abrupt when the powers are expressed as linear voltages. With this scale, upper frequency activity, up to 12kHz and above, can be detected at the onset of the sound. The amplitudes are very small, but the broad band of frequencies can be observed like a long running ripple which appears immediately the sound begins. It is here that discrepancies between different clarinet/mouthpiece set-ups can be observed, especially when the graph is magnified. If this upper frequency energy is acknowledged, then a significant amount of 'brightness'[1] must be present in the tone. This seems to be substantiated by my earlier research, and, more recently, by results from work on the internal spectrum where the internal dimensions are shown to influence the inner harmonic content. If the sum of the amplitudes of these upper components is used when calculating a tristimulus graph, then the co-ordinates are changed and the image representing the timbre radically altered.

---

[1] Brightness might sometimes be interpreted as harsh or rough.

Detecting small changes in timbre with the probe microphone

To verify that the probe mike could be used to detect changes brought about by small alterations to the internal dimensions of the mouthpiece, BluTac was placed in the recess under the table, replicating one of the designs investigated in Chapter 11. This design feature has been thought by some players and makers to help produce a smoother tone. The late George Howarth and his son Jim, both respected English mouthpiece makers, believed in leaving material in the recess and filing a blunt edge at the base of the window.[2] They maintained that this encouraged a mellow tone. The following graphs demonstrate the curious effect of this intervention on the external and internal spectra.

The first graph (Test 4a) is the external spectrum, recorded close to the throat G tone-hole, before the introduction of the BluTac. Although fairly similar, the Louis has stronger upper frequency harmonics and partials. The data collection was repeated to ensure the accuracy of the results.

The second graph (Test 4b) shows the disturbance brought about by the introduction of the BluTac. In both clarinets the 2nd even harmonic has diminished. In the R13 mid-band, even harmonics have all disappeared or been greatly reduced whilst the 5th has grown in strength. The overall effect on the R13 has been a thinning out of the even harmonics, a slight strengthening of the mid-band range of components and a small rise in the cut-off frequency. The most significant change to the Louis was the loss of the 2nd harmonic, a lowering of the 3rd and an increase in the 5th and 7th. The mid-band activity was again stronger and cut-off frequency raised, as with the R13.

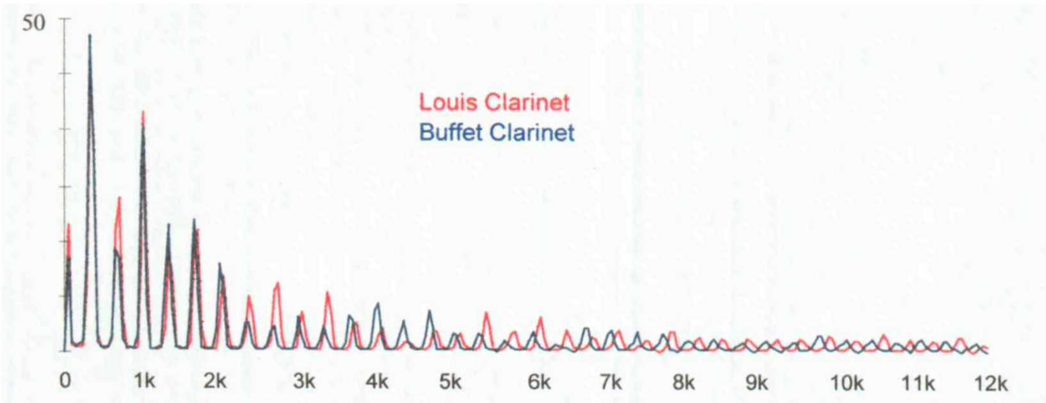
---

[2] Richard Addison owns a bass clarinet mouthpiece made by George Howarth (the date this was made is uncertain but probably during the 1930s or 1940s) which has a large amount of material in the recess. The result is a much smaller, almost square aperture into the bore and a very thick, blunt edge at the bottom of the window. However, the tone is remarkably clear.

Test 4a

Graph 37

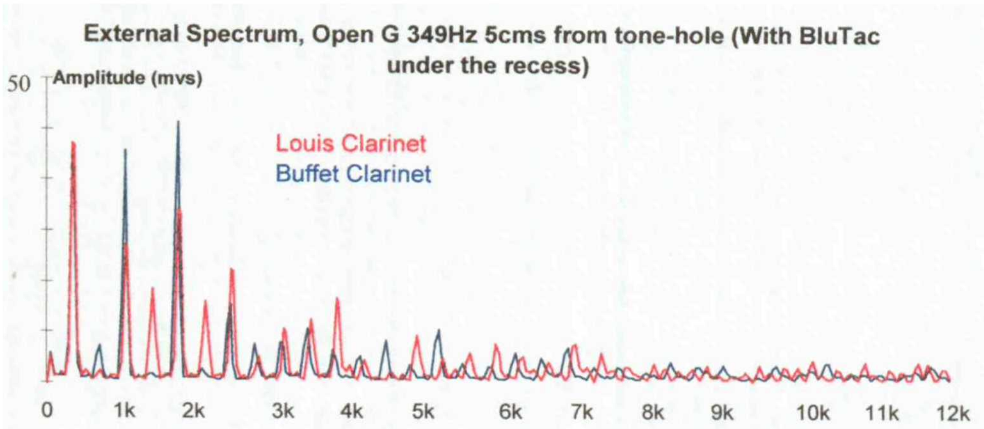
Amplitude (mvs) **External Spectrum Open G 349Hz 5cms from tone-hole**



Frequency (kHz) Pico ADC 100 & PicoScope Software

Test 4b

Graph 38



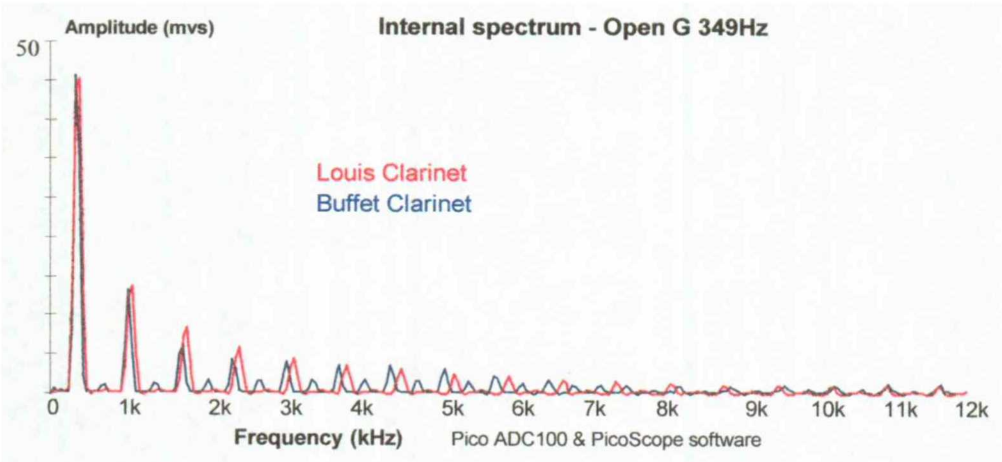
Frequency (kHz) Pico ADC100 & PicoScope Software

In the following graphs of the internal spectra (tests 4c and 4d), the effect of the BluTac has been to align all the amplitudes of the harmonics in both clarinets. In the graphs without BluTac the Louis instrument has stronger 3rd and 5th harmonics, an absence of measurable even harmonics and a slightly higher cut-off frequency. The R13 is flatter in pitch (verified by pitch meter) and shows clear, even harmonic activity, growing in strength towards 4kHz and diminishing again towards cut-off. The extraordinary phenomenon observed in the spectra with the BluTac in place is the rapprochement of the two instruments; the even harmonic components are now the same, and level throughout. The most significant change is the identical lowering of the cut-off frequency to below 5kHz in both clarinets.

This evidence would seem to lend credence to the belief that less recess and a blunt lower edge to the window makes for a smoother, more mellow sound. Conversely, to increase the 'fizz' and 'buzz' in a clarinet, the recess needs to be deeper and the window edge sharper.

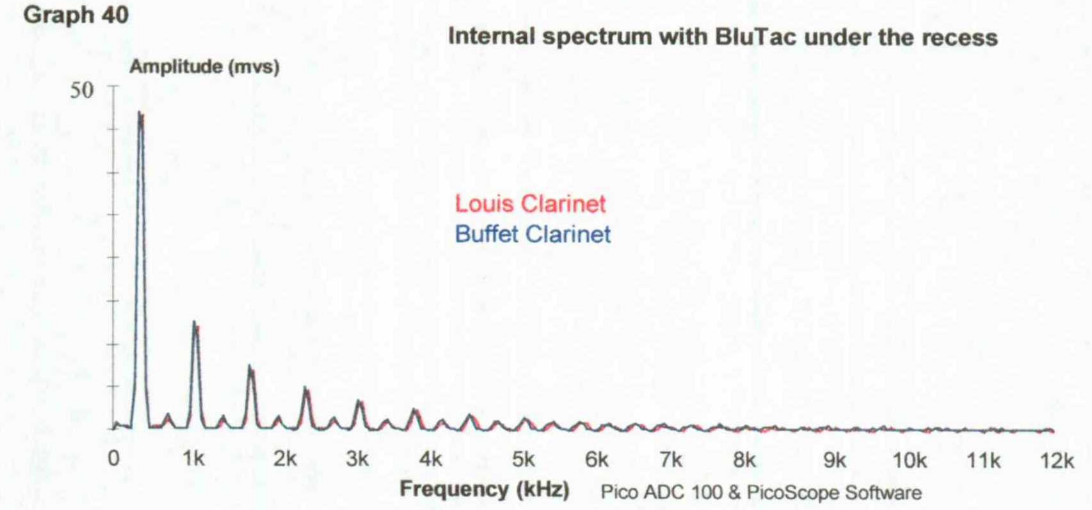
Test 4c

Graph 39



Test 4d

Graph 40



The internal spectrum, obtained from the insertion of a fine probe microphone, seems to be a consistent and stable means of data gathering, so long as this is used in conjunction with analysis of the external spectra. In most cases the internal graphs appear to be clearer and easier to interpret than the external, where dependable data is often difficult to collect.

A note on the performance of the Louis and Buffet clarinets (Test 4)

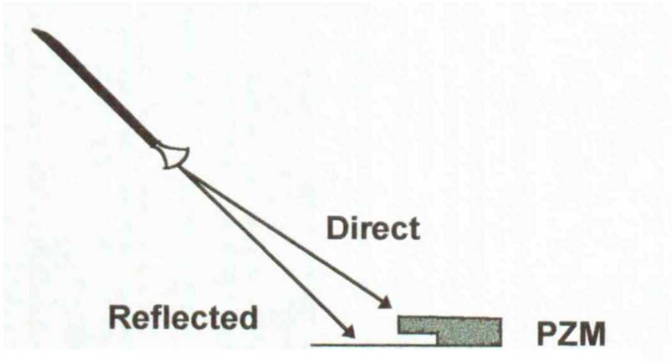
It must be remembered that, although the 'feel' and dynamic response of the two clarinets was different, the tone from both instruments was good and their sound not dissimilar one from the other, especially the throat G which was the subject of a large part of this study. This good tone I believe to be due in part to the design of the mouthpiece which creates a good internal spectrum, but also because well designed instruments exert an extraordinary influence over spectra initiated by the mouthpiece/reed excitation. This influence can bring about dramatic transformations to the 'internal sound' by reinforcing or filtering components and altering the cut-off frequency.

Other Uses of a Probe Microphone

With a probe microphone it was now possible to envisage other experiments, including the ability to examine the harmonic activity inside the mouth whilst playing the instrument (vocal tract resonance). The question of the influence on tone exerted by the vocal tract resonance and the shape and dimensions of the inside of the mouth is discussed in Chapter 7.

The Use of PZM Microphones

The use of PZM microphones helped minimise the incidence of unstable and erratic data often associated with conventional microphone set-ups. After much experimentation, good spectral graphs with robust fundamentals were found by positioning the microphones off-centre and 500mm from two opposing walls, with the clarinet in-between. One microphone was positioned at 1.5m distance facing upwards, the other approximately 2m facing inwards. Any movement by the player now had a minimal effect on the amplitudes of the frequencies in the spectral graphs and much less effect than would have been the case with conventional mikes. The room's small volume, irregular angles and high level of damping helped to keep the resonance low and minimise sound reflection. Pressure zone microphones would appear to be better suited for recordings destined for subsequent analysis than ordinary microphones as they are not hindered by interference between sound coming directly from the source, with sound reflected from the primary boundary (wall, floor or ceiling closest to the microphone). Reflected sound from the primary boundary reaches ordinary microphones later than the sound coming directly from the source. This unwanted interference causes reinforcement of some frequencies and cancellation of others, resulting in an unnatural sound and, more seriously for the purposes of this research, confusing and contradictory spectral graphs. The PZMs eliminate this interference and use a combination of direct and reflected sound to achieve reproduction with a natural quality and very high fidelity. A PZM contains an electret microphone capsule permanently mounted a short distance from its attached primary boundary plate. When sound waves hit this plate, a pressure zone is created in the space between the electret element and the boundary plate. Within the pressure zone, the direct and reflected sound waves are always in phase and reinforce each other. The electret capsule detects the pressure changes in the zone rather than the moving sound waves and is therefore unaffected by the distance or angle from the sound source, as long as the source is within the large hemispherical pattern above the boundary plate.



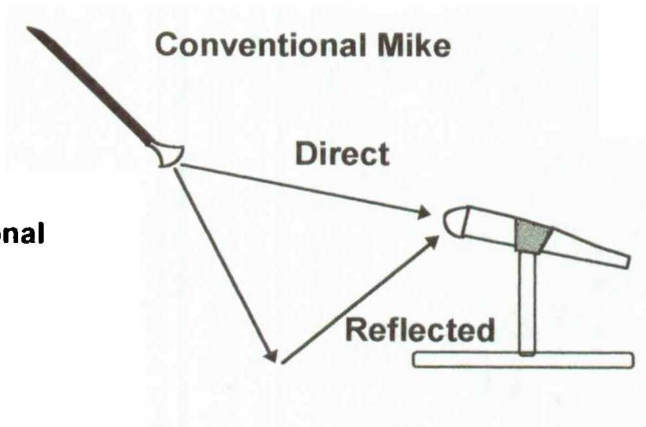
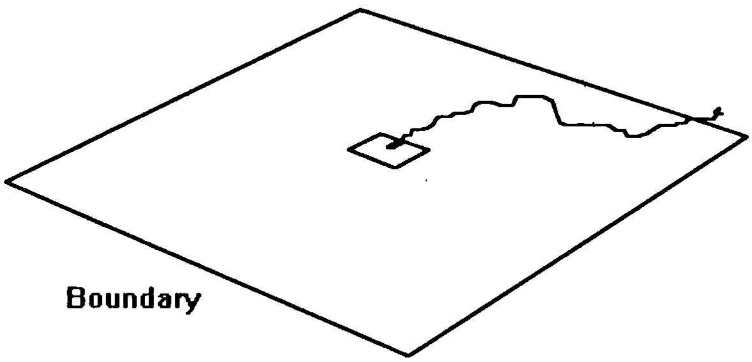


Fig.11

Comparison of PZM & Conventional Microphone Recording Patterns

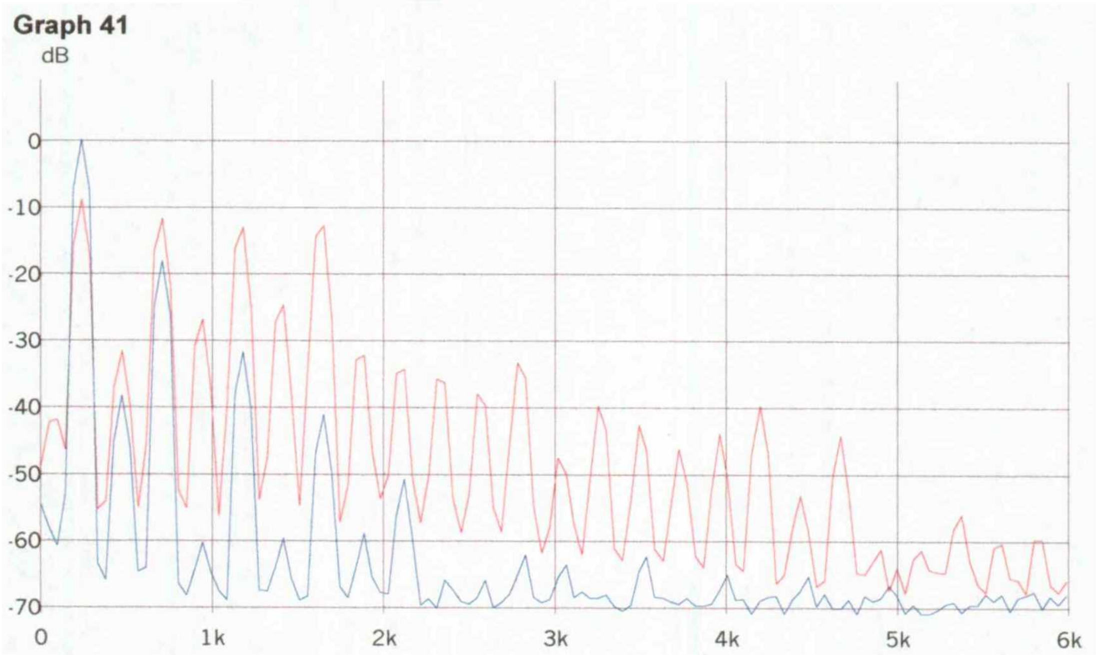
Hemisphere Pattern



Preliminary results suggested that spectral graphs obtained using this method of external recording with PZMs were very good. These microphones and their placing appeared to be a better alternative to close miking in front of tone-holes or beyond the bell.

The following graph demonstrates the difference between the internal and external spectrum. The data was acquired simultaneously with the PZMs positioned as described above.

Experiment using the internal probe microphone and two external PZM microphones simultaneously. Key: Blue - Internal, Red - External



Frequency (Hz) Pico ADC100 & PicoScope Software

Other Microphone Types

1. Dynamic
2. Ribbon
3. Condenser
4. Carbon
5. Crystal
6. Electret

Dynamic and Condenser were the only microphones worth considering; ribbon types were expensive and fragile, carbon gave poor sound quality, and crystal, although efficient and possessing a wide bandwidth, also gave inferior reproduction.

Dynamic/moving coil

A diaphragm attached to a small coil which is free to move between the poles of a magnet. Sound waves hit the diaphragm which in turn moves the coil, generating a small current. Very common and can be of high quality

Condenser/capacitor

A flexible diaphragm forming a plate that is set close to a rigid backplate. The capacitance formed makes one element of an electrical circuit. Diaphragm movement produces a voltage change. A power supply is needed to maintain a polarising voltage across the capacitor. A pre-amp is also needed as this type of mike is of low sensitivity. Usually high quality.

Electret

These microphones are similar to condenser types but do not require a polarising supply voltage as electret is a material that can hold a charge permanently. The electret material is placed between two plates. These mikes also need their own pre-amp, usually battery powered. They are often very small and can be of high quality.

What Form Of Analysis

The sound generated inside the mouthpiece consists of two consecutive portions, the onset transient and steady state.
The onset transient, sometimes known as the attack transient, is the very start of the note where, from the onset of the sound, the note builds up to full amplitude.
Steady state tone is any period during the length of the note, after which time full amplitude has been reached and the note is vibrating steadily.
For the purposes of the research, information needed to be gathered and analysed from both these areas.

Analysis of the steady state tone is relatively straightforward, the number, range and amplitude of the components (true harmonics and all other partials) of the sampled sound being collected and considered. For the purposes of the present research, a form of data acquisition was required that could perform accurate and retrievable FFT analysis (Fast Fourrier Transforms) displayed as spectral graphs.

The onset transient presents a more complex analysis problem. Here, careful study must be made of the sound during the brief time it takes for a note to begin. To the player and listener, the onset transient signifies the articulation of the note, that is, the time it takes for the note to reach maximum amplitude and a steady state regime of oscillation; this accounts for the first 50 or 150 milliseconds of the sound. It is a vital part of the note and that which enables one instrument to be identified more easily from another. It is, for example, difficult to distinguish between a clarinet and a flute playing the same high note until you hear that note articulated, at which point it becomes immediately recognisable. This phenomenon is not surprising, as analysis of flute and clarinet steady state sound in a high register shows that they produce similar wave forms and FFTs (sine waves with even harmonics). The importance of the transient where significant differences are displayed is thus highlighted.

To study the transient, small 'slices' of the tone taken from the very beginning of the note at around ten or twenty millisecond intervals must be analysed. This form of analysis usually requires expensive, sophisticated and powerful tools, but after much experimentation, it became possible to achieve good results using the affordable phasevocoder and short term spectrum analyser within the Vwaves software for PC. This technique could have implications for music technology students, instrument makers and musicians as it is both accurate and affordable, and its development was a gratifying by-product of the present research.

Methods of Data Acquisition and Analysis in the Initial Research

At the beginning of this research, various options for the analysis of tone were investigated. Equipment already available at the LGU was considered and much advice sought from staff. Specialists and data acquisition companies from outside the University were also contacted. Dr. Ragmil Fischman at Keele University was particularly helpful and suggested several approaches. He was also the first to intimate the difficulties which lay ahead.

One of Dr. Fischman's suggestions was The Composers' Desktop Project (CDP) in York. This organisation was keen to help, in particular, Tom Endrich and Richard Dobson. Initially, it was felt that the Phasevocoder and other data analysis programmes supplied by them would be able to do all the work envisaged. Unfortunately, these programmes were entirely without graphics and produced vast quantities of numbers for even the shortest sound. The huge amount of data proved very difficult to decipher and this system was finally abandoned.[3] Nonetheless, the experience of working with CDP and learning how to understand and use digital sampling, processing and analysis was of enormous help later in the research when assessing the efficacy of other analysis products.

DAT Recordings

In the early part of the research where commercial mouthpieces were being tested, DAT recordings were used to store the sound tests prior to analysis. The recordings were of the high quality demanded, but as it became possible to record samples and tests directly

[3] At the time of writing, Richard Dobson was working on graphic versions of the software.

onto the PC hard drive, the DAT recordings became obsolete. This was particularly so once PC software was used for the analysis. DAT recordings were still occasionally used for gathering examples of live playing away from the laboratory, and to retrieve, for example, synthesised clarinet tone sent to me on DAT tape for comparative study.

Artificial Blowing

In the initial stages it was felt that the use of an artificial embouchure in the mouthpiece tests would enable the blowing parameters to be carefully controlled and monitored and the experiments to be repeated accurately and consistently.[4] The artificial embouchure was indeed used for a great deal of the early research and in other investigations, including the survey of commercially available mouthpieces and the work to discover the effects of bore size on tone and response. The device worked better than anticipated and assisted in the compilation of some valuable information.

As the research progressed however, it became clear that some aspects of the procedures were making the work unnecessarily arduous and confusing. At each incremental change effected to the design of a mouthpiece, large numbers of notes were recorded and analysed. This produced vast numbers of spectral graphs for every experiment carried out. The main purpose of the tests was to discover exactly what effect alteration in design had on the tone and response by observing changes in the harmonic spectrum. Unfortunately, every note on a clarinet has itself a unique harmonic spectrum, making comparison between each stage exceedingly difficult, and an overall picture of the effect of the alteration almost impossible to assess.

A different approach was called for. The copious amount of data acquired by the methods adopted at the outset was indeed confusing, but certainly contained within it the information that would reveal the effects on the harmonic structure of any design alteration.

---

[4] A detailed description of this device is contained in Chapter 6, p 52.

An important feature of spectral analysis is the ability to average the results from a series of 'slices' of sound (samples), as opposed to a single analysis being made at one particular point. The advantage of this is to remove the danger posed by a rogue result or an anomaly caused by a poorly aligned window affecting the accurate analysis of the sample. Averaging was used in every spectral analysis performed throughout the present research. An extension of this averaging technique was found to revolutionise the way in which the information retrieved in each test could be analysed, viewed and compared. It was also felt to be a better representation of the impression formed by players and listeners who had been asked to assess the difference in playing properties caused by any kind of alteration in design.

Changing a reed or a mouthpiece affects the performance of a clarinet dramatically. Their influence does not affect all notes equally however. A spectral graph constructed from the averaged amplitudes of all (or a large proportion of) the notes on the instrument smoothes out any unevenness in tone and gives a representative snapshot of the performance of that particular set-up. The technique is helpful when comparing alternative set-ups e.g. German v. French, or where small alterations in design have been made. This kind of graph (Long Term Average Harmonic Spectra) is unlikely to be exactly the same as a graph resulting from the analysis of any single note, nonetheless this method of data processing became a powerful tool in the quest to understand what happens to the harmonic configuration of the sound when small alterations are made to the design. The technique could be applied to internal as well as external component data and also to pressure transfer functions.

Due to the large number of notes, the method used for the final computation of an LTAHS graph was fairly laborious, even when aided by computer macros. A simple, fast method based on programmes capable of automating the procedure fully would have been beneficial. Nonetheless, the advantage of LTAHS was to minimise the effects that uncharacteristic notes might exert on the data. The recording set-up became less critical and it was possible to play the instrument normally, achieving results that showed clearly any change in the harmonic structure .

At the time of writing, the feasibility of analysing a glissando on the mouthpiece alone, from the lowest to the highest frequency possible, simulating a frequency sweep, is being evaluated. This would make analysis of mouthpiece tone production quicker and easier.

Data Acquisition, Analysis Hardware and Software

A well equipped laboratory is not now essential for accurate data acquisition and analysis. Several excellent, inexpensive, plug-in data acquisition modules with powerful software for personal and laptop computers are now available. Acoustical researchers and musical instrument makers both have high resolution digital storage scope, spectrum analysers and frequency meters at their fingertips, with easy transfer of data to spreadsheets and other documents possible. Two types of module were used in the course of the research; the first, a MiniPod from Computer Instrumentation Limited and the other, an ADC 100 from Pico Technology Limited. Both systems used a small analogue to digital converter inside a little box which was attached to the parallel port. The MiniPod plugged directly into the port whilst the Pico ADC was connected via a cable. Both worked well, but for sheer ease of use, good resolution and excellent software, the Pico became the preferred device.

MiniPod 402, 2 Channel 'Scope Pod' and Software

The Mini-POD 402 is a two channel high speed A-D converter for use with accompanying DavScope Oscilloscope display software. Analogue inputs are +/- 10V with 12 bit resolution a typical sampling rate around 40kHz and <1% accuracy.

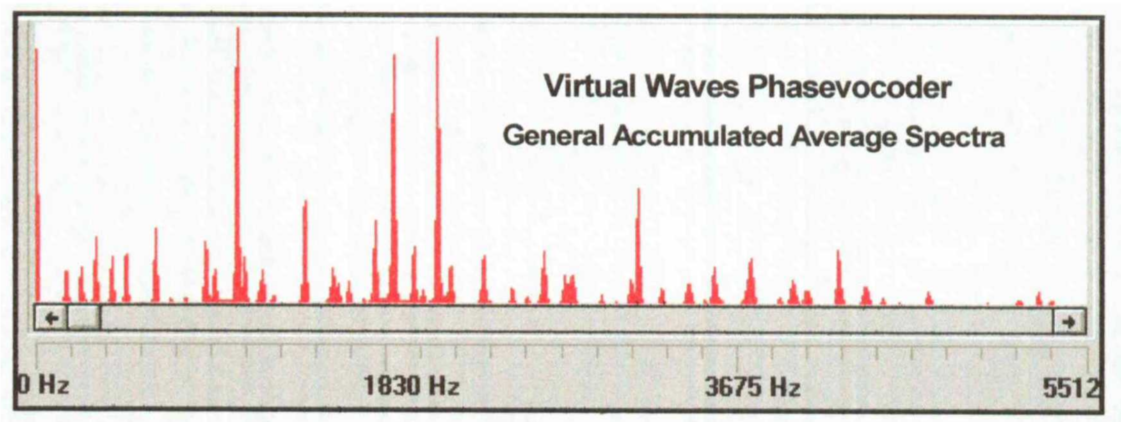
PICO ADC 100 and Software

The Pico ADC 100 offers 100kHz sampling with 12 bit resolution, two channel and a variable input range up to $\pm$20V. The PicoScope software has four virtual instruments; digital storage scope, spectrum analyser, voltmeter and frequency meter. The oscilloscope offers all the usual features including moveable rulers for event timing and annotation of graphs. The spectrum analyser features real time display of amplitude and frequency, linear or logarithmic display and signal averaging.

General Accumulated Average Spectra (GAAS)

The General Accumulated Average Spectrum is an interesting and fast way to view the structure of an instrument's tone. The phasevocoder component of the Vwaves software allows the viewing of the analysed data in several ways; as a simple FFT of the steady state tone, as a 3 dimensional mountain range graph over time, as a two dimensional frequency/amplitude graph at specific intervals over time (useful for study of the attack transient) or as an accumulation of all averaged frequencies in the sample. A GAAS graph could be said to be another kind of 'fingerprint' of an instrument's overall performance, rather like the LTAS graph described later in this chapter. The advantage of using the

Vwaves phasevocoder was speed. The disadvantage was that, at the time of writing, there was no way of exporting the digital information to other applications such as a spreadsheet programme. The phasevocoder did allow the use of a mouse controlled cursor to gather amplitude and frequency from any point on the graph window, although this was a laborious way to collect data.



Tristimulus Graphing Methods

Of interest was the concept of tristimulus graphing as a means of describing timbre simply, either as a steady state complex wave, or by plotting change to the component strengths at timed intervals during the onset transient.[5] It became clear that this might be a useful way of comparing the timbre of the commercial mouthpieces tested and of comparing the tone produced by individual players. As the method requires averaging of the amplitudes of blocks of harmonics and then the calculation of these blocks as fractions of the total (Total = 1 as in a percentage of the whole), it was less crucial that the sound be recorded in exactly the same way or even at precisely the same dynamic, although it was desirable that conditions for the experiments remain constant. The method also appeared to iron out the small changes in the amplitude of the harmonics, or compensate for the way in which these harmonics could become masked. The system allowed for small discrepancies in blowing pressure and made allowances for slight differences in software operation. The calculations refer to the fundamental and other components as a percentage, rather than an absolute measurement in millivolts, dB, phons or sones.

Tristimulus graphs display data as though there are only three components to the sound, Low, Medium and High (in the same way as a television uses only three colours to

[5] There is a clear and concise description of the way to calculate and plot these graphs, and the uses to which they can be put in *The Musician's Guide To Acoustics* by Murray Campbell and Clive Greated.

produce the whole colour spectrum). As there will be a whole range of harmonics in the data these have to be grouped a certain way e.g.

LOW	Harmonic 1 (Fundamental)
MIDDLE	Harmonics 2,3 & 4
HIGH	Harmonics 5,6.7,8,9 upwards (The rest)

Formula

LOUDNESS (amplitude) = N (This is the spreadsheet average)

Fundamental = Nf (Harmonic1)

Middle = Nm (Harmonics2-4)

High = Nh (Harmonics5—>)

Total Loudness N = Nf + Nm + Nh

The proportions of loudness in each of the regions can be expressed as:-

Fundamental $\frac{Nf}{N}$ Middle $\frac{Nm}{N}$ High $\frac{Nh}{N}$

As $\frac{Nf}{N} + \frac{Nm}{N} + \frac{Nh}{N} = 1$, only two values are needed to obtain the third!

Procedure for making a tristimulus graph

Collect wave data several times and analyse as separate FFTs

Export (ASCII) to a spreadsheet and calculate the average (mvs)

Filter out the main components (mostly true harmonics) and create new short sheet

Add all the values of amplitudes of all the harmonics (= total power)

Take the value of the fundamental and divide by the total (= fundamental tristim. value)

Average harmonics 2,3 & 4 and divide by the total (= middle frequency tristim. value)

Take away the result for middle frequency from 1 (= high frequency tristim. value)

On an x-y graph, plot the position representing the timbre using only the middle and high frequency values.

X axis (middle frequency value) max = 1
Y axis (high frequency value) max = 1

It was decided that millivolts be used as the unit of power for the harmonics as these were absolute values transferred from the oscilloscope programme to the spreadsheet. This was instead of 'sones', which are a scale of values for relative loudness. The reason for adopting millivolts may be better understood by a description of sones.

If we first look at loudness in terms of phons,
ppp (extremely quiet) = 30 phons
fff (extremely loud) = 100 phons
Threshold of pain = 120 phons
A perceived halving of the loudness = a drop of 10 phons

Therefore 10 phon steps double or halve loudness

Doubling sones doubles loudness. 2 sones is twice as loud as 1 sone and 8 sones is twice as loud as 4 sones.

i.e. 50 phons = 2 sones
60 phons = 4 sones
70 phons = 8 sones etc.

It was decided not to use sones in the calculation of values for the graphs. Campbell and Greated agree that the numerics need to be treated with some scepticism. Decibels as units of measurement do resemble the response and sensitivity of the human ear more closely and in some research this could be advantageous, but in the context of the present research it would have presented the data in a vague and imprecise manner. Recent tests by Warren (1977) suggest that doubling loudness corresponds to a change of only 6 phons. Ultimately, it matters little which method is adopted providing that the one chosen is used consistently throughout. It is also important to use the same bandwidth and range of harmonics.

Can tristimulus graphs be of any value?

In the tests using the artificial embouchure, values were calculated to enable the plotting of graphs for the most common commercial mouthpieces. It was encouraging (and a relief) to find that the varied spectra of harmonics initially observed proved more consistent once converted into tristimulus values. For the purposes of comparison, it was decided that the same method should be used to quantify the results obtained from analysing recordings of live playing, as the method was less sensitive to variations in set-up .

The reliability and consistency of the method was confirmed by the results of tests on Vandoren mouthpieces. It would have been expected that the harmonic spectra of several Vandoren mouthpieces of the same model, sharing the same bore and tone chamber dimensions, would be similar (discounting the effect of the lay profile). On an initial examination of the bar and line graphs, certain similarities were certainly evident, but not so as to link them immediately to the same family. On conversion into tristimulus graphs, a much more coherent picture emerged. Not only was it now possible to see their similarities more clearly but also to appreciate to what extent Vandoren mouthpieces differed from other makes. The mouthpieces that performed particularly badly showed a vivid picture of inadequacy on a tristimulus graph.

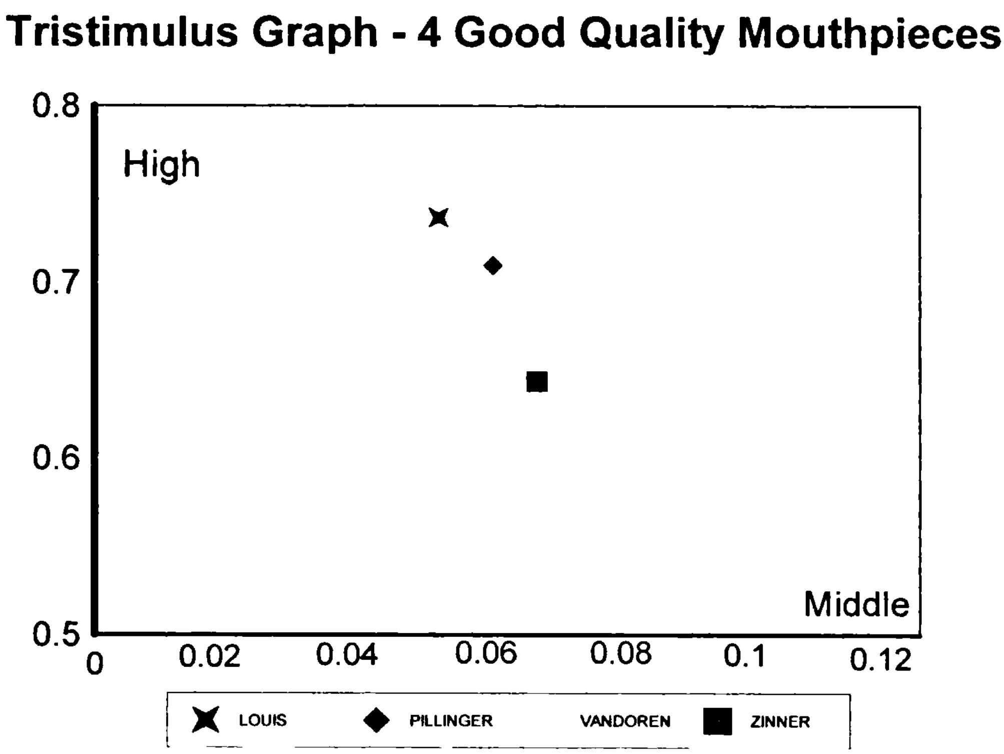
Recordings of live playing which were plotted on a tristimulus graph demonstrated that, although each player performed on a different clarinet and mouthpiece, their tone overlapped in places, with the timbre more alike in some registers than in others. This analysis strongly supported the impression already formed aurally. It also demonstrated the similarity in the perceptions of good tone amongst players, and to what extent skilful players can achieve this on widely differing equipment. It was curious how subtle the variation in tone between the players was, bearing in mind the huge difference most of them believed to exist.

Live playing resulted in a tristimulus graph which presented no surprises, the points on the graph occurring in an area consistent with the balance of middle and high frequency encountered in reasonable clarinet tone. The results from the artificial embouchure were somewhat different; it was later discovered that this was because the mouthpieces had been tested at very high air pressure and the recordings made too close to the tone holes. Recent experiments carried out at lower, more normal *mf* playing pressure, with the microphone positioned so as to capture a more realistic balance of sound from the whole instrument, resulted in tristimulus graphs similar to live playing.

Whilst these graphs did not pinpoint very precisely any alteration to the harmonic structure caused by changes in design, they did show the direction in which the timbre was moving and were helpful in assessing and comparing tone.

In the following example of a tristimulus graph (Graph 42), four good quality mouthpieces have been compared. The x and y axis have been scaled in a way that makes it possible to differentiate between them. If normal scaling had been used, the points would have overlapped. Although the tone was very similar, the graph shows the Zinner to be the darkest and the Louis to be the brightest.

Graph 42



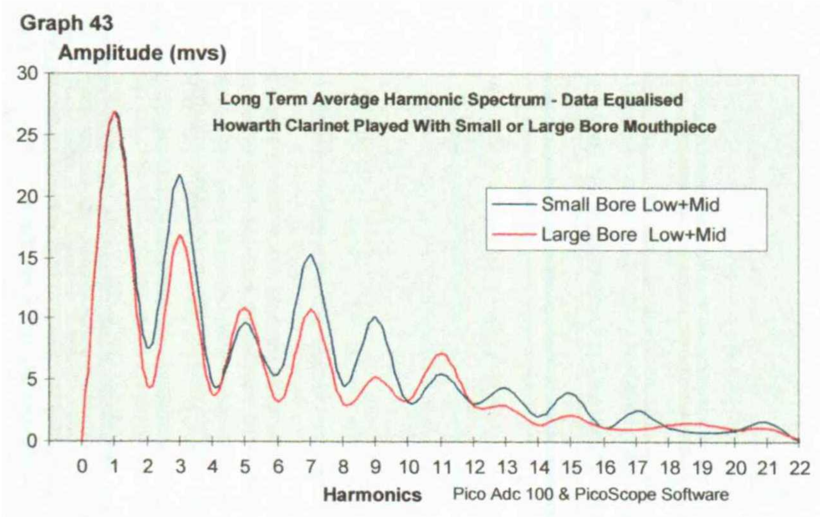
C 234Hz

Long Term Average Harmonic Spectra (LTAHS)

Examination of every note on the instrument entails gathering large amounts of data and lengthy analysis, resulting in numerous spectral graphs. This can help to reveal problem notes and areas of the instrument that have timbral problems. But the advantage of Long Term Average Harmonic Spectra is to enable an overall description of the tone of an instrument to be drawn up easily, and, as a result, swift comparisons between different set ups to be made.

LTAHS, condenses harmonic data by averaging the powers of every harmonic of all the notes tested, and presenting them as one wave-form, in other words, a spectral graph of averaged harmonic amplitudes If the original data has been acquired in a reliable fashion which also incorporates averaging methods, then LTAHS can provide a representative picture of an instrument's overall properties. As with all averaging methods this will also help to reduce the effect of rogue results and diminish the effect of any notes which may be out of character with the rest. In some instances it may be more beneficial to present an LTAHS for each register, if for example, it was felt that an instrument worked particularly well in one register but not another.

The following is an LTAHS of the Bb Howarth Clarinet Retest comparing two sets of data



The above graph (LTAHS Howarth retest) has had the data equalised. The recording system and blowing pressure were the same for both mouthpieces and the first unequalised graphs computed showed that the small bore mouthpiece set-up produced less power in all components. This explains why the large bore set-up was described as being more dynamic. The tone was also described as having extra gloss and bloom. However, the reason for this did not become apparent until the data had been equalised and the overall effect on the timbre brought about by using a large bore mouthpiece shown to move relative amplitudes of harmonics towards a more Germanic configuration.[6] This would not have been apparent by looking at the spectra of individual notes.

These results emphasise the importance of analysing data in several different ways if a more complete picture is to be obtained.

[6] See Chapter 3, p. 28, 'Comparison of German and French Tone'

Pressure Transfer Function (PTF)

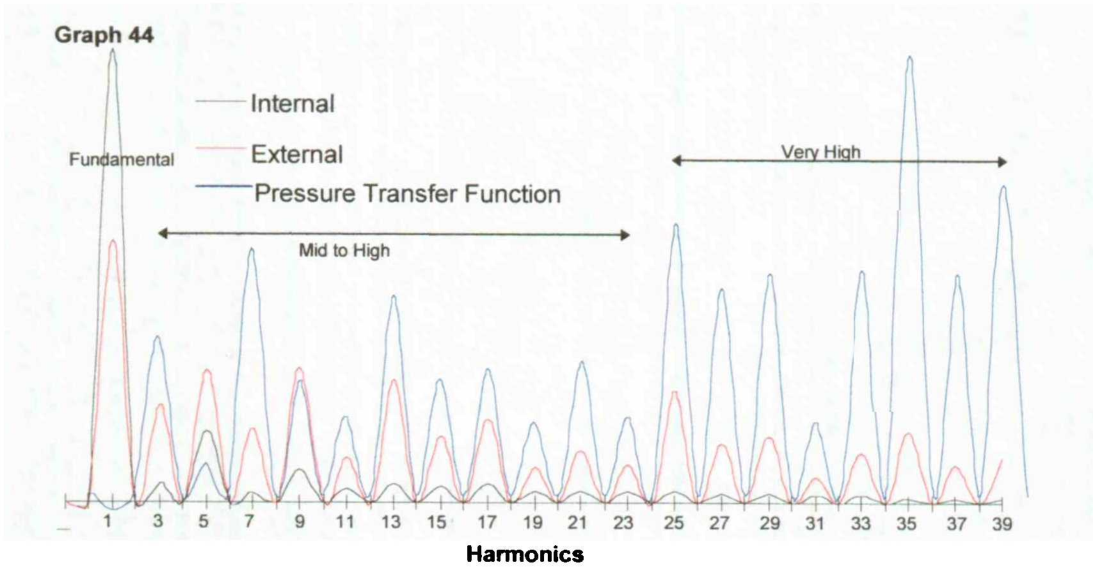
Once it became possible to measure the internal spectrum via a probe microphone inserted into the mouthpiece, so it became possible to calculate a Pressure Transfer Function for the instrument with various mouthpiece alterations and compare the differences.

The Pressure Transfer Function is the relationship between the internal spectrum (standing wave) and the sound radiated from the instrument. The normal arrangement would be to inject a sound of continuously varying pitch at the mouthpiece end and capture the internal wave via the probe and express this as an impedance graph. The externally radiated sound would be captured at a position best determined by the type of instrument and the room acoustic. The relationship of the two waves is expressed as a ratio of the output from tone holes and bell to the input pressure in the mouthpiece, usually expressed in decibels as follows:-

$PTF = 20\log(P_o/P_i)$ where P_o is the output and P_i is the input.

In this research, the clarinet was played normally over a wide range of notes, each note's internal and external sound separately analysed. The values for the harmonics were then averaged, as in calculating LTAHS graphs. This data was then used to build a composite hybrid PTF in the normal way, by expressing the numbers as a ratio.

For comparison between different set-ups to be made, it was not necessary for the measurements to be absolute, but it was essential that the method of gathering data be consistent for each test and between different experiments.



The above is an example of a graph where internal, external and PTF data has been plotted together. The internal values show a strong fundamental and reasonable third and fifth, but very low power for all the rest. This was typical of the many internal spectra analysed. Both internal and external waves used the same scale for amplitude. The PTF has been superimposed with its amplitude scale increased by several orders of magnitude so that a clearer picture can be seen.

Study of the PTF in conjunction with what is already known about the behaviour of sound waves in cylindrical tubes demonstrates how a clarinet processes tone.

A small reflection within the tube means a large transmission of sound, and a large reflection means a small transmission of sound. In the above graph we see that for this particular set-up there was a poor transfer for the fundamental (negative value), good transfer for the middle to high frequency components, and very good transfer of extra high frequency components. Generally, this clarinet can be said to have been efficient in radiating middle and upper frequencies and very well suited to radiation of very high frequencies. Comparison of these kind of graphs for different set-ups, or where alterations have been made, will give a good indication of the strength and location of any changes in the sound pressure transfer.

9

Repeatability & Other Tests

In early mouthpiece tests it was noted that, although the results of testing on a single day were consistent, the control mouthpiece (Vandoren B45•) produced varying results when tested on different days. As expected, the results obtained from testing batches of mouthpieces with the same dimensions (such as the set of B40s and moulded Yamaha 4Cs and 6Cs) were very similar when analysed acoustically. This only made the day to day inconsistency of the control both curious and disturbing.

It was becoming apparent that consistent and accurate measurements could be obtained when setting up and testing throughout one session, but some aspect of the system was changing when the experiments were reset on a different day, in spite of the equipment remaining in the same position and the same methods being used. The steady state analysis of the 50 or so commercial mouthpieces did show marked differences between what, by anyone's standards, would be considered to have very poor or very good tone and response. Also, a recent recording and analysis of a glass Pomerico mouthpiece produced scopes of components that were very similar to those of an identical mouthpiece tested at the very outset, which tends to support the methodology. It was decided to carry out a thorough examination of all aspects of the equipment to try and establish the reason for the inconsistency in the results from the controls and to make sure that the procedures produced accurate and repeatable results. Repeatability tests were devised. If the numerical values did seem to fluctuate from test to test (possible reasons discussed later), then the results of numerous tests of a single alteration would have to be averaged to gain a meaningful measurement.

Equipment:

Centrifugal air compressor with electronic varispeed

Manometer (water type) calibrated in inches

Artificial Embouchure with fully adjustable lip plate (vertical & horizontal) and tonguing device

Hygrometer 32%-95% RH, Maplin humidity module ZA38

Sound Level Meter, Castle Associates CS.15C

Pitch meter, Korg AT-1

Pulse generator, PG58A

Microphone, Fostex M501

Bb clarinet mouthpiece, copy of a Louis c.1930 with a close lay (0.75 x 20)

Rico 3½ strength plastic coated reed

Delrin 30mm diam. rod bored to 14.9mm and length cut to produce 240Hz

Pentium P75 computer

MiniPod 402 plug in A\D converter, 12 Bit, 30k sampling, Computer Instrumentation

'DavScope' software

Task List Of Repeatability Tests

Test the Computer Set-up

MiniPod and 'DavScope' software

Pulse generator square wave

Korg crystal tuner 440Hz wave

Method

1) Without moving the mouthpiece in any way, take a number of scopes. Place the results in a spreadsheet and make averages of the values.

2) Repeat test after a lapse of several hours.

3) Repeat test next day.

4) Repeat test after two days.

5) Repeat after a lapse of one week.

6) Remove the mouthpiece from the artificial embouchure then replace and repeat the process of taking scopes and averaging the results in the spreadsheet. Repeat several times.

Further Tests:

Test the effect of using different strength reeds.

Test the reeds over a range of pressure to produce very quiet (pp) tones to very loud (ff) tones, corresponding to approx. 4" to 20" air pressure.

Compare data.

Test the effect of reducing the volume of the artificial embouchure, alternately filling the cavity with soft and hard material.

There now follows a description of the tests along with my comments and conclusions as the work proceeded.

The Pulse Tone Generator

The second test results with the Pulse Tone Generator gave average values that were slightly different from the first. Great care had been taken not to move any of the controls or alter the settings on the device in any way. It was then realised that a machine such as the PG58A Generator could not be relied upon to remain consistent in itself and that it was apt to drift. Perhaps the variations, mainly in the strength of the fundamental, were caused by this. However, once the graphs were completed, it was surprising to see little difference between the averages of the results of both days' tests. Certainly all the frequencies were identical, even if the amplitudes did vary by a small amount. Inaccuracies can occur when DavScope data is exported to a spreadsheet via a file of comma separated values (csv), the numbers then being placed into the nearest value cell. In this case, where a bandwidth of 5k was being used, values were placed into cells 10Hz wide (500 cells). Inevitably, not all the values end up in adjacent cells for averaging purposes. It was essential to be aware of this, and when averaging values from scopes taken in later tests, it was possible to juggle some of the values that corresponded to known harmonics and their positions. In fact, this misplacement of data only occurs at high frequencies where the amplitude values of harmonics might be placed in cells one higher or one lower than another.[1]

---

[1] Later in the research, data acquisition was made using a Pico ADC 100 analyser and software which gave accurate and consistent results.

Korg AT-1 Tuner

The Pulse Tone Generator proved to be unreliable. The stability of a crystal based device was needed to check the accuracy of the computer and DavScope software. The Korg tuner generates a steady 440Hz sine wave tone that can be linked directly to other electronic equipment. It also has the advantage of having no exterior controls that might be moved inadvertently. This was connected to the MiniPod and a repeat of the tests for the PG58A was carried out.

The results using the Korg were remarkably consistent, indicating that the MiniPod, the software and the tuner were all working accurately. As additional confirmation, the tests were repeated the following day with identical results. These first tests were run at the bandwidths most commonly used in the experiments, namely 2.5k and 5k. Other bandwidths were also investigated and it was discovered that the MiniPod was less precise below the 2.5k band, but accurate at bands above this.

The 2.5k band is good for spreadsheet work as there are only 5Hz between cells. As a result of information gathered in later experiments however, I realised that, for the purposes of the research, a 5k band would be necessary. I subsequently used the Korg tuner to test the correct operation of the electronics before each testing session.

Complete System Repeatability Tests

Tests one to six were carried out using a length of 30mm diameter rod made from Delrin, a dense homopolymer. This was bored to 14.6mm (a common clarinet bore size) and cut to produce a 250Hz tone. The length of this tube was shorter than a normal Bb clarinet but was perfectly adequate for the repeatability tests where my sole aim was to verify that there were no inconsistencies in the results obtained from the same tests when repeated several times.

The lip assembly in the artificial embouchure was set approximately 10mm from the tip of the mouthpiece, the usual position for most players. The downward pressure on the reed was adjusted to give the fullest tone whilst maintaining the correct pitch. In effect, this meant increasing the pressure to the point just prior to the tone going off centre and beginning to deteriorate. At this stage, 19" was being used as the blowing pressure. This pressure produced tone which was slightly too loud for comfort, a much lower pressure of around 8" appeared to produce a kinder mf tone which was better suited to assessing the quality of a mouthpiece and clarinet. The microphone was set very near to the end of the tube for every repeatability test. This is not the ideal position for recording a realistic and balanced blend of an instrument's harmonics, but in this instance it was the best way of obtaining clean sound from the set-up, with a good signal to noise ratio and minimal interference from the effect of room acoustics.

Microphone gain was increased to approximately 4 volts by the computer sound card (Vibra 16) and then fed directly into the MiniPod. This further improved the accuracy of the MiniPod. A new, full length clarinet tube in Delrin was made, omitting all the tone holes, apart from low F and a speaker pipe. A taper was machined in the bore at the lower end and a clarinet bell fitted, making it possible to produce the fundamental of a Bb clarinet as a true 'bell note'.

This longer pipe had immediate advantages:-

1. The scopes contained more component data.
2. The pitch of the note was more stable, the lower notes of a clarinet being less susceptible to variation in pitch by lip pressure.
3. Set-up procedures were easier.

It was decided to use this length of tube from now on, unless certain experiments demanded that a real clarinet be used.

The bell produces E_3 (D_3) on a Bb clarinet. This is a notorious note on clarinets, as is the 2nd register note B_6 (A_5) a 12th above. As both these notes emanate from the bell, they have a different timbre from the other notes that lie on the parallel part of the bore. On most clarinets and on French style instruments in particular, the tone of these notes is usually less focused and of poorer quality. Also, if the 2nd register is tuned correctly, then the lower fundamental is invariably flat. Some manufacturers, particularly German makers,[2] drill a small hole through the bottom tenon or high on the side of the bell, to sharpen the fundamental. This extra 'tone-hole' is usually fitted with a key operated by the right hand thumb so that it can be opened for the fundamental (to raise the pitch) and closed for the middle register note. Although the bell notes are often problematic, the function of the bell is crucial to the overall performance of the instrument, and good makers will usually experiment with many different bells to find the one

[2] e.g. Wurlitzer

that enhances the overall tone of the clarinet and produces a good low E and middle register B. This invariably leads to a degree of compromise.

It is worth noting that, for the note one semitone above the bell note F_3 (Eb_3) overblowing to C_5 (Bb_5), more energy, mostly in the form of upper harmonics, emanates from the bell than is emitted from the tone hole. To enable testing of a low tone-hole note, I drilled a 12.5mm hole for F_3 in the correct position above the bell (F_3 and its corresponding 2^{nd} register note C_5 are normally good sounding notes). In addition, I pierced the top joint at the location of the speaker pipe so that the second register of the two lower notes (the 12ths) could be obtained if required, I then made simple plugs and sleeves to blank them off when not required.

Most clarinets considered 'in tune' have low E_3 & F_3 a few cents flat (some as much as 20-30 cents). Being a little flat in this region of the instrument is more comfortable than being sharp, particularly as pianissimo playing on these low notes sharpens them considerably. The modal ratios (12ths) at this point are commonly a little wide, so that an instrument with B_5 and C_5 correctly tuned will inevitably have a flat E_3 and F_3.

The clarinet length tube was 5 cents flat on low E_3, and 10 cents flat on low F_3. When this was connected to the artificial embouchure, extra squeeze on the reed and mouthpiece, achieved by turning the screw adjuster on the lip mechanism (increasing the lip pressure) would bring the E_3 up to pitch and the F_3 to a pitch only 5 cents flat. It was possible to achieve the same improvement in intonation when the tube was blown by a clarinettist and the embouchure was tightened. However, excessive pressure exerted on the reed produces tone that is thinner. This served to highlight one of difficulties inherent in the testing regarding the point along the width of the note at which the analysis should be made. Should the lip mechanism be set at the position where the 'centre' of the note is perceived to be relative to a given air pressure (similar to manually turning the tuning dial of a radio to find the central and strongest part of the signal) or should the lip be set where the note is best in tune? Tightening the lip raises the pitch, and loosening flattens the pitch, but as the adjustments are made, the timbre and therefore the harmonic spectrum of the note can be heard to change quite clearly.
Eventually, it was decided to plump for the 'centre' of the note as this was the only way to maintain consistency in the latter part of the repeatability tests where the combined mouthpiece, reed and ligature were removed from the artificial embouchure, completely dismantled, then reassembled and replaced.

An alternative way of setting up the system was by playing the note normally with a good full tone and determining the pitch. Using the artificial embouchure, the controls were then adjusted to obtain the same pitch and the quality of the note assessed i.e. was the tone centred now that it was being played artificially? If all was satisfactory, then the instrument was being played as in normal playing and this would be the way the equipment should be set for each run. At the same time, if a scope of both normal and artificial playing were taken, then another comparison and check could be made to see if the spectra of harmonics were also similar.

Experiments with the new tube were revealing. I was aware that the upper harmonics were directional, but I was unaware of the full extent of this directionality. Sampling the low F_3 with the microphone close to the tone hole produced far less upper harmonics in the sound than positioning the microphone directly in front of the bell. This went some way towards explaining the discrepancies I had found between the test results of commercial mouthpieces and those from normal playing. The recordings had been made with the microphone far too close to the tone-hole concerned and it therefore received very little information from the tone-hole lattice below or from the bell. Nonetheless, this did not nullify the results as the aim was to discover any differences in response that could be found while subjecting each mouthpiece to the same playing conditions. However, it did mean that a direct comparison with live playing would be difficult, although converting the results into tristimulus values[3] would go some way in ironing out this problem.

The microphone position was a factor that would have to be considered very carefully in future experiments. A position based on the experiments described in chapter 8, that would capture a true and realistic blend of components, was going to be essential.
Until this point it had been believed that testing within a bandwidth of 2½k would be ample to cover the highest of the harmonics and components in the tone. Results from the analysis of both the bell note and low F_3 revealed components as high as 4k (especially from the bell) but little or nothing above this frequency. Analysis of data up to 5k would be performed from now on.

---

[3] See chapter 8, p.105

Matters arising from the repeatability tests

The mouthpiece must be placed in precisely the same position in the artificial embouchure, and identical air pressure for every test must be maintained.

Although the results of the tests were consistent, maintaining this consistency was difficult if major changes were made to the set-up. On two separate occasions the experiment had to be completely dismantled so that the equipment could be demonstrated using different mouthpieces and with real clarinets. Returning to the repeatability tests after this proved to be very difficult, and for a while it seemed that it may be impossible to have the system working and producing results as before. Playing other mouthpieces in the artificial embouchure necessitated moving the lip mechanism a good deal, and to get it back to precisely the original settings was very problematic. It was clear that much care was needed when handling the equipment, it was also clear as to why the repeated tests with the control had been inconsistent. The timbre (harmonic spectrum) was easy to change by means of the slightest alteration in pressure (undetectable even by the manometer). The most minute turn of the lip mechanism or smallest twist of the mouthpiece in the barrel caused a noticeable change in timbre and spectrum analysis. To bring the data in line with the previous tests, a complex procedure was required whereby the pitch was adjusted whilst at the same time carefully listening to the tone (tuning in) and maintaining the correct air pressure. It was possible to regain the original spectrum, but the implications for future analysis were worrying. To aid re-assembly of the system, the mouthpiece was scribed with a fine line at the join with the barrel. A pencil line was also drawn at the position on the mouthpiece where the lip should bear down on the reed. Similar markings on the Vandoren Control mouthpiece would have been of enormous benefit and would have resulted in closer scopes.

That infinitesimally small changes can provoke such a wide variation in timbre confirms the belief that a good player can manipulate the tone of the instrument by subtle changes to air and lip pressure alone, and not through changes to the shape of the mouth or throat as suggested by many players and teachers. It also explains how experienced players can make a poor instrument sound acceptable, and how these same players can be recognised as having their own unique sound on virtually any combination of mouthpiece and clarinet.

This was further demonstrated when conducting experiments with John Playfair on several of his mouthpieces. These mouthpieces differed widely, but we were both able to play them all with reasonable tone and response. However, we both agreed that two of them were particularly difficult to manage; a glass Orsi (By Pomerico), and a mouthpiece whose tone chamber John had filled with resin and then reshaped to resemble the style of certain older saxophone mouthpieces. He had rounded the tone chamber sidewalls to form a circular entry into the bore (throat); the area of the cross section here was made so as to be the same as the rectangular throat of a typical clarinet mouthpiece. John already had a rough idea as to how the tone of these mouthpieces would be represented in spectral graphs and, most crucially, which harmonics might be missing. His glass Pomerico was found to have a serious lack of upper harmonics, which would explain its plain, thin tone. A glass mouthpiece with a similar shape had been tested before as part of the commercial mouthpiece survey, and it too showed the same lack of upper components. As to whether or not this poor response is caused by the design alone or has also to do with the nature of glass is as yet unsure. By contrast, the mouthpiece filled with resin gave a much more complex spectrum, with the middle and upper harmonics very strong and similar in amplitude. There was no tendency for the harmonics to trail off, as is usual, and there were many even harmonics present. However, this mouthpiece was unsatisfactory and gave very poor tone, explaining why the design has never been used widely for clarinet mouthpieces.

The spectrum analysis that resulted from these investigations showed the wide variety of harmonic components that was produced by these untypical mouthpieces. The FFT analysis also confirmed our suspicions regarding their tonal strengths and weaknesses.

There remained one particular difficulty for the research. If lip and air pressure were adjusted in a particular way, then it was possible to suppress, augment or even mask certain harmonics to make one mouthpiece behave and sound much like another. However, from this, it did not follow that variety in the design of mouthpiece was unnecessary, or that research to improve mouthpieces was superfluous. To achieve a specific tone from a mouthpiece not designed for the production of that spectrum of harmonics can be difficult and stressful for a player, and in the attempt, other qualities may have to be sacrificed. The dynamic range or clarity of articulation might be diminished and the effort of playing expressively and with good tone difficult over long periods. The goal was to develop mouthpiece designs which would liberate players from these constraints and enable them to perform expressively, dynamically and efficiently.

10

Mouthpiece Materials

When Backus investigated the timbre of Boehm clarinets made from different materials, he was disappointed to find that, contrary to his expectation, there was little difference to be observed between the spectral graphs of the tone from plastic and wooden instruments [Backus, J. 1964]. Although it was not within the scope of the present research to investigate the effects of materials on the wider playing properties of clarinets, the influence they might have on mouthpieces was relevant.

If a material is sufficiently dense and stable, then it may be suitable for the manufacture of clarinets. Fine clarinets have been made from plastic, ebonite (vulcanised rubber), metals and various hardwoods. Overall design, the extent or lack of tone-hole undercutting (fraising) and the finish of the surface of the bore probably exert the greatest influence over the final playing properties, but it is possible to detect a subtle difference between a cocuswood and a grenadilla or between a boxwood and a grenadilla clarinet. The listener may not be able to detect any difference between an instrument made from plastic, ebonite, resin, metal or wood, but most clarinettists insist that they can both feel and hear a difference, however small. These same clarinettists display an even greater awareness and sensitivity to mouthpieces made from different materials, and their claim is supported by Krüger's theory.

Krüger's convincing hypothesis states that, once the reed begins to beat against the tip-rail of the mouthpiece, a complete series of uneven harmonics is produced in the primary wave. This would be seen as a square wave when viewed on an oscilloscope. The reed hits the tip-rail with considerable force. Energy is transferred from the tip of the reed to the tip of the mouthpiece which will try to resonate in sympathy. The stiffness of the mouthpiece material in this region will affect the way in which the tip of the mouthpiece copes with this excitation and, accordingly, there will be varying degrees of damping or reinforcement of components in the primary wave as energy is passed backwards and forwards. The degree of flexibility of the mouthpiece material, its flexural strength and elasticity along with its density and hardness, will therefore have an effect on the reed excitation and the establishment of the primary wave.

This explains how a metal saxophone mouthpiece with the same internal dimensions and lay profile as an ebonite mouthpiece, can sound brighter, clearer and often louder. It is curious however that metal *clarinet* mouthpieces with a large tone chamber and a close lay profile can produce tone very little different from ebonite clarinet mouthpieces. A good example of this is a pre-war silver-plated brass example belonging to Nick Shackleton. This mouthpiece with its large tone chamber and close lay profile produced a spectrum of sound similar to that of other, similar ebonite designs of the period.

Many clarinettists and makers of the 19th and early 20th century favoured cocuswood as a material for mouthpieces. This species of hardwood is relatively resistant to water and has good tonal qualities. The German company Zinner still offers exotic hardwood mouthpieces as an option today. Unfortunately, as with all woods subjected to high levels of humidity and wide variation in temperature, there is a tendency for warping to occur. Playing on a wooden mouthpiece does have its risks as its dimensions can change radically during a performance, making the clarinet difficult to blow and occasionally rendering it completely unplayable.

Ebonite is strong, durable, resistant to moisture and very stable up to approximately 60 deg.C and it has been the traditional material for mouthpieces since its invention in the mid 19th century. It is still the material preferred by most professional players who are reluctant to consider other materials despite the emergence of many excellent, new plastics whose mechanical properties exceed those of ebonite. These polymers do not however share exactly the same tonal characteristics as ebonite, although acrylic, some epoxies and urethanes can be formulated to come very close, and there are a growing number of players who appreciate and even prefer the tonal qualities afforded by acrylic and synthetic resins.

From a manufacturing point of view, ebonite is an unpleasant material to use. It is a tough, durable material that machines and polishes well, but its heavy sulphur content smells very unpleasant when worked. But it is resistant to water, can withstand knocks, is reasonably abrasion-proof and remains physically and chemically stable for decades. Breakdown does not appear to occur for at least 100 years, although it does suffer in sunlight, oxidation causing it to change to an unattractive reptilian green colour.

New York Hamburger of Hamburg in Germany is one of the few producers of instrument quality ebonite, supplying material for traditional manufacturing methods (turning, milling and filing). A few mouthpiece manufacturers produce their own ebonite which is formulated for compression moulding processes. But Schreiber, the company who supplied mouthpieces for Buffet clarinets, recently created a new factory set-up to produce mouthpieces moulded in acrylic rather than ebonite and when questioned as to their reasons, the reply was that 'it would be foolish to set up an expensive production line making mouthpieces in a material that may eventually be unavailable or obsolete'.

A constant review of materials suitable for use in the manufacture of mouthpieces is essential. I have been in contact with various suppliers of specialised plastics and the Institute of Materials, a government organisation set up to assist manufacturers. The company Ensinger have been helpful in supplying many samples free of charge. I also attended the 'Government Forum For London' at the ICI headquarters in Westminster. Innovation in materials was part of the programme and I was able to put forward the case for finding new materials for musical instrument making. This was accepted by all those present as being a matter of necessity, bearing in mind the finite resources of hardwoods.

Acrylic is a material that has been used very successfully for manufacturing mouthpieces, particularly in Germany. Acrylic, known on the continent as Plexiglas and in this country by its ICI trade name Perspex, is commonly found in a clear form. It is difficult to colour large sheets due to the manufacturing process. Large thickness' are achieved by gluing layer upon layer, so colouring the perspex would result in a colour variation through the layers. For the purposes of machining [milling and turning], the cast form is superior to the extruded type and it is this which is required for hand making mouthpieces.[1] An increasing number of modern mouthpieces are now produced by injection moulding with extrudable acrylic.[2]

---

[1] Northern Cast Acrylics (UK) now produce short billets up to 50mm diameter in any colour including black.

[2] Jon Steward (Howarth clarinets) believes that acrylic is a particularly good material and that it is superior to any of the plastics commonly used in cheaper moulded mouthpieces. Its tonal qualities are similar to cocus wood. I have made some very successful mouthpieces using this material.

Casting Resins

Epoxy and polyurethane resins are essential materials for use in moulding and casting copies of rare mouthpieces and short production runs. The density, hardness and flexibility can be varied to suit individual applications, and the choice of resin, epoxy or polyurethane is dependent upon the properties required in the finished mouthpiece. Exciting effects on timbre and response can be the result of experimentation with different formulations. Durability, resistance to abrasion, and heat and light tolerance must be taken into account when making a selection. Some varieties give excellent results with accurate dimensional stability (very low shrinkage) and superb tonal characteristics, often surpassing the original master mouthpiece .

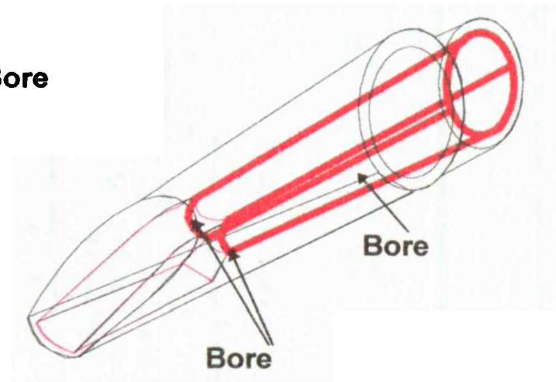
11

Experiments: Part One

Bore Dimensions

The effect on tone, response, dynamic range and intonation through extensive research with the new *Howarth* clarinets.

Fig. 12 Mouthpiece Bore



Shoulders

These experiments into bore size are described in more detail than the other experiments since, although techniques were refined, most of the procedures used in these tests were the same as those used subsequently. A large number of spectral graphs and the results from re-testing are included. This is in order to illustrate the confusing nature of the results obtained from an analysis of individual notes, and to demonstrate how these results can be simplified by using alternative graphing techniques.

The Howarth Clarinets

Large Bore v. Small Bore Mouthpiece

The aim of this work was to test the hypothesis that the tone, response and overall 'feel' of the new Howarth clarinet is significantly improved by the use of a much larger, conical bore mouthpiece. Since the bore of these instruments is typical of most modern small bore clarinets, the hypothesis could be applied to many other makes too. [1]

---

[1] This hypothesis was first put forward and practised in the 1960s by Alan Hacker.

The Howarth instruments have a fairly typical, modern French bore size of 14.7mm, and are designed for use with a standard modern French bore mouthpiece where the bore is a maximum 55mm in length, with a 0.6° taper, giving 14mm at the top of the bore and just under 15mm at the end of the tenon. The baffle of this type of mouthpiece is usually set at 20°, with vertical side walls which taper inwards towards the bore. This produces a kind of bocal at the end of the chamber where they meet the top of the bore.

Evidence that large bore mouthpieces were used with small bore instruments in the past was found when, in the late 80s I bought a pair of Louis clarinets c.1921. When using a mouthpiece with standard dimensions (French bore) these played very sharp, they were even a little sharp when using an original Louis mouthpiece (similar to the one described above). But I found that by making barrels 4mm longer than those supplied with the instruments, the problem was corrected. When inspecting the original barrels, there was evidence to suggest that these had been shortened at some time (ring thickness and wood not matching the diameter of rings). This would suggest that a mouthpiece that blew flat had been used.[2] There can only be two reasons for this flatness, either the mouthpiece was over-long (unlikely, since even a 89mm modern type plays sharp) or the capacity of the mouthpiece was much bigger, and this is the more likely.

Part of the research involved making copies of pre-war Boosey mouthpieces. These had a large, almost parallel bore and produced a beautiful tone which was pure and clear and I was interested to try these on the small bore Louis instruments. Predictably, the intonation was atrocious, especially in the throat notes which became very flat. The 12ths had become a little wider (between registers 1 & 2) and the top register sharper, although this was not altogether disadvantageous; small bore, French clarinets frequently have narrow 12ths between the first and second register i.e. modal ratio less than 3:1, especially in the lower, middle half of the instrument.

I was convinced that the clarinet needed shortening at the top end so used the two original, short Louis barrels. With these in place, most of the intonation problems were resolved and the instruments functioned well across the whole range. The 12ths were, admittedly, still wider than in the original set-up, but this made the instrument easier to manage, as the tendency for the right-hand low register notes to sharpen when playing

[2] Even taking into account the fact that the pitch was lower in those days (A=435-439)

sotto voce[3] was much reduced. In spite of the overall improvement in intonation, the parallel nature of this type of mouthpiece was still causing sharpness in the upper (3rd) register. A mouthpiece with a more conical bore would almost certainly rectify this problem.

Since tone and response is greatly affected by the lay profile, the experiments on the Howarth clarinet were to be carried out twice using contrasting lays, one close and the other moderately open. To this end I made two identical mouthpieces, using the internal dimensions specified by Alan Hacker for the Howarth instruments. The bore size of these mouthpieces began at 14mm-15mm for the first run of tests and enlarged to 14.3mm - 15.8mm for the second run.

Procedures

Two lays selected, 0.75mm x 20mm(close) and 1.10mm x 20mm(open).

- Two identical mouthpieces made (89mm long with a small 14mm-15mm bore).
- One mouthpiece faced with the close lay, the other with the open lay.
- Intonation and playing response checked.
- A complete diatonic scale covering all three registers recorded to disk with each mouthpiece, this smaller bore size requiring the longest Howarth barrels (65mm) in order to play in tune.
- Mouthpieces then re-bored to the large 14.3 x 15.8 dimension.
- Complete scales recorded to disk with each re-bored mouthpiece, this bore size requiring the short length barrels(62mm) to achieve good intonation.

The volumes of the mouthpieces and appropriate barrels were measured before and after re-boring:

Small bore mouthpiece + long barrel = 18.25mls

Large bore mouthpiece + short barrel = 18.00mls

It was interesting to note that the use of a short barrel to rectify the intonation after re-boring resulted in the overall volume of the clarinet remaining constant, suggesting that the volume of the bore is as crucial as the length. Naturally, the effect on perturbation is different and this accounts for the widening 12ths between the 1st and 2nd register and a sharper 3rd register.

---

[3] Playing very quietly with a veiled tone containing few upper harmonics.

FFTs were made for each note and graphs drawn for comparison.

Previous testing had shown that the shape of the formant and therefore the strength of partials and harmonics were affected by the slightest movement or subtle changes to breath and lip pressure. For this reason, a different method of playing and recording the scales was adopted and the artificial embouchure developed to try and eliminate these problems.[4]

But the aim of the Howarth tests was not only to try and establish the reasons why a larger bore mouthpiece sounded better (a difference sometimes only appreciated by the player), but also to discover why it 'felt' so much better. Could this elusive 'feel-good' factor be identified and shown by spectrum analysis and, if it could, might this only be present when the notes were played as part of a musical phrase rather than as steady state tones? The wave content of notes produced as part of a musically shaped phrase might differ from that resulting from long single notes where the sound might be coaxed, then maintained and the dynamic level more carefully controlled. It was crucial that the recordings be made by the same person under the same recording conditions and using the same reed. This last requirement imposed a time element into the testing due to the inevitable deterioration of the reed. In order to recreate a more normal playing situation, a range of notes was played at a moderately slow speed throughout the whole compass of the instrument and this was recorded, the individual notes were then retrieved and looped for analysis. This method is similar to the way in which many professional players assess the quality of an instrument; a quick flourish up and down the instrument revealing enough information for a judgement to be made.

---

[4] See Chapter 8, p 112

The mouthpiece alteration dilemma

Since supposedly identical mouthpieces (mouthpieces from the same mould, or produced by computer controlled machines) gave differing traces when undergoing analysis, it looked as if any attempt to effect and compare changes in design using these mouthpieces could be flawed. Any changes I might bring about could too easily be mistaken for differences already present in the mouthpieces themselves. The best solution for ascertaining changes in the harmonic structure brought about by small alterations to the design seemed to lie in using the same mouthpiece for all stages in the alteration process. In this way, the same reed could be used and all aspects of the mouthpiece not undergoing change would remain constant for every test. The results could be verified by repeating the experiment using a fresh mouthpiece.

The Howarth instrument was tested first with the small bore mouthpieces (one close lay and one open). These were then bored out to the much larger size and the test repeated. Each mouthpiece had its own reed throughout the tests, the open lay a medium strength (no.3), the close lay a medium hard (no.4). The difference in the lays dictated the strength of the reed (an open lay generally requires a soft reed, a closer lay a harder one.)

In spite of the one day time delay between testing whilst boring was carried out, it was reassuring to discover that the results confirmed what my ear was telling me, that on some notes the change in bore size had made little or no difference.

The graphs overlapped with uncanny precision in harmonic output and strength e.g.:-

Open Lay - G_3,F_4, A_4 and D_5
Close Lay - F_5 & G_5

B_5 was seen to be very close in both pairs but with the close lay scope showing a much clearer tone; a total lack of even harmonics when compared to the open lay set-up.

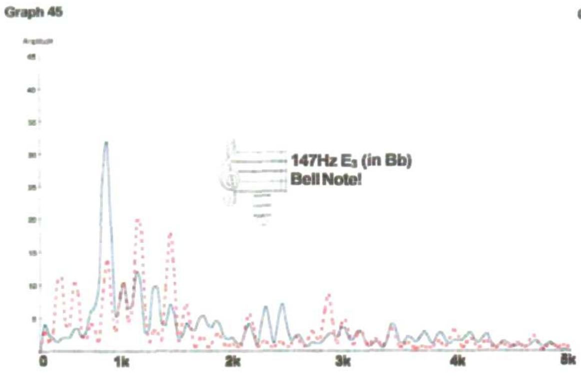
Interestingly, the most significant change in timbre appeared to have been brought about by the change in lay profile. The small bore set-up had some notes which were noticeably duller; these poor notes were less apparent with the large bore mouthpieces, irrespective of the lay. In general, the larger bore seemed to make the instrument play more evenly.

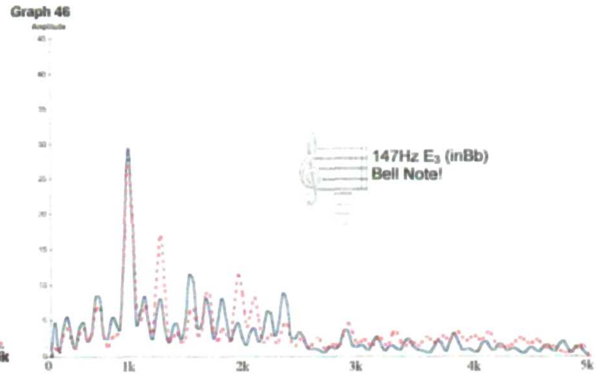
Low register (Lowest note)

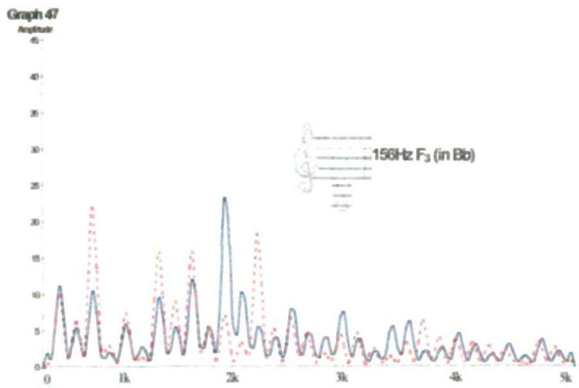
Amplitude in millivolts. X-axis = Frequency (kHz). Pico ADC 100, PicoScope Software.

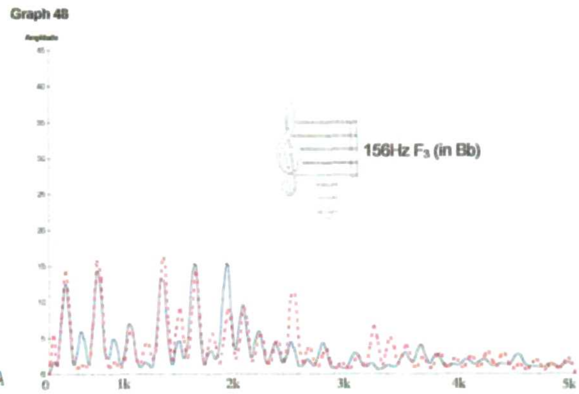
Key: ------ Small Bore Mouthpiece ------ Large Bore Mouthpiece

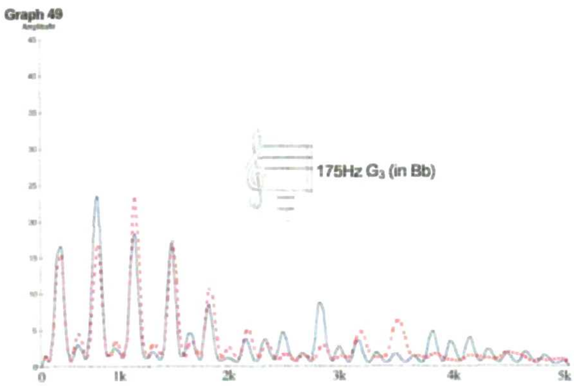
Left: Medium Lay (1.10x20) Right: Close Lay (.75x20)

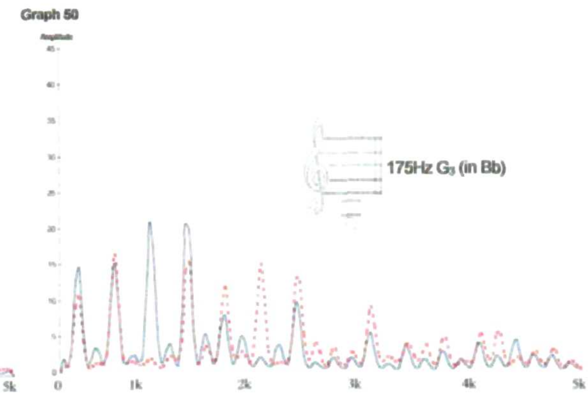










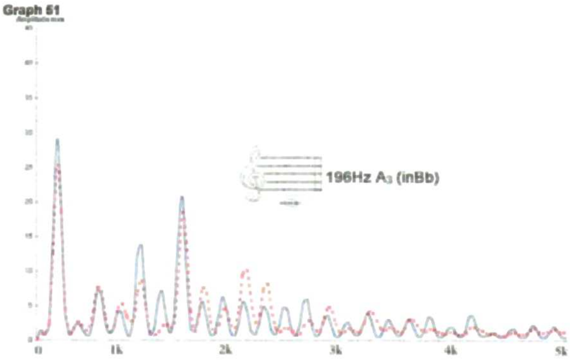


Amplitude in millivolts. X-axis = Frequency (kHz). Pico ADC 100, PicoScope Software.

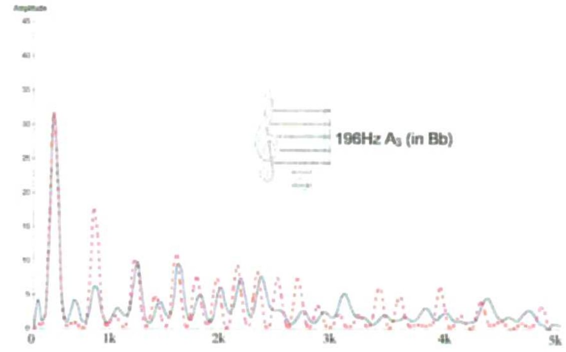
Key: ------ Small Bore Mouthpiece ------ Large Bore Mouthpiece

Left: Medium Lay (1.10x20) Right: Close Lay (.75x20)

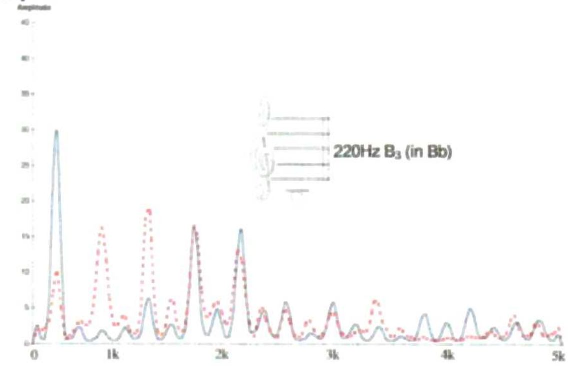
Graph 51



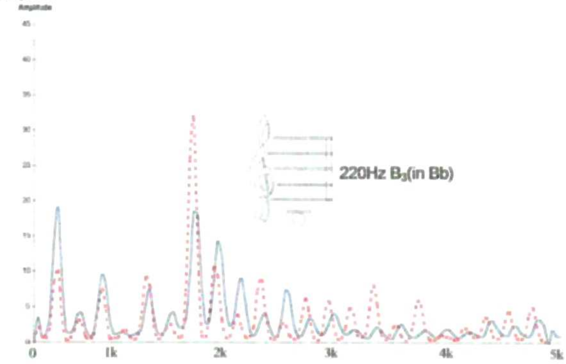
Graph 52



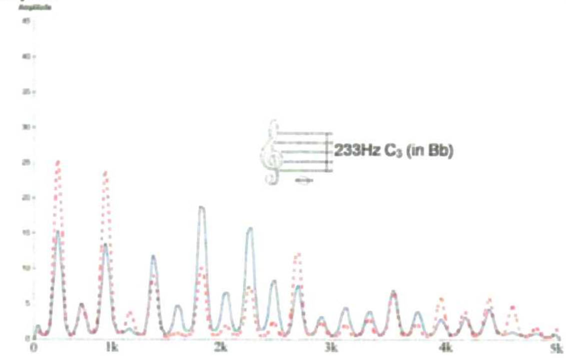
Graph 53



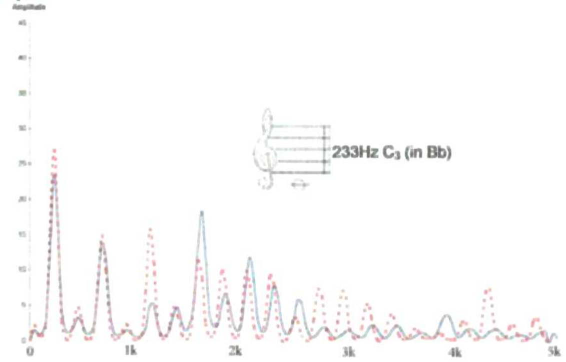
Graph 54



Graph 55



Graph 56

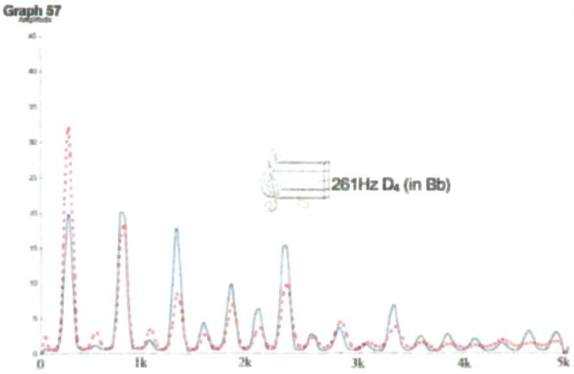


Amplitude in millivolts. X-axis = Frequency (kHz). Pico ADC 100, PicoScope Software.

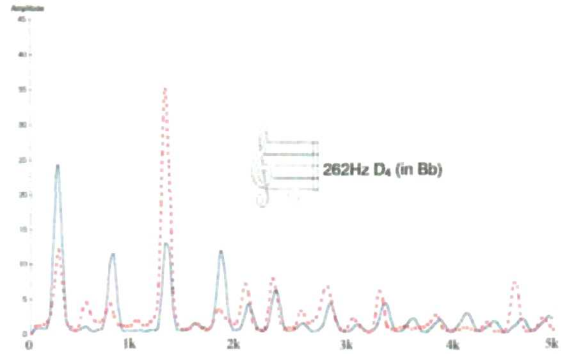
Key: ------ Small Bore Mouthpiece ------ Large Bore Mouthpiece

Left: Medium Lay (1.10x20) Right: Close Lay (.75x20)

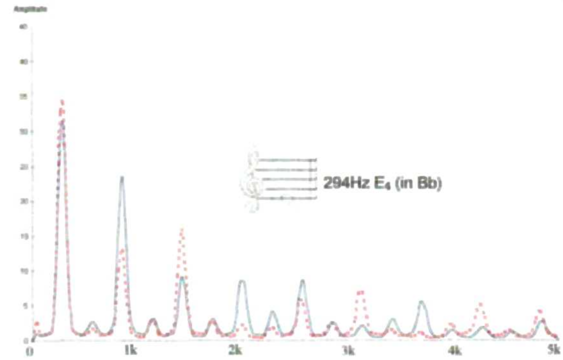
Graph 57



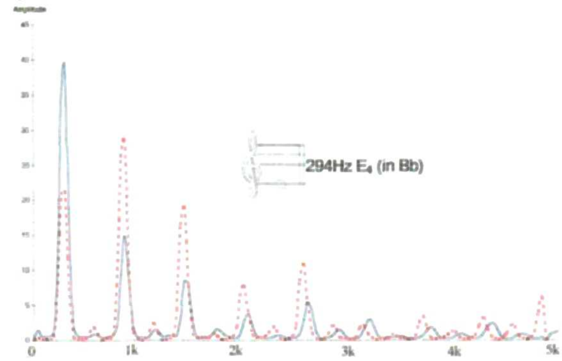
Graph 58



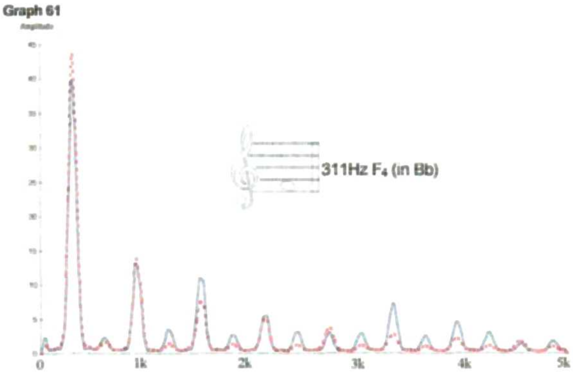
Graph 59



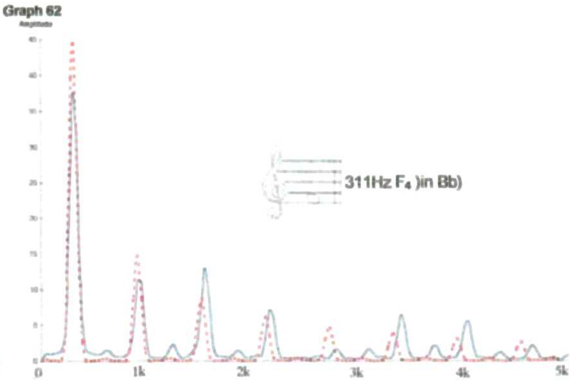
Graph 60



Graph 61



Graph 62

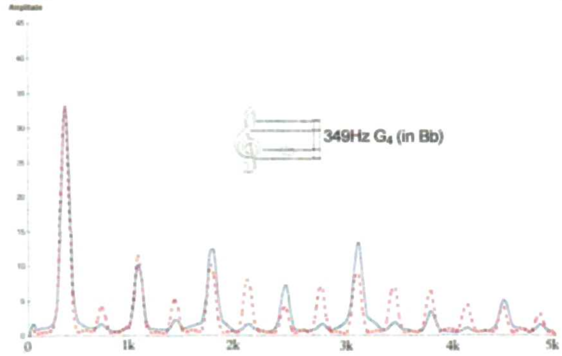


Amplitude in millivolts. X-axis = Frequency (kHz). Pico ADC 100, PicoScope Software.

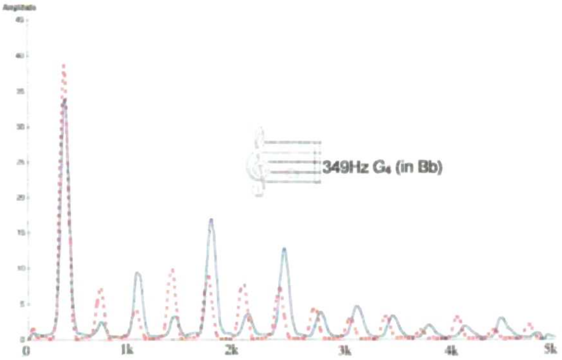
Key: ------ Small Bore Mouthpiece ------ Large Bore Mouthpiece

Left: Medium Lay (1.10x20) Right: Close Lay (.75x20)

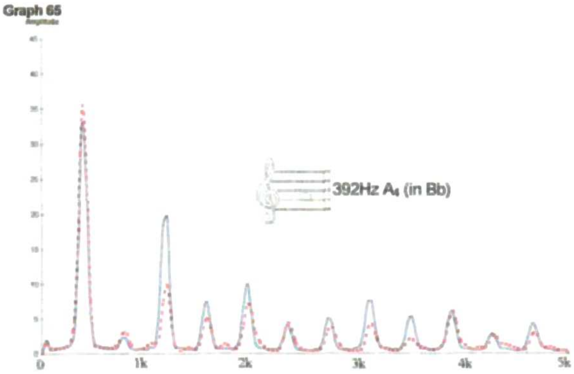
Graph 63



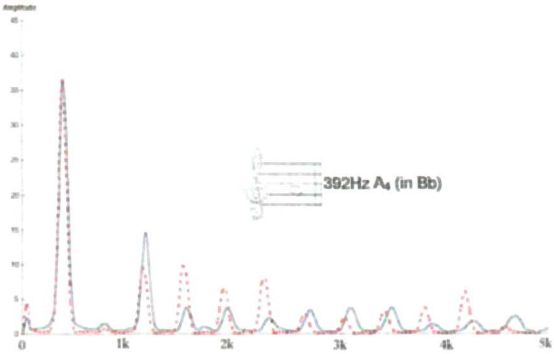
Graph 64



Graph 65

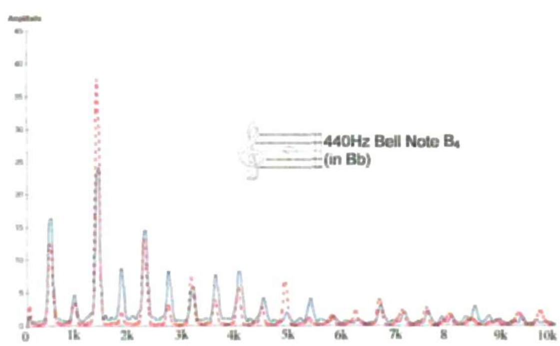


Graph 66

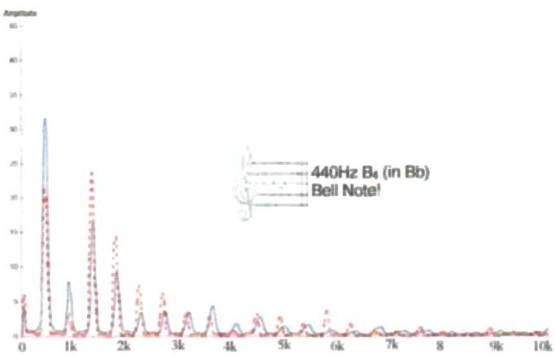


Middle Register (1st note in 2nd register)

Graph 67



Graph 68

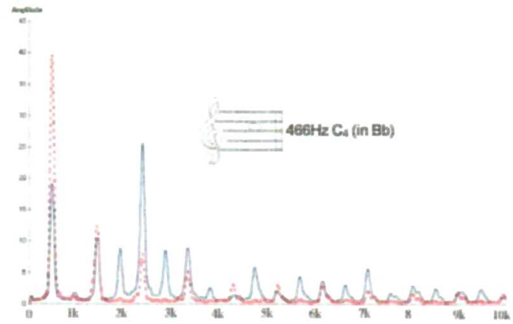


Amplitude in millivolts. X-axis = Frequency (kHz). Pico ADC 100, PicoScope Software.

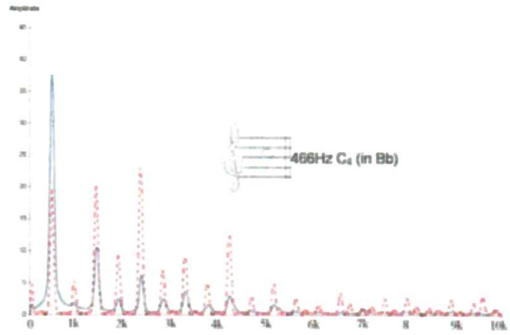
Key: ------ Small Bore Mouthpiece ------ Large Bore Mouthpiece

Left: Medium Lay (1.10x20) Right: Close Lay (.75x20)

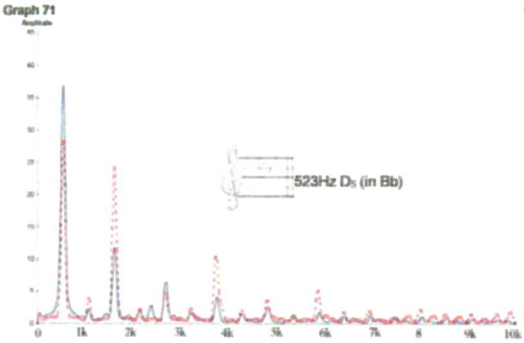
Graph 69



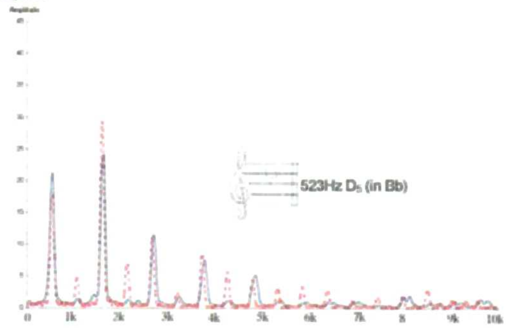
Graph 70



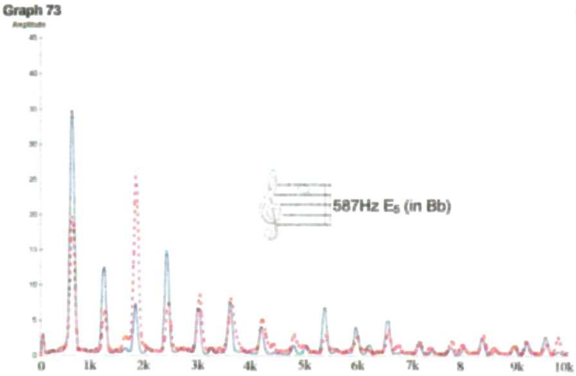
Graph 71



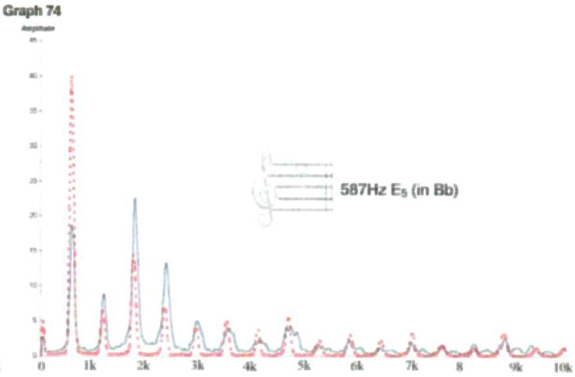
Graph 72



Graph 73



Graph 74

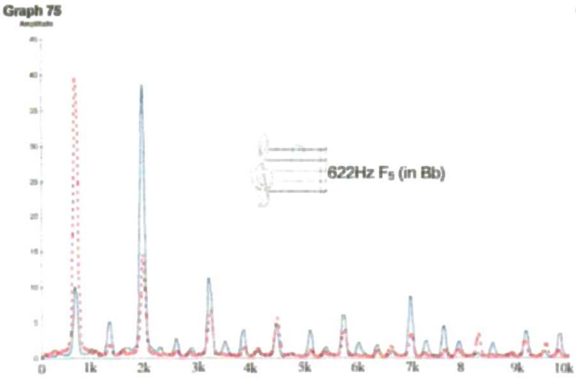


Amplitude in millivolts. X-axis = Frequency (kHz). Pico ADC 100, PicoScope Software.

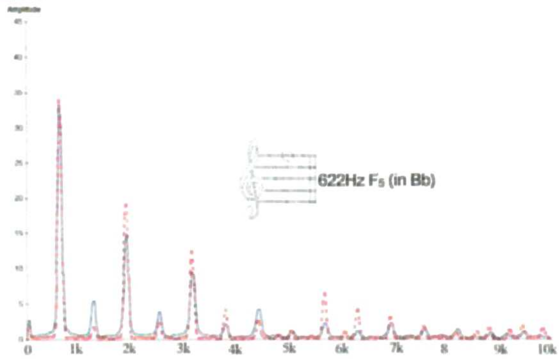
Key: ------ Small Bore Mouthpiece ------ Large Bore Mouthpiece

Left: Medium Lay (1.10x20) Right: Close Lay (.75x20)

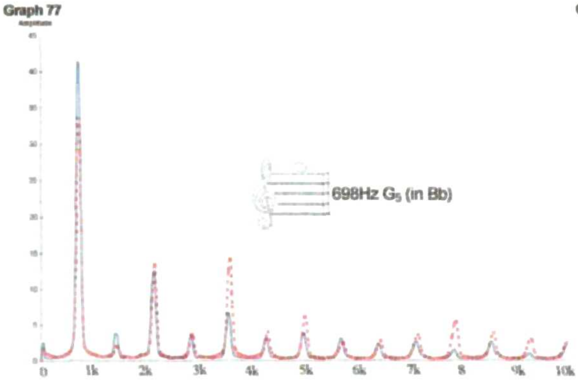
Graph 75



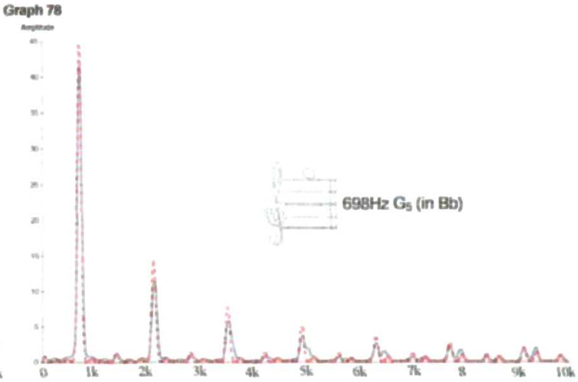
Graph 76



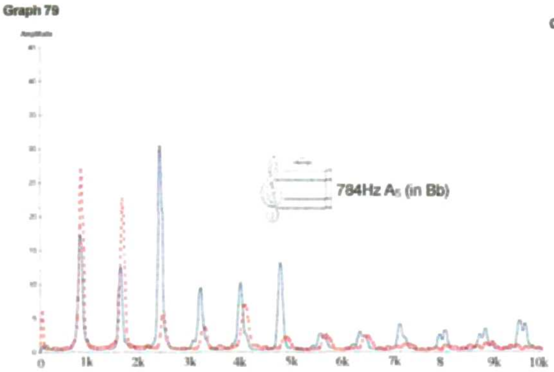
Graph 77



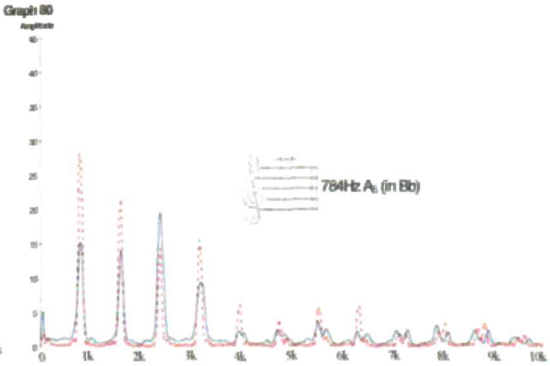
Graph 78



Graph 79



Graph 80

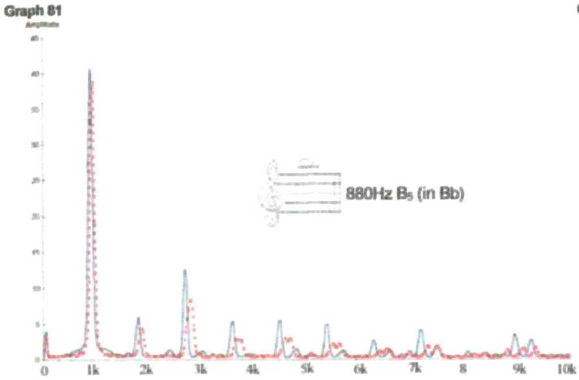


Amplitude in millivolts. X-axis = Frequency (kHz). Pico ADC 100, PicoScope Software.

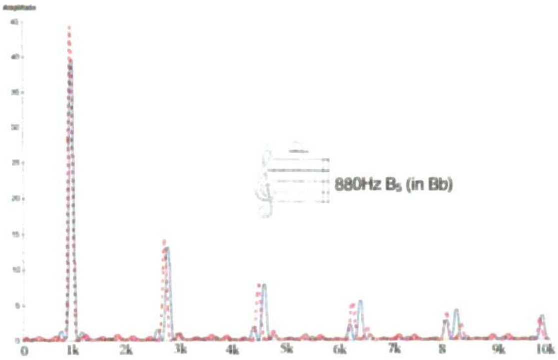
Key: ------ Small Bore Mouthpiece ------ Large Bore Mouthpiece

Left: Medium Lay (1.10x20) Right: Close Lay (.75x20)

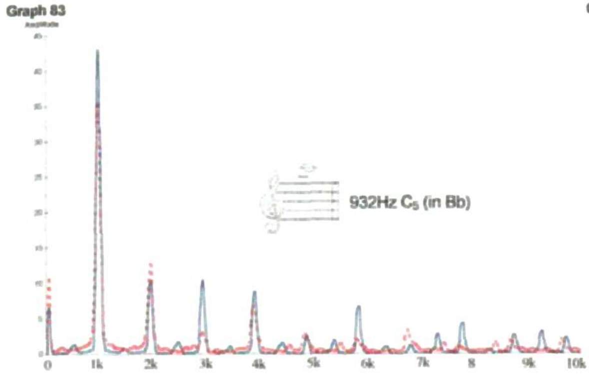
Graph 81



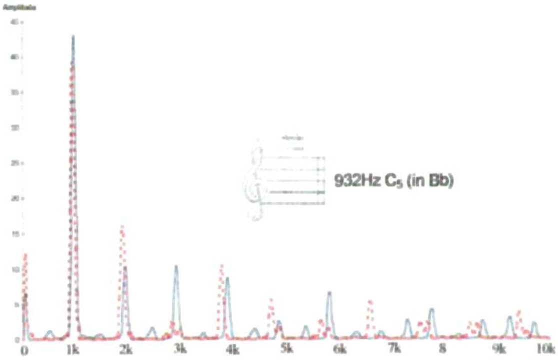
Graph 82



Graph 83

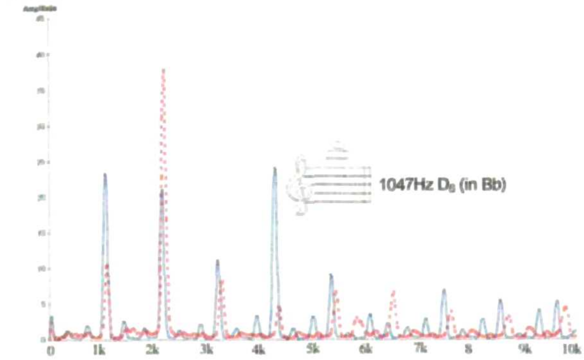


Graph 84

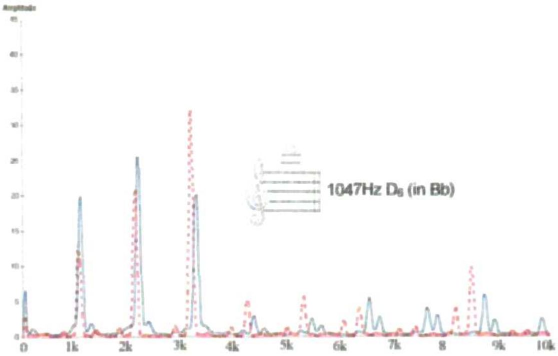


High Register (3rd or top)

Graph 85



Graph 86

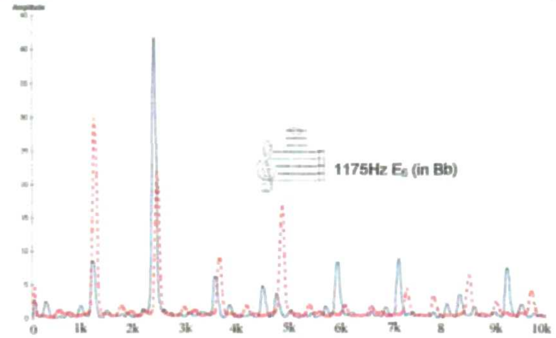


Amplitude in millivolts. X-axis = Frequency (kHz). Pico ADC 100, PicoScope Software.

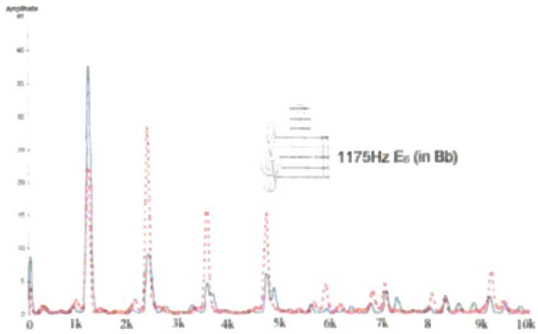
Key: ------ Small Bore Mouthpiece ------ Large Bore Mouthpiece

Left: Medium Lay (1.10x20) Right: Close Lay (.75x20)

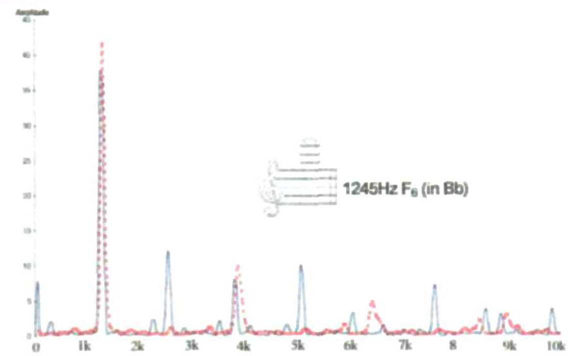
Graph 87



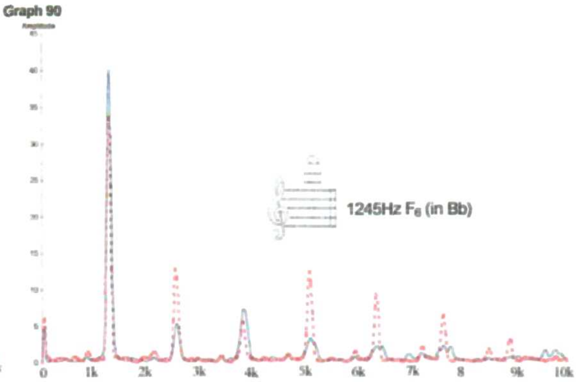
Graph 88



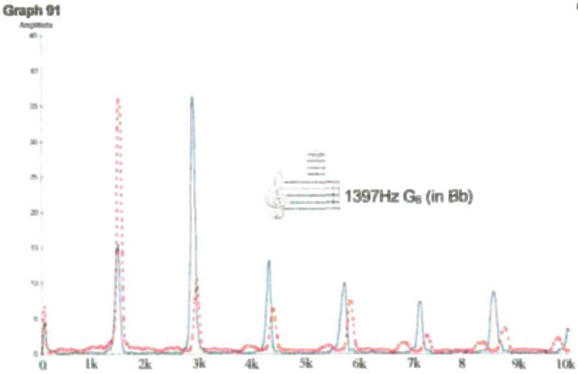
Graph 89



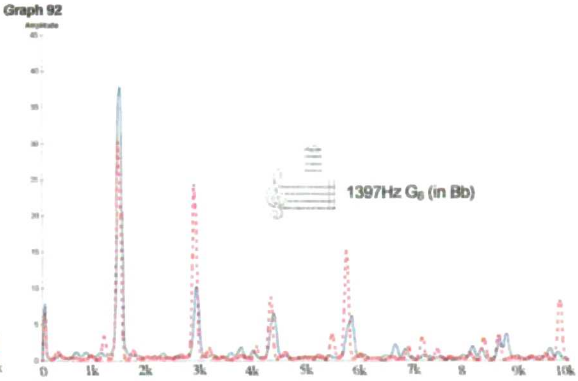
Graph 90



Graph 91



Graph 92



The Howarth Clarinets Re-Tests (Bore Dimensions)

Re-tests of selected notes from the whole range

3 Octave F Arpeggio - Bb Clarinet. 3 Octave F# Arpeggio - A Clarinet

The aim of these re-tests was to verify the results of the first tests and to check that the first experiments did not contain rogue results. In the initial tests, a typical modern French style mouthpiece was used to play and record a three octave scale on the Howarth Bb clarinet. The mouthpiece bore was then enlarged and the scale re-recorded. All the notes from both recordings underwent spectrum analysis and graphs were drawn so that comparisons could be made. These tests were carried out twice, firstly using an open lay mouthpiece and secondly using a close lay. The resulting graphs did reveal some differences and these corresponded to the changes in timbre and response which had been perceived aurally. The brighter tone was often represented in the graphs by a presence of harmonics and partials in the middle and upper frequencies. Very high frequency components were small in amplitude but varied considerably between the two mouthpieces. Where there was no improvement from using the large bore mouthpiece or where the effect was even detrimental such as with throat 'A', then this was reflected in the graphs by the characteristics being reversed, the large bore mouthpiece giving the wave shape usually associated with the small bore. It should be born in mind that greater differences in timbre were brought about by the use of contrasting lay profiles and this is investigated in more detail in chapter 12.

In the re-tests, the same procedures were followed as before, using the same mouthpiece throughout with only the bore dimensions altered. The mouthpiece was a typical French style model, intended for 14.6mm bore French style clarinets. The bore was 50mm long with a 0.66° taper, resulting in a 14mm diameter at the shoulder where it met the chamber and 15mm diameter at the end of the tenon. Outside length was 89mm, tone chamber baffle 20° with slightly outward tapered sidewalls. The lay profile had a popular tip opening, curve and length (1.10 x 20mm), requiring medium strength reeds (3-3½). The larger bore was achieved by reaming to the same 50mm length but with a more conical taper (1°), giving a diameter of 14.2 at the shoulder and 15.8 at the tenon. The mouthpiece with the bore enlarged, in conjunction with the shorter 63mm barrel, created almost the same combined internal volume as the small bore + long, 66mm barrel (small bore mouthpiece + long barrel = approx.17.5mls, big bore mouthpiece + short barrel = approx. 18mls).

The listening tests were carried out by a panel (a pianist, violinist, 'cellist and myself), comparing the looped tones of the recorded notes of each set-up. The recordings were listened to repeatedly and an appropriate word agreed upon to describe the sound quality accurately. The tone and intonation from both set-ups was good, but there were differences. Tone described as poor was a relative assessment within the context of overall good sound. Most of the large bore notes were clearer and brighter than the small bore, they also played more responsively and had a bigger dynamic range. However, one or two small bore notes were more successful than the large bore, as shown in the following graphs, notably throat A (392Hz).

The A clarinet was tested using the same method and found to be similarly, if less dramatically affected as the Bb.

It can be seen that the maximum frequency employed for the spectrum analysis changes at the onset of the second register. Low register analysis max. frequency is 5000Hz, changing to 10,000Hz for registers 2 and 3, meaning that all the significant harmonics and partials can be observed in all the notes of the scale or arpeggio. The first 7 harmonics can still be seen in the analysis of top F in the 3rd register.

Unlike the initial tests, it was not felt necessary to analyse every single note of the scale unless serious discrepancies became apparent. Instead, a full range, 3 octave arpeggio was employed, enabling sufficient notes from each formant area to be compared. As clearly shown in the graphs, similar changes did indeed occur, thus verifying the initial results. By studying these results as they appear in the spectrum analysis and in conjunction with the written descriptions, some light may be shed on the way harmonic spectra need to be structured to produce certain tone colour. In these experiments, the change was brought about by using a large, conical bore mouthpiece. This would be considered a drastic measure by many clarinettists.

Howarth Clarinets (Bore Dimensions)

Spectral Graphs from the re-tests of selected notes (3 octave F arpeggio)

Amplitude in millivolts. X-axis = Frequency (kHz). Pico ADC 100, PicoScope Software.

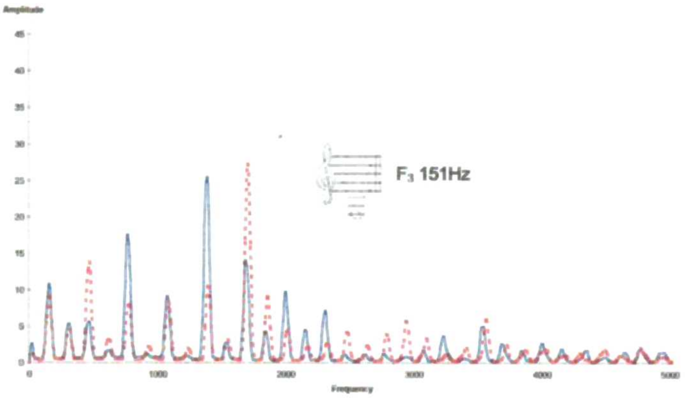
Low Register

New mouthpiece, 1.10 x 20 lay, 20° baffle, Bb clarinet

Key: Small Bore   Large Bore

Listening panel's description of the sound from each set-up

Graph 93



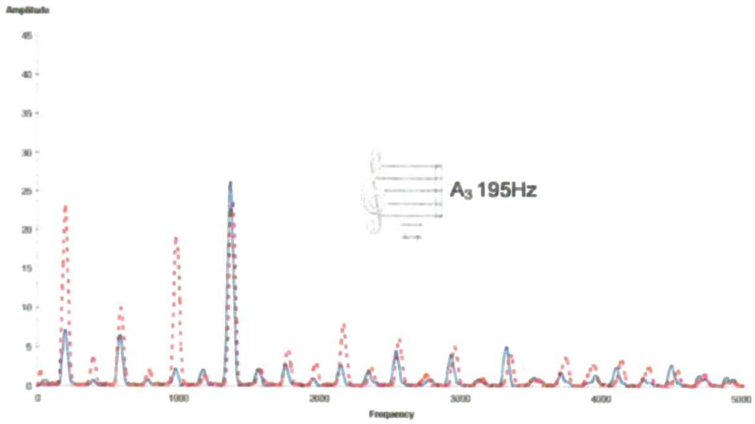
Small bore:

Slightly 'stuffy' or unfocused with some buzz.

Large bore:

More vibrant

Graph 94



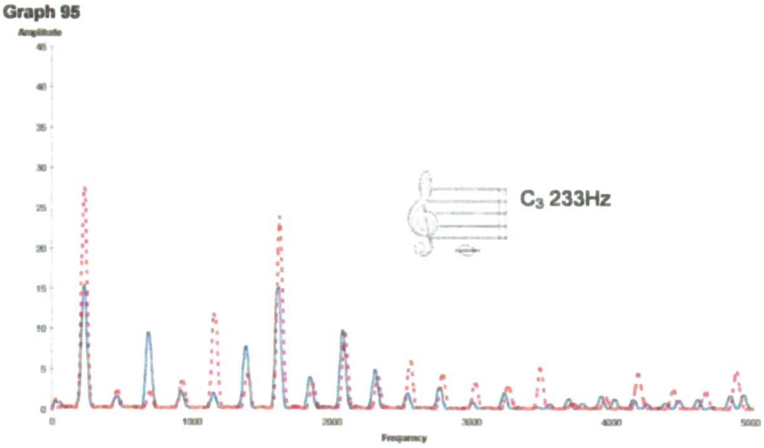
Small bore:

Dull

Large bore:

Lively/Brighter

Graph 95



Small bore:

Slightly dull

Large bore:

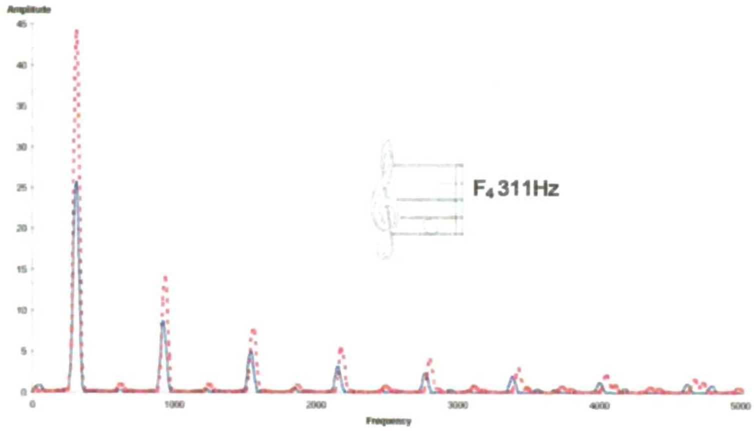
Much clearer

Amplitude in millivolts. X-axis = Frequency (kHz). Pico ADC 100, PicoScope Software.

Key: —— Small Bore ····· Large Bore

Listening panel's description of the sound from each set-up

Graph 96



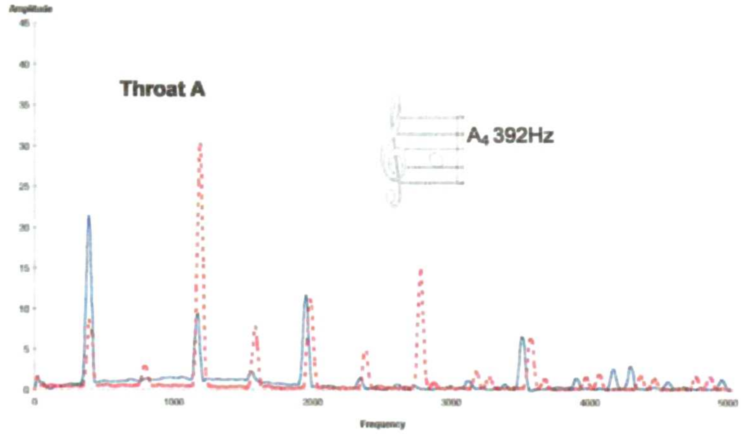
Small bore:

A little dull

Large bore

Bright but rounded

Graph 97



Small bore:

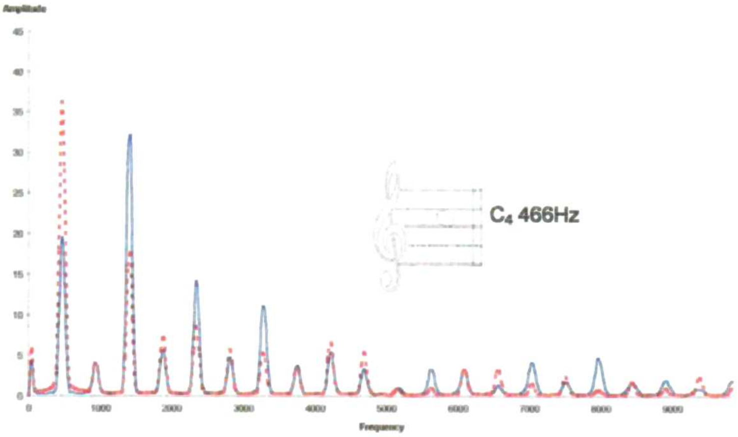
Good rounded

Large bore:

Thin tone but brighter

Middle Register

Graph 98



Small bore:

Edgy tone

Large bore:

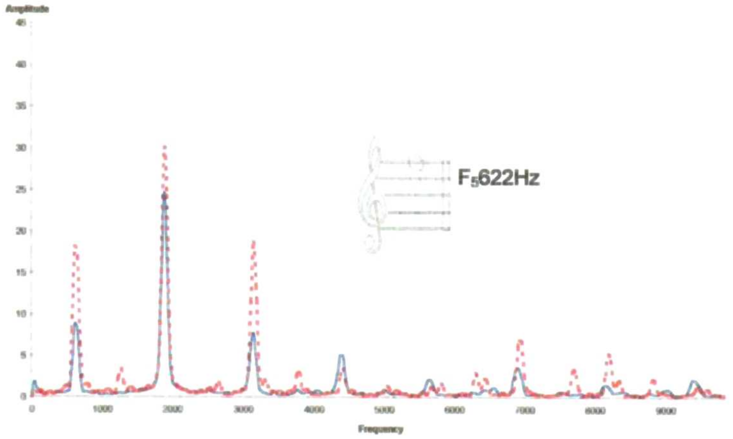
Full, rounded

Amplitude in millivolts. X-axis = Frequency (kHz). Pico ADC 100, PicoScope Software.

Key: Small Bore Large Bore

Listening panel's description of the sound from each set-up

Graph 99



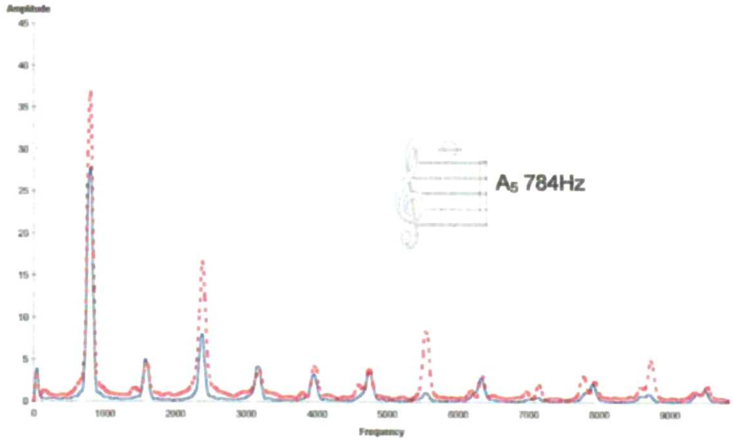
Small bore:

Slightly dull

Large bore:

More ring,brightness & fizz

Graph 100



Small bore:

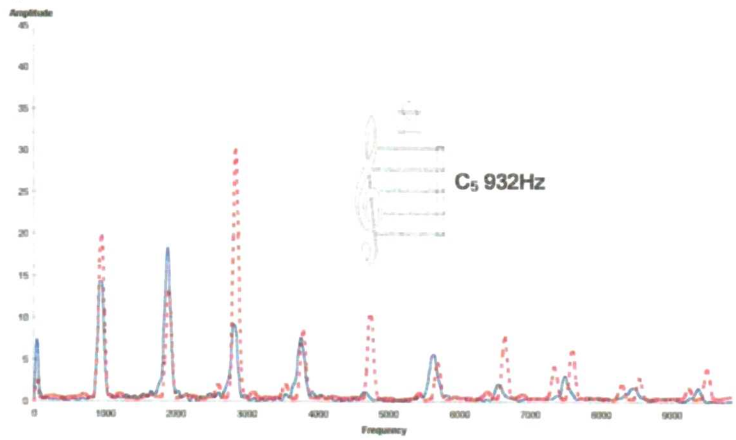
Good but a little dull

Large bore:

Real ping & ring, very good

Perhaps a little harsh

Graph 101



Small bore:

Good reedy quality

Large bore:

Pingy & rounded

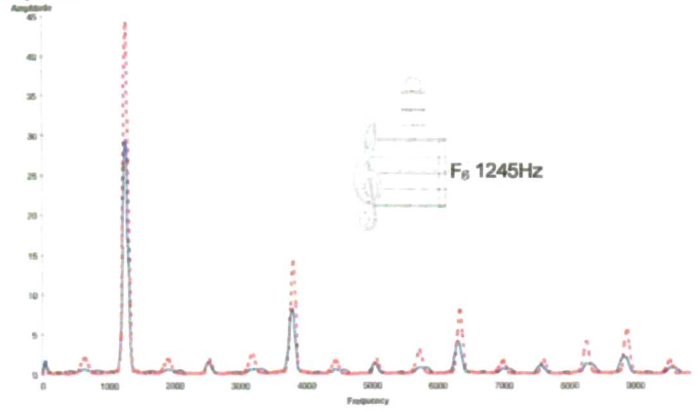
Amplitude in millivolts. X-axis = Frequency (kHz). Pico ADC 100, PicoScope Software.

Key: Small Bore Large Bore

Listening panel's description of the sound from each set-up

High Register

Graph 102



Small bore:

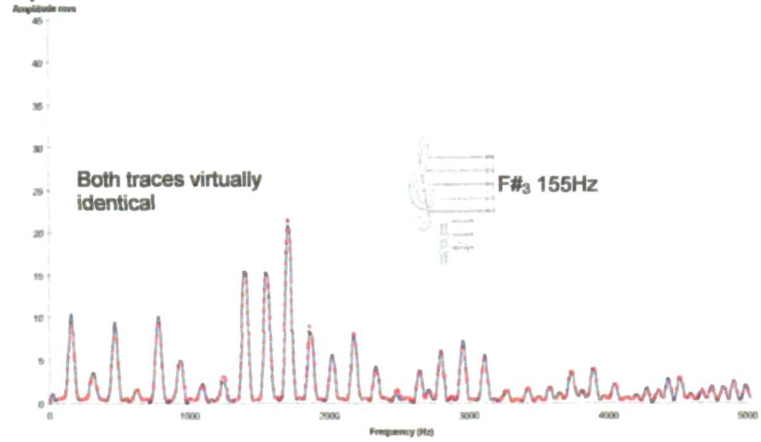
Clear, bright & slightly piercing

Large bore:

Rounded, pure & less piercing

Howarth Clarinet in A Spectral Graphs

Graph 103



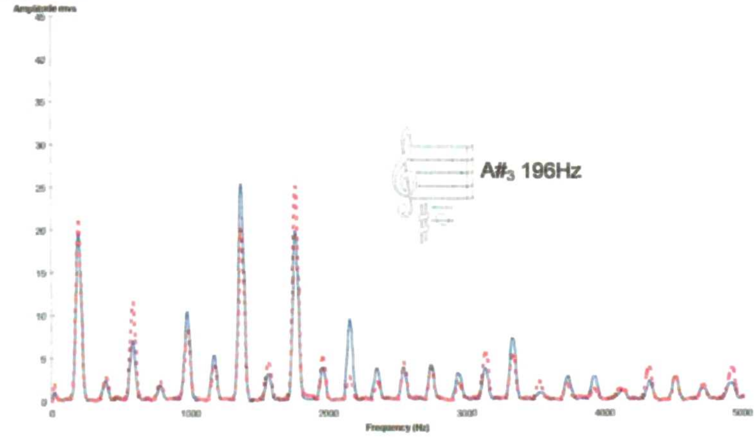
Small bore:

5 cents flat, slightly dull but good

Large bore:

In tune, more robust & vibrant

Graph 104



Small bore:

In tune, slightly dull

Large bore:

In tune, little brighter

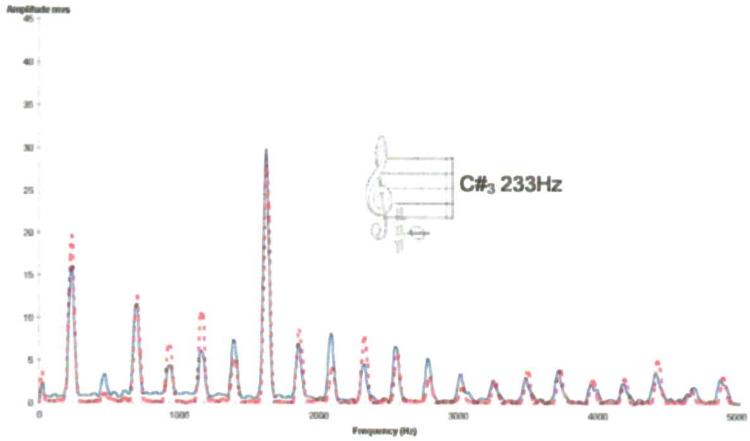
Both good

Amplitude in millivolts. X-axis = Frequency (kHz). Pico ADC 100, PicoScope Software.

Key: —— Small Bore ······ Large Bore

Listening panel's description of the sound from each set-up

Graph 105



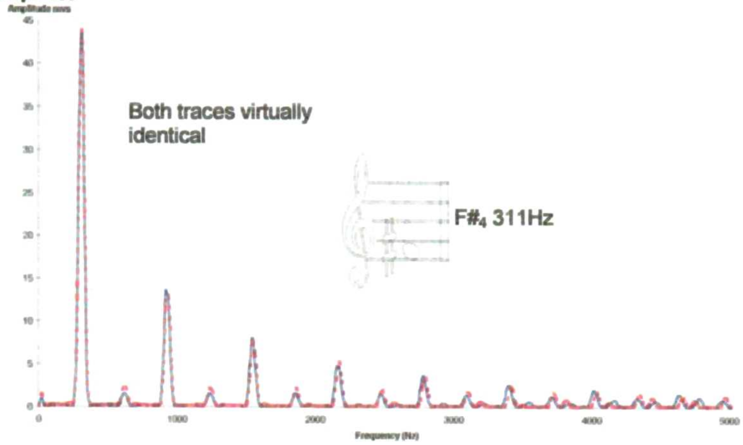
Small bore:

Nasal, 5 cents flat

Large bore:

In tune, clear, centred

Graph 106



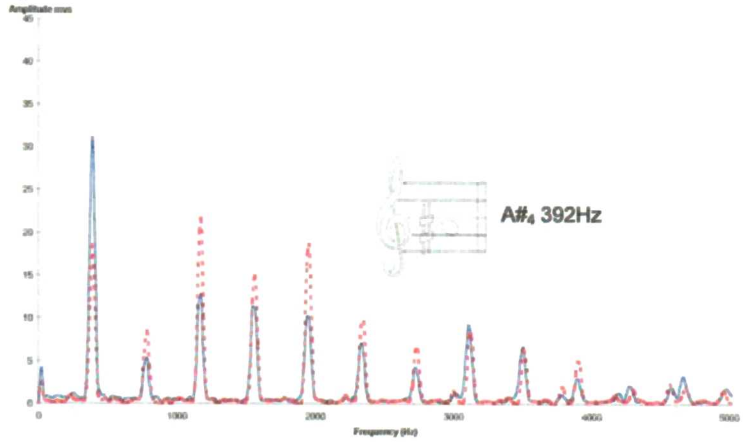
Small bore:

7 cents flat

Large bore:

In tune & slightly clearer

Graph 107



Small bore:

Rounded tone, 10 cents flat

Large bore:

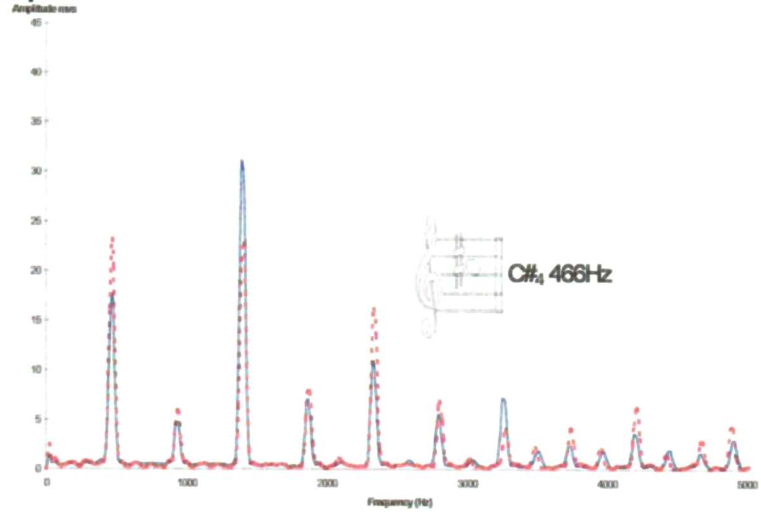
5 cents flat, thinner tone

Amplitude in millivolts. X-axis = Frequency (kHz). Pico ADC 100, PicoScope Software.

Key: Small Bore Large Bore

Listening panel's description of the sound from each set-up

Graph 108



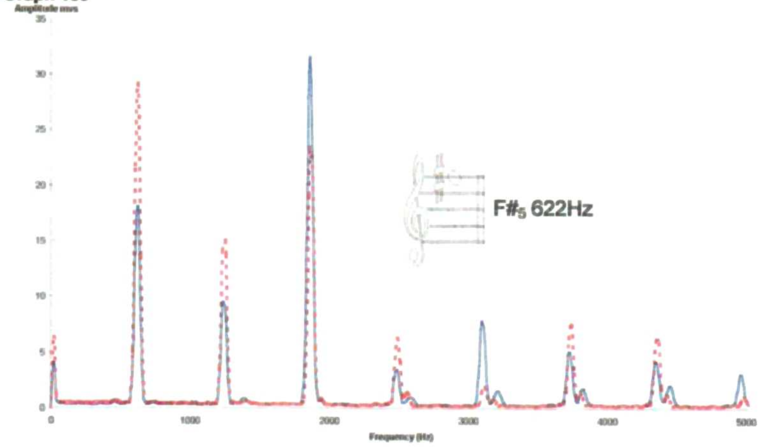
Small bore:

2/3 cents flat, dull

Large bore:

In tune, little brighter

Graph 109



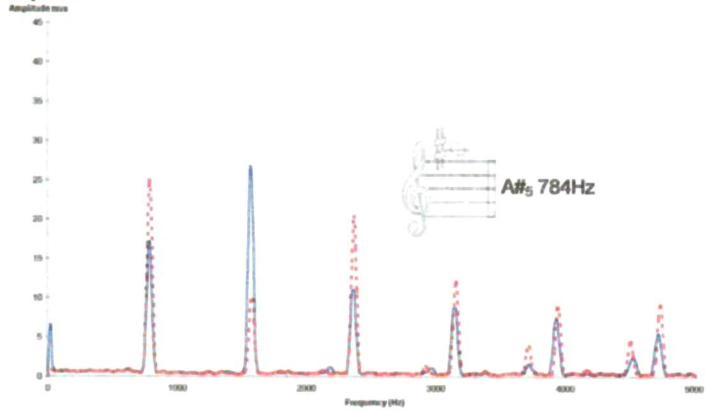
Small bore:

Good, 5 cents flat

Large bore:

Very good tone, alive, 5 cents sharp

Graph 110



Small bore:

In tune, slightly muffled/grubby

Large bore:

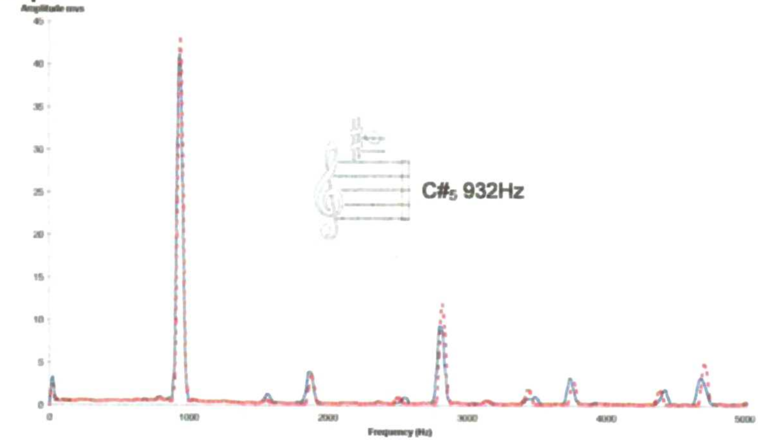
Brighter, clearer 5 cents sharp

Amplitude in millivolts. X-axis = Frequency (kHz). Pico ADC 100, PicoScope Software.

Key: Small Bore Large Bore

Listening panel's description of the sound from each set-up

Graph 111



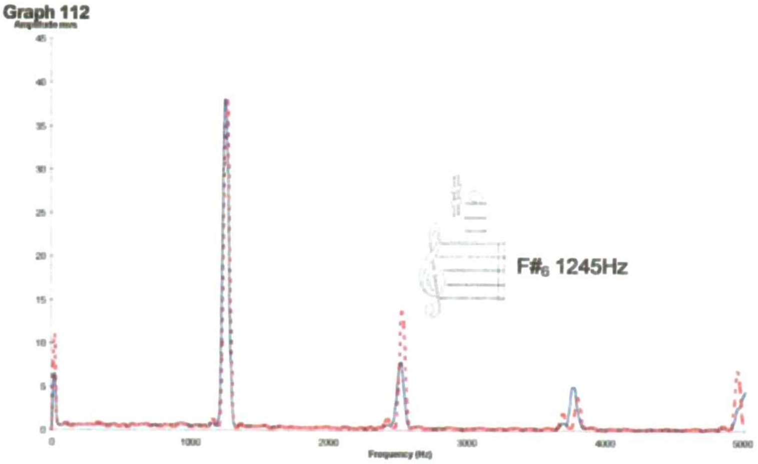
Small bore:

3 cents sharp, fuzzy

Large bore:

8-10 cents sharp, rounded

Graph 112



Small bore:

Clear tone, 5-8 cents sharp

Large bore:

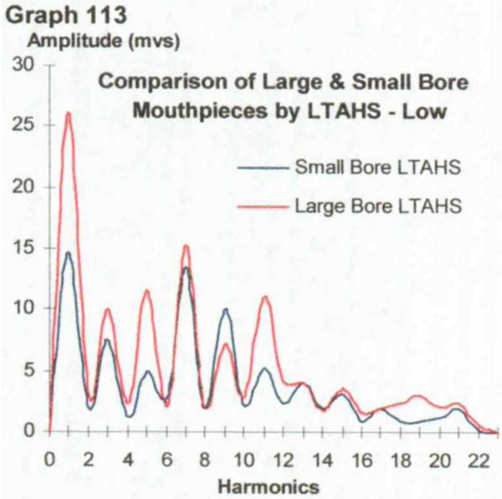
Thinner tone, 10-15 cents sharp

Long Term Average Harmonic Spectra

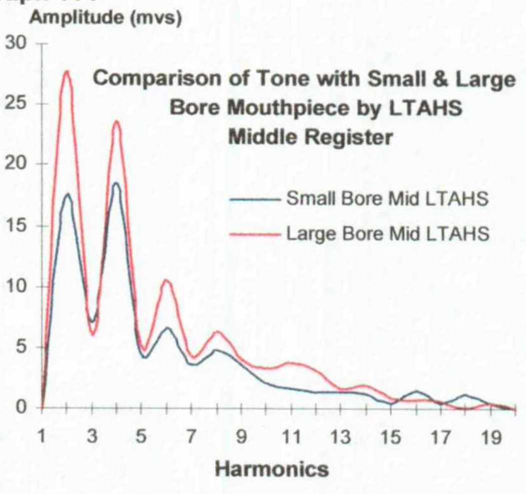
Long Term Average Spectra (LTAHS), the method of condensing harmonic data by averaging the powers of each harmonic from all the notes tested and presenting them as one spectrum (described in chapter 8), was used to present an overall picture of the instrument's tone when the change had been made to a larger bore mouthpiece. An unequalised LTAHS of each register was produced to show the difference in power output in each, then the registers combined for the overall result.

The following are LTAHS Graphs from the Bb Howarth Clarinet Re-test

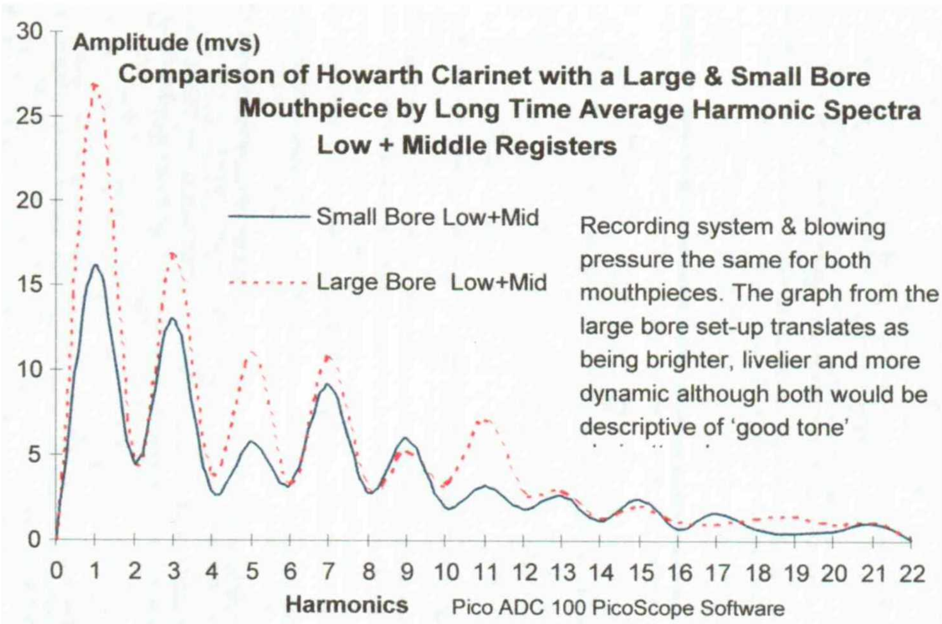
Graph 113



Graph 114

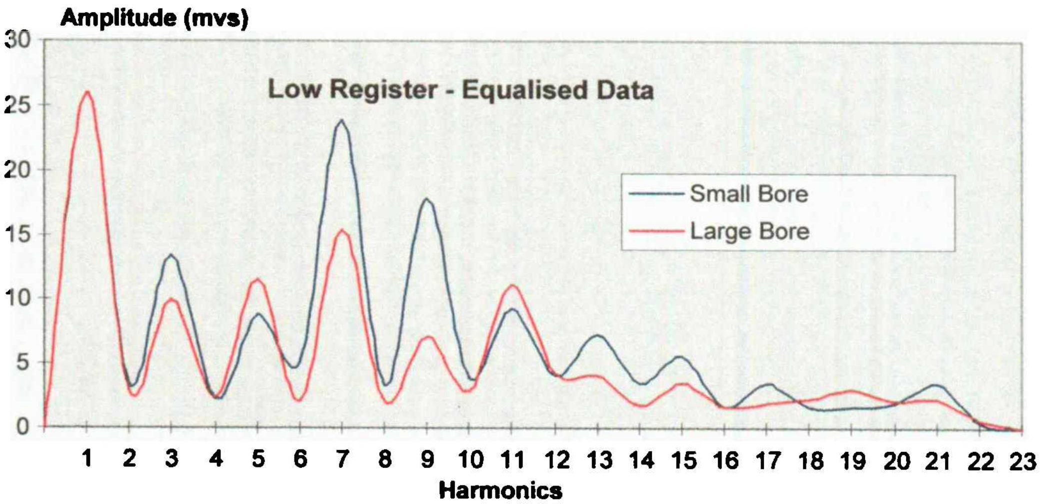


Graph 115

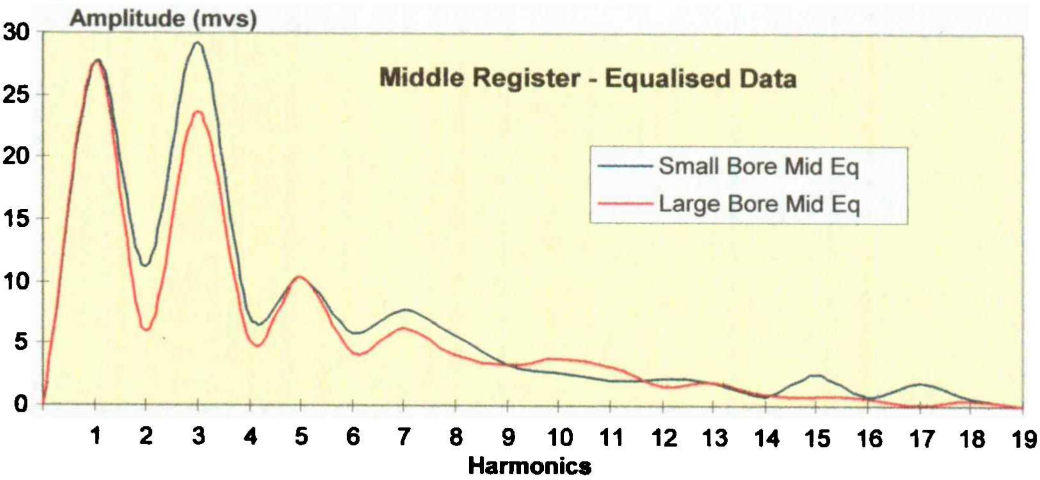


The above graphs show the clear distinction between the two set-ups, but these could still be misconstrued. Blowing pressures were the same for both sets of tests and these graphs indicate that the large bore mouthpiece actually produced more power, along with timbral differences in both registers. In fact, this exactly supports the response from players who prefer the playing properties of a large bore mouthpiece; the instrument is not only often described as being more dynamic, but also, the tone more rounded. To get some idea of the true difference in tone, we must assume that a player would compensate for the lower power output of a small bore mouthpiece set-up and blow a little harder. In graphic terms this would be similar to equalising the data, plotting the graph of the two spectra with equal magnitude fundamental frequencies.

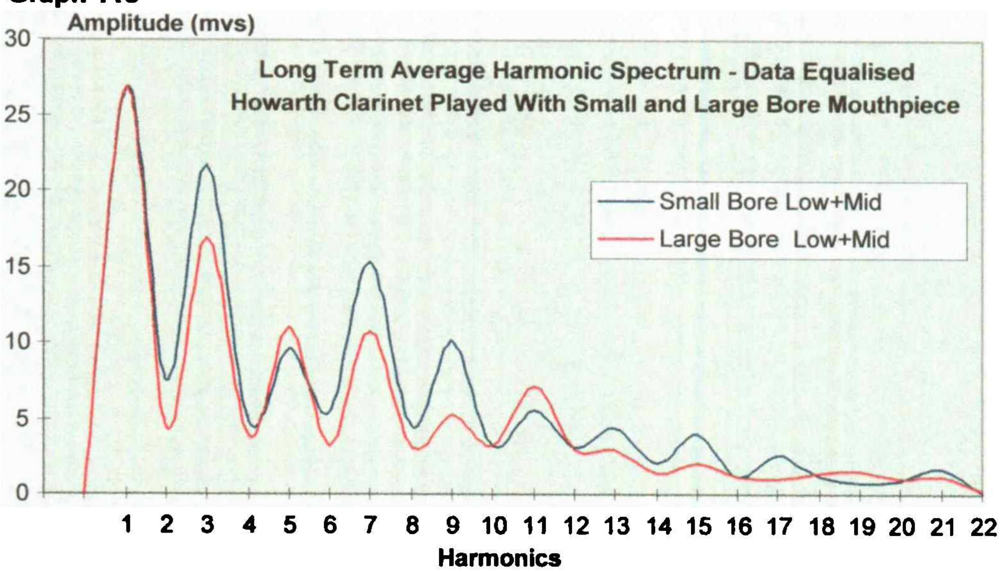
Graph 116



Graph 117



Graph 118



The data organised in this way appears to turn everything on its head, but actually makes the functioning of the two mouthpiece bore sizes much clearer. The very large number of individual spectra shows us that there were significant differences between the large and small bore mouthpiece's radiated sound, but equally, that there were big differences between a large number of the notes on the same instrument. In the LTAHS unequalised state we could see that the differences were actually more uniform than first appeared and, more importantly, the power output with a large bore mouthpiece was shown to be higher, especially in the fundamental. To view the real change in timbre it was necessary to equalise the data. We then found that the spectral graphs supported the listeners' and players' interpretation of the changes in tone. In both registers there was a definite move towards a more Germanic shape spectrum (Graph 117).

The low register attenuation of the 7th and 9th harmonic definitely removed harshness and softened the tone whilst the dominant 3rd harmonic produced by the small bore mouthpiece in the middle register was also reduced in magnitude so that it became better related to the fundamental. Very high components were also attenuated a little by the large bore mouthpiece in this middle register. The composite 3rd LTAHS graph gave a good overall picture of the timbre as a whole and suggested that in most cases it would suffice for the study of the change in tone through alteration in design.

Overall Impression

Both set-ups gave good intonation with modal ratios within acceptable tolerances. Players who prefer wider 12ths between the low and middle register, and higher pitch in the top register would probably like the large bore set-up. There was less timbral difference with the A clarinet, but both the Bb and A clarinets gained in brightness, extra gloss and bloom from the large bore mouthpiece for the majority of the notes over their whole range.

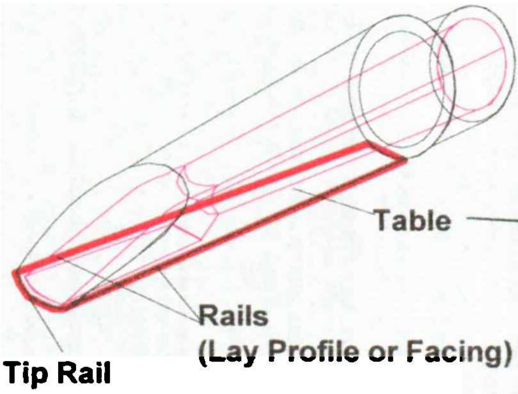
12

Experiments: Part 2

1. **Baffle Angle** The effect of raising the baffle angle. Shown to add a different brightness to the tone from that achieved by leaving material in the slipway. Baffle angles most commonly in use shown to produce reasonably balanced tone.
2. **Tip rail and area immediately below** Experiments on baffle angle and improvements in response to be gained through attention to this critical area.
3. **Side Walls** Effect of 'U Frame' and 'A Frame' configurations at various angles.
4. **Recess or Slipway** (the slope opposite the baffle, under the table into the bore). The effect on timbre and response of removing material from the recess. Findings suggested that this region was more crucial to certain aspects of tone than previously acknowledged.
5. **Lays** Assessment of the effect on tone and response of a range of lays (facings). LTAHS & Transfer function (lay data in appendix F) **Lays 2** Profile of the reed under deflection.
6. **Density** The effect of material density and hardness on tone. Differences highlighted by magnification of the data e.g. in a tristimulus graph.
7. **Mouthpiece wall thickness** (body of the mouthpiece). Difference perceptible, but little measurable change in the spectrum of harmonics.

Areas briefly touched upon

- **Facings** Measurement of numerous typical openings (deflection) and length (distance from tip to axis)
- Comparison with **lays** in common use which produce good performance.
- Area of the **window under the reed** not covered in this research but deserving of investigation. Some useful observations regarding effective dimensions.
- **Lay side rails** Also warranting thorough work. Thin side rails influence response differently from thick rails. Current observation suggests that the rails should lie just inside the width of the reed and that they should be thin for the first 12mm to 15mm from the tip of the mouthpiece.



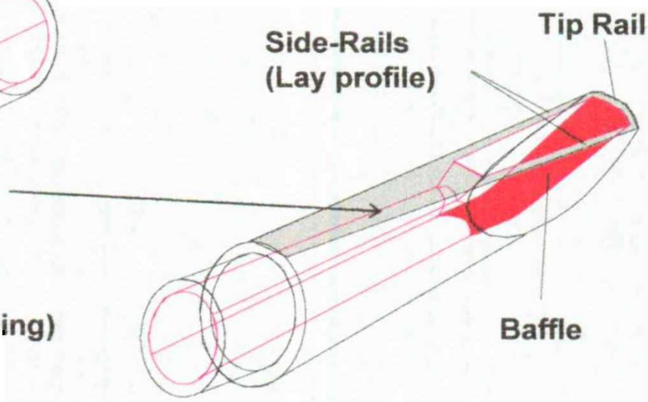
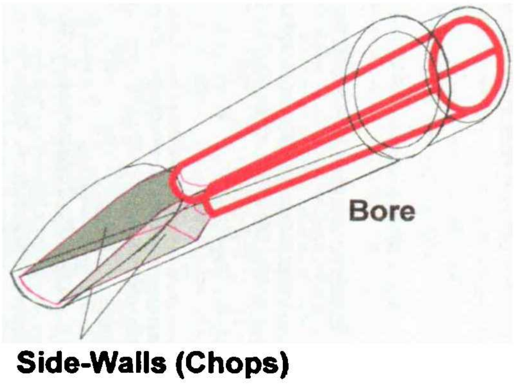


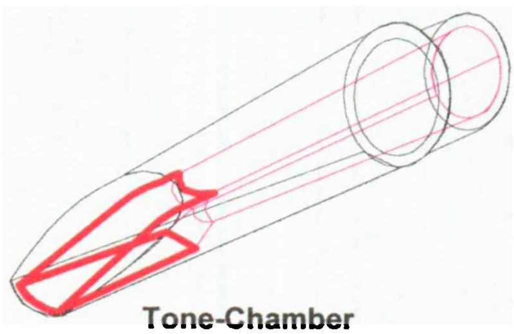
Fig.13

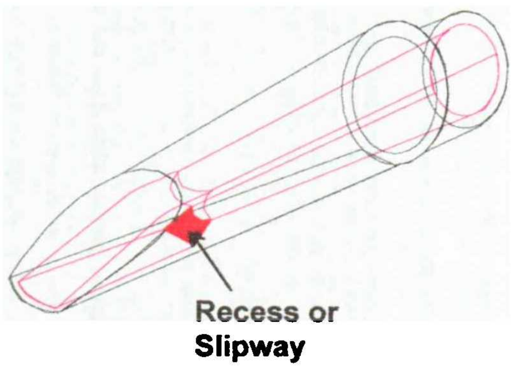
The Clarinet Mouthpiece

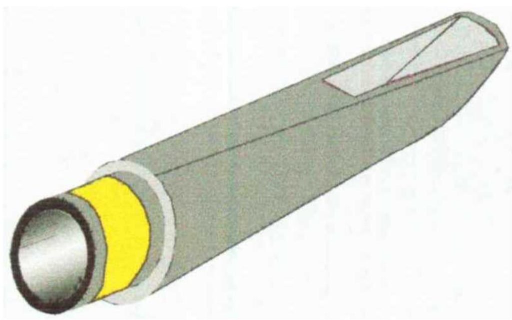
Interior and Exterior Shapes

The Areas of Investigation









1. The Effect of the Baffle Angle on Timbre

Baffle set at 17, 20 & 24 Degrees to the Centre Line of the Bore

In these experiments, alterations to the baffle angle were made to the same mouthpiece. The method used in the practical aspect of the work became standard practice i.e. recording a representative selection of notes to disk after each stage in the experiment and working swiftly so as to be able to use the same reed throughout.

Equipment:

Buffet R13 Clarinet.

Custom-made resin mouthpiece, incorporating a standard conical bore and parallel side walls. Lay profile was set at 1.10mm tip opening x 20mm long (popular curve). No.3 reed.

Baffle angle made 17° to the bore.[1]

Baffle reworked on a milling machine and hand finished.

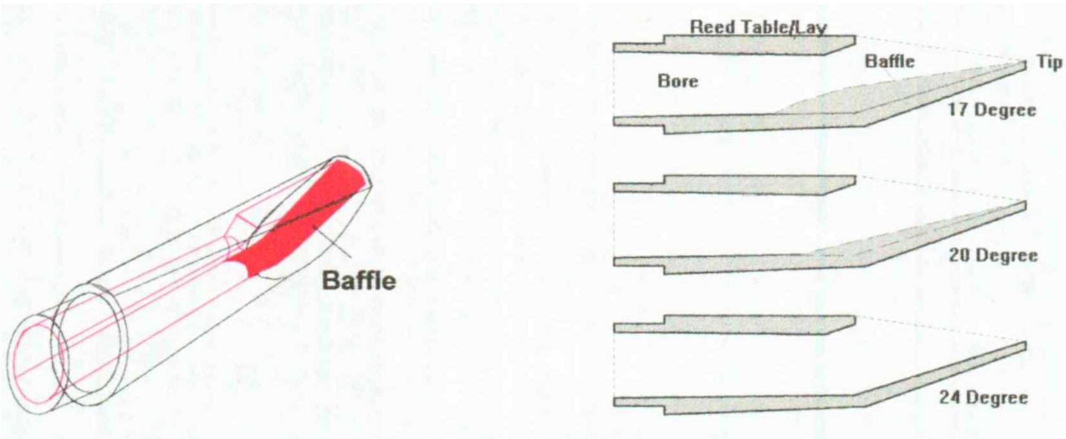
Recording direct to computer hard drive at 44Khz(*SoundForge* software).

PZM microphones for external recording.

Internal probe microphone for recording inside the mouthpiece.

Sounds looped in *SoundForge* and analysed via *Pico ADC100* A/D converter and *PicoScope* software.

Fig. 14 Baffle Angles



Most of the commercial mouthpieces had baffle angles of around 20 degrees, with the exception of some Zinner mouthpieces which had been made with a 24° baffle; these had above average performance. I also measured several 'Jazz'[2] mouthpieces which incorporated high baffles (between 17° and 18°) presumably to generate a more piercing

[1] If the baffle angle is to be calculated in relation to the table, then four or five degrees must be added to the baffle/bore angle.

[2] Mouthpieces with very open lays.

tone. In early experiments it was interesting to see to what extent material filed away from the slipway under the reed table affected timbre[3] and to note that the results were not dissimilar to the effect of varying the baffle angle. It was also evident that the region below the tip rail was crucial to good tone, response and dynamic range, and that the angle here should be relatively steep (20° or more). This angle was difficult to achieve if the baffle angle as a whole was set high. A solution for the high baffle was to incorporate two angles, the first machined steeply below the tip for approximately 10mm (20°-24°), the second, set higher into the bore for the rest of the length (18°). This can also be achieved by making the centre of the baffle convex, as when adding Blu-Tack or resin. I successfully modified several mouthpieces (Bb and bass clarinet) by applying a small epoxy resin mound centrally onto the 20° baffle, thereby maintaining the slope angle just below the tip rail. This is an effective design if the aim is for a penetrating tone quality but with no loss of dynamic response.

Results

The graph of the external, Long Term Average Harmonic Spectral (LTAHS) envelope shows the different response produced from each set-up. The first test, using the mouthpiece incorporating a 17° baffle, produced the poorest performance; the mouthpiece felt constricted and harsh, the tone quality was shrill and it had a surprising tendency to squeak. Once the baffle was lowered to 20° it performed immeasurably better, there was no longer any propensity to squeak, the tone had become full and smooth and the set-up felt good. The next stage, milling the baffle to 24° did not improve the mouthpiece, but did subtly change the character of the sound. Although the tone was fatter, the 'feel-good factor' was slightly diminished. Some players might enjoy this deep baffle angle.

The structure of the spectra for these baffles was interesting. The results of the averaged data needed to produce LTAHS gave fundamental strengths that were very close in value, indicating a reliable testing regime. The data was equalised to further highlight the true differences between the harmonics. The bandwidth used was 0 - 10khz, so the right hand portion of the graph contained the averaged data of the upper harmonics of the low to middle range of notes (the highest notes analysed have only around nine harmonics in this bandwidth). The 17° baffle had more upper harmonic activity in this region, with stronger peaks at the 18th and 25th harmonic. More importantly, in the bandwidth where the ear is particularly sensitive, the 3rd and 9th harmonics were more powerful, with stronger, even harmonics, especially in the lower harmonic numbers. The 24° angle spectral envelope was, predictably, much closer to the 20°, given their similar performance, but harmonics from the 5th upwards were noticeably stronger. The shallow

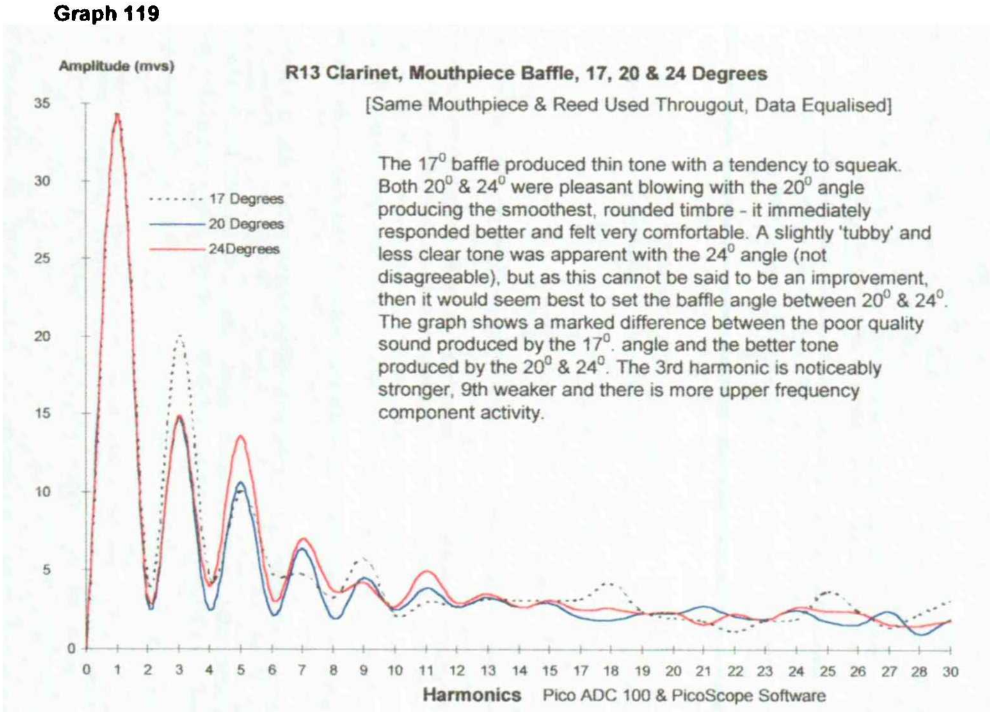
---

[3] See Recess Tests, p 181

17° baffle encouraged upper harmonics, sounded shrill and felt constricted. The 24° baffle did not encourage upper harmonics and felt freer but the tone was 'tubby'. The 20° baffle gave the smoothest results and it was satisfying to note that the spectral envelope was very similar to the graphs produced in previous experiments where 'good' tone had been produced.[4] Harshness in the tone with the 17° set-up was particularly in the low notes, and would appear to be as a result of the higher frequency components generated by this aspect of the design. The feeling of constriction might have been, in part, due to the smaller air cavity under the reed adding acoustic stiffness to the system. This stiffness did not greatly affect intonation, but the 24° baffle with a larger internal volume and less spring in the air cavity was a few cents flatter.

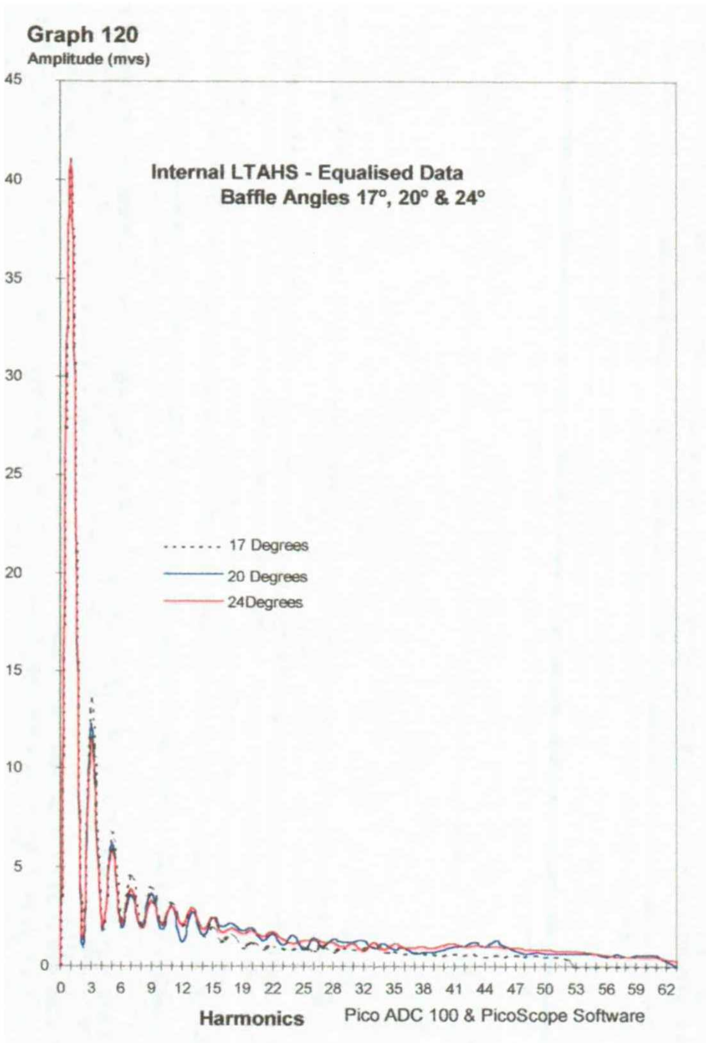
External Spectra with three different baffle angles

Graph 119



[4] See Chapter 11, p130, Howarth tests, & Chapter 3, p28 'comparison of German and French tone'

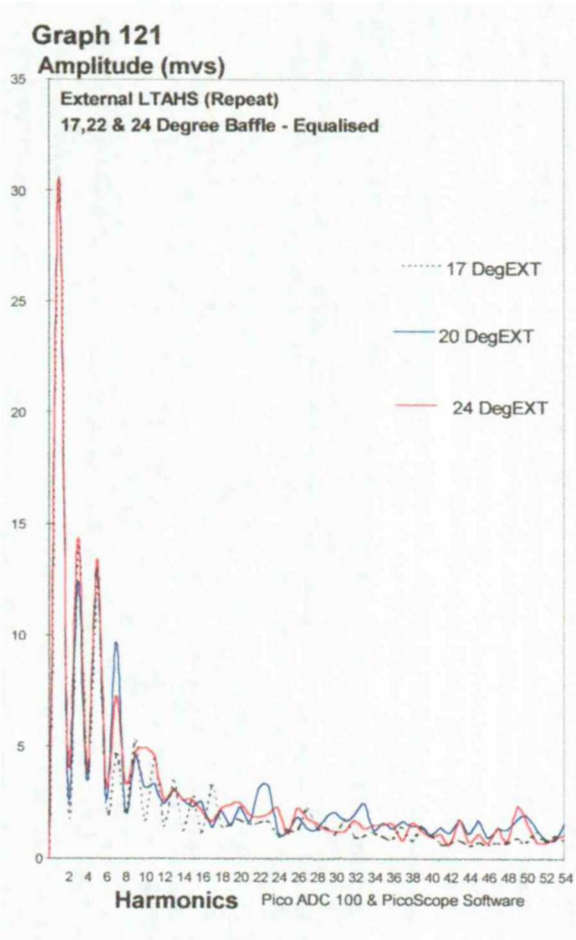
The graphs of the internal LTAHS envelopes are, predictably, remarkably similar, especially for the 20^0 and 24^0 baffle angle. However, the poor performing 17° set-up, stands out from the other two. As with the external results, the spectra for each baffle angle are averaged values of the amplitudes of the harmonics and partials over the whole range and, as such, similar, but not exactly the same as an impedance curve generated by a tone of continuously varying pitch (a frequency sweep) injected into the mouthpiece. This means that these internal envelopes are an indication of the reflected components inherent in the standing wave (the lower the notes below the cut-off frequency, the more of the wave travelling down the instrument from the mouthpiece is reflected [Campbell, 1987]). The graph shows strong peaks for the lower components of each set-up, which diminish towards the instrument cut-off. This reflection is necessary to form the standing wave. By contrast, the smaller the peaks, the stronger the possible output of radiated sound.

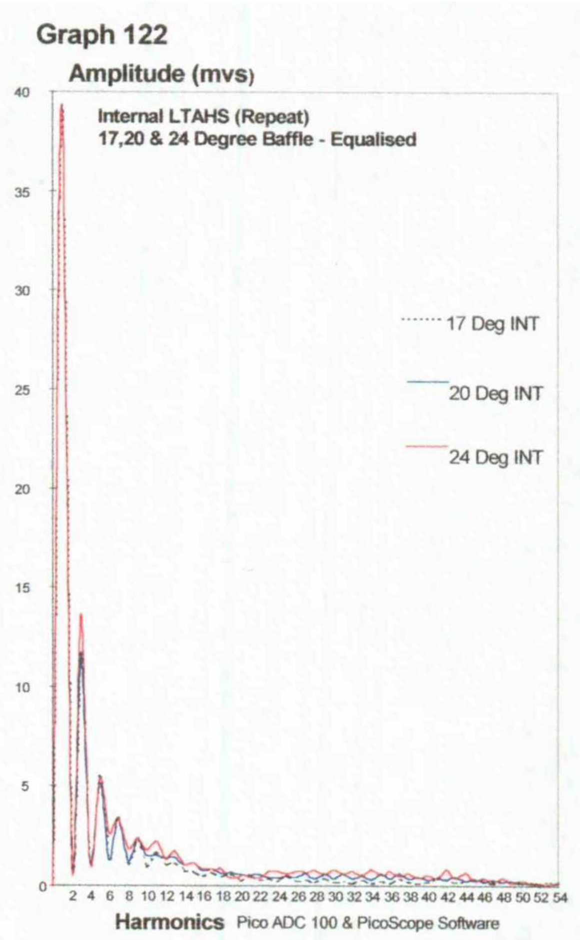


The cut-off frequency for the clarinet varies from instrument to instrument and is dependent on several factors, including bore, tone hole and mouthpiece dimensions. It is also different in each register. Experiments in related parts of this research have shown a large drop in energy at around 3kHz in most set-ups, which is in accord with Benade et.al., but the absolute cut-off appears to be somewhat higher at 6khz or above.

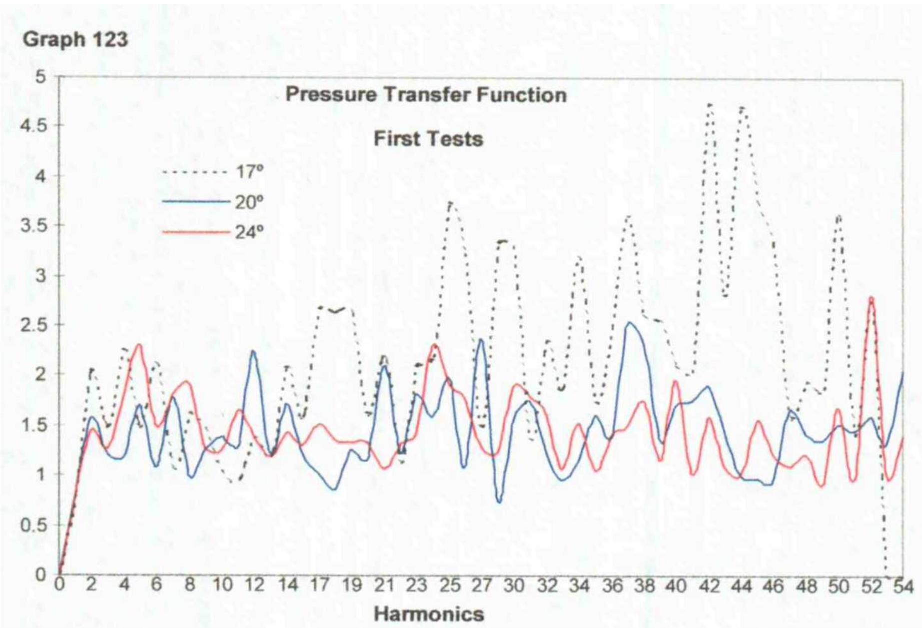
The relationship between reflection and radiation can be studied if the results of internal spectra are compared with the external spectra. This can be achieved by using the *Pressure Transfer Function* (Campbell, 1987, p. 347) which compares the two signals by showing them as a pressure ratio, normally expressed in decibels: $T = 20 \log (p_o / p_i)$, where p_o is the external radiated sound pressure and p_i is the internal pressure in the mouthpiece.

Initially, the repeat tests were disappointing since the LTAHS results were not as similar to the first experiments as had been expected, particularly when bearing in mind that, at the outset, the second mouthpiece with its original 17^0 baffle setting had been just as unresponsive and shrill as the first. It was curious that the second mouthpiece did not improve as dramatically as the first when the baffle was progressively lowered. I believe this to be as a result of a less responsive lay profile/reed combination. It did, however, lose the restricted and harsh quality when the baffle was machined to 20°, and the tone and response was marginally better at 24°. LTAHS of the repeat test does show the 17° baffle to be distinct from the 20° & 24°. The external graph shows this angle to generate stronger middle band activity and a clearly defined upper band pattern. The internal repeat graph shows the 17° baffle with a lower amplitude spread of mid to upper frequency harmonics and partials in the standing wave indicating a greater degree of radiation and less reflection in this region, as was the case in the first tests. Neither were so clearly defined as in the first results until the pressure transfer function (PTF) was applied to the data.

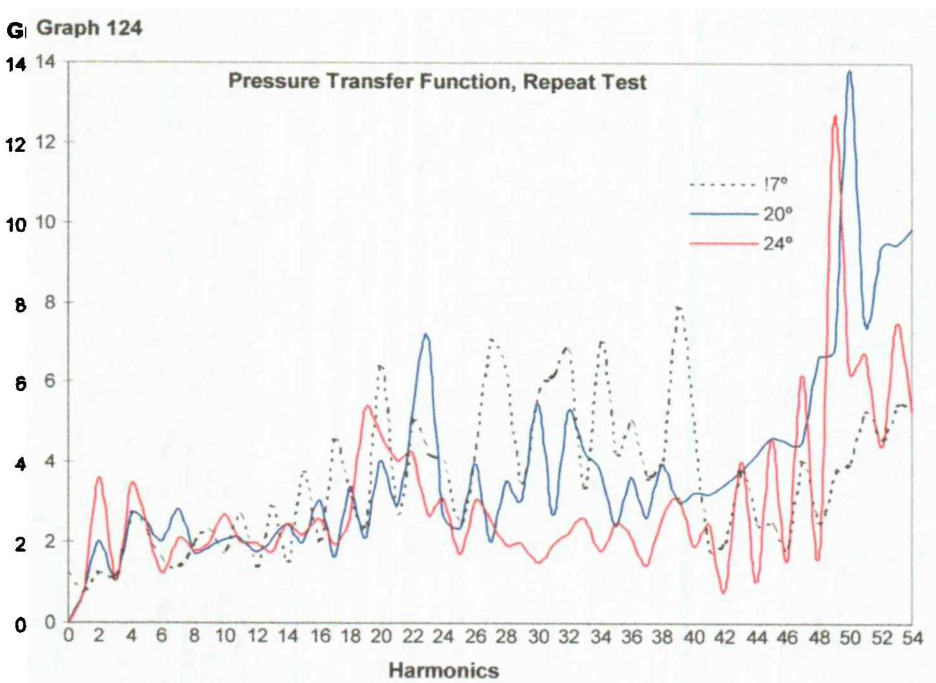




Graphs created from the data acquired by applying the pressure transfer function to the equalised results of both sets of baffle tests (original and repeats) gave a much improved picture of the performance of the three angles.



In the above graph (PTF, graph 123) we can clearly see how upper harmonics and partials from the 17° setting are radiating more strongly from the instrument and not reflecting back as part of the standing wave. Response from the 20° and 24° was quite even, confirming the similar, good tone from both these angles. In the following graph of the repeat test data, where it was more difficult to determine the differences, the transfer function allows us to observe a very marked differentiation between the very poor 17° baffle and the less poor 20° and 24°. Harmonics from 16 to 40 are stronger and have a similar power to the harmonics in this region from the first test. Overall, this mouthpiece can be seen to behave less well than the first, with uneven response from all three set-ups.



A comparison of the internally generated sound with the externally radiated sound by means of the pressure transfer function is helpful in explaining the unusually poor response from clarinet bell notes and demonstrates why the bell is such an important feature of the instrument. The bell note and first note up, along with the corresponding bell note a 12th above, are usually of less good quality than notes firmly situated on the straight portion of the bore of the instrument. Nearly all these notes, analysed during the course of the research, displayed weak external fundamentals in relation to the rest of the spectrum, whatever the microphone position.[5] The bell causes greater reflection of sound

[5] Refer to Campbell and Greated [p.346-347] for an explanation of the influence of the bell in relation to the standing wave.

components the lower their frequency, and this aids the establishment of a strong standing wave. The bell is a kind of 'no go area' for low frequency. The higher the frequency, the more the sound is allowed to penetrate this area and radiate from the bell. This explains why the bell appears to behave like a high pass filter. The clarinet's lowest note has no alternative but to emanate from the bell[6] and so is subject to the full effect of this reflecting and filtering, so an adverse proportion of middle to high frequency components appear in the radiated sound. The next note up is still partially on the flare of the bell[7] and is therefore also subject to this influence, but to a lesser extent, since the note also has a tone hole from which more fundamental is allowed to escape, but less high frequency (i.e. behaving like a low pass filter).

Conclusions

It is important for a clarinet mouthpiece to have a tone chamber cavity whose minimum volume is approximately 3ml. In a normal set-up this corresponds to a baffle angle of around 20°. Angles less than this encourage a tone which contains a high proportion of more powerful middle and upper harmonics which eventually produce a shrill, harsh quality. A high baffle angle appears to affect the behaviour of the standing wave in such a way so as to allow more of the high frequency components generated in the mouthpiece to radiate more efficiently than low frequency, and not to be trapped as part of that wave. Baffle angles between 20° and 24° encourage a more even response over the audible bandwidth. The baffle angle was shown to play a significant role in the quality of the clarinet's tone colour.

---

[6] Except for instruments with a small key vent to sharpen the bell note as on certain German clarinets.

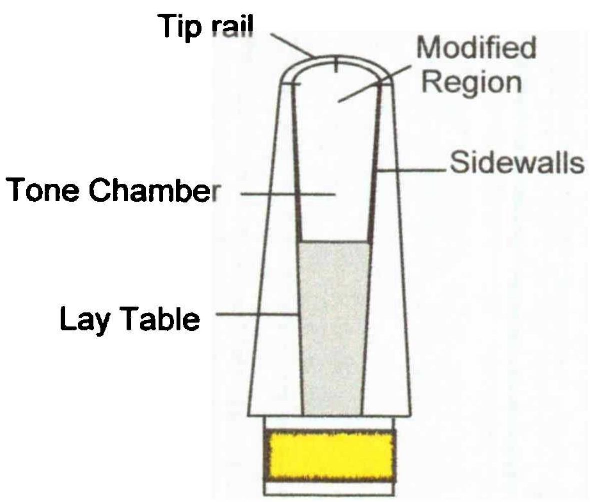
[7] German style instruments usually have a much shorter flare so this tone hole may be located above it on a straight section of the bore.

2 Tip Rail Region

The effect on tone & response of alteration to the top half of the tone chamber (immediately below the tip rail)

Mouthpiece : Pillinger, ebonite, medium bore (14.25mm x 15.25mm, 0.5° taper)
22° baffle & close lay profile (0.75mmx20mm).
Clarinet: Louis Bb c.1920 & Buffet Bb c.1980, both 14.6mm bore.
Analysis Equipment:
Pico ADC100, Picoscope software & Fostex M501 microphone.

Fig.15 Baffle Region Close to the Tip



It was found that significant improvements could be made to the dynamic response of a mouthpiece by ensuring that the region directly below the tip rail on the inside of the tone-chamber be made sufficiently deep, and as wide as the reed would allow. The importance of this area became apparent when, having made a copy of a 1930s Boosey & Co. mouthpiece in acrylic, using traditional methods (turning and milling from solid rod), it was clear that the copy was not as responsive as the original. Close inspection of the copy revealed that the portion of the baffle below the tip had been left slightly high, and that the side rails were a little closer (no more than 0.2mm.) The difference between the two mouthpieces was minimal but when these areas were corrected, the mouthpiece became as responsive as the original.

In the above example it was felt that both the tone and response of the copy had improved after the corrections had been made. A test was then performed on a mouthpiece with a slightly raised baffle and narrow side walls near the tip. The aim was to see if any changes could be detected in the spectrum of harmonics from a similar modification. Material was filed away from just below the tip rail to approximately half way down the chamber and the outer rails were widened and undercut. Testing was carried out at the start, and at three subsequent stages. The results of this experiment suggested that the response alone was affected by these modifications, and not the tone. The reason for the original misconception over the improvement to both the tone and response will be understood when bearing in mind that if a mouthpiece is more responsive in terms of articulation and dynamic range, then it is likely that a performer will play more expressively, the overall impression being that the tone is therefore better.

The results from the analysis conducted at each stage were curious. The first spectrum analysis (FFT) showed the unaltered mouthpiece in the low & middle registers. The second FFT was made after the removal of a small amount of material from below the tip and from the centre of the baffle; this gave the baffle a more concave aspect and increased the angle at the tip. Rather than improve the tone, the sound became less pure and rounded with no noticeable difference in dynamic response. The surfaces of the upper sidewalls and top of the baffle were now quite rough, and this may have contributed to the deterioration in the tone quality.[8] The analysis at this stage showed a dramatic change in the spectrum of harmonics. Even harmonics were introduced at the lower end, with the power of the 3rd and 5th harmonic being reversed. There was more upper harmonic activity at low power levels, a phenomenon which had been observed in other mouthpieces with similarly harsh tone. The middle register had also altered, but less dramatically. Again the 3rd and 5th harmonic powers were reversed but the upper harmonics remained unchanged.

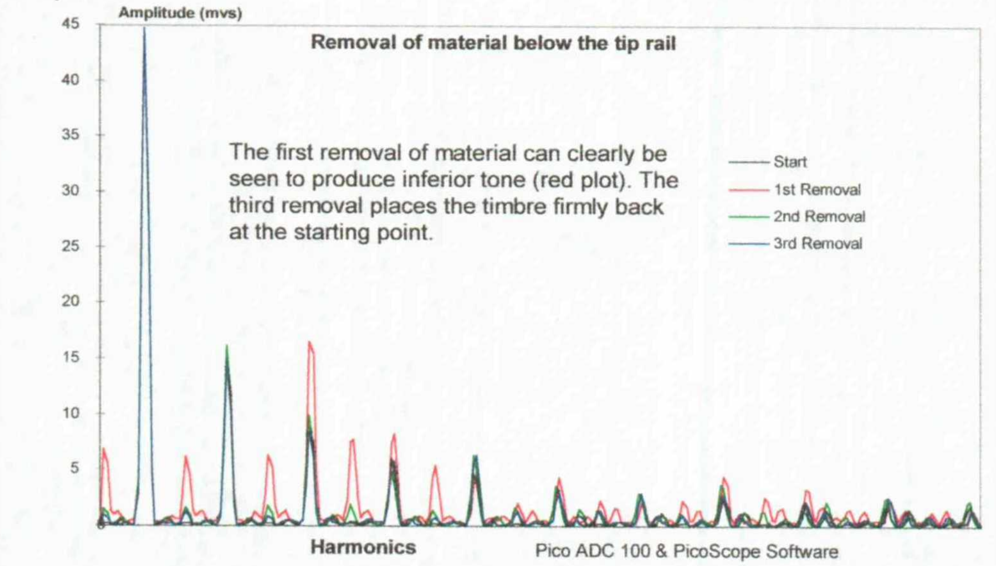
The second stage in the removal of material resulted in the mouthpiece blowing well again, and there was now a sense that the response was freer but that the tone was still inferior to the original. Analysis of the spectra showed a movement towards the original pattern of harmonics. The even components had disappeared and the familiar downward steps of harmonics 1,3,5, and 7 could be seen. This time, the 7th and 9th harmonics had reversed powers in relation to the original state. Middle register tone was virtually the same as the first specification.

---

[8] The sound quality, response and feel of a clarinet can often be improved by carefully polishing all inner surfaces. Rough surfaces can absorb high frequency components to some extent.

The final removal of material was made. All file marks and scratches were removed and all surfaces polished. The tone now seemed to have regained its original roundness and clarity, but with an improvement in the dynamic response and punchy quality of the mouthpiece The analysis of the low register showed an almost complete return to the original spectrum with the exception of a very small increase in the power of the 9th harmonic. Middle register tone seemed to be better, but the new spectrum indicated only a small increase in the strengths of the 3rd and 7th harmonics in respect to the 5th. It was possible that this small variation in the formant wave was evidence of the slight improvement in the tone

Graph 125



The changes had been brought about by small amounts of material being removed from the mouthpiece. The alteration to the baffle angle at the tip was no more than one degree, and less than 0.2mm of material had been scraped from the baffle and side walls. There was no doubt that these modifications had caused the mouthpiece to become more efficient and dynamic, but improvement to the tone was confined to the middle register. These results highlighted the importance of this area of the mouthpiece

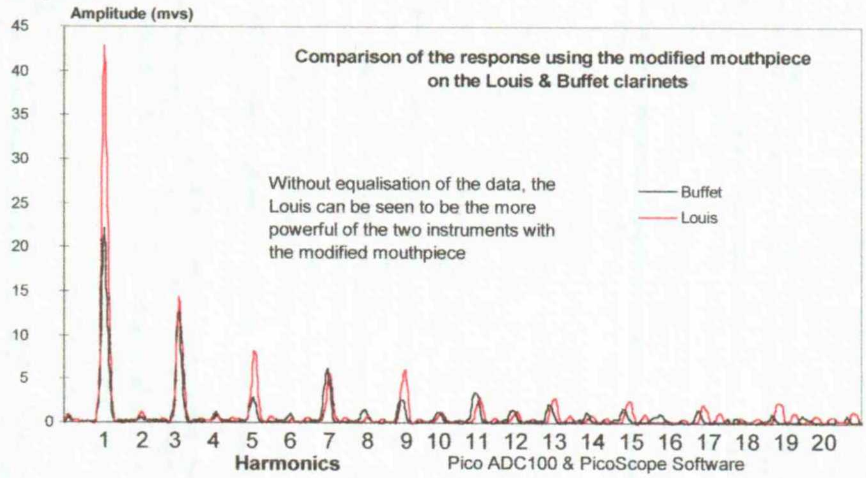
The baffle angle (commonly 20°) dictates the depth of the region below the tip rail [9] The character of a mouthpiece incorporating a 24° baffle is quite different from one with a 20° baffle; the tone is usually more mellow but can be lacking in focus. Good results can be achieved by using a less steep angle for most of the length of the baffle, but combining this with a steeper initial slope under the tip. I have made some good mouthpieces in this way Acoustically, more volume under the tip reduces springiness in the air beneath the

[9] Some of the more exciting mouthpieces tested had steep baffle angles (as much as 24° or 25°), automatically deepening the area below the tip. The only modification possible here would be by alteration to the side rail width.

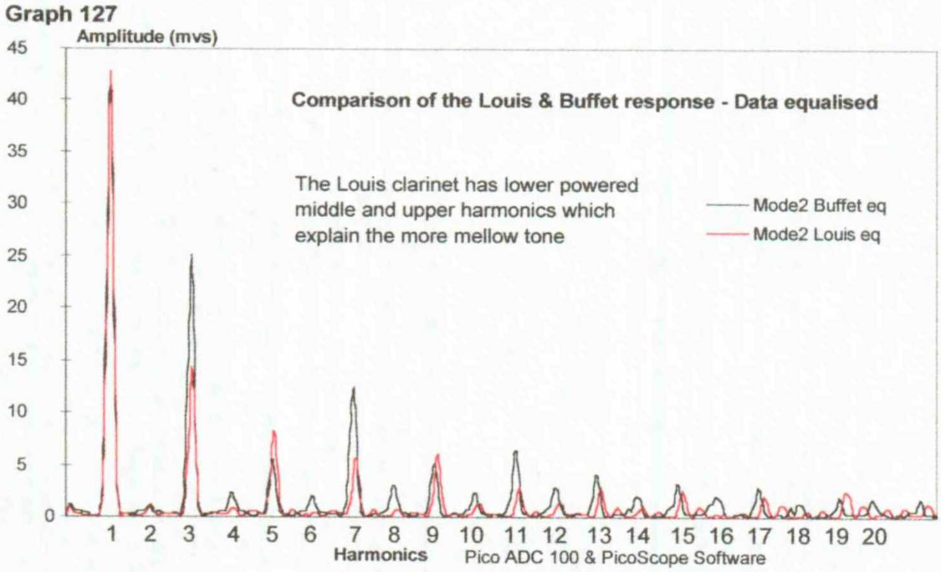
reed and therefore lowers resonant frequency whilst also reducing the damping effect on the reed, thereby allowing freer movement. As a result of the extra width, side rails are narrowed, and this further reduces reed damping [Krüger, 1997]; this may contribute to the improved dynamic response.

As a final experiment, the altered mouthpiece was transferred from the Louis clarinet to a typical French clarinet (Buffet R13). The fundamental (C_3\$Bb_3$) remained at the same pitch but the second register (G_5\$F_5$) was slightly sharper as a result of the 12ths widening. This is as would be expected when using a larger bore mouthpiece on a small bore clarinet.

Graph 126

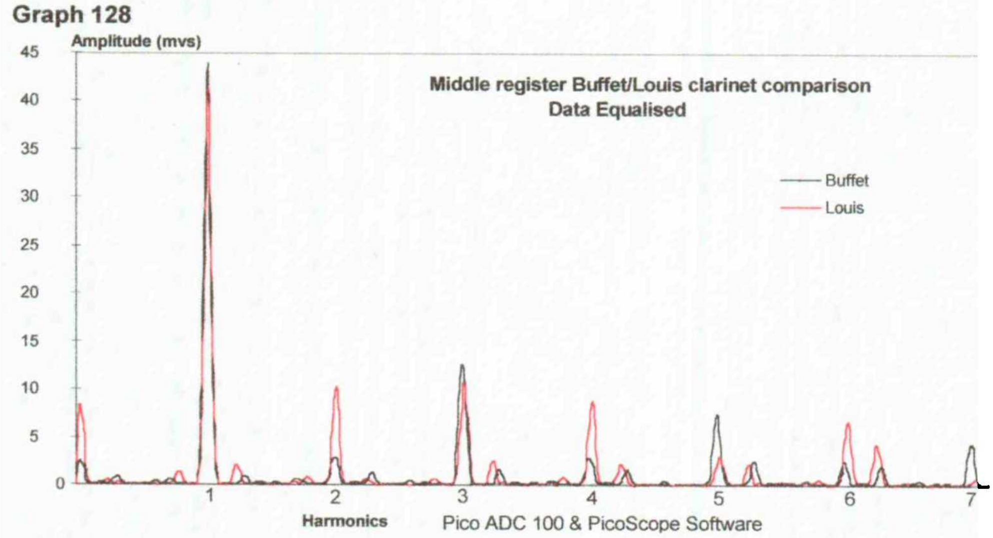


Graph 127



The two spectral graphs demonstrated clearly the influence of clarinet design on tone. The first graph with pure data showed the Louis to have a more powerful response. In the graph with data equalised, a comparison of the amplitudes of the components could be made. In the Buffet, the 3rd, 7th and 11th harmonics were much stronger with additional even harmonic activity, and this was consistent with its brighter, rougher timbre. The tone of the Buffet also lacked smoothness and focus. The Louis spectral graph showed weaker upper harmonics and a better balanced 3rd and 5th harmonic. However, the middle register of the Buffet displayed a ringing tone that was superior to the Louis, with the FFT describing a more square wave style tone with an ordered progression down through harmonics 1,3,5, and 7, in comparison to the more sinusoidal results obtained from the Louis. The wave form of the Buffet is characteristic of a clarinet with a good middle register, and the harmonic structure to aim for when designing a mouthpiece to complement a specific instrument. Why the Buffet 2nd register was superior is not clear, but it may have been due to the change in response as described in the Howarth tests where a large bore mouthpiece was shown to improve the tone of a small bore clarinet.

Graph 128



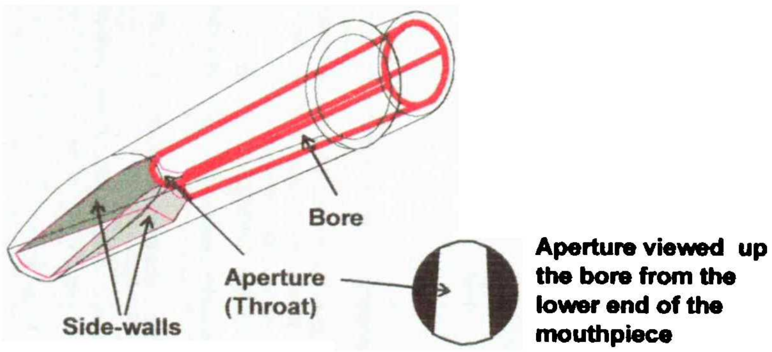
This simple experiment demonstrated the importance of the relationship between clarinet and mouthpiece but it also showed that any modification made to a mouthpiece will not necessarily result in the same changes in response in every make of clarinet.

3 SIDE WALL ANGLE

Experiments to Determine the Effect of Different Angles Applied to the Sidewalls

The majority of mouthpieces currently available to players (with the exception of some German and handmade mouthpieces) incorporate a tone chamber with gently tapering, vertical sidewalls from the mouthpiece tip to the entry into the top of the bore (throat). The resulting aperture into the bore has parallel sides (U-frame) clearly visible when viewed up through the bore from the lower end of the mouthpiece. This design is in contrast to many mouthpieces made in the 18th, 19th and early part of the 20th century, where the sidewalls were generally angled outwards for the whole length, sometimes by a considerable degree, resulting in an A-frame aperture into the bore.

Fig.16 Side-Walls, Aperture and Bore



The effect of widening the angle from U-frame to A-frame

1. The baffle area is enlarged and remains more or less parallel for its whole length.
2. The baffle is forced into a more concave shape.
3. The volume of the chamber is increased.
4. The window under the reed (reed aperture) becomes undercut.
5. The area of the aperture into the bore is enlarged.
6. The bocal effect is reduced or eliminated.

The reason that so many manufacturers adopt the parallel, vertical side wall is understandable. It is widely accepted that this design will work tolerably well on most instruments and will usually make indifferent clarinets seem more alive and dynamic. The design of the modern Boehm clarinet has certainly created and maintained a need for this sort of mouthpiece. In essence, this is a safe design, and also one that, when incorporating an open lay, is ideal for music requiring a loud, piercing tone which projects well, such as jazz, rock or some ethnic music. The drawback is that this design can sometimes result in a single dimensional, light tone quality. However, the experiments in this research concerning the slipway under the table were carried out using mouthpieces with only slightly angled side walls, and the results showed that very interesting mouthpieces producing a colourful timbre could be made by actually increasing the bocal. This was done by leaving material in the recess thereby creating a slightly smaller aperture into the bore.

Equipment

For these experiments a standard design mouthpiece was used.

Bore size: 14mm x 15mm (55mm long)

Table angle: 4 degrees

Baffle Angle: 20 degrees

Lay Profile: 1.05mm x 20mm with medium strength reed (no. 3)

Clarinet: Louis Bb Boehm 14.6mm bore

Dynamic Probe Microphone inserted 25mm from tip into the baffle

PZM external microphone

Recordings direct to computer hard drive using *SoundForge* software.

Analysis with Pico ADC100 and *Virtual Waves* software.

Test (a) Parallel Walls (0 Degrees)

Test (b) Wall Angle Approximately 2 Degrees

Test (c) Wall angle Approximately 3 Degrees

Test (d) Wall Angle Approximately 4 Degrees

Test (e) Wall Angle Approximately 5 Degrees

In order to produce the different angles, the whole length of the wall was carefully filed, avoiding alteration to the width of the rails inside and below the tip. This gradually created a small under-cut along the length of the side rails.

Playing Response - First Impressions

The instrument set-up for the first test with the parallel walls felt slightly hard and brittle. The tone was bright, but a little thin and lacking in warmth.

The second test, with the walls filed out to approximately 2 degrees, produced playing qualities that were noticeably better. The tone and response had become smoother and more refined. This is the kind of shaping I would normally apply to the chamber when making a good, general purpose mouthpiece.

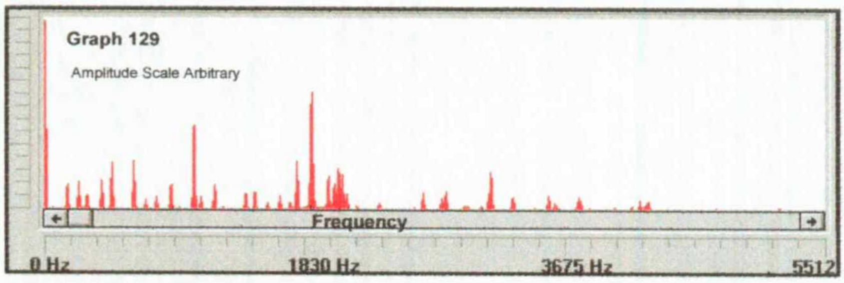
The third test, with the mouthpiece filed further (to approximately 3 degrees) was just as good, although there was a subtle change in the feel, with the mouthpiece becoming more open and expansive.

The mouthpiece wall angle for the fourth test, at approximately 4 degrees, produced a rewarding set-up, very warm, no sense of harshness and a vibrant quality to the tone. The fifth test, at approximately 5 degrees, was still good but less resonant.

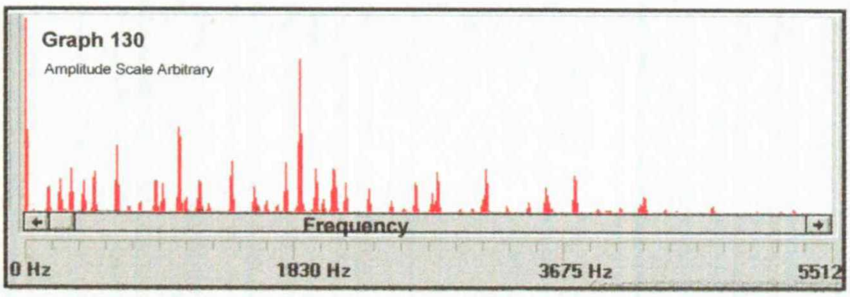
Analysis

Test (a), 0^0

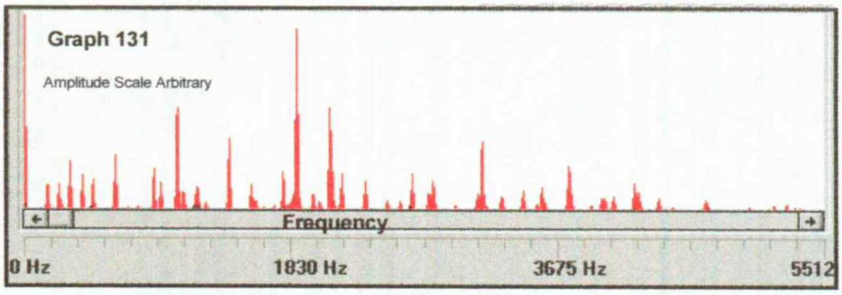
General Accumulated Average Spectrum (GAAS) from *VirtualWaves* (Vwaves)



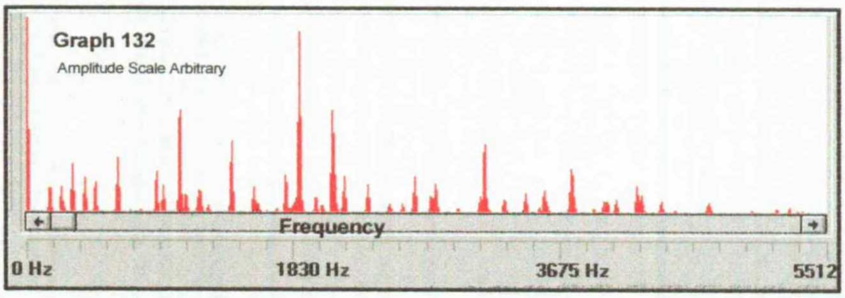
Test (b), 2^0



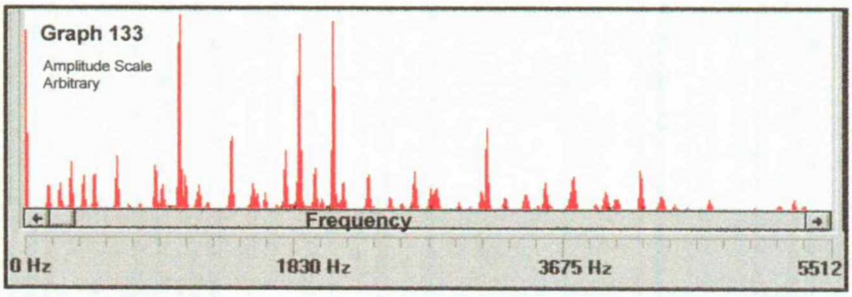
Test (c), 3^0



Test (d), 4^0



Test (e), 5^0

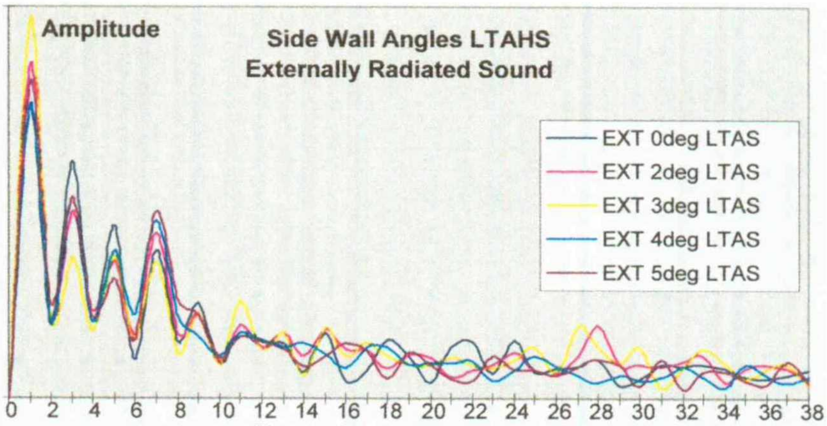


The most significant change in the GAAS graphs was between the 1st and the 2nd tests, the second showing an increased richness in the timbre. This accorded with playing impressions. The best tone was achieved when wall angles were between 3^0 and 4^0 and it was here that the feel-good factor was the most pronounced. There was a marked difference in the fifth graph where strong peaks could be observed around 1khz and 2kHz, but a slight reduction in richness and amplitude in all other frequencies.[10]

[10] See chapter 8, p107 for more information on GAAS.

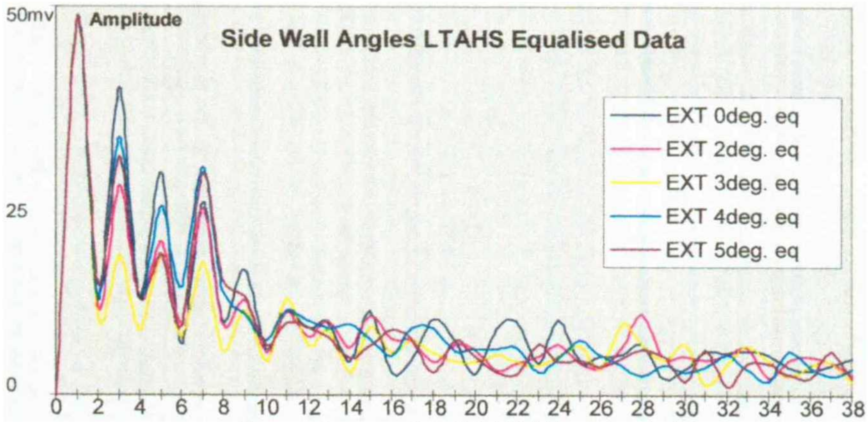
The LTAHS graph format was more revealing:

Graph 134



Harmonics Pico ADC 100 & PicoScope Software

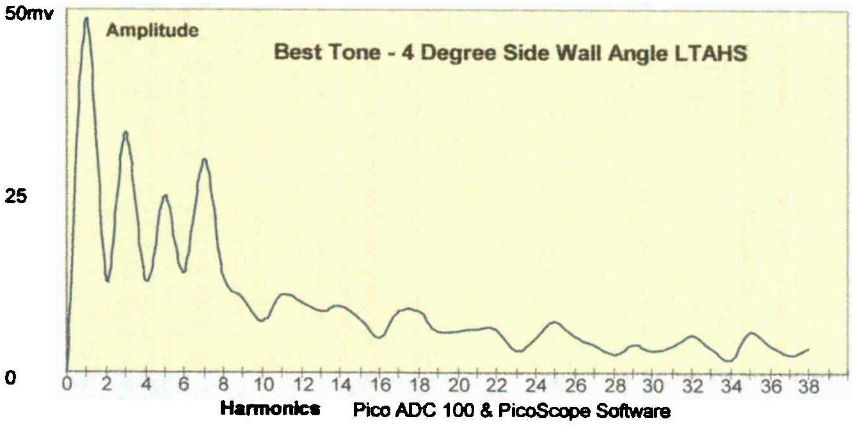
Graph 135



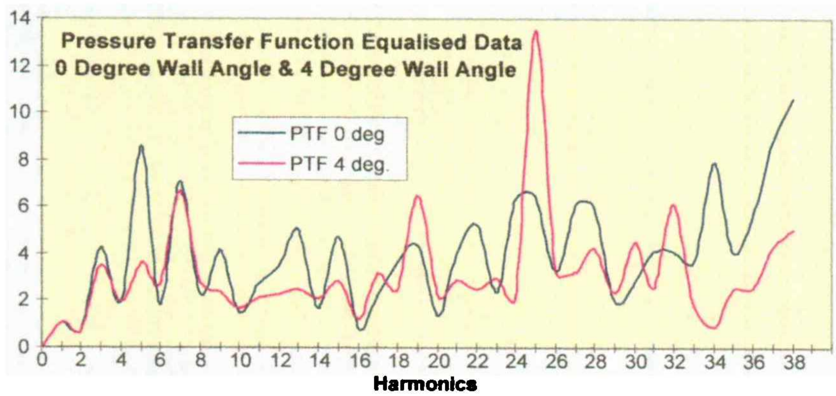
Harmonics Pico ADC100 & PicoScope Software

Both LTAHS graphs showed that the greatest ratio of fundamental to mid and upper frequency components was to be found where the side wall angle was set at 3^0, in the mid-way position (A-frame). The smallest ratio was to be found where the wall angle had no rake (U-frame). The equalised graph showed that the 0^0, U-frame design produced the brightest tone, having high magnitude 3^{rd}, 5^{th} and 7^{th} harmonics, as well as higher strength upper band harmonics and partials. The most rewarding set-up was at 4^0, where mid-band harmonics were slightly reduced in power, but where those in the upper band were markedly attenuated in proportion. Both 2^0 and 3^0 wall angles were very good, and these were characterised by much lower power in the mid and upper bands. A curious finding from these results was to observe that a small angle A-frame (2^0) would improve the tone in all aspects; slightly larger than this appeared to affect the harmonic structure more dramatically and there was a noticeable change in the feel, with strong attenuation of all mid and upper harmonics. The best balance seemed to be achieved by increasing the angle a little more (to 4^0), at which point the tone regained its substance in the mid-band (accounting for the resonant quality) but retained the low power, upper harmonics, so helping to preserve warmth in the tone.

Graph 136



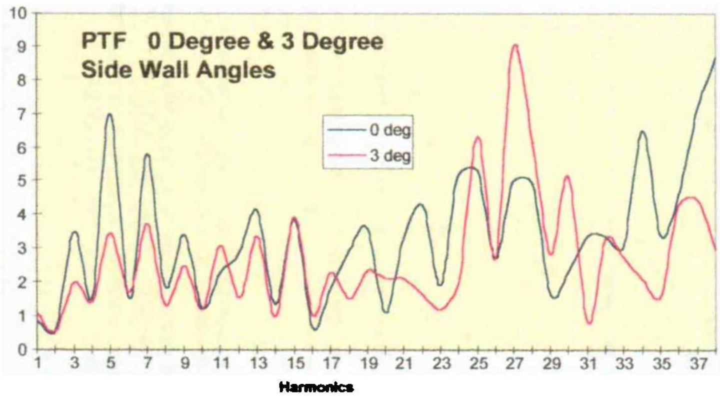
Graph 137



Pressure Transfer Function and the two extremes of timbre produced by the different wall angles

The parallel, U-frame wall configuration (0^0) resulted in a more even response throughout the range of harmonics. This tone had focus and brightness but was a little lacking in depth. The 4^0 A-frame was more erratic, especially in the middle to high region, but there was a lower pressure transfer in the very high components of the sound. Although this revealed a good deal about the uneven way in which the clarinet processed tone when aperture shape and size were altered, it was puzzling that the A-frame radiated sound was not irregular, but produced an ordered spectrum with a lower cut-off frequency. The change in dimensions was having a fundamental effect on the primary wave near to the point of excitation, which in itself was influencing the way in which the clarinet bore and tone-holes were producing sound. It was interesting to note the more efficient transfer of the 5th harmonic and the very low transfer of the 9th, 11th and 15th in the A-frame spectrum; in the experiments conducted, this always appeared to be associated with darker tone and less harshness.

Graph 138



A slight variation in the angle, to 3^0 produced a mellow tone, with a spectral graph which had a steeper cut-off. In the PTF graph this appeared as a flatter response in relation to the internal spectrum in the low, mid and high frequencies, but retained the peaks and sudden return to the mean levels in the very high region. If a player requests this kind of tone, then it is important that the design of the mouthpiece creates a PTF which includes these peaks, whether by changing the chamber wall angle or by other means.[11]

In conclusion, a PTF should not be expected to be uniform. If particular properties of the tone are known to be dependent upon a specific harmonic or region in the spectrum, a PTF will help to identify the set-ups that encourage improved response in those areas.

Furthermore, as small variations in the internal spectrum produce a wide variation in the PTF, and as the internal spectrum is dependant upon the primary wave produced at the point of excitation (the tip of the mouthpiece and reed), so the importance of a player's embouchure and blowing technique which control excitation can be seen to be vital in the production of a varied timbre.

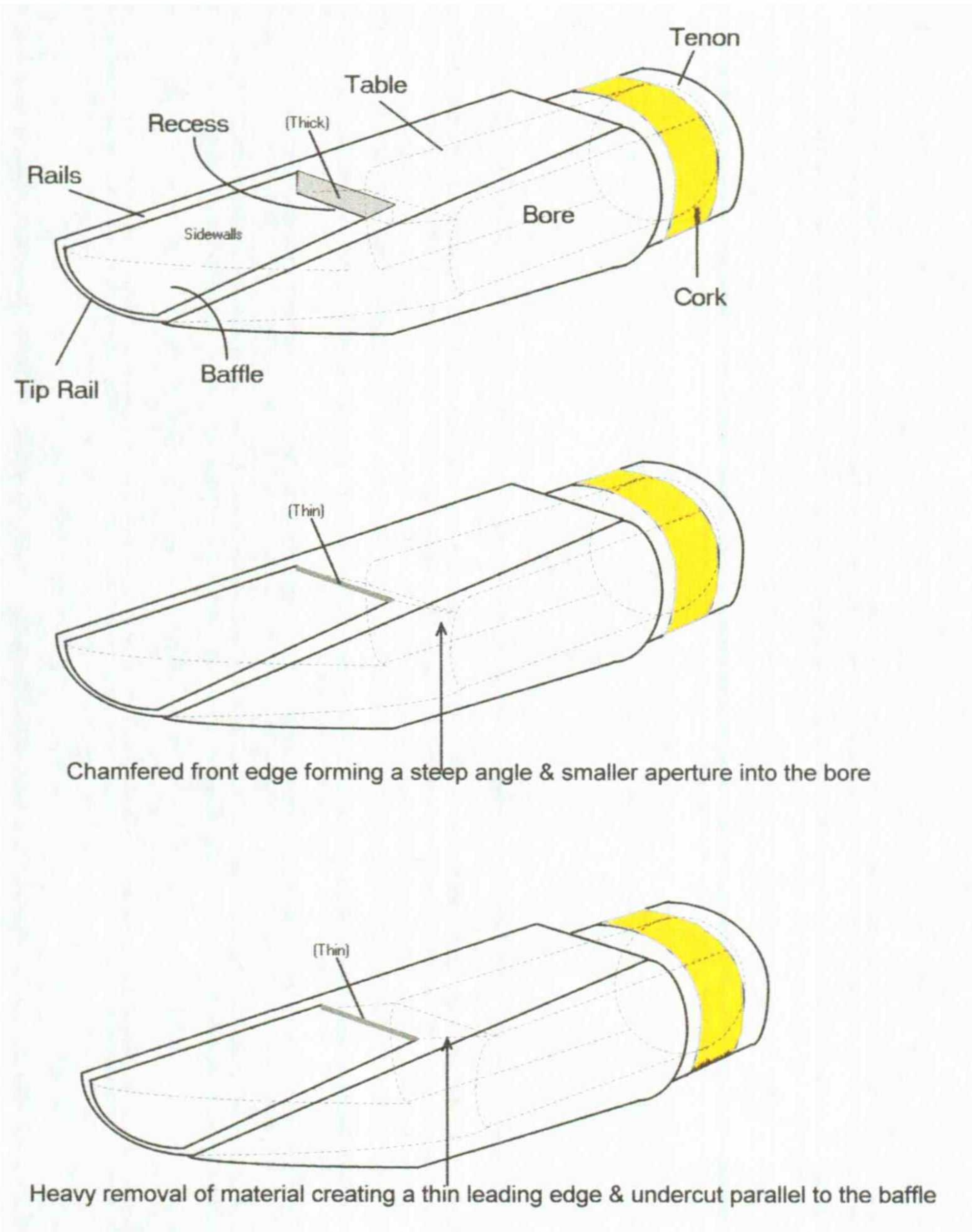
NB As PTF graphs display differences in power transfers within set-ups, data should not be equalised when comparing performances of different set-ups.

---

[11] Change of baffle angle or shape.

4 The Effect of Various Degrees of Undercut to the Recess Under the Table

Fig.17 Mouthpiece Recess



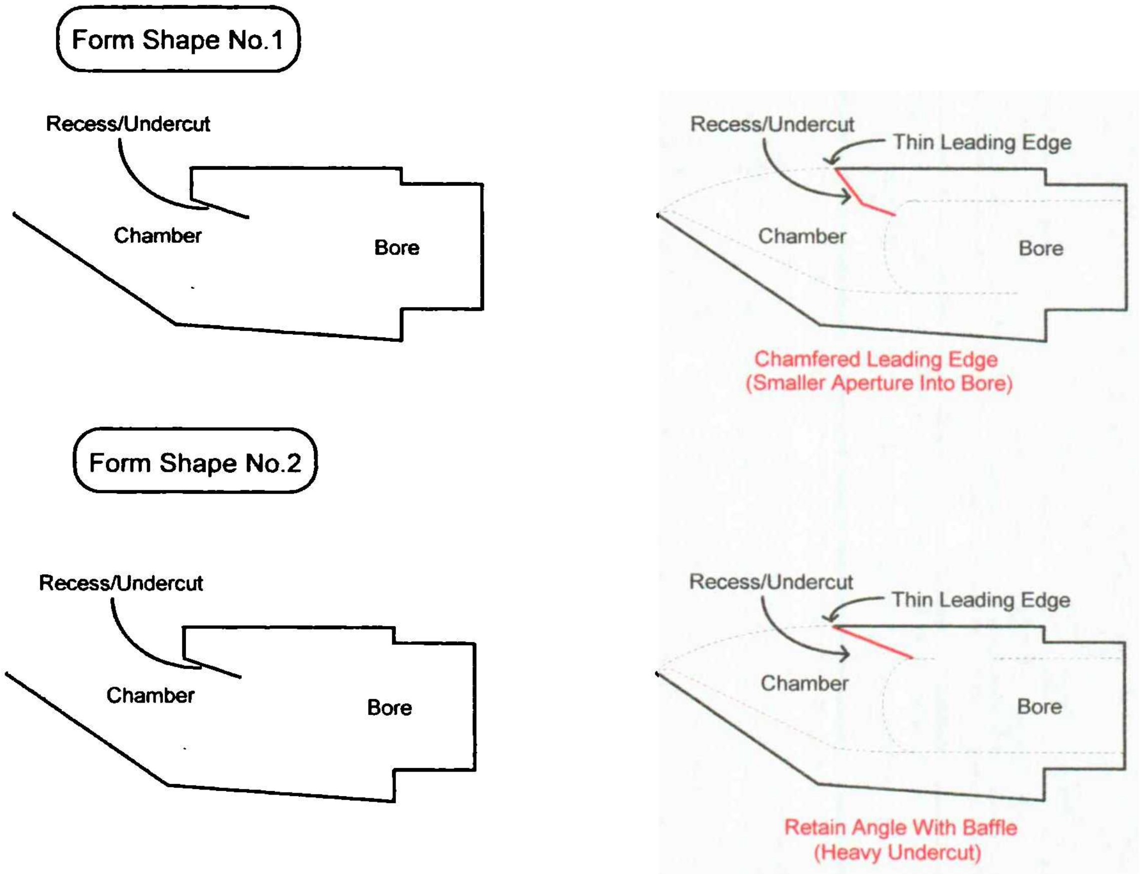
Aim

To discover the effect on timbre and response of removing material from the recess beneath the lay table, with analysis being made at incremental steps.

Methods

Form Shape No.1 by chamfering off the leading edge

Fig. 18 Recess - Cutaway Views



Form shape No.2 by removing material along the whole length of the recess, retaining the original angle with the baffle (20°)

Starting Point

Lay profile 1.15mm x 20mm

Bore diameter tapered from 14.2mm to 15.2mm bore length, shoulder to tenon 55mm (suitable for a Louis clarinet or French instrument requiring a larger bore)

Baffle angle 20°

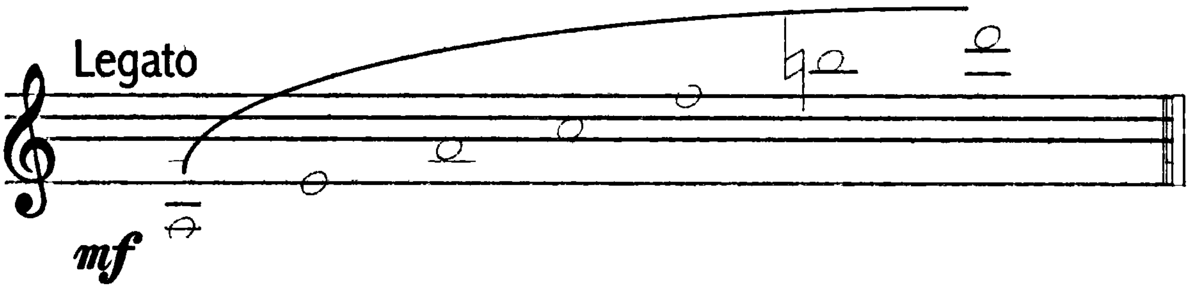
Leading edge 4mm thick

Recess angle 20°

Artificial Embouchure with Delrin tube cut and tone hole drilled to produce F_3

Dynamic mf/f - full tone without distortion (10" water air pressure)

Notes for 'live' tests (examples from each register covering all formant wave shapes)



Testing every note of the instrument would have been extremely time consuming. Nevertheless, it was important to test a representative range of notes in order to be able to compare the whole instrument and to include all the different formant wave shapes. Rogue notes were avoided.[12]

At each change to the size of the recess, the way the notes changed within legato as well as staccato were investigated.

Playing Properties

Without doubt the 'feel' of the set-up changed with each successive alteration to the recess, whether the alteration were made by chamfering the edge or by filing the edge parallel to the baffle. This change in the 'feel' was quite subtle, particularly in the bevelled modifications. Not surprisingly, there was little discernible change to the spectral graphs of individual notes, and seemingly few clues as to what was actually happening to the sound. Once LTAS was applied the effects became apparent.

---

[12] Bell, throat, and any other weak notes.

Benade favoured placing the microphone very close to the tone-hole of the note to be investigated [Benade,1985]. Although this does eliminate the effect of reflected sound or other room resonance characteristics interfering with the note's spectrum, it also prevents any sound from the bell or tone-hole lattice below the note from blending with it in a normal way. To some extent the tone-hole behaves like a low pass filter and this may be one reason why Benade set clarinet cut-off frequency so low. The bore transmits high frequency components more efficiently, and these, along with a weaker fundamental, pass out of the instrument via the bell. A simple test to verify this is to run an oscilloscope in real-time FFT mode whilst holding a microphone a short distance from low F_3 (last hole on the clarinet) and then slowly move the microphone round, to a position a short distance from the mouth of the bell. If real-time analysis is not available, then a 'one shot' method will work just as well. It is clearly noticeable that the spectrum at the tone-hole position shows a strong fundamental with a stepwise decrease in the amplitude of the harmonics, with cut-off at about 3kHz, just as Benade describes. The microphone placed at the mouth of the bell shows a small decrease in the amplitude of the fundamental, but a totally different spectrum for the rest of the harmonic components, the middle band harmonics 3, 5 and 7 steadily increasing to peak at the 9th harmonic. From here, the components steadily decrease in power until there is a cut-off at around 6kHz. Overall, much more upper frequency activity is seen to be emanating from the bell, extending well up to 10kHz. Although the power of these components is relatively small, they are probably significant in contributing to the overall tone.[13]

For these experiments on the recess undercut, the microphone was positioned one metre from both the bell and the tone-hole. The mouthpieces were high quality ebonite (hard rubber) with an unusually large amount of material left in the recess. These were made specifically for the tests.

---

[13] See Chapter 8, p72 for recording techniques

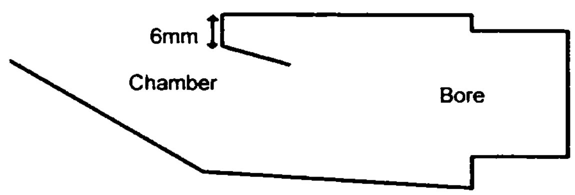
First Investigation of the Recess

Incremental removal of material along the whole length of the slope, maintaining a parallel aspect to the baffle.

Mouthpiece	Bore 13.9/14.9mm x 54mm
Lay	1.09mm x 20mm. No.3 reeds Medium Vandoren
Baffle	21° (equal to approximately 26° angle to the lay)
Sidewalls	Slight outward angle from parallel
Recess	6mm thick with slope parallel to the baffle
Recording	Direct to hard disk via SoundForge, PZM microphone
Analysis	Pico ADC 100 + software

Artificial embouchure and live playing - Delrin tube with R13 bell and R13 clarinet

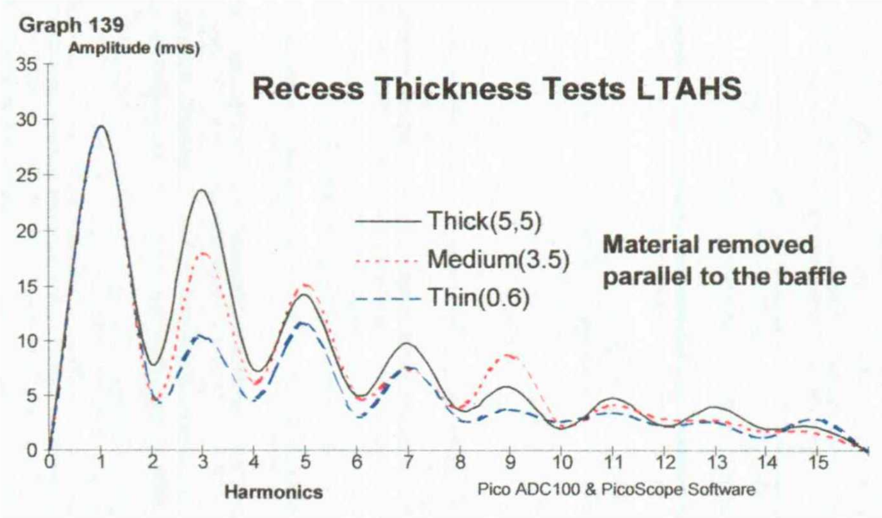
Fig.19 Recess Modifications 1



First impressions of the performance from this mouthpiece were that the tone was quite clean and smooth with good articulation, but that there was some resistance to playing loudly, feeling undynamic. Curiously, and despite this one negative aspect, the measured power output was not significantly reduced by the large amount of material remaining under the table, nor by the small aperture into the bore that this created. It was surprising that the mouthpiece played as well as it did and this caused some radical rethinking about the design in this region of the mouthpiece. The intonation was very good with the Buffet R13.

The undercutting was done in six stages and at each stage a live recording was made of the sequence of notes on the clarinet, followed by a recording of a sustained low F_3 on the clarinet length tube attached to the artificial embouchure. When the artificial embouchure recording was made, the sound pressure level (SPL) was also noted at the microphone placement one metre from the sound source.

Results



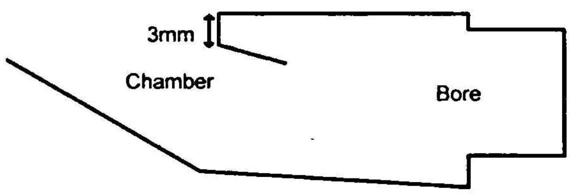
Second Investigation of the Recess

Incremental removal of material from the under-table recess by chamfering the edge (bevelled cuts).

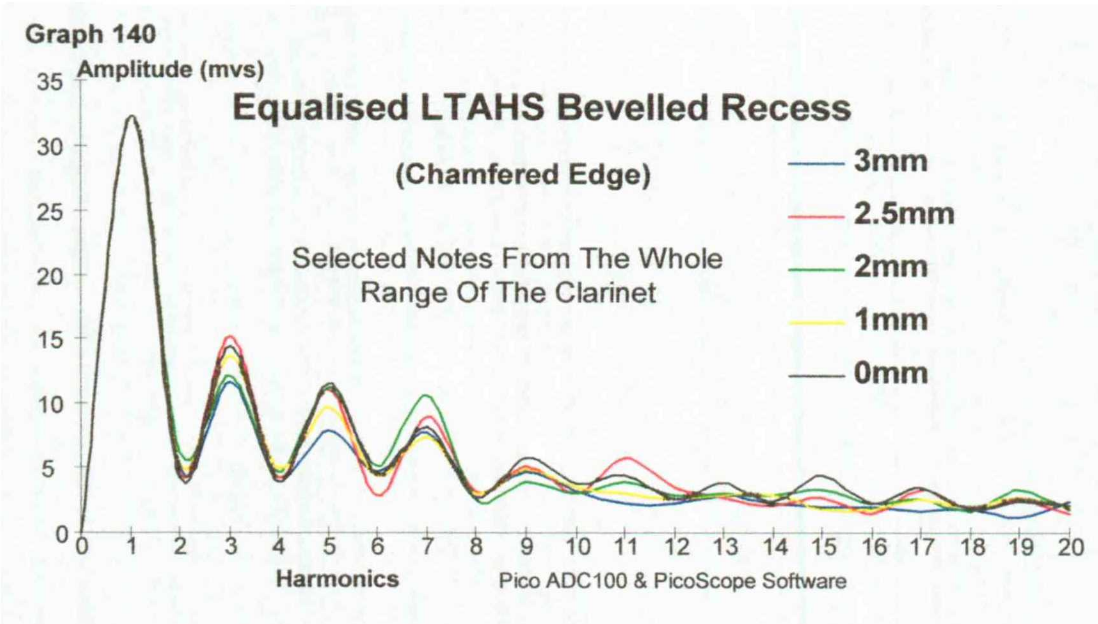
Mouthpiece	Bore 14.25mm/15.25mm x 54mm (shoulder, tenon, bore length)
Lay	1.09mm x 20mm No.3 reeds Medium Vandoren
Baffle	21° (equal to approximately a 26° angle to the lay)
Sidewalls	Slight outward angle from parallel
Recess	6mm thick with slope parallel to the baffle
Recording	Direct to hard disk via SoundForge PZM microphone
Analysis	Pico ADC 100 + software

Artificial embouchure and live playing - Delrin tube with R13 bell and R13 clarinet

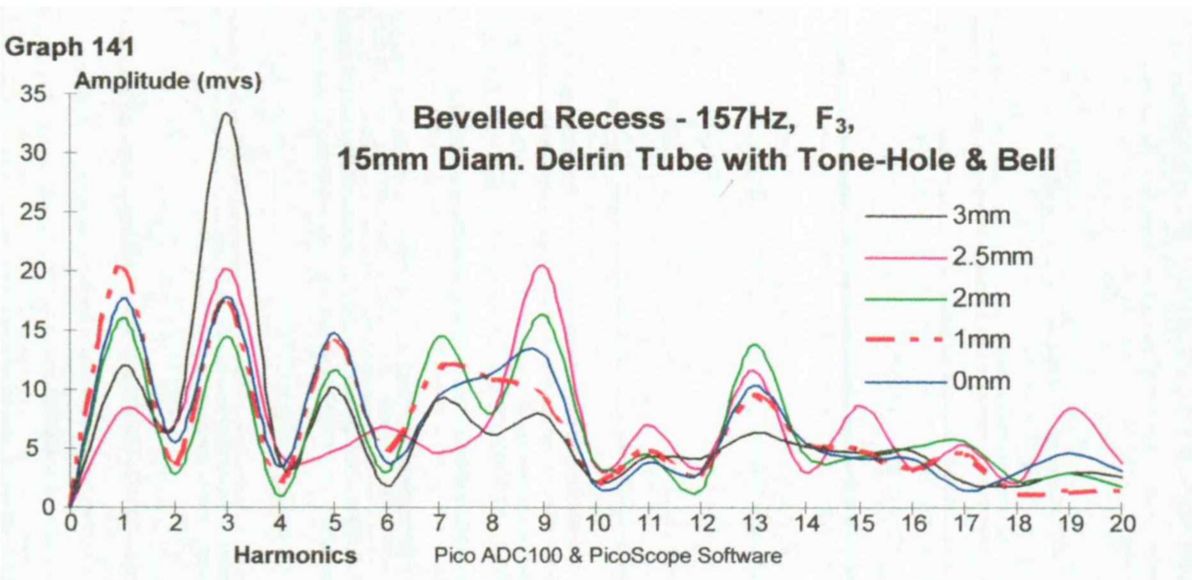
Fig.20 Recess Modifications 2



Once again, this mouthpiece responded quite well before any modification. The tone and response were good and it was less restricted, probably because the original amount of material left in the recess was less than in the first test example.

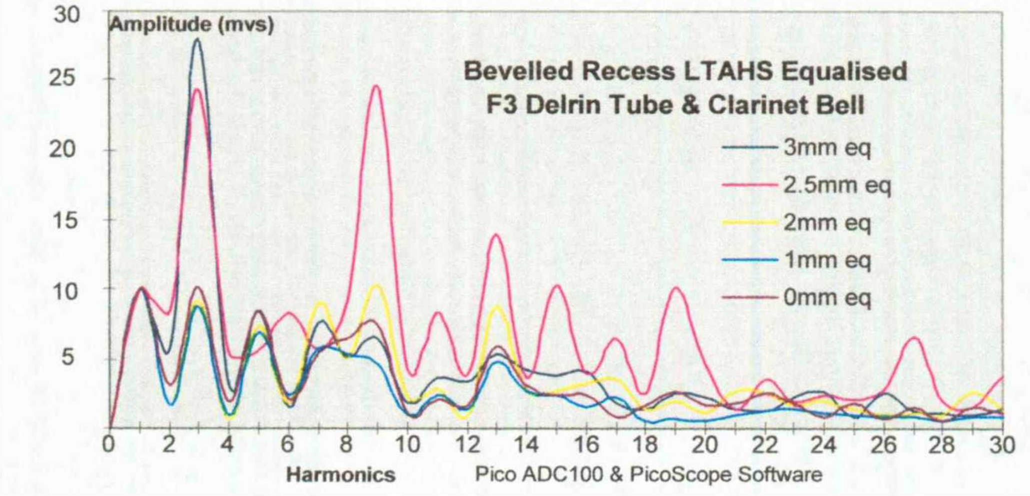


The results from the artificial embouchure and single Low F_3 on the clarinet length Delrin tube were more erratic. This method appeared to have some deficiencies when compared to the system of analysis adopted later when averaged and equalised data from notes over the whole range of the instrument were used.[14] The LTAS graphs are included here simply to highlight the clarity of the new method.



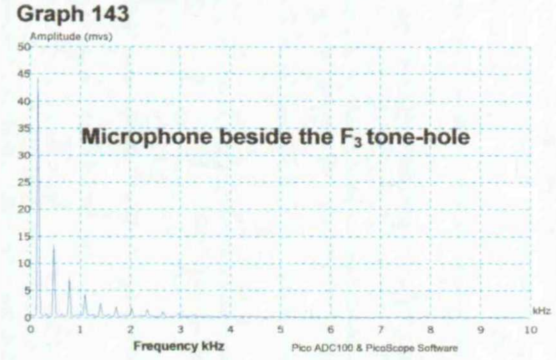
[14] Although a large number of harmonics are present in a note at this pitch, the vicinity of the note on the bore taper near to the bell means that the tone and the resulting spectral graph are atypical.

Graph 142

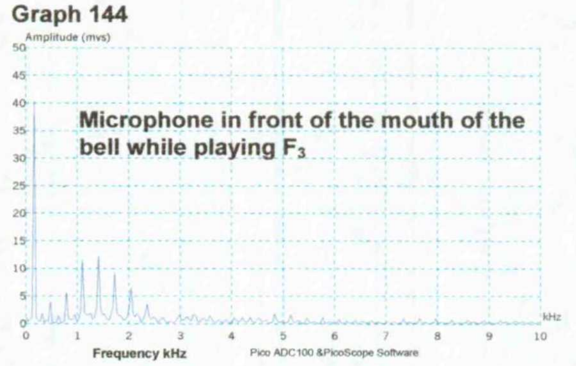


In the above graph the data has been equalised to the weak fundamental and, as previously stated, the microphone placed 1 metre in a direct line from the bell. The results would have been quite different if the microphone had been placed either much closer to the tone hole, or at least 2 metres away. There is a detailed account of recording techniques and associated problems in chapter 8, but the following graphs show the stark contrast between the recordings made at the two positions during this experiment.

Graph 143



Graph 144



For the purposes of detecting change in timbre, the microphone position may not be crucially important, so long as enough content is captured and that the acquisition of this data remains consistent. Nonetheless, changes to the dimensions of the mouthpiece may affect tone-hole and bell emissions differently. If the subsequent test results from the recess modifications show little or no change to the wave structure, even though this can be sensed by the player, then recording at a distance of 1m or over may indeed show that a microphone behaves in a similar way to the human ear in that it is unable to detect the small and subtle sensations of the player.

The tests and experiments for the recess were recorded with the microphone placed 1 metre from the sound source (live and artificial embouchure) and the playbacks sounded natural. Curiously, the lowest notes on the instrument (E_3 to G_3) produced curious spectral graphs when recorded in this way, yet sounded normal in the playbacks. These pitches all have weak fundamentals, with most of the power centred around the 3rd and 5th harmonic. The bell-note is often a problem, invariably sounding diffuse and uncentred. The reason is, in part, due to the non-division of sound between a tone-hole and the bell, resulting in a higher proportion of upper frequency components in the sound. In Boehm clarinets this poor tone is further exacerbated by the large taper in the bore as it reaches the bell (many German design clarinets with a short, small taper suffer less in this respect). In effect, a clarinet bell coupled with a large leading taper, acts much like a simple high pass filter.

Conclusion

Although benefits to the 'feel' of a clarinet's behaviour can be brought about by modification to the recess, little difference may be detected by the listener.

5 Lay Profile Experiments

Aim

To assess the effect on tone and response of a range of lays (facings) with tip openings between 0.8mm (close) and 1.23mm (open)

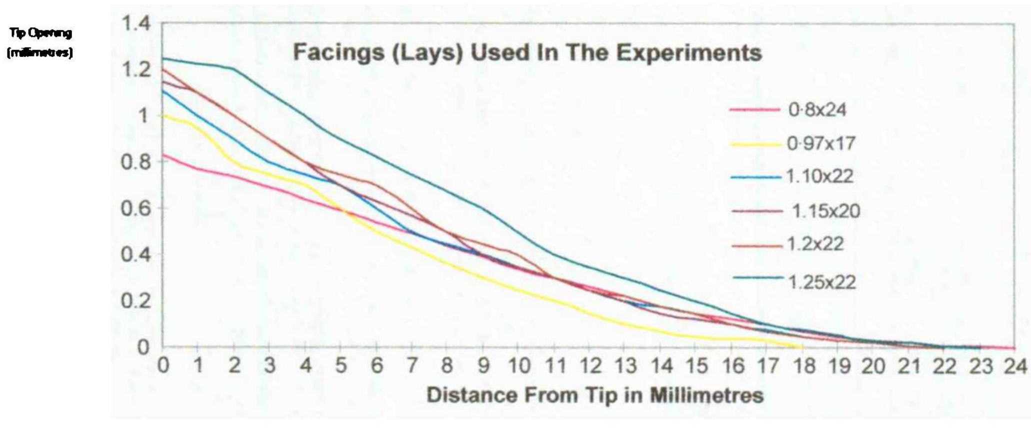
Set-up as for sidewall angle tests.
Standard French mouthpiece with deep baffle.
Parallel sidewalls and U-frame aperture into the bore.
Microphone positioned 1m to the side of the clarinet.
Sampling rate 22kHzm, 0-6k bandwidth

Lays:

Test 1	**1.23mm x 21mm**
Test 2	**1.15mm x 20mm**
Test 3	**1.07mm x 19mm**
Test 4	**1.01mm x 19mm**
Test 5	**0.80mm x 20mm**

Each lay applied to the mouthpiece by hand using feeler gauges and a dial gauge tip measuring tool.

Graph 145



This was a particularly difficult experiment to evaluate. Each lay normally requires a different reed in order to respond well. However, the No. 3 Vandoren reed worked well on all the lays, with the exception of the German style 0.80mm x 20mm which required a harder No. 4 reed to prevent the reed from closing under lip pressure at the tip. The No.4 reed was selected in order to give as similar a response as possible to the other set-ups.

The lays were selected from among the vast number measured over the period of the research. The five chosen had been found to work consistently well and have since been applied to mouthpieces I have made for many professional players. The lays were considered to be a representative range from close to open, with tip openings from 0.80mm to 1.25mm, although some jazz players occasionally use wider openings (up to 1.45mm) and some Viennese players closer, at 0.6mm. The lays used were all considered to be good examples of their type, despite the differences in tip opening and length. Openings around 1.25mm are used by many players who prefer wide openings where, if using light weight reeds, the tone is easily manipulated by the embouchure. Openings around 1.15mm are popular, medium-open set-ups, favoured by many classical players of the English, French and American schools, and 1.05mm to 1.10mm tip openings usually help to encourage a smooth, classical, centred tone. Tip openings in the region of 1mm were popular earlier this century and usually give an easy blowing, rich quality. 0.80mm - 0.95mm is typical of older German profiles. Precisely how well a lay will facilitate good tone and response is not only dependent upon the tip opening and length, but also on the nature of the curve. The curve may be single, double or multi-gradient, high or 'flat'.

Tests began with the open lay, so that subsequent closing of the tip to create the closer lays only required work on the table and lower portion of the lay. This meant that the side rails, tip rail and the depth of the chamber under the region near the tip remained the same in this crucial area.

The tests were performed on two notes, one from the low register and one from the middle register. F_3 was used as the representative for the low register and C_4 was used for the middle register.

The data was compiled from analysis using the phasevocoder and short term spectrum analyser in the *Vwaves* computer programme .

Attack Transient Differences and the Quality of Articulation

Experiments were carried out to examine:

1. The speed of attack, or the time taken for the sample to reach maximum amplitude and a complete harmonic spectrum.
2. The harmonic structure at timed intervals, using short term FFTs plotted on spectral graphs with a time domain (harmonic evolution of the sound).

Results of the lay profile experiments

1.25 Excellent feel and response.

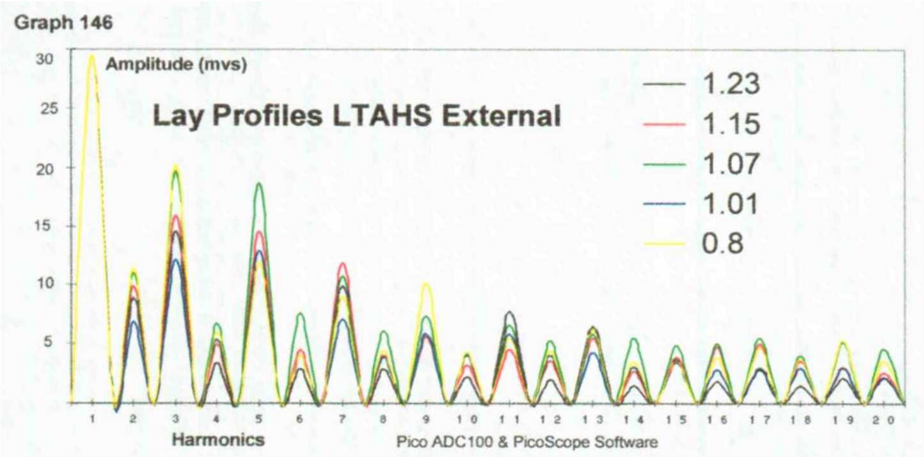
1.15 Very good.

1.07 Still good with cleaner articulation.

1.01 Good.

0.80 (different reed) A little wooden and firmer in quality.

Results of steady state analysis



All the lays enabled good tone to be produced, with the 1mm opening giving the darkest timbre. This was confirmed by the above spectral graph (blue wave) where mid and upper harmonics were the weakest and cut-off frequency the lowest.

Speed of Attack

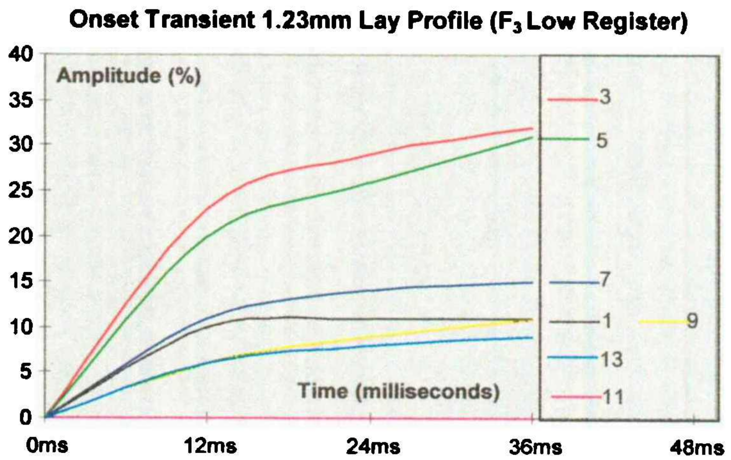
This is one aspect of the clarity of articulation. A very short transient length may indicate a crisp clean attack, but will not show the nature of the sound, that is, whether or not the articulation is harsh.

Results (milliseconds)

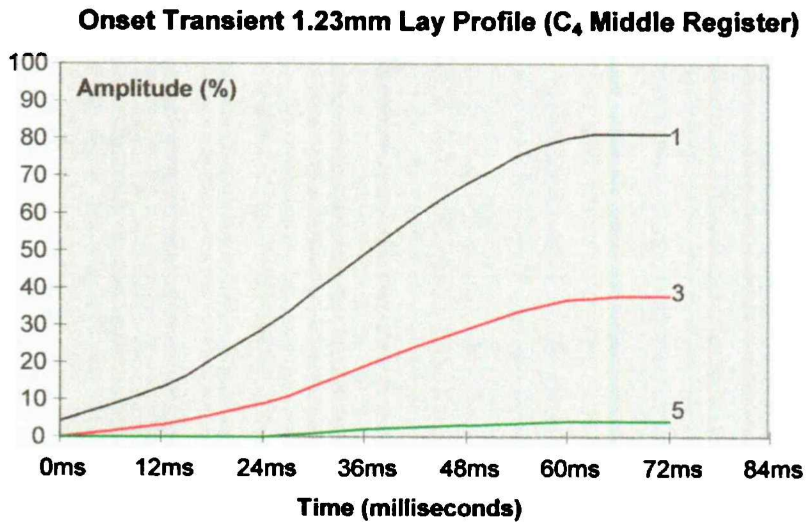
1.23 Tip Opening	Register 1 Register 2	36ms 60ms	Good response & clarity
1.15 Tip Opening	Register 1 Register 2	157ms 60ms	Good but less responsive
1.07 Tip Opening	Register 1 Register 2	145ms 108ms	Good but less responsive
1.01 Tip Opening	Register 1 Register 2	108ms 72ms	Quite good
0.80 Tip Opening	Register 1 Register 2	193ms 100ms	Less responsive

It is interesting to note that, in these experiments, low register transients were distinguished by rapid growth of the third harmonic with the fifth harmonic close behind. By contrast, the fundamental was always the fastest growing component in middle register transients. There were a large number of harmonics in the low register transient and these behaved chaotically in comparison to the smooth, ordered progression of the harmonics in the middle register transient. The jockeying for position amongst the low register harmonics may have contributed to the slower rate of articulation, and the poor performance of the fundamental the reason for the lack of definition.

Graph 147

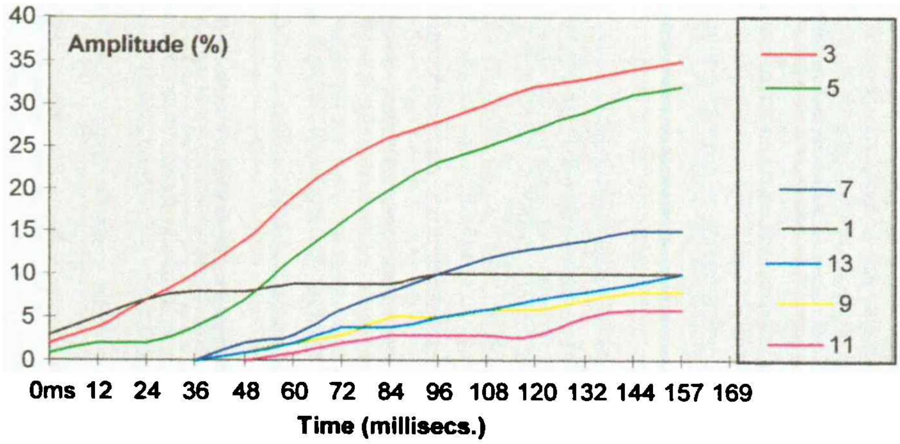


Graph 148



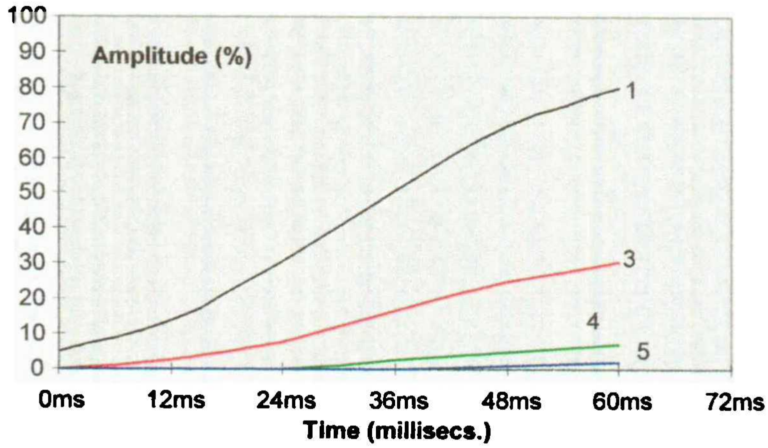
Graph 149

Onset Transient 1.15 Lay Profile F_3 Low Register



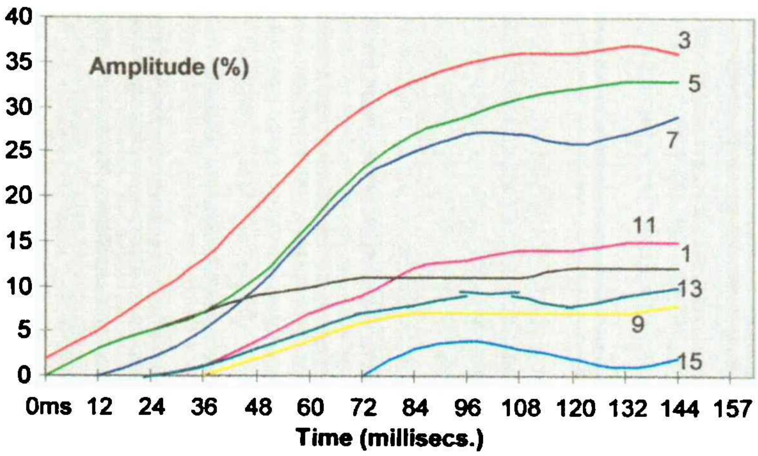
Graph 150

Onset Transient 1.15 C_4 Middle Register



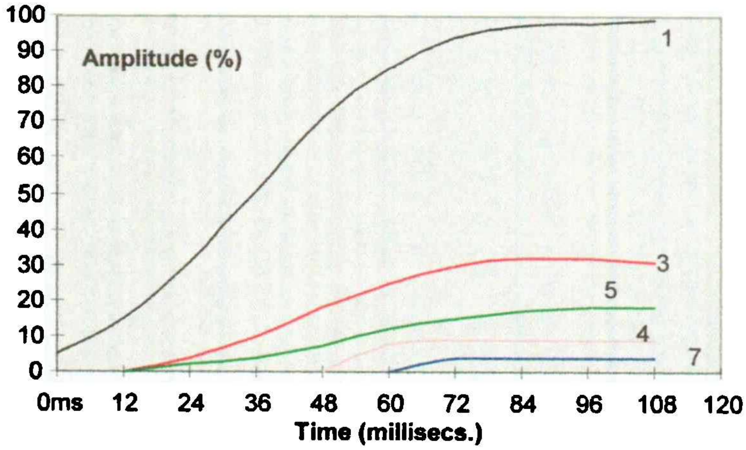
Graph 151

Onset Transient 1.07 Lay Profile F_3 Low Register



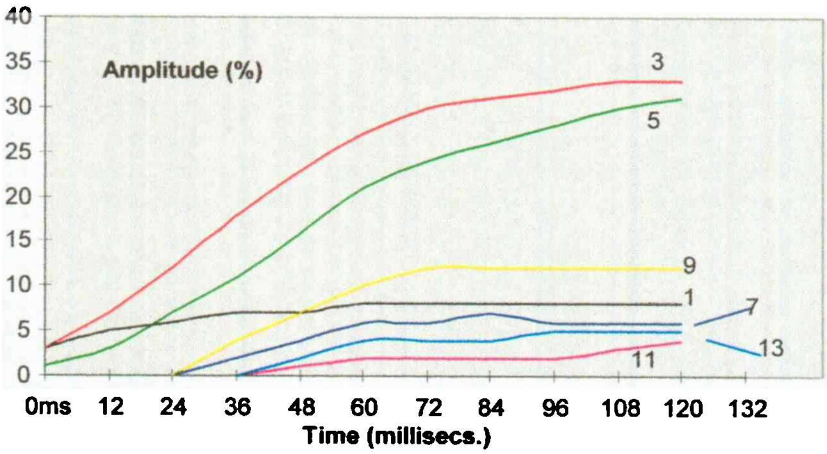
Graph 152

Onset Transient 1.07 Lay Profile C_4 Middle Register



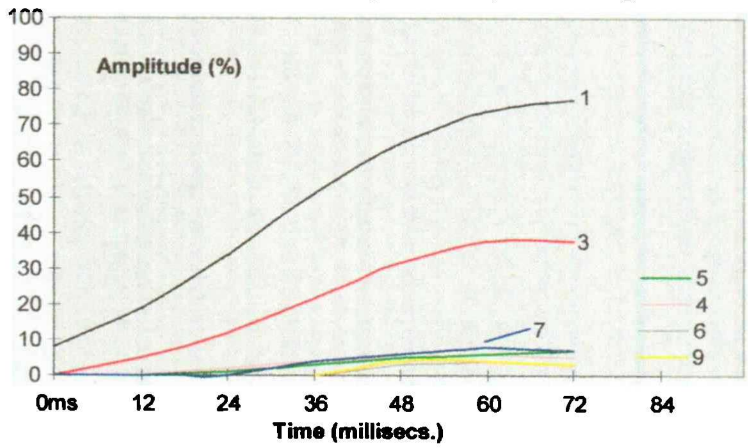
Graph 153

Onset Transient 1.01 Lay Profile F_3 Low Register

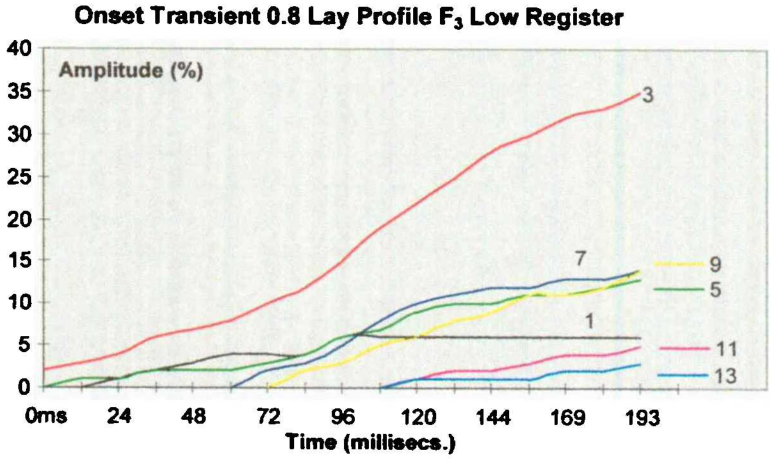


Graph 154

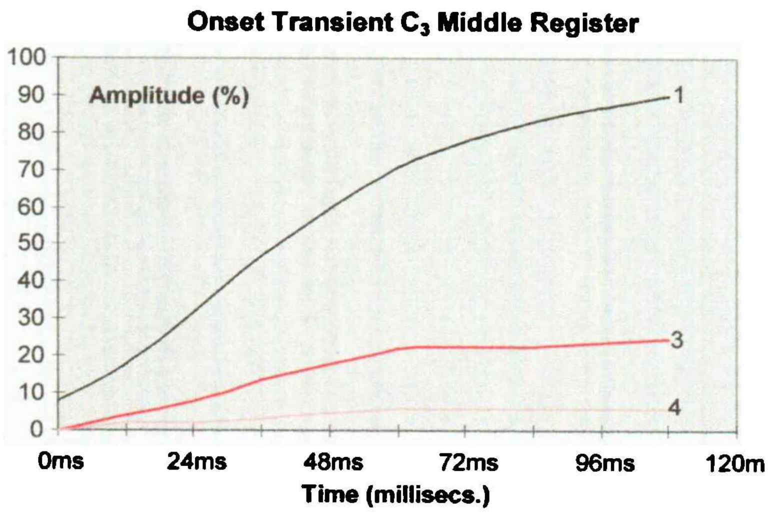
Onset Transient 1.01 Lay Profile C_4 Middle Register



Graph 155



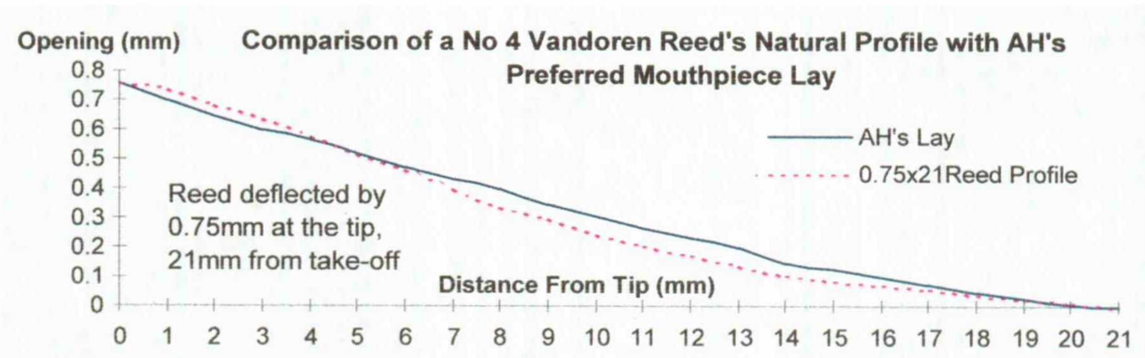
Graph 156



Natural Contour of a Clarinet Reed Under Deflection

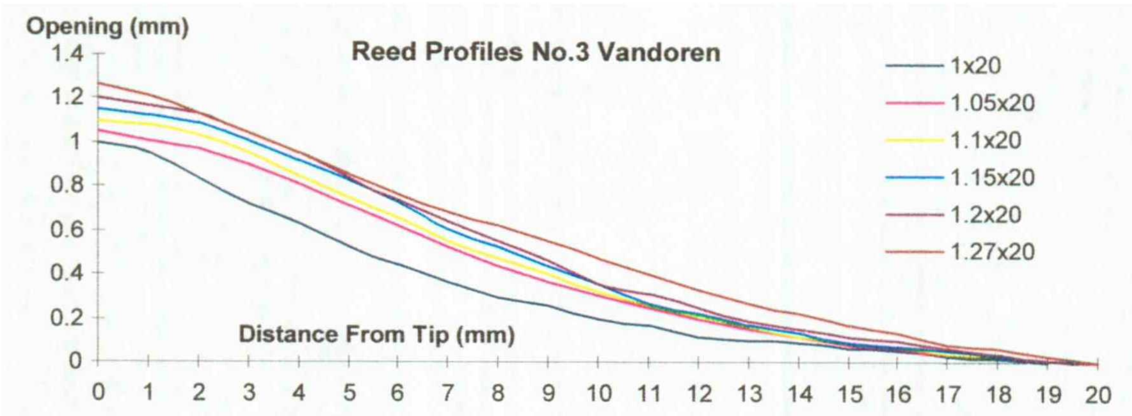
It is a widely held view amongst performers and teachers that the reed's ability to 'roll' around (or along) the lay is crucial for a set-up to speak well and produce good tone. Although deserving of a more thorough investigation, preliminary experiments strongly suggest that the tip opening, length and curve of a good lay facing is indeed closely related to the reed's natural profile under deflection so that, as the reed vibrates, it is able to close neatly and easily over the tip and side rails. That is to say, when the reed is deflected at the tip by an amount equal to the lay's tip opening and pivoting about a point equal to the lay length, then the curve measured under the bent reed is as near as possible to the measurements of the facing. To test this hypothesis several tools and devices were made and these enabled accurate measurements of both the facings and the reed curvature to be taken.

Graph 157

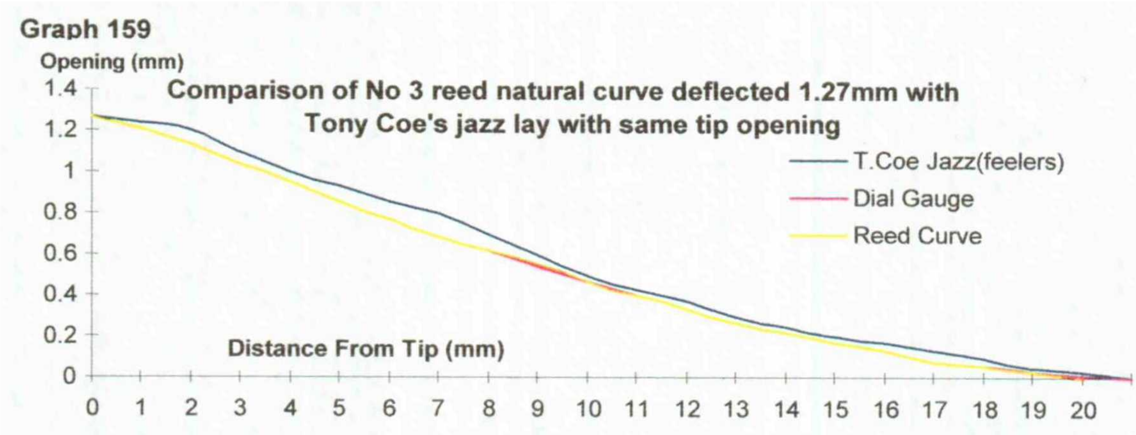


In the above close lay set-up, the reed's natural curve can be seen to closely follow the lay profile.

Graph 158



These contours (graph 158) produced by a medium strength reed deflected by a range of amounts equal to some of the most common facings in use, conform very closely to lay profiles found on several good mouthpieces.



In this last graph, the reed curve is so similar to the lay profile, measured accurately by dial gauge, that the two plotted lines have merged.

Fig.21

Single Reed Mouthpiece
Lay Profile (Facing)
Measuring Tool

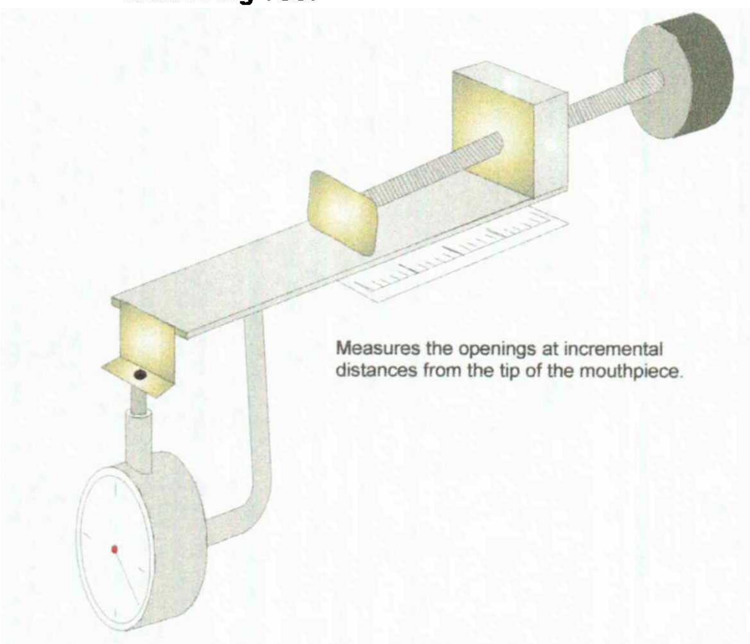


Fig.22

Lay measuring device. Mouthpiece in position showing the wiper against the lay take-off point

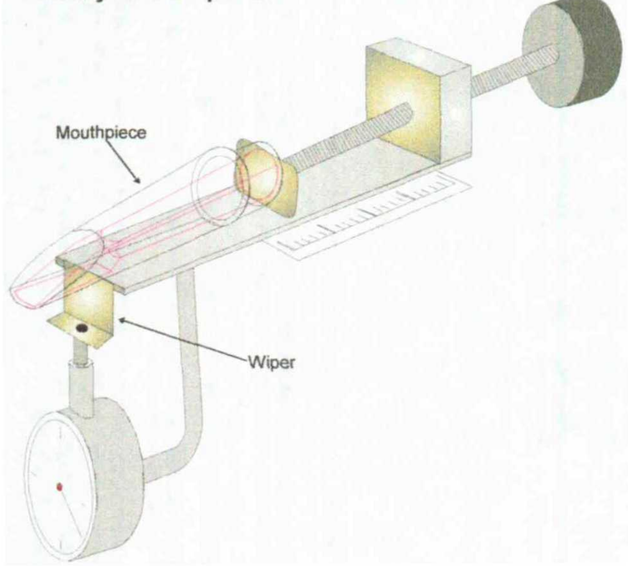


Fig.23

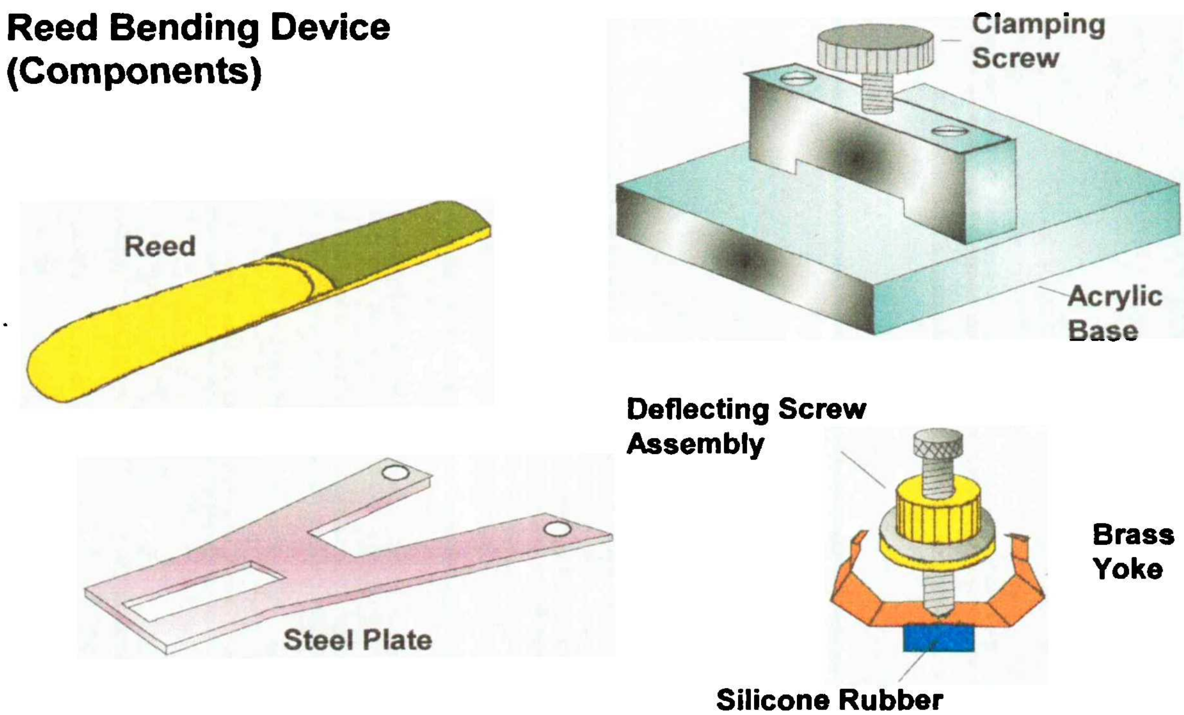
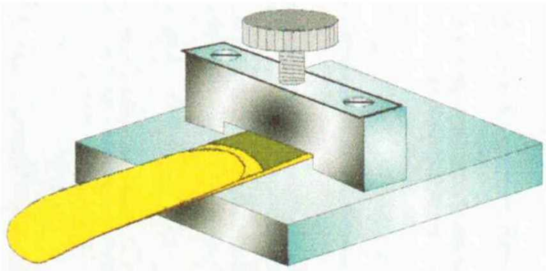
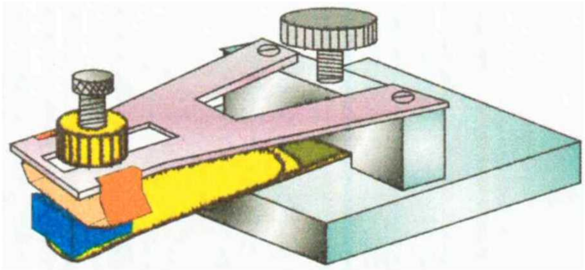


Fig.24

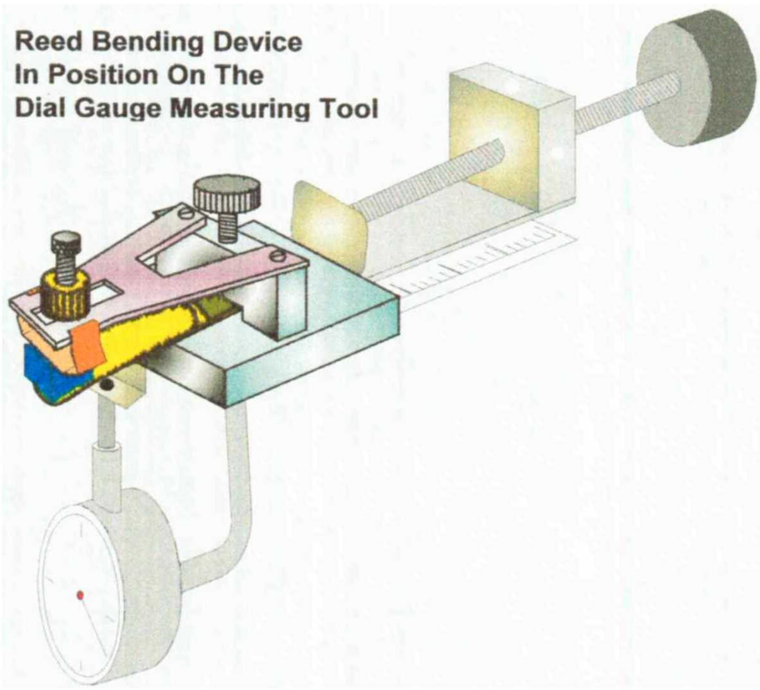


Reed Clamped In The Holder



Complete Assembly

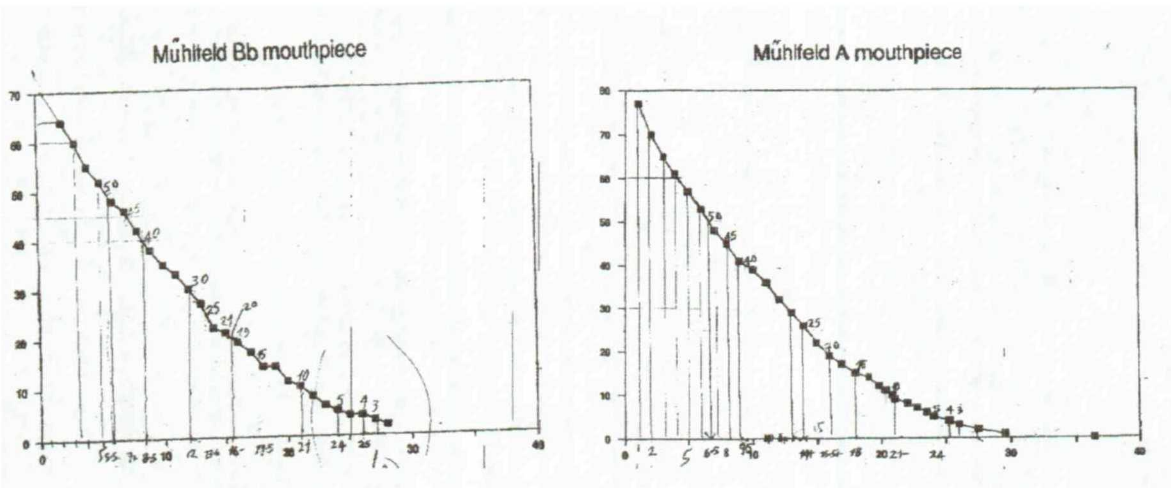
Fig.25



The Mühlfeld Mouthpiece Lay Profile

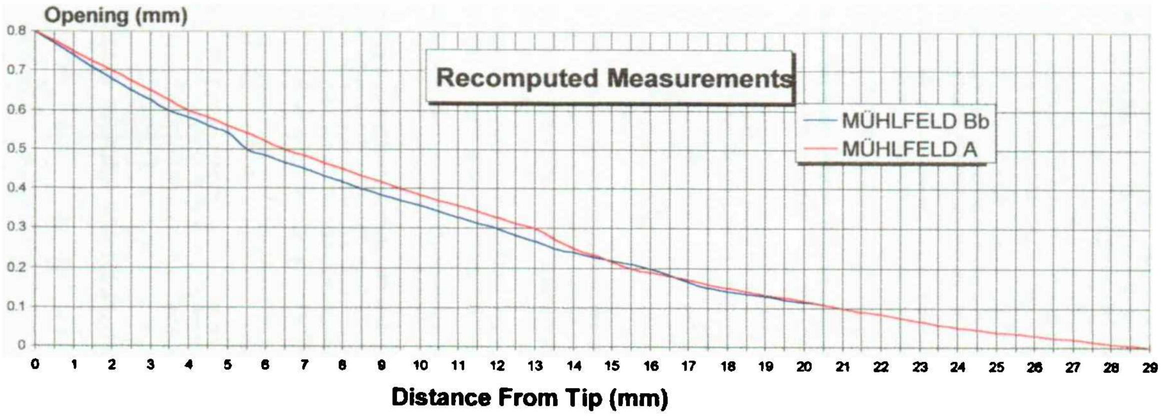
I was recently asked to make some copies of a Hess classical Bb clarinet mouthpiece. These were to be used with copies of Richard Mühlfeld's[15] Ottensteiner clarinets. Hess worked for the clarinet maker Ottensteiner and continued in the workshop after Ottensteiner's death. The mouthpiece to be copied was very close in dimensions to the mouthpiece made by Ottensteiner himself. The Hess mouthpiece was beautifully made in blackwood and the lay and table were overlaid with silver. Despite the metal finish, the original lay was uneven and had poor playing properties so a better lay was needed for the new resin copies. A similar mouthpiece belonging to a classical clarinet player was measured and, as this worked well, its lay was a possibility. An alternative and historically interesting solution, was to use the original lay used by Richard Mühlfeld himself. Nick Shackleton and Keith Puddy had measured the original Mühlfeld mouthpieces some time previously and Nick was able to supply the following two graphs from which it was hoped to define the final lay curve. The measurements had been obtained by feeler gauges so the graphs were somewhat lumpy. Also, the crucial tip openings for both Bb and A lays were missing. Some recomputation was needed to establish the true original lays. This was achieved with the aid of a computer spreadsheet programme. Once the errors had been removed and the missing co-ordinates found, the A and Bb lays were found to be very similar. The original lay, would probably have been the same on both mouthpieces. The recomputed lay worked well on the new mouthpieces.

Images from a facsimile



[15] Richard Mühlfeld 1856 - 1907, celebrated clarinettist for whom Brahms wrote his two clarinet sonatas.

Graph 160


Opening (mm)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Recomputed Measurements
MÜHLFELD Bb
MÜHLFELD A
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29
Distance From Tip (mm)

6 The Effect of Material Density and Hardness on Tone (Resins)

Equipment

The mouthpieces used in these experiments were copies of a 1930s *Boosey & Co.* mouthpiece. They were all produced from the same mould using resins with a variety of different densities and hardness.

Live testing using Buffet, Leblanc and Louis clarinets.
FFT analysis using Pico Analyser.

Aims

1. To find suitable resins for moulding clarinet mouthpieces (epoxy/polyurethane)
2. To assess the effect on timbre brought about by a change in density and/or hardness.
3. To display the results in tristimulus graphs.

A large number of different formulations of epoxy and polyurethane resins were tested to assess their suitability for mouthpiece making in the relatively small numbers required for the research. There were a number of considerations when making a selection. High strength, durability and resistance to abrasion and moisture were high on the list of properties, but stability and heat tolerance were also an important issue since some epoxies were found to become soft and unstable at only a little above body temperature. This obviously had serious implications for a material which was to be held in the mouth for lengthy periods of time, and many epoxies had to be eliminated for this reason alone. Finally, and perhaps most importantly, the material used must enable excellent tone to be produced from the mouthpiece. Tone quality was found to vary considerably depending upon the different combinations of density, hardness and flexibility of the materials, and varied widely with the different formulations. Several excellent epoxy and polyurethane resins were found to make exceptional mouthpieces.

Results

Density above I.15 (s.g.) was preferred, but good tone was produced with density as high as 1.7 (glass has a density of around 2.0 and is used for mouthpieces but it is not widely appreciated). Resins with a density of 1.1 or less were not so successful, the material was light and the resonant frequency low, the mouthpieces felt and sounded 'buzzy'.[16]

---

[16] Despite this, I have made some successful open lay jazz/big band mouthpieces using lighter weight resins.

Since all the mouthpieces were identical, it would have been surprising if there had not been similarities in the acoustic analysis, and this did indeed prove to be the case. It required considerable magnification of the data contained in the graphs to highlight the differences. Listening tests of live playing found that the mouthpieces all possessed good tone with similar character. However, players could detect subtle differences in the 'feel' and the timbre. It was thought that these differences must be caused by the material. Two of the resins stood out from the others in imparting a good-feel factor to the mouthpiece in addition to good tone, with another resin a close third.

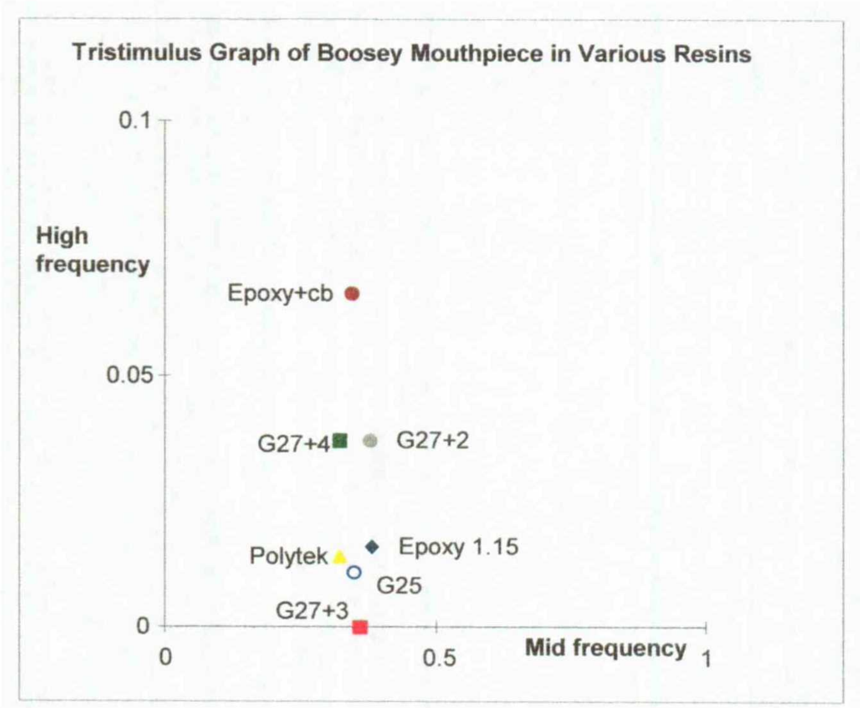
Analysis of the small differences in harmonic structure between the mouthpieces showed the two preferred copies to have the closest ratio of mid to upper harmonics in both registers. The third preferred mouthpiece did not appear to be significantly different from all the others. The least successful (although still with acceptably good tone) was noticeably different from the rest, with greater upper harmonic activity in both registers.[17]

Initially, results on the tristimulus graph, with x and y axis to the same scale, located the timbre of each material at co-ordinates which overlapped each other, indicating very similar tone. Increasing the y axis scale (Graph 160) had the effect of zooming in on the results and, interestingly, showed the three best mouthpieces still in close proximity, with the worst mouthpiece high on the graph, indicating a much brighter timbre. A curious result of this re-scaling was that the G24 polyurethane crept in along with the best. A distinguished player commented that he found this mouthpiece lively but lacking in a harmonic layer (sic). From these results it can be concluded that epoxy is a good resin for moulding (mechanically and acoustically) and that fast cure polyurethane resins with the addition of generous amounts of filler can be considered where speed of production is essential.

[17] Mouthpieces with some degree of roughness in the tone show extensive low magnitude upper harmonic activity above the 11th harmonic in the low register, and above the 7th harmonic in the middle register.

Tristimulus Graph

Graph 161



7 Mouthpiece Body Wall Thickness

This investigation was a late entry into the scheme of experiments and the work was performed quickly and without repeat tests. The limited results are included as the preliminary findings suggest that this area has a noticeable affect on timbre and the 'feel' of a set-up and is a strong candidate for more extensive study, together with related work on materials.

Mouthpiece	Bore 14mm/15mm x 54mm
Lay	1.07mm x 20mm No.3 reed Vandoren
Baffle	20° (approximately a 25° angle to the lay)
Sidewalls	Slight outward angle from parallel
Recess	1mm thick with slope parallel to the baffle
Recording	Direct to hard disk via SoundForge PZM microphone
Analysis	Pico ADC 100 + software
Outside Diameter	28.5mm at the connection with the top of the clarinet barrel
Outside Taper	3.5^0

Reduction in girth by 0.5mm increments 28mm, 27.5mm & 27mm

Playing Impressions

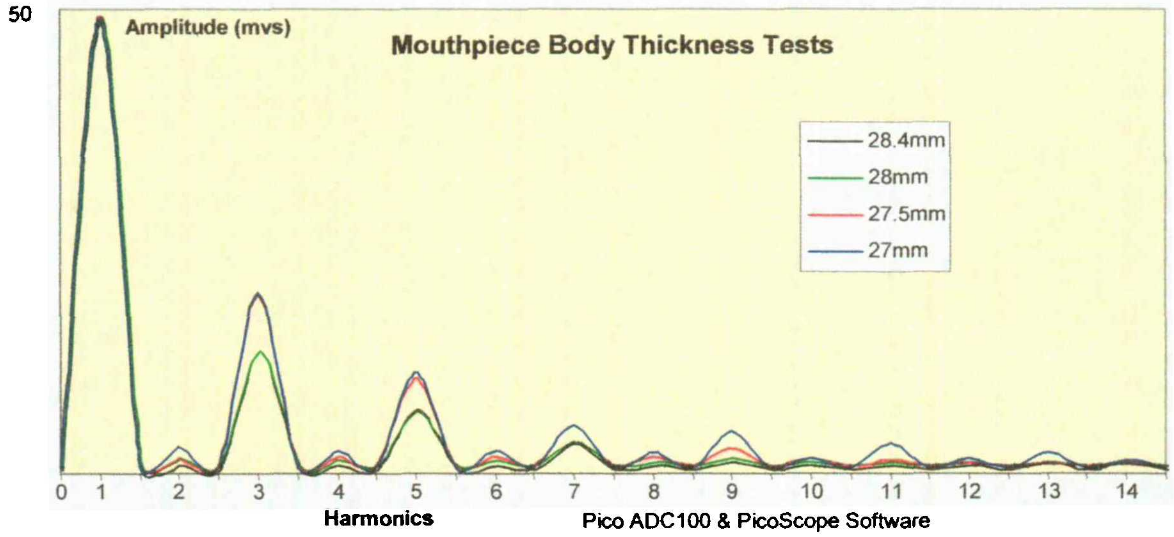
A definite change in the 'feel' of the mouthpiece that became more pronounced at each stage. The mouthpiece seemed to become livelier and more resonant with each modification, the final alteration resulting in a mouthpiece which was quite different from the original. But the end result was not appreciated by everyone.

To have continued removing any more material would have made the mouthpiece too slender for the reed and the appearance of the clarinet as a whole would have been spoilt. But it is interesting to note that many pre-war English and German mouthpieces were very narrow, and several German mouthpieces have retained this design which suits the narrower reed used with the German system clarinet.

Results of the Analysis

The initial results looked inconclusive until the data had been equalised. The graph showed clearly that the timbre was affected by a reduction in the girth and mass of the mouthpiece.

Graph 162



13

Conclusions

It has been shown that the role of the mouthpiece in the performance of a clarinet is crucial. Without a good mouthpiece an excellent instrument will sound substandard, while a good mouthpiece will help a poor instrument to play satisfactorily. Certainly the design of the clarinet is of prime importance; the tone hole size and degree of undercutting (fraising) will affect the cut-off frequency, dynamic range and clarity of individual notes and therefore the overall timbre of the instrument. The bore of the clarinet will also have an influence on modal ratios and intonation and will affect the dynamic range and tonal stability. But the overall tone and response of a clarinet will depend upon the strengths and weaknesses of the instrument and the mouthpiece in combination.

The lay

This the most vital area of the mouthpiece. Without a properly shaped and proportioned profile, the reed will not respond and articulate well. If the lay is poor, damaged or too asymmetric, it can, in some instances, render the mouthpiece and clarinet unplayable. Being critical to the formation of the primary wave, the effect on tone is also marked. The present research has highlighted the need for extreme care in the fashioning of the lay profile. During the course of the work many good dimensions were found, also curves to suit a wide range of tip openings, from 0.6mm to 1.45mm. The setting of the lay was found to be critical, even the slightest inaccuracy in dimensions resulting in a mouthpiece that would fail to respond well or produce good tone. Good lay profiles enabling a smooth, clean and dynamic response, were found to match closely the natural curvature of the reed when deflected by an amount equal to the tip opening and pivoting about a point equal to the lay length from the tip (see Chapter 12). The strength of reed was dependent upon the tip opening; the experiments used thick, hard reeds for close lays, and thin, soft reeds for more open lays, as in normal playing. More research could be carried out here. A vibrant, but arguably less smooth response, was found to be encouraged by lays which had two distinct levels and gradients along the profile when plotted as a graph, the smooth change in angle being around 10mm from the tip. This may appear to confuse the situation insofar as future application of the research is concerned, but whilst these contrasting effects undoubtedly make the choice of lay more difficult, it does increase the possibilities available when adapting a mouthpiece's characteristics to the needs of the instrument and player.

Bore size (mouthpiece)

The mouthpiece bore size was found to affect both intonation and timbre. In the experiments carried out on the Howarth clarinets, an effect on timbre was noted when using a large bore mouthpiece on these small bore instruments; the power of the middle harmonics was diminished and the result was a more rounded tone. As expected, there was also an alteration to modal ratios, with a widening of the twelfths between register 1 and 2, (low and middle) resulting in the 3rd register becoming higher in relation to the lower register. This is often desirable on small bore French style clarinets if the 3rd register notes are flat. This shifting of the registers can bring about a better alignment of the harmonics giving the instrument a better 'feel'. Players who adopt this set-up maintain that there is more sparkle in the tone and that the clarinet feels freer and larger.

Tone chamber

Baffle - *Straight* A 20^0 baffle angle (angle measured in relation to the bore and not as a line at a tangent to the table) was found to give a satisfactory timbre, neither too dark nor too bright. 18^0 became shrill and bright, even harsh. Around 24^0 was about as deep as it was possible to go before the tone became over-heavy and plummy. No mouthpieces deeper than 24^0 were found during the course of the present research. Aurally, there seemed to be very little difference between baffles which were flat and those which were slightly curved between the side walls, with good examples to be found in both designs.

Baffle - *Concave/convex*. A mouthpiece with a 20^0 baffle and a high convex shape towards the middle of the descent into the bore was found to produce a similar tone to one with a baffle at a raised angle of less than 20^0. The tone became piercing and bright, possibly suitable for jazz, rock or outdoor playing where a penetrating tone is required. Many beautiful sounding mouthpieces had deep, concave baffles shaped around a 20^0 or 24^0 mean angle. The influence of concave shaping on the tone was interesting. Although the effect was similar to lowering the baffle angle, with a darkening and mellowing of the sound, there was also often an additional quality which was difficult to quantify, but which added pith to the sound. This was particularly in evidence when this concave shape was combined with outwardly sloping side walls. However, the set-up did not suit all instruments. When the walls were set at a very wide angle, the tone occasionally became grubby and ill defined, and some players disliked the timbre produced, finding it too thick.

In the small bore French clarinet, the effect was to lower the power of the middle harmonics and attenuate very high frequency harmonics, lowering the cut-off frequency and moving the tone towards a more Germanic sound. When the baffle shape and angle was deepened, the pitch became progressively lower, particularly in the throat region.

Ultimately, the choice of baffle angle and shape will depend upon the character and properties of the clarinet with which a mouthpiece will be used.

Side walls

Players' opinions differed widely as to whether or not the side walls (chops) should slope away from under the lay rails making the volume of the chamber bigger, with a large aperture into the top end of the mouthpiece bore, or, if the walls should be set vertically, resulting in a smaller volume chamber with a tighter aperture into the bore. There is a tendency for the majority of modern mouthpieces to have the latter configuration. This is understandable to some extent. Many modern clarinets lack fizz and focus to the tone, and a mouthpiece with a small chamber and a small, narrow aperture (bocal) will help to disguise this inadequacy. This design of mouthpiece does produce a brighter tone and can help the left hand middle register notes to ring. However, the tone produced is somewhat lacking in colour and can limit the potential of better quality clarinets.

The question over the angle of the side walls remains open. To obtain tone with a broader sweep of colour, some angle is desirable, but unfortunately there are instruments that will not respond well to this design. There are also players already producing a diffuse tone, who find that this design causes an unwelcome reduction in tonal centre. The section of the research concerned with recess thickness[1] found that height of aperture in combination with sloping walls in a certain configuration resulted in brightness which had tonal centre and clarity, yet no harshness (see next paragraph).

Aperture into bore (throat)

The side wall and baffle configuration determine the shape and size of the aperture into the bore, although the recess under the table can be filed to increase the height of this rectangular window. When the sidewalls slope outwards, this aperture, as viewed along the bore from the tenon end of the mouthpiece, has been described as an 'A' frame. If the walls are upright and more or less parallel, the aperture is described as a 'U' frame.

---

[1] See Chapter 12, p177-181

On some mouthpieces, the shape defined by the end of the walls tends to veer in slightly at both the top and the bottom, giving an almost oval appearance to the aperture. When this aperture is small (8mm x 14mm) it forms a bocal, as in certain saxophone mouthpieces and double reed staples. The effect of the bocal was significant; when narrow (U-frame), the tone produced was centred and bright and the pitch well maintained, particularly in the throat note region. The mouthpieces projected well, but the sound was sometimes thin, monochrome and edgy. However, if the walls were angled wide (A-frame) and the height increased by heavy filing under the recess parallel with the baffle (making the height between 15mm and 16.5mm) then a large reduction in middle and upper harmonics occurred and the sound became darker, more rounded and the harmonic spectrum much more in keeping with a German style tone. The edgy tone disappeared and the sound seemed to be richer in harmonic colour, the ear now able to focus more easily on the important fundamental and first five harmonics of the new harmonic configuration. A good compromise was arrived at using a moderate A-frame aperture into the bore in conjunction with less height, achieved by leaving material inside the recess. The tone and response with this set-up was still bright and clean, but with a liquid, smooth quality without harshness or shrillness. The pitch was found to hold up well if used in conjunction with a moderately angled baffle (c. 20^0) with concave shaping so that it was possible to further enhance the playing properties by using a slightly oversize bore (14.1mm - 15.2mm, similar to many Boosey & Hawkes '926' mouthpieces). Best results were obtained by filing the leading edge of the recess (bottom of the chamber window) making the mouthpiece look quite conventional. This design was used by at least one mouthpiece maker during the 1920s and 30s and is proving popular as a feature of one of my own mouthpieces.

Window under the reed

This region of the mouthpiece is the open area which lies under the top half of the reed whose boundary is the tip rail, side rails, and top edge of the recess. The tip rail and upper half of the side rails, anywhere between 16mm-28mm from the tip, constitute the working parts of the lay profile and these are machined or hand finished to a special gradient (lay profile or facing) which is crucial to the successful functioning of the mouthpiece. Spectral analysis was used to examine lay profiles and the region of the baffle just below the tip rail, but not to investigate changes effected to the window. Nevertheless, experience gained from working on lays and measuring the tip and side rails of a huge number of mouthpieces revealed that the window was a crucial area of influence on tone production. Of particular importance was that the width of the rails should match the dimensions of the reed, especially at the tip. If we take a French style mouthpiece used with a typical French reed, then the width at the top of the reed should be 13mm, tapering to 11.5mm at the bottom. Ideally, the reed should lie on the table such that the tip and side rails are just covered. To achieve good dynamic response the rails should not be too thick, especially in the upper portion; lmm at the tip end and not more than 1.5mm halfway down the window. As both maker and player, I favour a narrow tip rail, 1mm or less, as this assists dynamic range and crisp articulation. There are other makers who leave the tip as wide as 1.5mm. A wider tip rail does mean that the reed strength can be adjusted by moving it up or down the lay slightly, obviating the need for trimming.

Some mouthpieces were found to have slender side rails, but the distance between the inner edges at the tip was only 10.5mm. This would suit a German style reed, but French reeds would overlap the rails at the side and be stifled unless they were narrowed. The distance between the rails should be between 11.5mm and 12mm (maximum) for optimum reed response. Nearly all the mouthpieces that were too narrow in this area were greatly improved by filing out to 11.5mm.

There are two other dimensions in the window which have an effect on the performance of the mouthpiece; the bottom of the window between the rails at the edge of the recess, and the distance from the centre of the tip rail to the centre of this lower edge.

The bottom cross section of the window can be anywhere between 7.5mm and 8.5mm, the wider dimension appearing to improve dynamic range, speed of attack and resonance. Spectral analysis would be beneficial to ascertain any measurable differences and optimum dimensions.

The tip rail to lower edge measurement proved to be linked with good response. In successful mouthpieces, this was invariably between 32mm and 33mm. Success was even possible using a measurement of 34mm. Mouthpieces with smaller dimensions did not seem to maximise the potential of reeds and felt rather 'tight' and thin in character.

Mouthpiece internal volume

In general, the total volume of a mouthpiece varies from approximately 11ml for a standard French bore design to approximately 12ml for a large bore design. It is important that these volumes be adhered to if the overall intonation of the instrument is not to be affected. Early in the research it was shown that if a large bore mouthpiece was used on an instrument tuned to work with a small bore mouthpiece (see Chapter 11) any increase in volume brought about by the larger capacity mouthpiece could be compensated for by either shortening the barrel (2mm-3mm), reducing the bore-size of the barrel, slightly reducing the bore and shortening the barrel, or reducing the length of the mouthpiece and barrel a combined total of around 3mm. The decision as to which part of the mouthpiece to adjust would depend on the intonation of the new set-up. If the 3rd register was already high, it should prove beneficial to shorten the top end of the barrel. Alternatively, the mouthpiece could be shortened from the tenon end, but not if this would result in the table becoming too short to accommodate the reed. If the 1st register notes, around the throat and just below, were only just in tune or a little flat, then a barrel with a smaller bore shortened from the bottom end would be a better choice.

Slender versus fat mouthpieces

Modern German and Viennese and many pre-war English mouthpieces measure lmm to 1.5mm less in diameter than most modern French examples. This may be one of the reasons for the distinctive woody sound characteristic of many players using this kind of set-up. To investigate this, a fat mouthpiece had its diameter reduced by degrees, and the tone was recorded and analysed at each stage in its diminution. There was an increase in material resonance and a pronounced change in the feel of the set-up brought about by this thinning, and noticeable changes in the spectra of radiated sound.

Materials

Although many players and teachers are reluctant to consider mouthpieces made from any material other than ebonite, the results obtained from testing mouthpieces made from a variety of other materials demonstrate that this remains an exciting area of research. The physical properties of various resins and thermoset polymers were found to have a big impact on the playing and tactile properties of the mouthpiece. The sheer number of experiments carried out during the course of the research necessitated the manufacture of large numbers of mouthpieces very rapidly. In order to make the high quality mouthpieces required, moulding and casting skills were acquired in addition to the more traditional techniques using lathes and milling machines etc..

Stiffness, hardness and density of the material affect the acoustic feedback between the tip of the reed and tip and side rails of the mouthpiece. This affects the primary wave produced by the mouthpiece which drives the acoustic system and accounts for the differing sensations experienced by the player. When using traditional methods, ebonite produced excellent results in both tone quality and appearance. However, acrylic was also found to machine and finish exceptionally well, producing mouthpieces with a beautiful, refined and dynamic tone quality much appreciated by many discerning players and critical listeners. Some polymers, such as PVC, acetal, nylon and polycarbonate, adapted less well, in spite of their success when used as materials for the body of an instrument. Acrylic, in a modified form, has the advantage of being suitable for use in injection moulding processes. Moulding and casting mouthpieces enabled experimentation with a wide range of epoxy and polyurethane resins where it was possible to alter radically their density, hardness and therefore stiffness. It was possible to imitate the characteristics of both ebonite and acrylic and experiment with mixtures that produced polymers with a wide variety of properties. It was found that some formulations of polyurethane resin produced mouthpieces that felt and played like mouthpieces made from hardwood rather than plastic or hard rubber, making these materials suitable for use in the reproduction of antique mouthpieces. Whilst the polyurethane resin helped to produce a tender tone quality, a harder epoxy was necessary if a more robust tone were demanded. Of surprise were the excellent tonal characteristics to be found in resins filled with large quantities of metal. One might have expected an uncompromising or ugly response from this formulation, but a mouthpiece with a clear, limpid tone, with clean attack transients was produced. Several professional players are now playing on mouthpieces which I have made from one of these materials.

The cumulative effect of modifications to a mouthpiece

Incremental changes made to the mouthpieces under investigation sometimes produced only subtle effects on tone and response even where the large amounts of material removed resulted in radical changes to the dimensions. But experienced players are sensitive to the most minor changes in response, and totally redesigning a mouthpiece can therefore make a significant difference to the possibilities for expressive playing and also to the level of comfort.

It is usually necessary to make a number of simultaneous modifications to bring about a worthwhile change. To illustrate this point we might take a typical French style mouthpiece, playing satisfactorily but needing a wider dynamic range, better articulation and more character and colour in the tone. The mouthpiece incorporates a standard bore, a straight, flat 20^0 baffle, parallel side walls tapering to a U-frame aperture, average side and tip rails, 11mm between rails at tip, 7.5mm at the bottom of the window and a distance of 30mm from tip to bottom of the window. The lay has a tip opening of 1.20mm and its length is 19mm. If the lay responds reasonably it is best to leave relaying until a later stage as there are several other procedures which can bring about a positive change. One single alteration is unlikely to make a huge difference in feel and response. If the tip rail and side rails are narrowed, the mouthpiece will offer a wider dynamic range, but it will certainly sound and respond even better if the distance between the side rails at the tip is widened to almost 12mm. Further improvement could be made if the bottom of the window was filed down another 2mm or 3mm and widened to 8mm or 8.5mm. These alterations should result in a noticeable improvement in dynamic range and articulation but will probably not improve the tone colour by a significant amount. To address this, the baffle will need to be lowered or scooped out, making it concave, preferably in both planes.

These preliminary modifications should have a mellowing or darkening influence on the tone, but if the tone is still too bright or harsh, the side walls under the side rails can be filed away by degrees at a slight angle (undercut) to form a larger A-frame aperture into the bore. If an even darker tone is desired, then filing away material from the recess under the table should help. If the tone is too diffuse, closing the tip opening and lengthening the lay profile to give a lay profile of approximately 1.05mm x 20mm should give more focus to the tone and produce a more classically refined timbre.

There remains the bore. Here it would be possible to begin experimenting with an enlargement but that would undoubtedly flatten the pitch excessively. This intonation problem could be corrected by using a shorter barrel. But even without alteration to the bore the mouthpiece should now be very different from the original and hopefully have acquired the qualities and properties that had been found lacking.

The present research has made several interesting findings and has also been able to substantiate by scientific analysis much empirical knowledge used by technicians over decades. The research has shown that several options and combinations of procedures are open to players and technicians when considering modifications aimed at improving or altering the playing properties of a mouthpiece. The data acquired from the experiments will hopefully benefit future attempts at such modifications and perhaps encourage the design and manufacture of new and exciting clarinet mouthpieces.

14

Recommendations for Further Research

The most crucial aspects of mouthpiece design and other additional parameters were investigated during the course of the research. As the work progressed however, some opportunities for additional research presented themselves. In the conclusions I suggested further work into the relationship between the facing and natural reed curvature, and a careful examination of the effects of different window geometry (the area between the tip and side-rails). Research on the following areas may also further our understanding of the acoustic behaviour of the mouthpiece.

1. The tone of all the notes of English, French and German clarinets[1] to reveal how the timbre changes when notes ascend and descend through the three registers.

2. The way the sound behaves when moving from one note to another. Under certain acoustic conditions, the steady state tone of German Schmidt Reform Boehm instruments can sound similar to that of certain French Boehm clarinet set-ups. Analysis of the tone is also virtually identical, especially in the middle register. However, the unique tone produced by German instruments is immediately recognisable in either tongued or legato passages. It is possible that this difference in the emission of notes is caused by the design of the instruments alone and may have little to do with the mouthpiece design, although German facings are generally much closer and narrower and require thicker, but more slender reeds. English, French & German clarinets need to be more thoroughly analysed to establish their tonal characteristics in more detail.

3. Length, shape and area of the window under the reed.

4. Side-rail thickness.

---

[1] The possible exception being some bell, throat and cross-fingered notes which may be uncharacteristic.

5. Bore shoulder shape - rounded or straight edged.

6. Thickness of the beak at the tip rail; various tip mass effects.

7. Overall beak thickness and angle.

8. Polished or unpolished interior.

9. Saxophone mouthpieces.

Appendix A

Conversation with Dave James, Boosey & Hawkes (now retired)

Boosey and Hawkes bought the French company Buffet Crampon et Cie in the mid 1970s. Around this time they also made the decision to cease the manufacture of clarinets at their Edgware factory, since, as one director said, " Why have two factories producing the same instrument in different countries, making it necessary to duplicate both machinery and expertise. Anyway the French could make clarinets better and more efficiently than we could at the time!"

Buffet clarinets had certainly become the most popular clarinet internationally, whilst B & H' sales had waned considerably, in part due to the intonation problems of the large bore 1010 instrument. At the time of the Buffet take-over, B & H was in severe financial difficulties. By selling the Regent Street Shop for a substantial sum, then leasing the property back, they were able to use the capital generated to buy Buffet, and at the same time retain the use of their prestigious showroom. The company has since gone on to acquire musical businesses throughout Europe and have become one of the world's most successful industries.

Dave James was responsible for mouthpiece production at B & H for much of the post-war period. Large numbers of plastic mouthpieces were cast, three at a time, in metal moulds. The injection process used plastic powder heated to a liquid which was then forced into the three part moulds under pressure. The mouthpieces for the better quality clarinets ('926' & '1010') came from Chédeville in Paris.[1] These were made from traditional ebonite and were supplied with the smaller 926 bore specified by B & H. Dave explained that, although B & H specified the bore size, Chédeville were left to shape and style the reed slot (tone chamber) in the manner they thought best.[2]

---

[1] Chédeville were highly respected mouthpiece makers. A family of players and instrument makers, they flourished in Paris during the 19th century. By the 20th century they had amalgamated with Lelandais, making and supplying woodwind instrument mouthpieces and accessories. They have now been acquired by the French reed manufacturer Glotin who have since abandoned mouthpiece making.

[2] Many respected mouthpiece makers have used Chédeville designs for the basis of some of their own styles of mouthpiece, including Hans Zinner in Bavaria and Frank Kaspar in the USA.

The lay profiles on the Chédeville ebonite mouthpieces used by B & H were based on the lay from a mouthpiece found in a drawer that had belonged to the clarinettist Sidney Fell. Fell enjoyed experimenting with mouthpieces and this was apparently one of his rejects! Dave thought that the mouthpiece worked 'quite well', so he designed three profiles based on its dimensions to produce three lays, close, medium and open (1, 2 & 3). "Players seemed to like them" he said. The emphasis at Boosey's seemed to be on doing the work quickly and efficiently, and not to make an adventure out of each mouthpiece (sic). Following the demise of the clarinet manufacturing side of the business at the Edgware factory, the moulding equipment used to produce their cheaper plastic mouthpieces[3] seems to have unaccountably disappeared. Neither Dave nor anyone else interviewed had any idea as to what had happened to it. From a personal point of view this was somewhat irritating as I had hoped to be able to purchase this equipment to make the mouthpieces for the research.

The subject of plastic moulding led the conversation into a discussion on the mouthpieces now supplied with Buffet's professional quality clarinets. At the time that B & H bought Buffet, they also acquired Schreiber, the German woodwind instrument manufacturers who made the cheaper Buffet Evette & Schaefer clarinets. Traditionally, Buffet clarinets were supplied with their own ebonite mouthpieces, but these were not popular and few players used them. Ernst Schreiber developed a process for producing plastic mouthpieces cheaply and with great precision[4] and now that the Schreiber company was under the wing of B & H, a decision was taken to allow the mouthpieces for all the clarinets to be made by Ernst Schreiber. Dave James assured me that these mouthpieces were well made and extremely good. Since our conversation I have visited Ernst Schreibers in Germany and can confirm their quality. The mouthpieces are supplied with all new Buffet clarinets over the entire price range, but the more expensive instruments have extra finishing. Rings are machined around the body to help align the ligature, and the bore appears to have been carefully reamed, presumably to remove a small moulding 'step' at the top of the bore at the entry to the tone chamber and correct any deficiencies in the bore dimensions. Although these are, essentially, injection moulded mouthpieces, they retail for approximately £60.[5]

[3] Sold under the name Calteau
[4] Using acrylic
[5] Since the time of writing, B & H have acquired Rico reeds and mouthpieces and no longer use Schreiber mouthpieces.

Appendix B

A visit to Four Major German Mouthpiece & Instrument Makers October 1997

German Trip - Manufacturers & Specialists
Die Romantische Strasse

Hans Zinner GmbH & Co PO Box 57 D 96362 Marktrodach tel. 09261 2347 fax. 09261 52329	Mouthpiece maker using high tech (CNC and injection moulding) and traditional methods.
Ernst Schreiber Zeller Str.10 D 64720 MichelStadt tel. 06061 71056 fax. 0601 72953	Mouthpiece maker using solely high tech (CNC and injection moulding).
Herbert Wurlitzer Rüchenstrasse 20 91413 Neustadt AISCH Tel. 00 49 (0)9161 2625 Fax. 00 49 (0)9161 7457	Traditional clarinet maker. Mouthpieces made by injection moulding and in ebonite, using traditional methods.
Guntram Wolf Imziegelwinkel 13 96317 Kronach Tel. 00 49 (0)9261 420	Instrument Maker using traditional methods; Modern Bassoons, Viennese Oboes and ½size Bassoons Reproduction Classical Woodwind and Early Instruments

Took:

Louis Clarinets	Papers:	Howarth Tests
Basset Clarinets		Formants -
Moulded Mouthpieces		German/French
Few Ebonite Examples		Density
Artificial Embouchure		Tristimulus Graphs
Cameras/film		Walter Krüger
		Design File

Questions

What is the philosophy behind the creation of the mouthpieces?

Are the eventual designs arrived at through -

1. Empiricism?
2. Traditional designs & drawings?
3. Demands of clarinet makers?
4. Players' wishes/ideas/demands?
5. Research & Development

Is the company involved in any formal research e.g. The 'Zwota Project' with Walter Krüger & Schreiber? Are there connections with researchers or universities? Is there anything envisaged in the future e.g. Joel Gilbert (Le Mans University) and Selmer?

Do players' comments and suggestions have any influence whatsoever?

Do tooling, machining methods and speed of production have a significant effect on the final product? (Influence of production techniques on design).

Are there any problems with materials? Is there general satisfaction with the current situation or is there a constant search for new or improved materials?

Is the material considered to be of the utmost importance for the quality of the mouthpiece? Might the prime concern be suitable density, hardness and machinability?

How are different styles and tastes catered for? e.g. What is the approach to German, Viennese, French or American styles of playing and tonal characteristics?

What would be done if more brightness or darkness or greater dynamic range were required?

Wurlitzer began to make their own mouthpieces some 20 years ago. Why? Was it for financial reasons, greater control over the product etc.?

Schreiber chose a plastic (acrylic) for the mass production of quality mouthpieces. Why, and how was this material assessed for suitability?

Would there be any interest in a research collaboration with the London Guildhall University in the future?

How much interest might be shown towards a Symposium between players, makers and acousticians in the near future? This might be hosted by The London Guildhall University.

Itinerary

Sunday evening(19th Oct):London-Dover,(ferry) Calais-Ostend-Brugges-Ghent-Brussels
Monday: Liège-Cologne-down Rhine Valley-Mainz-Michelstadt.
Tuesday:a.m. **Visit Ernst Schreiber** (Michelstadt). p.m. travel to Rothenburg
Wednesday: a.m.**Visit Wurlitzer** (Neustadt). p.m. travel to Kronach
Thursday: a.m. **Visit Guntram Wolf** (Kronach).p.m. **Visit Zinners** in Marktrodach
Friday: Begin return journey. Arrive home Saturday.

The so called *Romantic Road* runs north to south for 350 kilometres from the baroque town of Würzburg in Franconia to Füssen in the Bavarian Alps. It is something of a fabrication by the German Tourist board to encourage tourism but none the less makes for an enjoyable journey through beautiful countryside and chocolate box towns The visits to the instrument makers entailed criss-crossing much of this route with a stop-over in the beautiful town of Rothenburg.

Ernst Schreiber

This is a very impressive set-up. A totally CNC workshop, very high tech. The business is run by Ernst Schreiber, his daughter Cornelia and husband Paul Kinzelmann plus two additional full-time workers. Ernst started the mouthpiece making business and was responsible for the present set-up but he is now in his seventies and very ill, working only part-time.[6] The story behind the business is intriguing. Boosey & Hawkes bought the Schreiber firm of instrument makers from the two brothers Hugo & Ernst Schreiber about twenty years ago. Hugo remained as manager of the company after the take-over whilst Ernst went to Austria to begin a mouthpiece making enterprise. Cornelia married Paul who became an invaluable son-in-law with his talent and skill in engineering and business. Eleven years ago they all moved back to Germany and settled in a new industrial estate in Michelstadt. This is more like a prestige executive development set in beautiful rolling countryside, with a premises that includes a large workshop and two apartments for the two families.

A decision was made to use only modern materials and state of the art machinery. Computer control is used to finish the mouthpieces which are produced in acrylic from injection moulds. The material is certainly not a cheap plastic, but a high quality polymer which I have since discovered can have many different specifications according to the production methods and the desired properties. The type they use is also used for components in the space industry. Paul believes that there are some drawbacks to this

---

[6] Since this visit, Ernst Schreiber has sadly died.

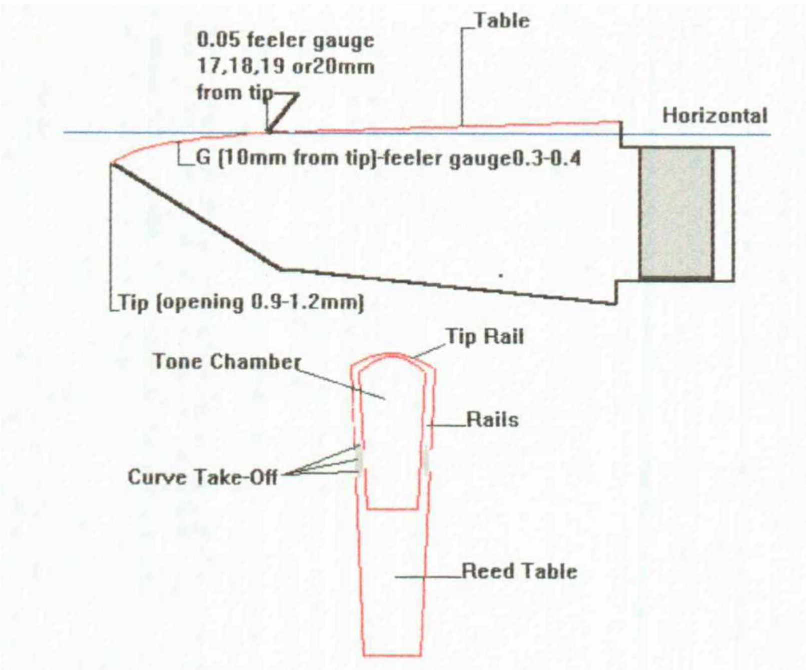
material and the method of manufacture, but that this is a compromise he is prepared to accept in order to produce the numbers required with a guaranteed level of accuracy and quality. With their modest workforce they can produce up to 500 mouthpieces a day. All the mouthpieces, both clarinet and saxophone, are made in a mould. This does impose certain restrictions as to the shape and dimensions of the mouthpiece in order for it to be lifted and demounted easily. The tone chamber must have a flat, straight baffle with a slight inverse taper so that the mould will break apart without damage. Paul also believes that acrylic (certainly of the type required for injection moulding) is inferior to ebonite from an acoustical point of view, even though the density and hardness are virtually the same.

Ernst designed much of the machinery used prior to the de-moulding process. The reboring, facings and tenons, are carried out using computer controlled lathes and other specialised equipment. The Swiss cutters are diamond tipped. The computer programmes were written by Sabine Meyer's husband.[7] There is some collaboration with a clarinettist in the Paris Opera for advice and testing.

I was particularly interested in the method used to compute lay profiles (facings) for use on the CNC profiling machine. The method involves taking a desired tip opening e.g. 1.15mm, deciding what the opening should be 10mm down the rails from the tip e.g. 0.30mm feeler gauge entry, and choosing the length of the lay by assigning a point along the lay from the tip where a 0.05 feeler would stop e.g.18mm. The programme then computes a smooth curve for the total length of the profile. In practice this method seems to work, and the mouthpieces I played on responded well. However, I am not altogether convinced by this procedure, as creating an overall curve from 3 points (tip-point, G-point and 0.05mm-point) does not allow for flatness towards the tip which can be desirable in some styles of lay. Also, although the actual take-off point for the start of a lay is normally 2-3mm further along than the 0.05 feeler position, it could be less or a great deal more, according to the style of lay. A German profile might be as long as 28mm, but a 0.05 feeler may only go in as far as 20mm. The effect of the take-off point is crucial to the overall response of the mouthpiece. This method of auto-computing the take-off point would probably be too short for a German or 19th century design lay.

[7] Sabine Meyer, international clarinettist and member of the Berlin Philharmonic Orchestra

Fig.26 Lay Configuration



Everyone at Schreibers was friendly, open and unguarded in response to my questions. Paul showed me round the workshop and described in great detail how it all functioned. He was interested in discussing the merits of different designs, in particular the types of English mouthpiece used in the 1920s and 30s. They were fascinated by the artificial embouchure, eagerly attaching it to their compressed air supply so that I could demonstrate its capabilities along with excerpts from the Mozart Concerto (no mouth contact!).

Schreibers were involved in the research into the dimensions of clarinet mouthpieces carried out by Walter Krüger in Zwota (1995-97). The critically fine tolerances demanded by this work were best satisfied by digitally controlled milling machines, and Schreiber mouthpieces were considered to fulfil their stringent requirements.

In a cruel turn of fate, the take-over of the American reed manufacturer Rico by B & H looks likely to result in Ernst Schreiber losing a very large monthly contract. Schreibers have been supplying mouthpieces for the Buffet (B & H) clarinets and saxophones made in the Schreiber (B & H) instrument factory, and for the professional instruments still made in Paris. Rico make an inexpensive range of mouthpieces and B & H wish to use these for instruments at the lower end of the market. Although Ernst Schreiber will retain the Buffet contract, this represents a huge loss of business. However, they have markets throughout the world, including Japan and the U.S.A., and Paul is optimistic about finding new outlets.

Wurlitzer

Wurlitzers proved difficult to find, being tucked away in a rather unassuming, middle-class suburban street, looking, from the outside like any other house in the area. Once inside however, there was an impressive extension not visible from outside which housed the workshop. This had been designed by Bernd Wurlitzer's architect wife.

As with Schreibers, the business was surprisingly small, bearing in mind their reputation, but obviously run with great efficiency and there was enormous pride in the Wurlitzer name.

The interview was rather difficult to manage. There was absolutely no question of seeing the workshop or any of the manufacturing methods, and the interview was confined to the reception room, with a constant eye on the clock. Herr Bernd Wurlitzer (he has adopted the family name) whose architect wife is Herbert Wurlitzer's daughter, was extremely polite, if a little cool and was keen to get on with the questions, which he photocopied.

Wurlitzer specialise in the German Oehler system clarinet and they are justifiably proud of the quality of their instruments. The only concession made to the Boehm system is the manufacture of a number of Schmidt Reform Boehms. I reeled off my questions in a rather perfunctory way as it was difficult to create much of a dialogue. Nonetheless, answers were given courteously and their senior technician was invited to join us. It was frustrating that language difficulties prevented us from communicating more freely as this craftsman was more forthcoming and, from my point of view, more interesting than Bernd, whose role and knowledge seemed to be geared more towards the business side.

The company's attitude towards design was quite inflexible, particularly in regard to the mouthpiece. These used to be supplied by Zinner, but for the last twenty years have been produced in-house. The mouthpieces are made in the traditional fashion in ebonite, and also by moulding in acrylic. Unlike Paul Kinzelman at Schreibers, Wurlitzer would not admit to any drawbacks to moulding, describing their acrylic models as 'perfect'. This rather begs the question then as to why their hand made ebonite mouthpieces are different in design from the acrylic models, particularly the tone chamber. The technician talked of the mouthpiece needing to be part of the instrument as a homogenous whole.

They seemed unimpressed with the research into the changing of mouthpiece bore size for the Howarth clarinets, in fact they had no knowledge of these instruments.

The technician suggested that using an oversize bore was an experiment confined to England in the early part of this century (it was in fact still being adopted in the 50s and 60s, with players using a larger bore B&H 1010 or 926 mouthpieces on small bore Buffet clarinets). When asked about the influence and suggestions of players etc., I was told with obvious relish that Bernd's brother in law was a player in the Berlin Philharmonic Orchestra, a teacher at the University in Wurtzberg, and that he was much involved with the company, advising on design and development.

Towards the end of the interview the atmosphere became a little more relaxed and I was shown some beautifully made tiny, high G clarinets. We talked about the work of Walter Krüger, they were keen that I should contact him and gave me his address in Markneukirchen.

In fairness to Wurlitzers, they may well have been suspicious of my motives and their initial reluctance to see me was understandable. They have been badly affected by the activities of a certain Far Eastern company which has copied their instruments and probably taken some of their home market. They were obviously genuinely pressed for time and possibly felt that the uniqueness of their instruments with the rather specialist market it occupies, rather precluded them from the remit of my research.
A difficult visit, but revealing.

Guntrum Wolf
This was one of the most exciting parts of the trip. I had not expected to learn very much about mouthpieces from this meeting, but had been advised by Nick Shackleton that Wolf and his collection of woodwind instruments were unique. They certainly were.

Once more, the set-up was quite modest, with a large workshop in the garden to the side of the house, and only a handful of people working in his woodwind instrument making company. The workshop contained modern machinery (little evidence of CNC) and again, the work space was impressively clean and tidy.

Guntrum has an extraordinary collection of old instruments, including classical bassoons, clarinets, basset horns, oboes and some interesting early bass clarinets. He makes a wonderful baby bassoon (octave higher) for children of six years upwards, and also some extremely simple, small maple clarinets for school use. He is presently making a maple, bass clarinet in the Heckel tradition. In spite of the obvious business attraction, he seems to have a genuine interest in enabling children to become familiar with reed instruments from as early an age as possible. I saw some beautiful Viennese oboes that he had made and also fine reproductions in stained boxwood of the Ottensteiner clarinets.[8]

I had taken Basset clarinets which I had made at the University two years ago and he was complimentary, commenting on their robust, clear tone and good intonation. He was very interested in my present research, in particular the application of moulding techniques for producing copies of classical mouthpieces.

I had taken some of the experimental polyurethane classical mouthpieces I had made from silicone moulds. These interested him enormously, and we experimented using these on several of his classical clarinets. He had commissioned Zinners to make a hand made ebonite copy of a classical mouthpiece, but found that my moulded version of a Lefevre model produced a warmer and more rounded tone with better forked fingerings. I gave him two of these mouthpieces for which he was very grateful, and he asked me if I might be interested in making some more and if I would be able to copy some early bass clarinet mouthpieces. We discussed ways of analysing tone and I was interested to find that he used *Sound Forge* with its wave analysis plug-in as a means to investigate timbre and response. He thought this was a very effective tool for an instrument maker. Guntrum organises a festival/symposium for the clarinet (classical & modern) during the summer each year in Kronach.

Zinner

The last port of call was to the company of Hans Zinner, a few kilometres away in Marktrodach. Again, a small firm in a rather ordinary, but very well maintained, private detached house, a 'Hans Zinner' plaque fixed to the front gate. It was rather reminiscent of a village G.P.'s house. It is amazing how all the companies that I visited appeared to be little more than cottage industries, with remarkably high outputs.

The firm Johann Zinner & Sohn began in 1920 in Raume, Graslitz. In 1947, Johann's son Hans began specialising in high quality clarinet and saxophone mouthpieces, and he soon became known throughout the world. His sons Hans and Jürgen took over in 1980. The present set-up in Marktrodach is simply a large workshop attached to the side and rear of a largish white two storey house where Hans lives. Jürgen lives a little distance away. There are two other workers in the workshop. Although I was warmly welcomed by Jurgen, I was not invited into the workshop and there appeared to be some suspicion on the part of the other brother Hans, as to the motives for my visit. Jürgen was extremely friendly and continuously hopped backwards and forwards to the workshop to bring me

[8] Copies of Richard Mühlfeld's instruments for authentic playing of the Brahms clarinet sonatas.

examples of work in progress. Hans insisted that they had also made mouthpieces for Walter Krüger's research. Perhaps this was not the same work with which Schreibers had been involved, as there are several papers on mouthpiece acoustics by Krüger dating from different periods. I have been told that at one time thirty people worked for Zinners. It is difficult to know if the drop to only four is due to the introduction of modern machinery or because of a reduction in demand. Zinners produce a wide range of high quality clarinet and saxophone mouthpieces with much of the work hand finished, at incredibly low prices (c.£18 trade price for an ebonite mouthpiece that would take up to a day to make by traditional methods). They make mouthpieces for Gregory Smith (2nd clarinet in the Chicago Symphony) marketed in the US. They also make mouthpieces to a design suggested by Tom Ridenour, the Leblanc American mouthpiece expert. Mouthpieces are also made for several other makers who then, with or without a minimal amount of modification, market them under their own name. Zinners seem quite happy for their mouthpieces to be marketed in this way.

Zinners appear to use similar material (acrylic) and moulding procedures to both Schreiber and Wurlitzer, alongside their more traditionally made mouthpieces. It is interesting to see the similarities between the acrylic mouthpieces made by each manufacturer. Not only are the materials alike, but the internal shapes also look very similar. Paul Kinzelman had told me that there were only two people in Germany capable of making the metal moulds for acrylic, so this may account for the close resemblance. The lays on the mouthpieces also have tell-tale semi-circular milling lines, demonstrating that the same method of machining the lay is common to each company.

Whilst accepting the advantages of acrylic, both Hans and Paul believe that ebonite still produce a better mouthpiece.

Since returning to London, ICI have been contacted concerning the type of acrylic suitable for use in injection moulding. There are many recipes for acrylic. ICI make a product called Diakon which has hundreds of formulations. Non-injection type is a high molecular grade. Granules for moulding can incorporate rubber molecules. Density is c. 1.18 & pencil hardness 7H.

ICI Technical 01254 874 429 Head of Acrylics (DIAKON), Ray Lincoln 01642 43 22 91

Appendix C

Published Paper

International Symposium on Musical Acoustics 1998 - Proceedings p. 191 -196

The Effect Of Design On The Tone & Response Of Clarinet Mouthpieces & PC Based Wave Analysis As A Design Aid

Edward Pillinger

Department of Musical Instrument Technology, London Guildhall University
41-47 Commercial Road, London E1 1LA, England

Abstract: This research has led to a number of discoveries and clarifications. The use of an artificial embouchure strongly suggests that there is minimal effect on the timbre from vocal tract resonance and that a player controls tone by lip pressure, lip position and variation of air pressure. Large bore mouthpieces add vibrancy to small bore clarinets and shift the spectrum closer to German tone. Baffle angle and shape, together with the slipway under the reed play an important role in balancing brightness whilst the reed lay profile arguably influences the tone more than any other parameter. PC based hardware and software were used to analyse the data and assisted design for specific tone by revealing the extent of the influence on tone from any modification.

This research was undertaken from the standpoint of a performer/maker and complemented previous research [e.g. Benade, Krüger and Wehner] by using sound analysis to measure timbral changes brought about by modifications to mouthpieces. Tests used clarinettists and a controllable artificial embouchure. Expert listening panels were used when it was considered beneficial.

In the initial stages, only differences in timbre were examined, and consideration was given as to how changes might best be described and quantified. Finding a method of using the analysis systems to reveal subtle timbral differences and the so called 'feel good factor' in an instrument set-up was difficult, repeated test results often containing substantial harmonic variation which was contradictory. The non-linearity of the reed and player and possible flaws in the data acquisition methods were the most likely cause. A method of simplifying and clarifying the data was vital.

The Areas Or Parameters Under Investigation

Bore, diameter, taper & length. Tone-chamber, including baffle angle & shape, side-wall angles and the area on the baffle below the tip rail. The size, angle & thickness of the recess under the table (slipway into the bore opposite the baffle). Investigation of a wide range of tip openings x lengths of lay profile. Tip rail and side rail thickness. Material density and hardness.

Large numbers of commercial mouthpieces were measured and tested revealing inconsistency as regards quality and performance. There was also a disappointing lack of variety in design, particularly with regard to French style instruments, most differences being confined to the lay profile. This may be more to do with the conservatism of players than the fault of the makers although manufacturing methods such as injection moulding, constrain design.

Artificial embouchure

The research required a system to examine each operating parameter in turn whilst stabilising all others. To achieve this, an artificial embouchure [AE] incorporating a lip pressure sensor, manometer, temperature sensor, hygrometer and air conditioning was constructed, along the lines of the Backus model [Bachus,1961]. Realistic clarinet tone was produced over a wide dynamic range and clean articulation was achieved by means of an artificial tongue. This was accomplished in spite of the device having a large volume, hard, angular surfaces and long, large diameter air supply line. When the same mouthpiece and instrument were used by a clarinettist and the microphones were positioned at the same distance and in the same trajectory, almost identical spectra were obtained. Many players were disconcerted by these results as they suggested that the shape and size of the vocal tract had very little influence on tone - heresy indeed! In order to verify these results, tests were conducted by filling the interior of the embouchure with various materials in order to reduce the volume and alter the damping factors, but this failed to alter the playing properties. It was found that very small changes to the lip position on the reed, lip pressure or variation of air pressure caused large changes to occur in the timbre and spectra. Combinations of these parameters produced a wide range of tone colour, suggesting that tone is controlled by a player's embouchure and blowing technique rather than a unique vocal tract or physiognomy. The artificial embouchure enabled the production of steady state tone avoiding a player's natural inclination to correct deficiencies; this was excellent for checking instrument intonation and evenness of tone throughout the range.

Recording System & Analysis Programmes

PZM Microphones were chosen for their wide flat frequency response, lifelike sound quality and freedom from phase/reflection interference. A dynamic earpiece was used for the internal probe transducer which was fed to the computer sound card via a Maplin amp/equaliser. Recordings were made direct to disk using SoundForge where sounds could be looped and further conditioned as necessary. Most analysis was carried out on the computer using a Pico ADC100 and PicoScope software in addition to SoundForge and Vwaves 2.

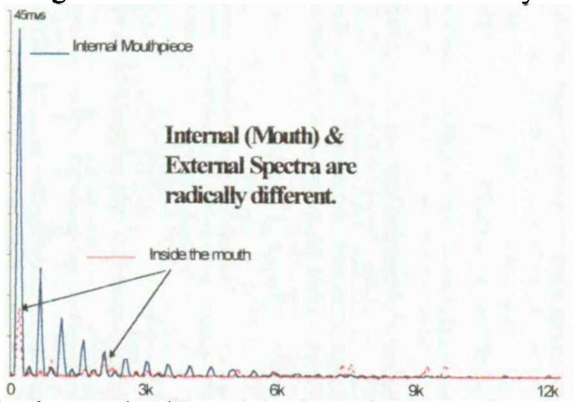
Problems of Microphone Placement

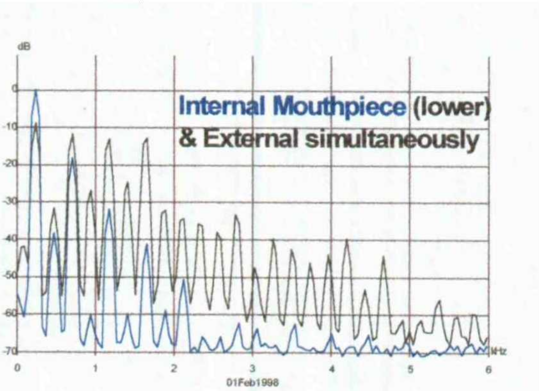
Regardless of the positioning of the microphones, the sound of the playbacks was consistently life-like, yet marked differences often manifested themselves in the graphs due to phasing, reinforcement and cancellation brought about by the room acoustic. This was somewhat unhelpful in deciding on the optimum mike placement for the experiments! Recording at the mouth of the bell captured more upper frequency components together with a good fundamental, than using the position close to the tone-holes. The position was critical if phasing and other problems were to be avoided. I found 7cm on a direct line from the bell gave consistent results over virtually the whole range.

Although some upper frequency components are lost when close to a hole, this position, (favoured by Benade) gives a broad band of components with a reasonably high cut-off frequency and has the advantage of eliminating reflections and other room acoustic problems. Some upper frequency energy is lost due to the hole's behaviour as a simple low-pass filter but the position produces clear, regular graphs from which to begin the work of detecting change in harmonic structure brought about by changes in design. There is little change to the spectra any closer than 5cm.

A position 25cm from the instrument tone-holes may be better when recording and analysing the instrument as a whole, in that the clear, ordered, step-like progression of components is still present, but with stronger 3rd and 7th harmonics. Going beyond this distance seems to create havoc with the spectral graphs of notes in the low register of the clarinet. Internal spectra always have more powerful fundamentals than any other component and the 'close to tone-hole' set-up also gives a sturdy fundamental for each note, therefore external spectra that have a very weak

fundamental are almost certainly being seriously influenced by the room acoustic and/or the mike position. Finding an optimum position for the mike at around 1.5 metres (the closest an auditor is likely to be in a concert or teaching situation) where stable, consistent and logical spectra can be obtained, is desirable and should be reliable for comparison of clarinet tone. The set-up, once found, has to be adhered to consistently if meaningful data is to be obtained from related experiments. I did eventually find locations in my workshop that fulfilled the criteria and I believe pressure zone microphones made the task easier, being less affected by reflected sound.
A simple probe microphone was built, using a dynamic earpiece attached to a 0.5mm diameter tube that which could be inserted into suitably adapted mouthpieces. The advantage of this device was its imperviousness to the outside environment. However it was not suitable for every experiment , the internal spectra being different from the external spectra which have been modified by the instrument. Nevertheless, results were consistent and were useful in tracking some of the effects brought about by design change.
The probe was used to check the sound activity inside the mouth to further verify the results obtained from the AE. The same note was played at the same dynamic level (loud without distortion), checked by sound level meter, first with the probe attached to the inside of the tone chamber and then inserted well into the side of the mouth. The graph shows the small number and magnitude of the harmonics inside the mouth; a small amplitude fundamental, tiny 2-8 harmonics and a 9th equal in strength to the mouthpiece spectra. There is no evidence of any resonance strong enough to have an influence on the externally radiated sound.

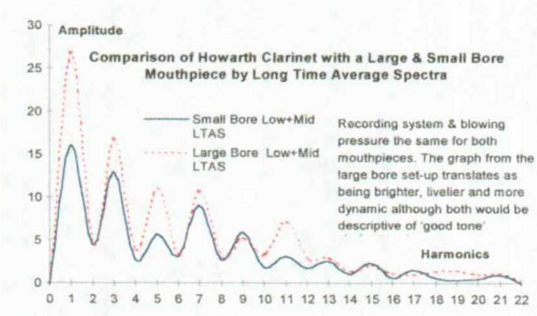


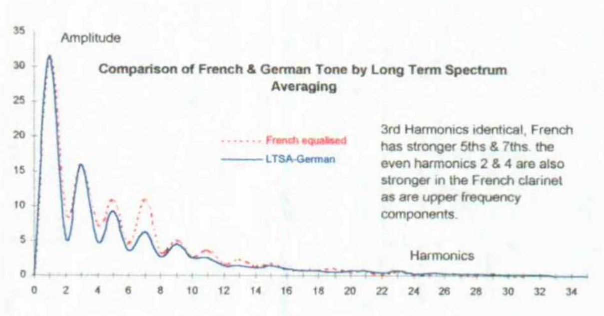


In the graph (dB scale) where the internal and external spectra are displayed together, the external mikes were located 1.5m from the source, and the probe was attached to the adapter, 25mm from the tip. A good match can be observed for the first five harmonics, but from there on, the external spectrum deviates wildly. One could assume from the internal spectra, that cut-off is around 2.3k. The external drops significantly a little below this but the true cut-off is not until around 5k. [Benades results & OHP]

Mouthpiece Bore Size and the Howarth Clarinet

In the experiments to test the hypothesis that the new Howarth clarinets are improved by the use of a larger bore mouthpiece, a different method was used to gather sound data, using live playing but without giving the player time to coax poor notes into shape. A series of representative notes from across the whole range was first recorded at a moderate tempo using the standard small bore mouthpiece. The notes were phrased musically, as in playing a melodic line. The requisite alteration to the bore size was made and the test repeated immediately so as to minimise reed deterioration. The bore was enlarged from the typical small French size of 14mm diameter at the shoulder, to 15mm diameter at the end of the tenon over a length of 50mm (0.66°), to 14.6mm to 15.8mm over the same length (0.9°). This was an enlargement of a high order of magnitude.
Overall the instruments became livelier and more colourful by substituting a much larger bore mouthpiece, provided that this was accompanied by a correspondingly shorter (smaller volume) barrel. Long Term Averaged Spectra (below left), show the change of spectrum (formant) brought about by this modification.

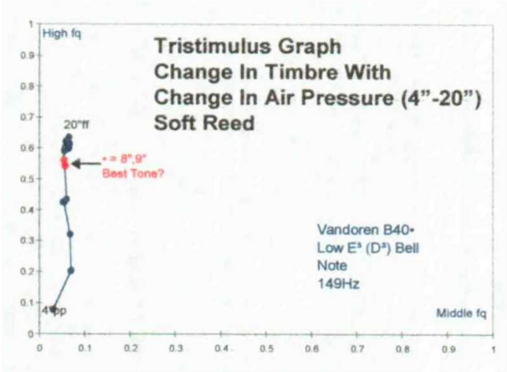




A similar approach was used to compare the tone between a German Oehler system clarinet and a French Boehm instrument(above right). In these tests the whole range was played moderately quickly. The German clarinet was a superb instrument by Warschewski c. 1930, and the French instrument, my own Louis c.1921 (English but French design). I try to produce as Germanic a tone as possible on my instruments, which is somewhat atypical, nonetheless, whilst certain individual notes were remarkably similar in both sound and spectra, the LTAS shows a difference in the formant. The French clarinet has stronger resonance peaks around the 5th and 7th harmonics. The German clarinet has a darker tone and this is born out by the weaker harmonics above the 4th. These results would be of help if the aim were to design a mouthpiece destined to make an instrument sound more Germanic. Of course it is the instrument itself which lies at the heart of timbral response but the part the mouthpiece plays is nonetheless crucial.

When comparing all four spectra, it is interesting to see that the large bore on the Howarth clarinet has produced a shape more similar to the Louis in the German/French graph. The Louis is considered to be a superior instrument and already closer to Germanic tone (demonstrated by the graph). The use of a large bore mouthpiece has moved the sound closer to this Germanic sound whilst retaining a measure of brightness. The small bore Howarth is far removed from this spectrum. The large bore Howarth tone was brighter but without any suggestion of shrillness. The sound might be better described as 'dark', yet with more colour and vibrancy, even though this appears to be contradictory. German clarinets, at their best, are warm and mellow, but sometimes lack the vocal quality of good French instruments. The LTAS of my Louis clarinet is similar to that of the Oehler instrument because the mouthpiece I made for this clarinet was designed to produce tone with intensity and colour, whilst retaining its vocal element.

A further simplification is to convert LTAS data into tristimulus graphs [see 'The Musician's Guide To Acoustics' Campbell & Greated]. Both LTAS and Tristims are helpful in clarifying the complexity of some spectral graphs so making quick comparisons possible. Since the tristimulus achieves this by displaying data as a single co-ordinate, a ratio of middle and high frequencies, the exact location of resonance peaks cannot be known. However they are good for plotting the development of transient harmonic structure over time and successful in showing differences when studying variation in timbre with change in temperature, humidity, air pressure or material density and hardness. Zooming the scale was usually necessary to highlight the results. LTAS are not suitable for the transient but have become my preferred method for displaying steady state data and comparing the effect of modifications on tone. Although not representative of any single note, averaging the product of the whole range of an instrument eliminates rogue notes and provides a 'picture' of a set-up which might be said to represent the tone of the whole instrument. Providing that the method of data acquisition is set up meticulously, then to some extent, the LTAHS's alleviate the problems associated with mike placement and room acoustics.



This graph demonstrates how the tone develops as air pressure increases and the instrument becomes louder. Middle frequency remains roughly static from soft to loud, but high frequency components, from the 5th harmonic upwards, increase rapidly to a maximum level at around 20" of water (50mb). Increase in pressure above this makes little difference to the harmonic content. Best tone was around 9".

Materials

Density and hardness have a noticeable effect on the 'feel' of a playing set-up, and analysis of the tone from identical mouthpieces moulded in resins of varying density and hardness seems to suggest that there is also an effect on the radiated sound. (OAP) Ebonite, the preferred material, does seem to have physical properties which suit most players, with hardness in the region of D85 and density around s.g.1.15. Resins such as epoxy, with similar hardness and density, usually make acceptably good moulded copies.

Onset Transient - Attack Transient

Tristimulus graphs produced from FFTs over time are useful in showing clean or ragged articulation as a simple picture and could be used as possible blue prints for optimum results. It is interesting to note that onset transients are similar to the development of the harmonic structure with increase in air pressure as in a crescendo. There is a uniform increase in upper harmonics starting from ppp with only the fundamental and 3rd harmonic sounding. Playing sotto voce (very softly with a veiled tone) also produces this simple, two component structure.

Baffle and Side-Walls

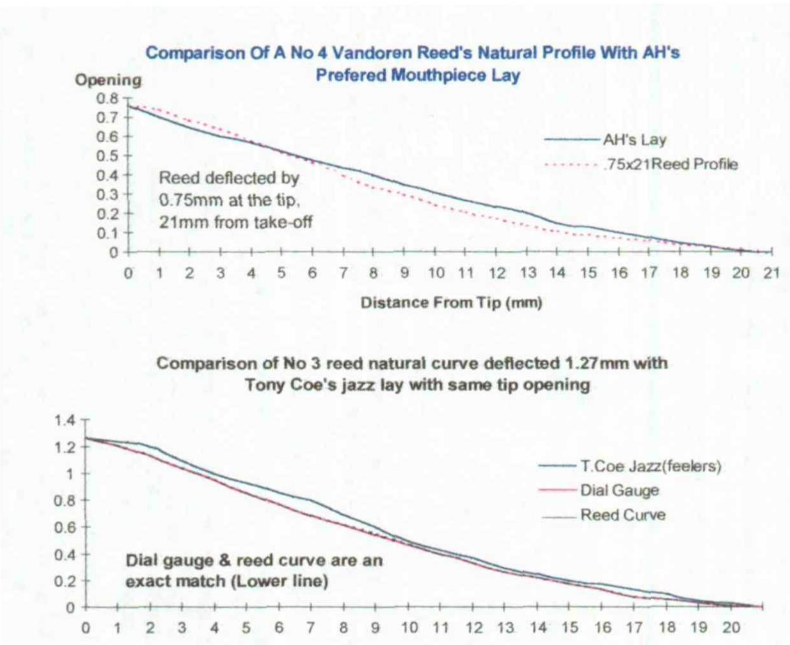
A baffle to bore angle of 20° - 22° (add 5° for baffle to table angle) gives a reasonable compromise between a timbre which is too dark or over bright. The angle can be increased to 25° before the tone begins to sound 'tubby'. Decreasing the angle to around 17° can lighten the tone but care needs to be taken to avoid harshness (e.g. combine the baffle angle with a different recess shape as described below). Raising the baffle simplifies the harmonic structure whilst the deeper angle encourages a more complex wave. Similar effects can be achieved by making the baffle more concave or convex. The permutations are endless.

RECESS (Slipway under the reed table)

Heavy filing of the recess parallel to the baffle until a knife edge with the table is created is a favoured option and appears to have a similar but more subtle effect to incorporating a deeper baffle. Leaving material under the recess and retaining a 2mm blunt edge with the table can increase clarity, and I have since discovered that George Howarth, who made mouthpieces for Louis between the wars, recommended this shaping for smoother tone, although he often left the recess thick but chamfered the leading edge. It is possible to visualise this the other way around; filing the recess parallel to the baffle, increases the height and area of the aperture into the bore and reduces the bocal which will also affect timbre. Howarth's method of chamfering the leading edge increases the bocal effect. The influence on the spectrum is clearly defined. A 5.5mm recess was too thick, making the instrument resistant. The middle thickness was quite successful in producing dynamic, clear tone, whilst the thin recess, still very good, was noticeably darker and the most mellow. (OHP)

LAYS

Large numbers of lays currently used by professional players, and a selection of the most responsive in terms of articulation, dynamic range and timbre, have been selected and measured for further study. The results from the Howarth tests showed that the effect on tone from using a very close lay (small tip opening e.g. 0.75), or moderately open (1.15), was often more significant than a change in the internal dimensions. Richness in harmonic colour is improved by a closer lay, but the feel of this set-up is very different, requiring a different blowing technique and is unacceptable to many players. Close lays are also often perceived as being less flexible. An area of particular interest concerns how the natural curve of the reed under deflection compares with the curve found on lays that are considered to work well. Players and technicians speak of the reed's ability to 'roll' around the lay profile, irrespective of the tip opening and length, and maintain that this is crucial to good playing properties. I have begun work measuring the natural curve on the reed under deflection and comparing these results with popular lays. An adjustable reed deflecting device has been made and this sits neatly onto a lay profile measuring tool in order that measurements might be taken from any take-off point along the reed (e.g. 20mm from the tip), to any desired tip opening. Preliminary results suggest that the best lays correspond extremely closely to the natural curve of the reed deflected by a distance equal to the size of the mouthpiece tip opening. If further research confirms this, then it might be possible to specify reed strength, tip opening and length and then simply select a profile to match. (results available)



Research has shown that the behaviour of the various parameters of the mouthpiece are extremely complex, but that account must be taken of these complexities when designing mouthpieces or solving mouthpiece problems. Greater understanding of the functions of the individual parameters will enable the maker to design mouthpieces to individual specifications incorporating specific characteristics.

Appendix D

Woodwind Acoustics

Some Basic Principles & Theory

This has been appended to assist readers with limited experience of woodwind acoustics and is not part of the reporting of research.

Clarinets (Closed Cylindrical Tubes)

There is always an odd number of ¼ wave lengths within the tube with one quarter wavelength in the fundamental (Mode 1) This produces a fundamental 4 times the length of the tube.

In other words,

THE TUBE IS ¼ OF WAVELENGTH FOR THE SOUNDING FREQUENCY f_0

If you know the wavelength of a sounding note, then a simple formula will tell you the frequency of that note i.e. what the note is.

$$f_0 = \frac{1 \times c}{4L}$$

Where f_0 = frequency(Hz), L = tube length & c = speed of sound (345 metres/sec @ 20deg C.)

Suppose our tube length is 1.5m, then the frequency will be $\frac{1 \times 345}{4 \times 1.5}$ = 57.5Hz. (low C in Bb)

1.5m is the approximate length of tube required to produce low C on a Bb Bass Clarinet.

Another problem, how long must a clarinet be made to produce a bell note E_3(147Hz)?

Using our formula in a different way, $4L = \frac{1 \times c}{f}$ or $L = \frac{c}{4f}$

Therefore $L = \frac{345}{147 \times 4}$ = 58.7cms.

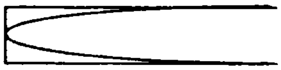
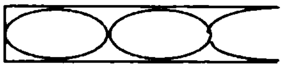
Clarinets are usually a little longer than this at 66cms, but in this calculation, no allowance has been made for the flare in the bell (which sharpens the low register more than the middle register) or end correction. The formula is more accurate for other notes on the tube.

The 1st harmonic f_3 can be calculated with the formula adjusted: $f_3 = \frac{3 \times c}{4L}$ or $3f_1$

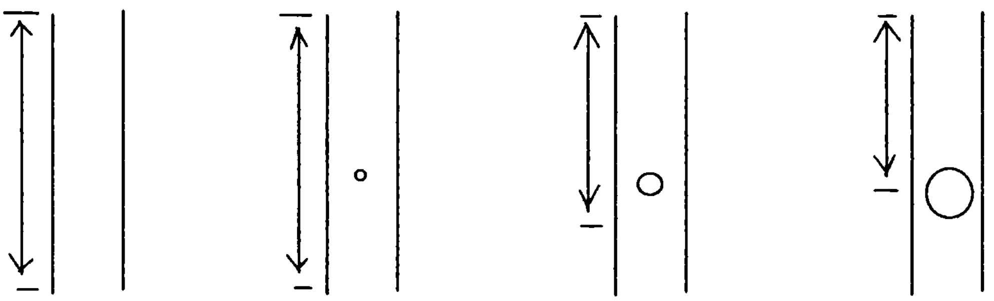
and the 5th harmonic = $5f_1$

To Summarise

L = Tubelength, λ = Wavelength, c = Velocity of sound in air (345m/s @ 20^{0}C)

Cylindrical tube closed at one end		**Wavelength**	**Frequency**	**Sounding**
	Mode 1	$\lambda = 4L$	$f_0 = \frac{c}{4L}$	Fundamental
	Mode 2	$\lambda = \frac{4L}{3}$	$3f_0$	12th
	Mode 3	$\lambda = \frac{4L}{5}$	$5f_0$	2 Octaves + Major 3rd

The Effect Of Tone-hole Size On The Speaking Length Of The Tube



Length of tube determines the frequency.	Small tone-hole has a negligible effect on frequency. Used as a speaker hole to assist production of upper modes.	Medium size tone-hole produces a partial reduction in speaking length.	Large tone-hole (almost bore diameter) behaves as an open end, giving a new wavelength and effective length of tube.

Reflected Energy and Standing Waves

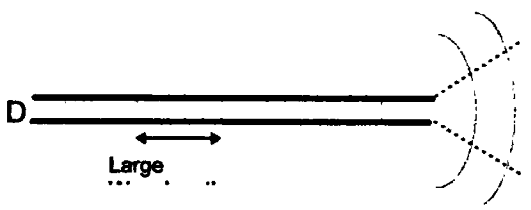
Standing waves can only be supported if energy is reflected back along the tube (wave reversal). The waves are **longitudinal,** moving along the tube in the form of **compressions** and **rarefractions**. This is distinct from string instruments where the waves are **transverse.** Magnitude is very small, even for loud sounds (1mm).The modes of vibration depend on whether the tube end is **open** or **closed,** as well as any perturbation. Waves will obviously be reflected when the tube end is closed.

In the case of an open ended instrument, reflection takes place because waves are diffracted (bent) outwards when they reach the tube end where the conditions are changed suddenly (as when light is refracted leaving glass or water). Some of the wave energy is reflected to maintain the standing wave, and the rest is transmitted to the outside where it can be heard. The amount of bending (diffraction) is dependant on the ratio of the wavelength (λ) to the bore diameter (D).

If the ratio is SMALL then nearly ALL the soundwave is transmitted.

If the ratio is LARGE then LITTLE soundwave is transmitted. There is a large diffraction and large reflection of the wave.

Diameter (D) less than λ (wavelength)

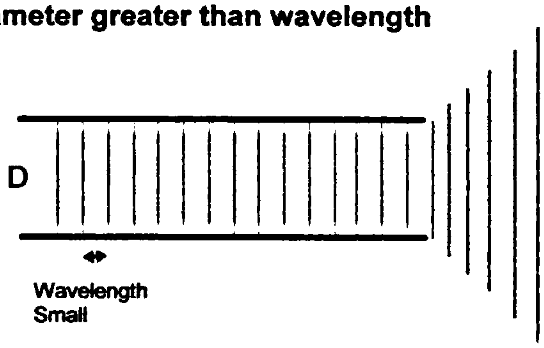


Diameter less than the wavelength
= considerable reflection

$\frac{\lambda}{D}$ LARGE RATIO

Effect similar to waves passing through a small diameter hole

Diameter greater than wavelength



Diameter greater than the wavelength
= little reflection, waves pass straight out

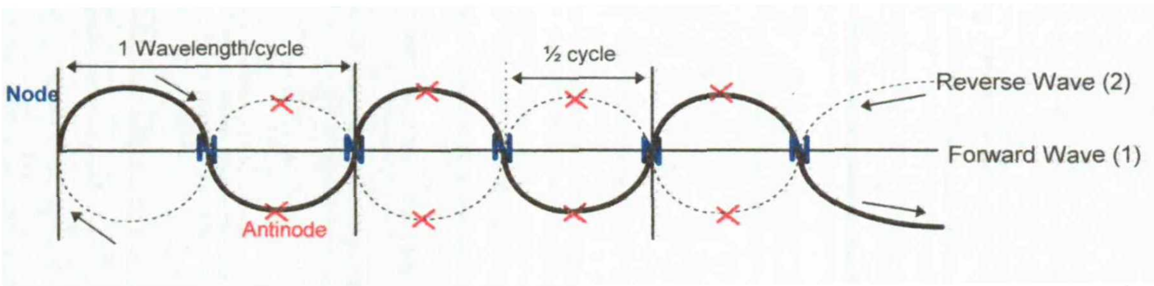
$\frac{\lambda}{D}$ SMALL RATIO

Effect similar to waves passing through a large diameter hole

Instrument design needs to be a balance between the two regimes, that is, between an instrument that has a smaller bore and is more stable, and one that has a larger bore and is more dynamic. To achieve optimum designs there should be a symbiosis between players and makers. Clarinets with small bores are popular at present, with well known makers such as Buffet, Selmer and Leblanc opting for bore sizes around 14.6mm. Large bore instruments, such as the Leblanc Dynamic H with a 15mm bore, and the Boosey and Hawkes 1010 clarinet, with an even bigger bore of 15.3mm have become less fashionable. However, there are makers who favour large bore designs, notably Rossi, Eaton and Frank Hammerschmidt. There has been a knock-on effect as far as mouthpieces are concerned, with a proliferation of small, conical bore mouthpieces which all share a similar design.

NODES and ANTINODES

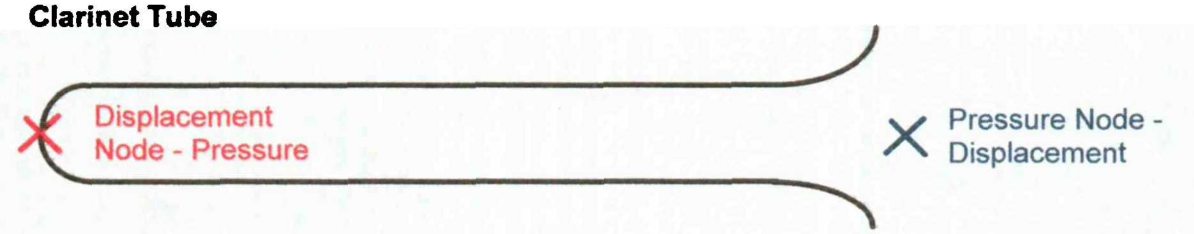
Standing Wave



Node = 'No' Displacement
Antinode = Maximum Displacement

Adjacent Nodes are ½ wavelength apart
Nodes and Antinodes are ¼ wavelength apart

Clarinet Tube

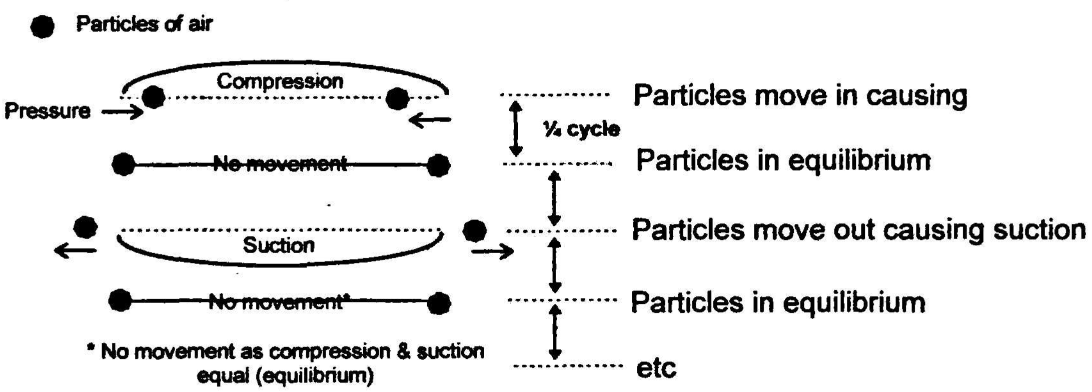


Pressure Node because no particle motions are possible at the closed boundary.

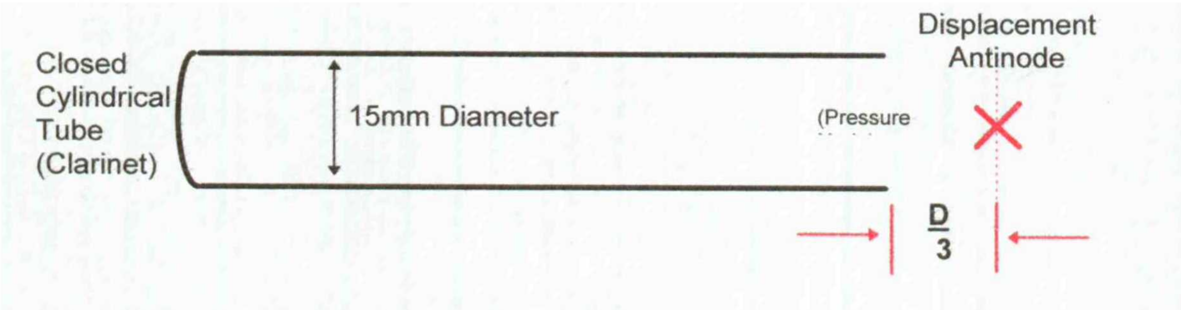
Open end is a Pressure Node as with tubes open at both ends.
Pressure must be atmospheric.
As air particles are free to move in and out they will also be **Displacement Antinodes**

Example for a tube open at both ends:-

Variation in pressure with particle positions during one cycle

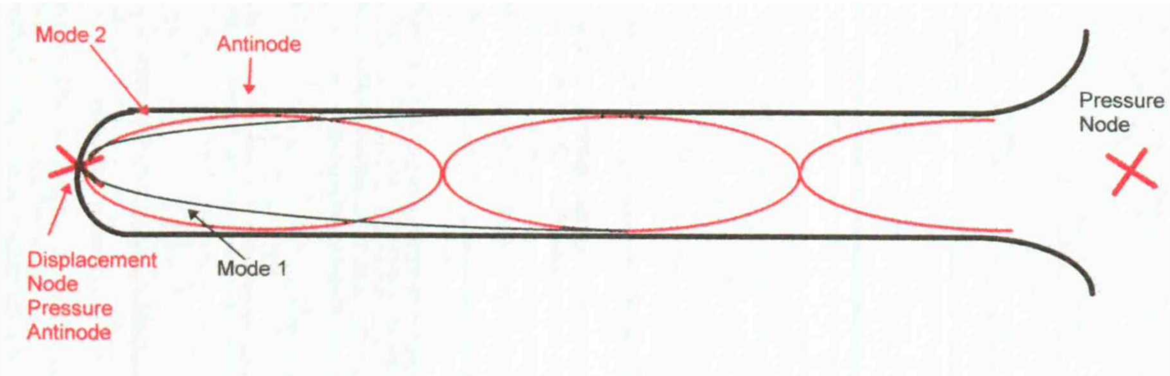


End Correction



Correct tuning should be achieved by shortening the tube by D ÷ 3, or, in the case of clarinets, enlarging the bore by inserting a cone (bell). Clarinets need to be shortened by approximately 5mm - 8mm when using the 12√2 for calculating the distance between tone-holes.

Intonation/Perturbation



Enlarging the bore at a Pressure Node will raise the frequency of notes in the immediate vicinity.
e.g. Flare in the bell to sharpen low E_3, has less effect in the middle register, better to shorten the clarinet.

Contraction of the bore at a Pressure Antinode will increase springiness in the system (stiffness) and the frequency will rise. Enlarging at the antinode will decrease the springiness and lower the frequency. Enlarging the barrel or pulling it out too far will create a large gap between the barrel and top joint and this will cause the throat notes to flatten more than any others as they lie in the vicinity of the mode 1 antinode.

'A localised enlargement of the cross section of an air column lowers the natural frequency of any mode having a large pressure amplitude (small flow) at the position of the enlargement, and raises the natural frequency of any mode having a pressure node (large flow) at the position of the enlargement.'

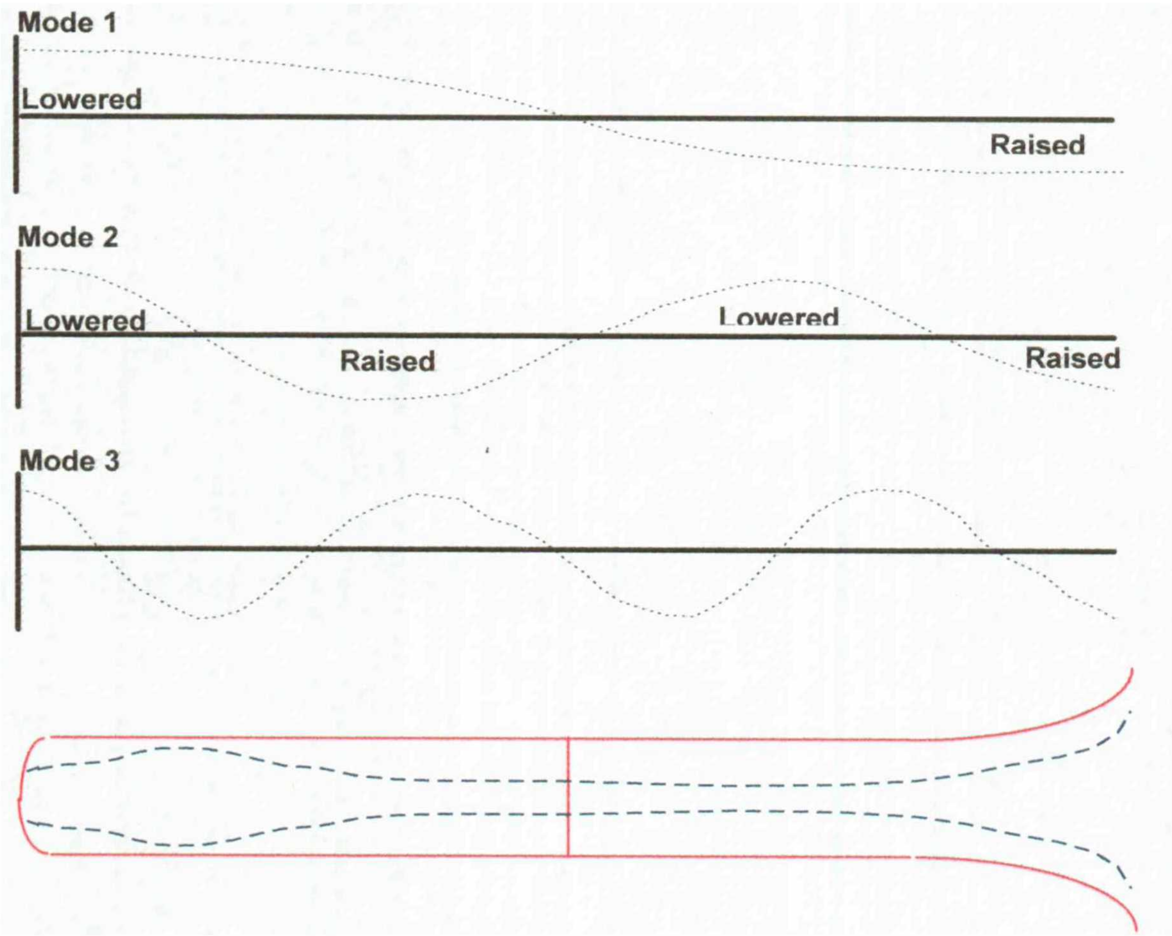
(From Benade, Fundamentals of Musical Acoustics, P.474)

1. In an air column, the frequency of any mode can be altered by perturbation, depending on where this occurs. Conical instruments are more sensitive to the effects of perturbation.

   Maximum frequency changes occur when the perturbation extends over a short segment located at the centre of an upward or downward hump of the perturbation curve e.g. the cavity produced when the barrel and top joint of a clarinet are separated too much, causing extreme flatness of the throat notes.
2. Gradual perturbation acts on lower modes more than higher ones.

Clarinet Bore

Change In Frequency By Enlarging The Bore



[From Benade, Fundamentals of Musical Acoustics, p.475]

The curves are not representations of wave shapes within the tube, but are derived from calculations using perturbation theory and are designed to show the effect of localised expansion or contraction of the bore. These curves are known as *Perturbation Weight Function Curves*. Any position along a dotted line situated above the axis line is a point along the tube where enlarging the bore lowers the mode frequency. Any position on the line that lies below the axis shows a point where the mode frequency will be raised.

The drawing below the set of curves shows a typical perturbation (not to scale) found in Boehm clarinets. The curve for mode 1 tells us that any enlargement in the bore to the left of centre (top half of the instrument) will lower the frequency of the low register i.e. flatten the clarinet. It also tells us that the higher up the tube towards the mouthpiece, the greater the effect. Enlargement around the middle of the instrument has little or no effect on the pitch, but increasing the bore size at points further down the tube will raise the playing frequency by increasing amounts, the closer the enlargement gets to the bell. From this we can see that a large bore mouthpiece will flatten a clarinet in all three registers but that a bigger bore barrel will flatten the lower, sharpen the middle but have little effect on the upper register. The significance, in so far as the bell is concerned, is that enlargement in this region raises the pitch of the low register by a considerable amount while sharpening the middle register by only a little, with the upper register virtually unchanged. This explains how a clarinet can be made with such a large but necessary cone or flare that begins roughly half way down the lower joint and extends into the bell. It is also possible to deduce that the effect of a narrowing of the bore at the top end of the mouthpiece will help to keep the pitch of a clarinet higher whilst maintaining or lowering the intonation in the upper register.

Transients,

Onset/Attack Transient

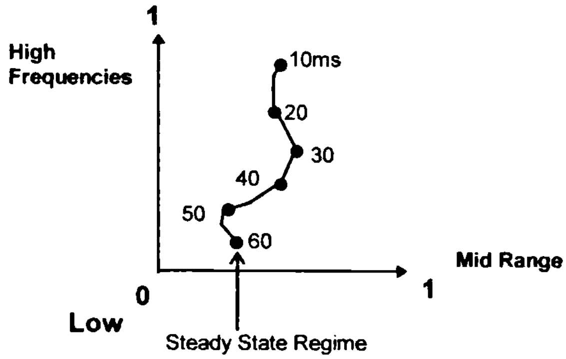
This is the crucially important beginning of the note that is the biggest factor in making one instrument discernible from another. Also known as the attack transient, it is the build up to full amplitude over the course of several periods of the vibration cycle.

1 Period (T) = 1/f

e.g. For the note G_4 f = 392Hz, therefore, T = 1/392 = 2.55ms (milliseconds)

Wind instruments are said to take approximately 6 periods to reach full amplitude i.e. 15ms. My own measurements of many attack transients of excellent clarinet players shows this to be optimistically short. I found it more common for the attack speed in the low register to be more in the region of 100ms or longer. The transient is usually quicker in the middle and upper registers, where 50 or 60ms is common. The amplitude of the vibrations grows from the onset of the note, and this is accompanied by a change in the spectrum. As the sound comes to life there is an evolution in the harmonic components or spectrum of the note. Not all of these components grow at the same rate, and it is this difference that forms the basis for the 'footprint' of the instrument, and often the player.

The important features of the spectral variation during the transient can be summarised and recorded in a special diagram called a **Tristimulus Graph**. A point or cross on an x-y graph represents the relative strengths of the wave components at specific time intervals along the transient, in other words, the ratio of fundamental, mid range and high frequency.



Tristimulus Graph

Shows the preponderance of high frequency components at the start of the note, the mid range increasing in strength, with the fundamental finally becoming the most powerful ingredient once steady state has been reached.

IMPEDANCE

Impedance

Ratio of **Pressure** (potential energy per unit volume) to **Rate Of Volume Flow**

Similar in electrical terms to **Voltage** / **Amperage** = (potential energy per unit change) / Current (flow)

For Mouthpieces = **Pressure in Mouthpiece** / **Flow Through Reed Aperture**

Impedance Z

P = constant pressure of the lungs (or artificial embouchure)

p = pressure difference across the reed

∴ pressure in the mouthpiece = P— p

Flow resulting from the pressure difference through the reed aperture = **U**

$$\therefore \text{ Impedance } Z = \frac{(P - p)}{U}$$

Some Clarinet Acoustic Properties:

Full tone without distortion, break-up or chaos occurs at around mf/f (85-90dB @ 1m). This usually corresponds to air pressure @ 8-10 inches of water but this will vary from player to player and according to the strength of reed.

ppp tone [sotto voce] = fundamental frequency + small amplitude 3rd harmonic <u>only</u> .

fff tone occurs @ around 16-18 inches where upper harmonic components are becoming extremely chaotic. Air pressure can go on increasing to over 24inches, but this rarely makes the sound any louder, in fact there is sometimes a decrease in volume as the reed begins to close off at the tip.

Varying air pressure influences harmonic structure and tonal qualities.
Testing mouthpieces at mf for live playing, and 10inches of water with the artificial embouchure where tone has fully developed and before any distortion occurs would appear to be sensible.

Component Energy Distribution

Cut-off frequency:

Low register E_3-C_3	Little activity above 5k
Low register (remaining)	Little activity above 6k - ripples 8k-10k
Mid register	Most contained within 6k band
	Ripples 6k-8k, tiny ripples 12-14k
G_5 into High	Most > 12k, some >14k, ripples>20k

Benade describes clarinet cut-off frequency as being around 1400/1500Hz and maintains that, in a good instrument, this is consistent throughout the range. i.e. the tone hole diameter reduces towards the top with sizes that maintain consistent and even tone. This seems to overlook upper frequencies that are clearly in evidence. There is scope for more research here.

Formants

There appear to be approximately 6 formant shapes throughout the range of the clarinet, with some rogue notes.

1. Bell E_3 & F_3	Special shape, unlike all the others
2. G_3-B_3	Similar shape, Bb usually a text book example. C_3 & C#$_3$ out of character
3. Throat notes	E_4 good example covering this region but Bb usually out of character
4. B_4-F_5	F_5 good shape, C_4-D#$_4$ slightly different
5. G_5-C_5	A_5 or B_5 both good
6. C#$_5$ Up	C#$_5$ standard wave shape

For the purpose of speedy analysis (involving the construction of LTAHS and other types of graphing), reliable results can be obtained by spectral analysis of selected notes from the above list. It is usually better to omit the bell note from calculations.

Appendix E

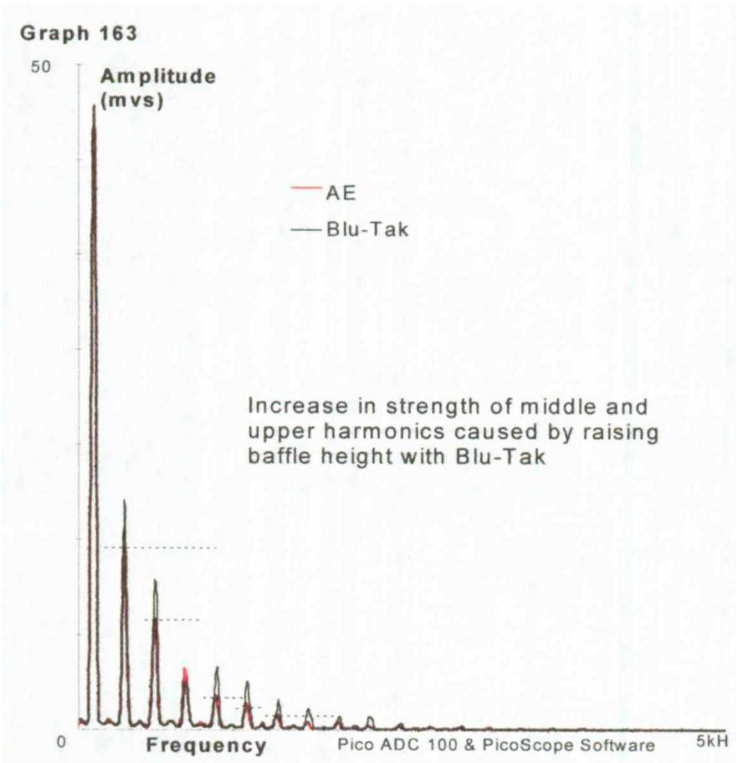
The Effect of Attaching Blu-Tak to the centre of the Baffle of a Clarinet Mouthpiece

The effect of sticking a small piece of Blu-Tak to the baffle of a clarinet mouthpiece was demonstrated at a seminar at the London Guildhall University in June 1996. There was unanimous agreement that the effect on the sound was dramatic. The mouthpiece used in the demonstration was a Louis c.1930. This mouthpiece had a fairly large, deep tone chamber and, pre-war, was considered to be a good choice for use in classical music because of its warm and mellow quality The gum-chewing jazz musicians of the time however, were after a louder and more piercing tone and they discovered that they could achieve this in both clarinet and saxophone mouthpieces by sticking some of their chewing gum onto the centre of the baffle.

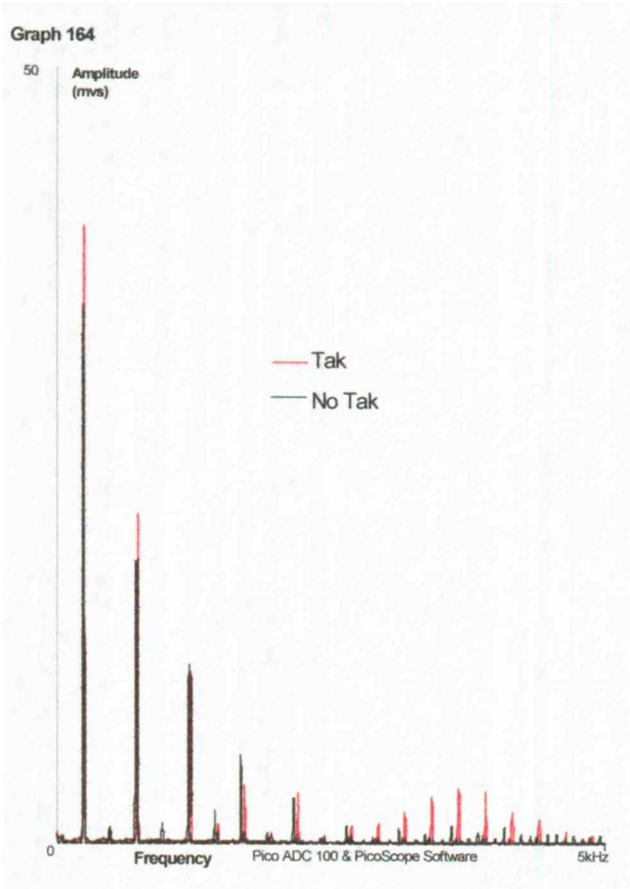
My demonstration showed that raising the central area of the Louis baffle by approximately 1.5mm caused a sharp rise in pitch of the fundamental, partials and harmonics. The tone was also transformed from mellow to bright, with a marked difference shown in the spectral graphs. From the unaltered state, the amplitude of the third harmonic increased by approximately 20%, the fifth harmonic decreased by a few per cent and the seventh increased by 5%. Also, there were two even harmonics present in the unaltered mouthpiece, the second at 5% and the fourth at 9%, which completely disappeared with the addition of Blu-Tak. This single alteration to the internal shape and dimensions had caused a significant change in the harmonic structure, certain components having been strengthened and others removed altogether, resulting in a spectrum that was less rich in harmonic colour.

Adding height to the baffle in this way can affect different mouthpiece and instrument combinations in various ways, but the result is invariably a brighter and sometimes more 'edgy' tone.

At a later date, the Blu-Tak experiment was repeated using the artificial embouchure to power the clarinet and the following spectral graph was obtained. Here, the addition of Blu-Tak to raise the baffle did not make the tone any less rich, nonetheless, with the exception of the 7th, all the middle and upper harmonics increased in amplitude.

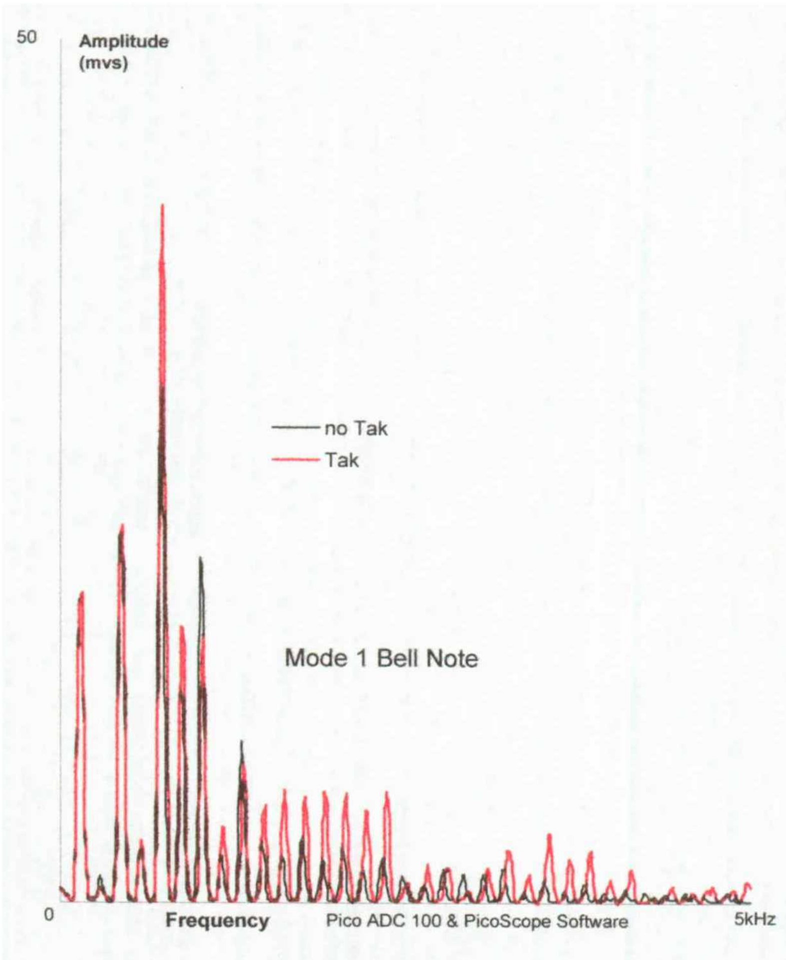


In the next example the mouthpiece incorporated a shallower baffle and the instrument was played live. Here the 3rd harmonic is stronger, but the most noticeable change is the broad sweep of increased amplitude in the upper harmonics.



Finally, the effect on a bell note using another modern style mouthpiece with a straight baffle, before the addition of Blu-Tak. Once again, raising the centre of the baffle has caused an increase in the 5th harmonic, but the increase in strength of all the middle and upper components is the most noticeable change.[9]

Graph 165



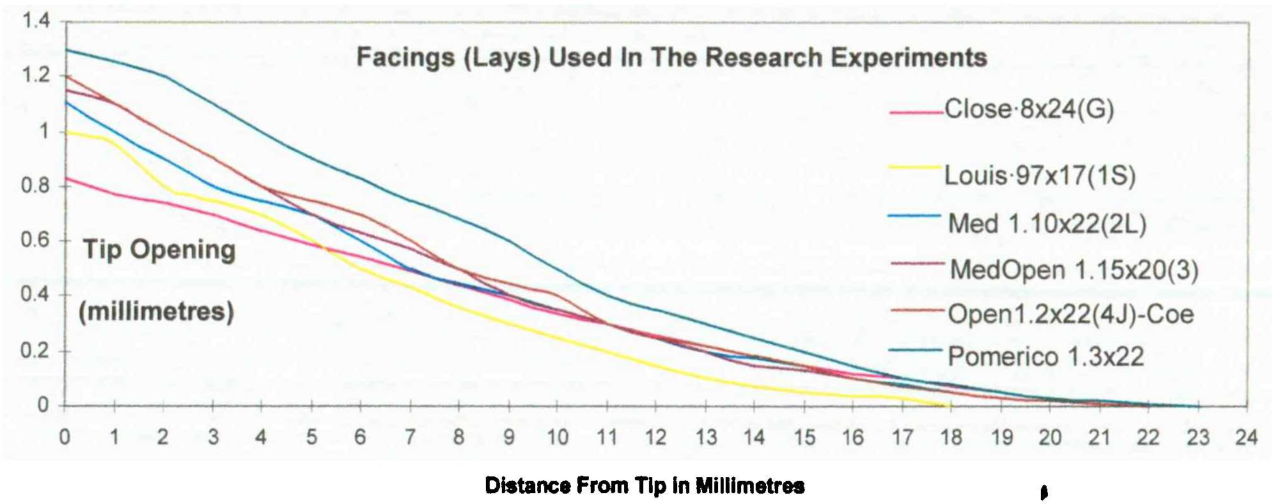
[9] More on the use of Blu-Tak in Chapter 8, p95-98

Appendix F
Mouthpiece Lay Data

Research Lays

Distance From Tip	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Close 0·8x24(G)	0.83	0.77	0.74	0.7	0.64	0.59	0.54	0.49	0.44	0.39	0.34	0.3	0.26	0.22	0.18	0.15	0.12	0.1	0.07	0.05	0.03	0.02	0.01	0
Louis 0·97x17(1S)	1	0.95	0.8	0.75	0.7	0.6	0.5	0.43	0.36	0.3	0.25	0.2	0.15	0.1	0.07	0.05	0.04	0.03	0.02	0.01	0			
Med 1.10x22(2L)	1.11	1	0.9	0.8	0.75	0.7	0.6	0.5	0.45	0.4	0.35	0.3	0.25	0.2	0.175	0.15	0.1	0.08	0.05	0.03	0.02	0.01	0	
Med open 1.15x20(3)	1.15	1.1	1	0.9	0.8	0.7	0.63	0.57	0.5	0.4	0.35	0.3	0.25	0.2	0.15	0.13	0.1	0.07	0.05	0.03	0.02	0.01	0	
Open 1.2x22(4J)-Coe	1.2	1.1	1	0.9	0.8	0.75	0.7	0.6	0.5	0.45	0.4	0.3	0.25	0.22	0.18	0.15	0.1	0.07	0.05	0.03	0.02	0.01	0	
Pomerico 1.3x22	1.3	1.25	1.2	1.1	1	0.9	0.83	0.75	0.68	0.6	0.5	0.4	0.35	0.3	0.25	0.2	0.15	0.1	0.08	0.05	0.03	0.02	0.01	0

Graph 166

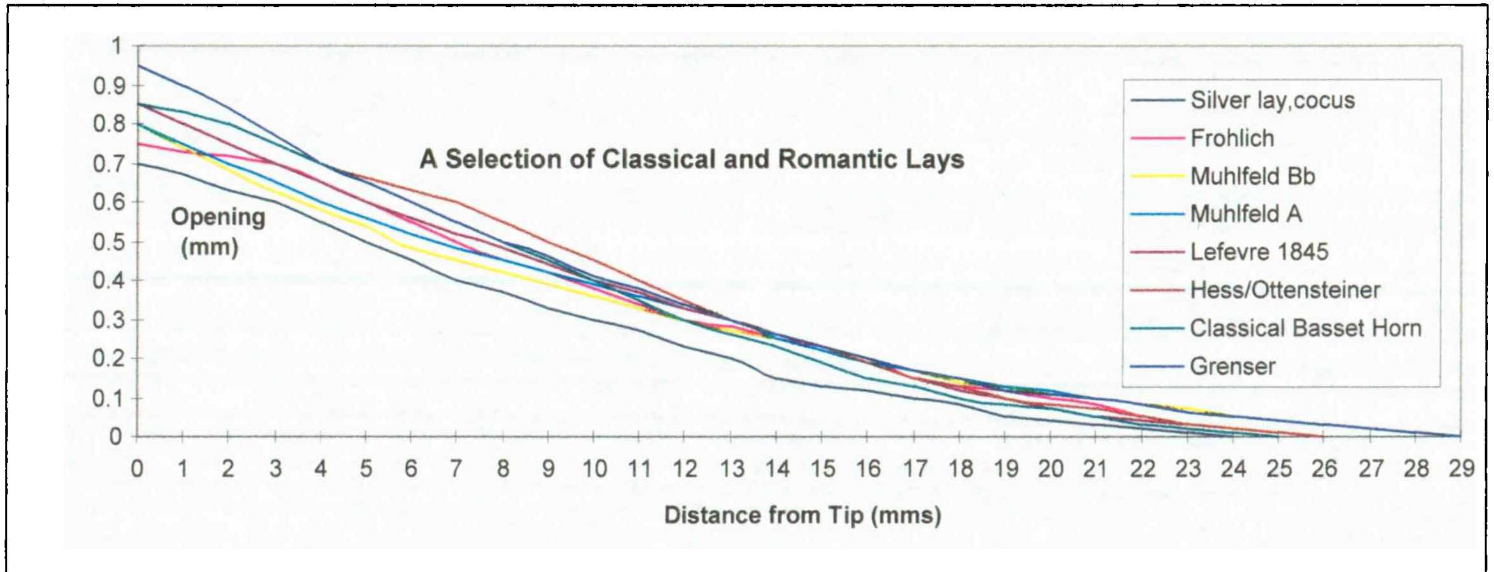


Historical Lays

Selection of typical facings

Distance From Tip	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Silver lay,cocus	0.7	0.67	0.63	0.6	0.55	0.5	0.45	0.4	0.37	0.33	0.3	0.27	0.23	0.2	0.15	0.13	0.12	0.1	0.08	0.05	0.04	0.03	0.02	0.01	0					
Fröhlich	0.75	0.73	0.72	0.7	0.65	0.6	0.55	0.5	0.45	0.42	0.38	0.34	0.3	0.28	0.25	0.23	0.2	0.15	0.13	0.12	0.1	0.08	0.05	0.03	0.02	0.01	0			
Mühlfeld Bb	0.8	0.74	0.68	0.63	0.58	0.54	0.48	0.45	0.42	0.39	0.36	0.33	0.3	0.27	0.25	0.22	0.19	0.17	0.14	0.13	0.11	0.1	0.08	0.07	0.05	0.04	0.03	0.02	0.01	0
Mühlfeld A	0.8	0.75	0.7	0.65	0.6	0.56	0.52	0.48	0.45	0.42	0.39	0.36	0.33	0.3	0.25	0.22	0.19	0.17	0.15	0.13	0.12	0.1	0.08	0.06	0.05	0.04	0.03	0.02	0.01	0
Lefèvre 1845	0.85	0.8	0.75	0.7	0.65	0.6	0.56	0.52	0.48	0.44	0.4	0.37	0.33	0.3	0.26	0.23	0.19	0.15	0.12	0.1	0.07	0.05	0.04	0.03	0.02	0.01	0			
Hess Ottensteiner	0.85	0.83	0.8	0.75	0.7	0.66	0.63	0.6	0.55	0.5	0.45	0.4	0.35	0.3	0.26	0.23	0.19	0.15	0.13	0.1	0.08	0.07	0.05	0.03	0.02	0.01	0			
Basset Horn	0.85	0.83	0.8	0.75	0.7	0.65	0.6	0.55	0.5	0.45	0.4	0.35	0.3	0.26	0.23	0.19	0.15	0.13	0.1	0.08	0.07	0.05	0.03	0.02	0.01	0				
Grenser	0.95	0.9	0.84	0.77	0.7	0.65	0.6	0.55	0.5	0.46	0.41	0.38	0.34	0.3	0.26	0.23	0.2	0.17	0.15	0.12	0.11	0.1	0.08	0.06	0.05	0.04	0.03	0.02	0.01	0

Graph 167

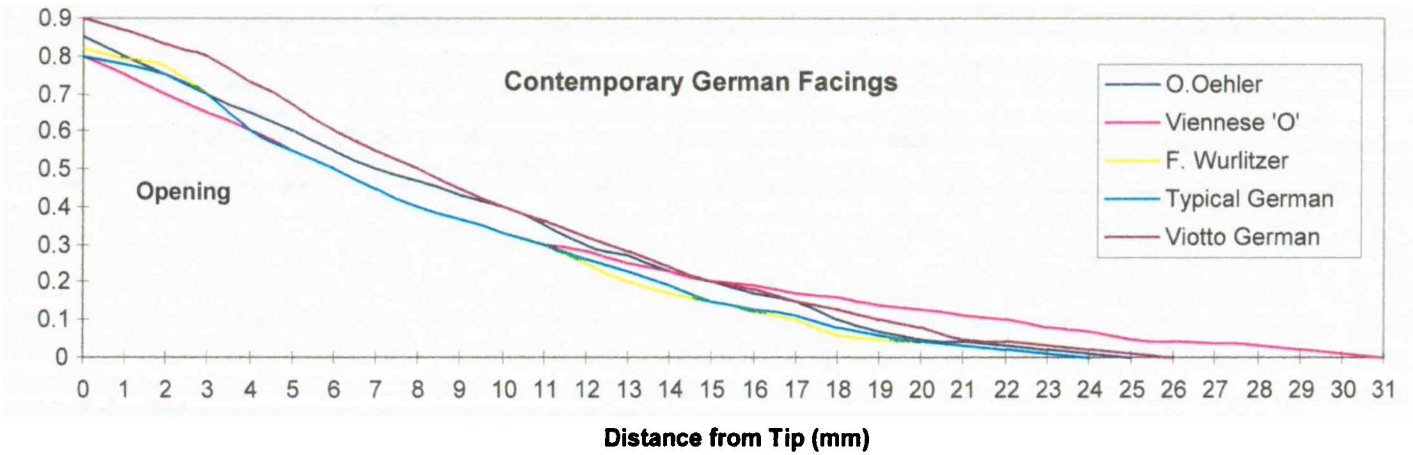


Contemporary German Lays

Typical facings including a Viennese style lay

Distance from tip	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
O.Oehler	0.85	0.8	0.75	0.7	0.65	0.6	0.55	0.5	0.47	0.43	0.4	0.35	0.3	0.27	0.23	0.2	0.17	0.15	0.1	0.07	0.05	0.04	0.03	0.02	0.01	0						
Viennese 'O'	0.8	0.75	0.7	0.65	0.6	0.55	0.5	0.45	0.4	0.37	0.33	0.3	0.28	0.25	0.23	0.2	0.19	0.17	0.16	0.14	0.13	0.11	0.1	0.08	0.07	0.05	0.04	0.037	0.03	0.02	0.01	0
F. Wurlitzer	0.82	0.795	0.77	0.7	0.6	0.55	0.5	0.45	0.4	0.37	0.33	0.3	0.25	0.2	0.17	0.15	0.12	0.1	0.06	0.05	0.04	0.03	0.02	0.01	0							
Typical German	0.8	0.78	0.75	0.7	0.6	0.55	0.5	0.45	0.4	0.37	0.33	0.3	0.26	0.23	0.19	0.15	0.13	0.11	0.08	0.06	0.04	0.03	0.02	0.01	0							
Viotto German	0.9	0.87	0.83	0.8	0.73	0.67	0.6	0.55	0.5	0.45	0.4	0.36	0.32	0.28	0.24	0.2	0.18	0.15	0.13	0.1	0.08	0.05	0.04	0.03	0.02	0.01	0					

Graph 168

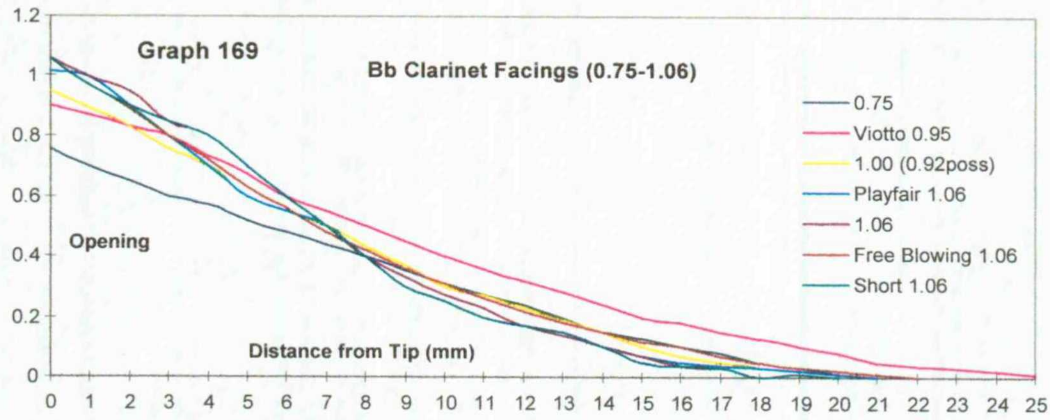


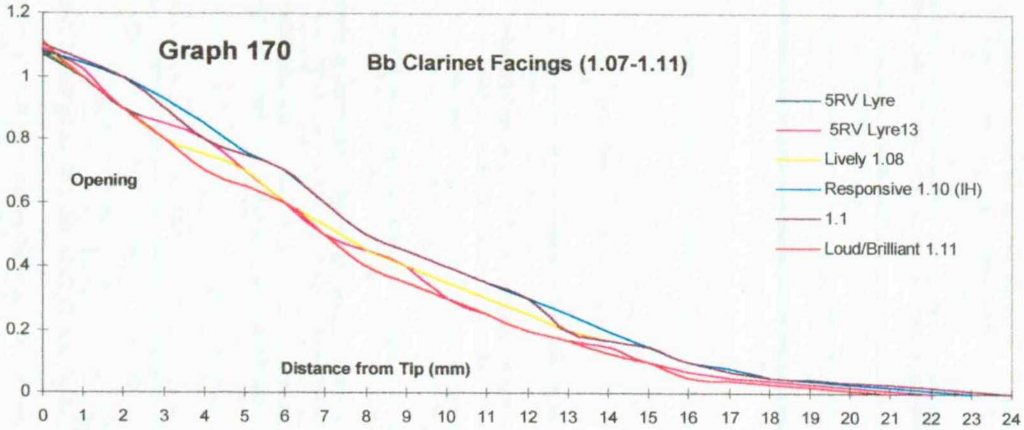
Contemporary Bb Boehm Mouthpiece Lays

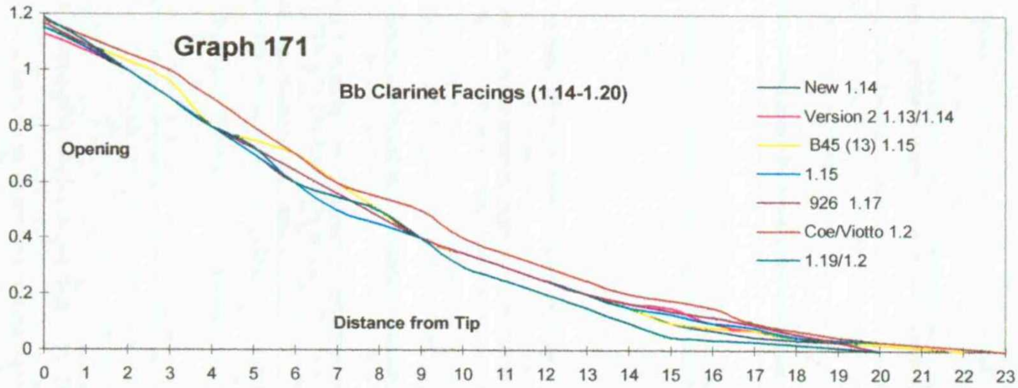
A range of contemporary facings in common use that allow good playing properties

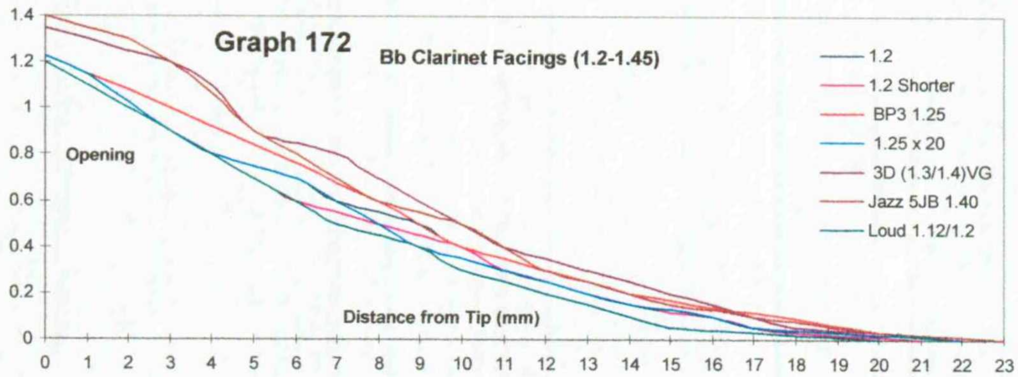
These lay profiles proved to be the most commonly chosen by players, and were selected from a very large database of facings.

Distance From Tip	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
0.75	0.76	0.7	0.65	0.6	0.57	0.52	0.48	0.44	0.4	0.35	0.31	0.27	0.24	0.2	0.15	0.13	0.1	0.08	0.05	0.03	0.01	0			
Viotto 0.95	0.9	0.87	0.83	0.8	0.73	0.67	0.6	0.55	0.5	0.45	0.4	0.36	0.32	0.28	0.24	0.2	0.18	0.15	0.13	0.1	0.08	0.05	0.04	0.03	0.02
1.00 (0.92poss)	0.95	0.89	0.83	0.76	0.7	0.6	0.55	0.5	0.43	0.37	0.3	0.27	0.23	0.19	0.15	0.1	0.07	0.05	0.03	0.02	0.01	0			
Playfair 1.06	1.02	1	0.9	0.8	0.7	0.6	0.55	0.5	0.4	0.3	0.25	0.2	0.17	0.15	0.1	0.07	0.05	0.04	0.03	0.02	0.01	0			
1.06	1.06	1	0.95	0.85	0.8	0.7	0.6	0.5	0.4	0.33	0.27	0.23	0.17	0.14	0.1	0.07	0.04	0.03	0.02	0.02	0				
Free Blowing 1.06	1.06	0.97	0.89	0.8	0.72	0.63	0.56	0.48	0.42	0.36	0.31	0.26	0.22	0.18	0.15	0.12	0.1	0.07	0.05	0.03	0.02	0.01	0		
Short 1.06	1.06	0.97	0.9	0.85	0.8	0.7	0.6	0.5	0.4	0.3	0.25	0.2	0.17	0.15	0.1	0.05	0.04	0.03	0.02	0.02	0				
5RV Lyre	1.07	1	0.9	0.85	0.8	0.7	0.6	0.5	0.45	0.4	0.3	0.25	0.2	0.17	0.13	0.1	0.07	0.05	0.04	0.03	0.02	0.02	0		
5RV Lyre13	1.09	1.02	0.9	0.85	0.8	0.7	0.6	0.5	0.45	0.4	0.3	0.25	0.2	0.17	0.15	0.1	0.07	0.05	0.04	0.03	0.02	0.01	0		
Lively 1.08	1.08	1	0.9	0.8	0.75	0.7	0.6	0.5	0.45	0.4	0.35	0.3	0.25	0.2	0.17	0.15	0.1	0.07	0.05	0.04	0.03	0.02	0.01	0	
Responsive 1.10 (IH)	1.08	1.04	1	0.93	0.85	0.76	0.7	0.6	0.5	0.45	0.4	0.35	0.3	0.25	0.2	0.15	0.1	0.08	0.05	0.04	0.03	0.02	0.01	0	
1.1	1.1	1.05	1	0.9	0.8	0.75	0.7	0.6	0.5	0.45	0.4	0.35	0.3	0.2	0.17	0.15	0.1	0.07	0.05	0.043	0.036	0.03	0.02	0.02	0
Loud/Brilliant 1.11	1.11	1	0.9	0.8	0.7	0.65	0.6	0.5	0.4	0.35	0.3	0.25	0.2	0.17	0.13	0.1	0.05	0.04	0.03	0.02	0.01	0			
New EP 1.14 vg	1.13	1.07	1	0.9	0.8	0.7	0.6	0.55	0.5	0.4	0.35	0.3	0.25	0.2	0.15	0.1	0.07	0.05	0.04	0.03	0.02	0.01	0		
Version 2 1.13/1.14	1.13	1.07	1	0.9	0.8	0.7	0.6	0.55	0.5	0.4	0.35	0.3	0.25	0.2	0.17	0.15	0.1	0.07	0.05	0.04	0.03	0.02	0.01	0	
B45 (13) 1.15	1.15	1.09	1.03	0.96	0.8	0.75	0.7	0.6	0.5	0.4	0.35	0.3	0.25	0.2	0.15	0.1	0.08	0.07	0.05	0.03	0.02	0.01	0		
1.15	1.15	1.08	1	0.9	0.8	0.7	0.6	0.5	0.45	0.4	0.35	0.3	0.25	0.2	0.15	0.125	0.1	0.075	0.05	0.04	0.03	0.02	0.01	0	
926 1.17	1.17	1.09	1	0.9	0.8	0.72	0.64	0.56	0.48	0.4	0.35	0.3	0.25	0.2	0.17	0.14	0.12	0.09	0.06	0.03	0				
Coe/Viotto 1.2	1.18	1.12	1.06	1	0.9	0.8	0.7	0.6	0.55	0.5	0.4	0.35	0.3	0.25	0.2	0.175	0.15	0.1	0.07	0.05	0.03		0.02	0.01	0
Sop Sax 1.19/1.2	1.19	1.1	1	0.9	0.8	0.73	0.6	0.55	0.5	0.4	0.3	0.25	0.2	0.15	0.1	0.05	0.04	0.03	0.02	0.01	0				
1.2	1.2	1.1	1	0.9	0.8	0.75	0.7	0.6	0.55	0.5	0.4	0.35	0.3	0.25	0.2	0.15	0.13	0.1	0.08	0.05	0.03	0.02	0.01	0	
1.2 Shorter	1.2	1.1	1	0.9	0.8	0.7	0.6	0.55	0.5	0.45	0.4	0.3	0.25	0.2	0.15	0.12	0.1	0.05	0.03	0.02	0.01	0			
BP3 1.25	1.23	1.15	1.08	1	0.92	0.84	0.76	0.68	0.6	0.5	0.4	0.35	0.3	0.25	0.2	0.17	0.14	0.12	0.09	0.06	0.03	0.02	0.01	0	
1.25 x 20	1.23	1.15	1.03	0.9	0.8	0.75	0.7	0.6	0.5	0.4	0.35	0.3	0.25	0.2	0.15	0.13	0.1	0.05	0.04	0.03	0.02	0.01	0		
3D (1.3/1.4)VG	1.35	1.3	1.25	1.2	1.1	0.9	0.85	0.8	0.7	0.6	0.5	0.4	0.35	0.3	0.25	0.2	0.15	0.1	0.05	0.4	0.03	0.02	0.01	0	
Jazz 5JB 1.40	1.4	1.35	1.3	1.2	1.07	0.9	0.8	0.7	0.6	0.55	0.5	0.4	0.3	0.25	0.2	0.15	0.125	0.1	0.08	0.05	0.03	0.02	0.01	0	
Loud 1.12/1.2	1.2	1.1	1	0.9	0.8	0.7	0.6	0.5	0.45	0.4	0.3	0.25	0.2	0.15	0.1	0.05	0.04	0.03	0.02	0.01	0				


Graph 169
Bb Clarinet Facings (0.75-1.06)
0.75
Viotto 0.95
1.00 (0.92poss)
Playfair 1.06
1.06
Free Blowing 1.06
Short 1.06
Opening
Distance from Tip (mm)


Graph 170
Bb Clarinet Facings (1.07-1.11)
5RV Lyre
5RV Lyre13
Lively 1.08
Responsive 1.10 (IH)
1.1
Loud/Brilliant 1.11
Opening
Distance from Tip (mm)

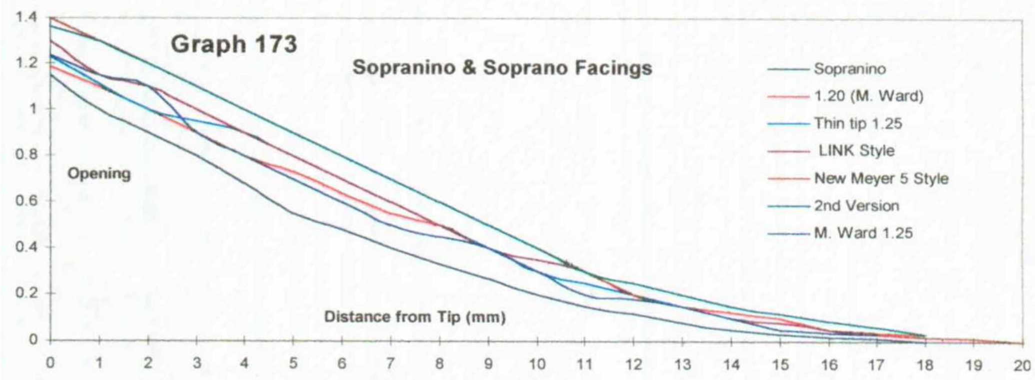

Graph 171
Bb Clarinet Facings (1.14-1.20)
New 1.14
Version 2 1.13/1.14
B45 (13) 1.15
1.15
926 1.17
Coe/Viotto 1.2
1.19/1.2
Opening
Distance from Tip

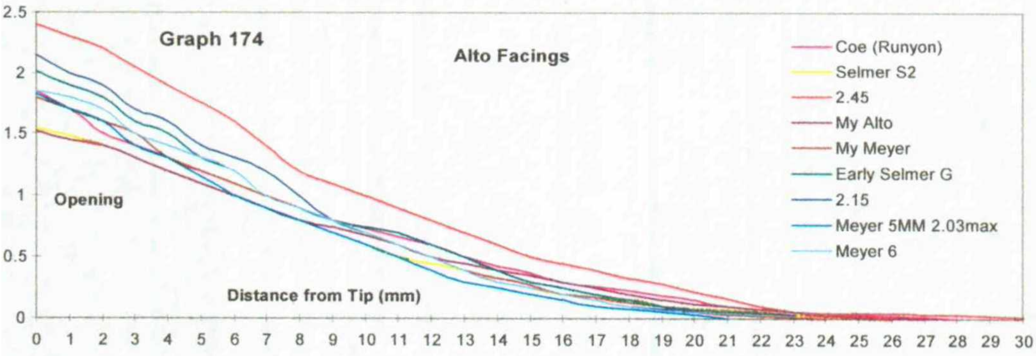

Graph 172
Bb Clarinet Facings (1.2-1.45)
1.2
1.2 Shorter
BP3 1.25
1.25 x 20
3D (1.3/1.4)VG
Jazz 5JB 1.40
Loud 1.12/1.2
Opening
Distance from Tip (mm)

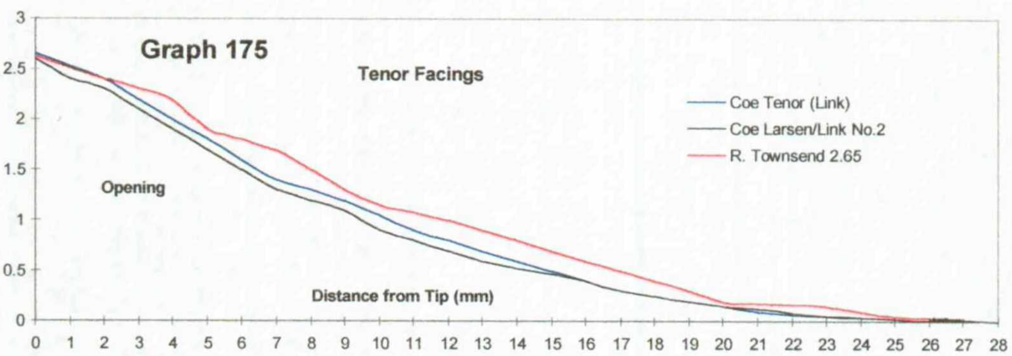
Saxophone Lays

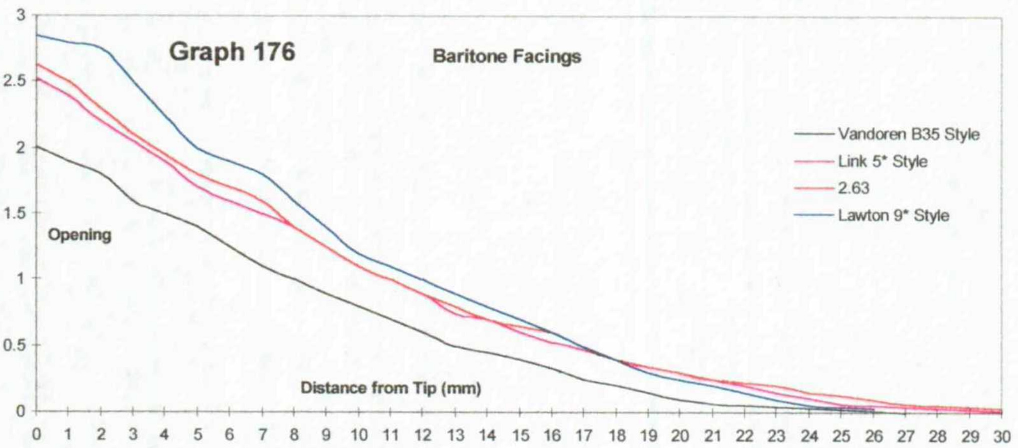
Facings selected from a large database that can facilitate good tone and response and dynamic range

Distance from Tip	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Sopranino	1.15	1	0.9	0.8	0.68	0.55	0.48	0.4	0.33	0.27	0.2	0.15	0.12	0.08	0.05	0.03	0.02	0.01	0												
SOPRANO																															
1.20 (M. Ward)	1.19	1.1	1	0.9	0.8	0.73	0.6	0.64	0.5	0.4	0.3	0.25	0.2	0.15	0.125	0.1	0.05	0.04	0.03												
Thin tip 1.25	1.23	1.115	1	0.95	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.25	0.2	0.15	0.1	0.08	0.05	0.03													
LINK Style	1.3	1.15	1.1	1	0.9	0.8	0.7	0.6	0.5	0.4	0.35	0.3	0.2	0.15	0.1	0.08	0.05	0.03	0.02	0.01	0										
New Meyer 5 Style	1.4	1.3	1.2	1.1	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.15	0.1	0.05	0.04	0.03	0.02	0.01	0										
2nd Version	1.36	1.3	1.2	1.1	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.25	0.2	0.15	0.12	0.09	0.06	0.03												
M. Ward 1.25	1.24	1.15	1.1	0.9	0.8	0.7	0.6	0.5	0.45	0.4	0.3	0.2	0.18	0.15	0.1	0.05	0.04	0.03													
ALTO																															
Coe (Runyon)	1.85	1.7	1.5	1.4	1.3	1.2	1.1	1	0.9	0.8	0.73	0.67	0.6	0.5	0.43	0.37	0.3	0.26	0.23	0.19	0.15	0.1	0.08	0.05	0.04	0.03	0.02	0.01	0		
Selmer S2	1.55	1.48	1.4	1.3	1.2	1.1	1	0.9	0.8	0.7	0.6	0.5	0.45	0.4	0.3	0.25	0.2	0.18	0.15	0.1	0.08	0.07	0.05	0.03	0.02	0.01	0				
2.45	2.4	2.3	2.2	2.05	1.9	1.75	1.6	1.4	1.2	1.1	1	0.9	0.8	0.7	0.6	0.5	0.45	0.4	0.33	0.28	0.22	0.16	0.1	0.05	0.047	0.045	0.04	0.035	0.03	0.02	0.01
My Alto	1.52	1.45	1.4	1.3	1.2	1.1	1	0.9	0.8	0.75	0.68	0.6	0.5	0.45	0.4	0.35	0.3	0.25	0.2	0.15	0.126	0.1	0.08	0.05	0.03	0.02	0.01	0			
My Meyer	1.8	1.7	1.6	1.5	1.3	1.2	1.1	1	0.9	0.8	0.7	0.6	0.5	0.4	0.33	0.27	0.2	0.17	0.13	0.1	0.05	0.03	0.02	0.01	0						
Early Selmer G	2.02	1.9	1.8	1.6	1.5	1.3	1.2	1	0.9	0.8	0.75	0.7	0.6	0.5	0.4	0.3	0.25	0.2	0.15	0.1	0.07	0.05	0.04	0.03							
2.15	2.15	2	1.9	1.7	1.6	1.4	1.3	1.2	1	0.8	0.7	0.6	0.5	0.4	0.3	0.25	0.2	0.15	0.1	0.08	0.07	0.05	0.04	0.03							
Meyer 5MM 2.03max	1.83	1.7	1.6	1.4	1.3	1.15	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.25	0.2	0.15	0.1	0.075	0.05	0.03	0									
Meyer 6	1.85	1.8	1.7	1.5	1.4	1.3	1.2	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.25	0.2	0.15	0.1	0.07	0.05	0.04	0.03								
TENOR																															
Coe Tenor (Link)	2.65	2.53	2.4	2.2	2	1.8	1.6	1.4	1.3	1.2	1.05	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.25	0.2	0.15	0.1	0.07	0.05	0.04	0.03	0.02	0.01	0		
Coe Larsen/Link No.2	2.6	2.4	2.3	2.1	1.9	1.7	1.5	1.3	1.2	1.1	0.9	0.8	0.7	0.6	0.53	0.47	0.4	0.3	0.25	0.2	0.15	0.12	0.08	0.05	0.04	0.03	0.02	0.01	0		
R. Townsend 2.65	2.63	2.52	2.4	2.3	2.2	1.9	1.8	1.7	1.5	1.3	1.15	1.08	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.18	0.17	0.15	0.1	0.05	0.04	0.03			
BARITONE																															
Vandoren B35 Style	2.01	1.9	1.8	1.6	1.5	1.4	1.25	1.1	1	0.9	0.8	0.7	0.6	0.5	0.45	0.4	0.33	0.25	0.2	0.15	0.1	0.07	0.05	0.04	0.03	0.02	0.01	0			
Link 5* Style	2.53	2.4	2.2	2.05	1.9	1.7	1.6	1.5	1.4	1.25	1.1	1	0.9	0.75	0.7	0.6	0.53	0.47	0.4	0.35	0.3	0.25	0.2	0.15	0.11	0.07	0.05	0.04	0.03	0.02	0.01
2.63	2.63	2.5	2.3	2.1	1.95	1.8	1.7	1.6	1.4	1.25	1.1	1	0.9	0.8	0.7	0.65	0.6	0.5	0.4	0.35	0.3	0.25	0.23	0.2	0.15	0.125	0.1	0.07	0.05	0.04	0.03
Lawton 9* Style	2.85	2.8	2.75	2.5	2.25	2	1.9	1.8	1.6	1.4	1.2	1.1	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.25	0.2	0.15	0.1	0.05	0.04	0.03				


Graph 173
Sopranino & Soprano Facings
Sopranino
1.20 (M. Ward)
Thin tip 1.25
LINK Style
New Meyer 5 Style
2nd Version
M. Ward 1.25
Opening
Distance from Tip (mm)


Graph 174
Alto Facings
Coe (Runyon)
Selmer S2
2.45
My Alto
My Meyer
Early Selmer G
2.15
Meyer 5MM 2.03max
Meyer 6
Opening
Distance from Tip (mm)


Graph 175
Tenor Facings
Coe Tenor (Link)
Coe Larsen/Link No.2
R. Townsend 2.65
Opening
Distance from Tip (mm)


Graph 176
Baritone Facings
Vandoren B35 Style
Link 5* Style
2.63
Lawton 9* Style
Opening
Distance from Tip (mm)

Bibliography

Angster, 1997. J.Angster,G.Paál, W.Garen & A.Miklós. Effect of Voicing Steps on the Stationary Spectrum & Attack Transient of a Flue Organ Pipe. International Symposium on Musical Acoustics (ISMA) Vol. 19:Part 5 p.285.

Backus, J. 1961. Vibrations of the Reed and the Air Column in the Clarinet. Journal of the Acoustical Society of America (J.A.S.A.) 33 (6).

Backus, J. 1964. Effect Of Wall Material on the Steady-State Tone Quality of Woodwind Instruments. J.A.S.A. Vol.36, No.10, Oct.1964.

Backus, J.1968. Resonance Frequencies of the Clarinet. J.A.S.A. 43.

Backus, J. 1977. The Acoustical Foundation of Music. W.W.Norton.

Backus, J. 1985. The Effect of the Player's Vocal Tract on Woodwind Instrument Tone. J.A.S.A. 78.

Bak, N. & P. Domler, 1987. The Relationship between Blowing Pressure & Blowing Frequency in Clarinet Playing. Acustica Vol.63.

Barlow, Claire Y. Materials Selection for Musical Instruments. Cambridge University Engineering Department, Mill Lane, Camb.CB2 1RX.

Benade, A.H. 1966. Relation of Air-Column Resonances to sound Spectra Produced by Wind Instruments. JASA Vol.40 (1).

Benade , A.H. & S.N. Kouzoupis, 1988. The Clarinet Spectrum: Theory & Experiment JASA 83 (1), Jan. 1988.

Benade , A.H.& P.L. Hoekje,1982. Vocal Tract Effects In Wind Instrument Regeneration. JASA 71:8916.

Benade, A. H. 1976 Fundamentals of Musical Acoustics Dover.

Benade,1985. Benade, A.H. & C.O. Larson. Requirements & techniques for measuring the musical spectrum of the clarinet J.A.S.A. 78(5), Nov. 1985.

Benade, A.H. 1970. On The Tone Color Of Wind Instruments. Selmer Bandwagon,59, pp.17-21.

Benade, A.H. 1971- Rough notes & drawings May.1971. Clarinet Mouthpiece Notes, Virginia Benade.

Benade, A.H. 1974 - Rough notes & drawings Dec.1974. School Of Music Seminar No.10 on Wind Instruments. Virginia Benade.

Benade, A.H. 1976 - Rough notes & drawings Oct.1976. A Clarinet Mouthpiece Problem Or Two. Virginia Benade.

Benade, A.H. 1978 - Rough notes & drawings Aug.1978. Clarinet Mouthpiece Work Virginia Benade.

Benade , A.H.1979- Rough notes & drawings Jan.1979. Clarinet Mouthpiece Notes Virginia Benade.

Benade, A.H. 1979 - Rough notes & drawings Aug.1979. Clarinet Mouthpiece Notes Virginia Benade.

Benade, A.H. 1980 - Rough notes & drawings Oct.1980. Soprano Sax Mouthpiece Virginia Benade.

Benade, A.H. 1994 Woodwinds: The Evolutionary Path Since 1700. Galpin Society Journal 47,63-110, 1994.

Benade, A.H.- 1983 - Rough notes & drawings Jan.1983. Clarinet Mouthpiece Notes. Virginia Benade.

Bishop, E.T. & S. Davison. 1969. Network Characteristics of the Thermoplastic Elastomers. Shell Development Co. Emeryville, California 94608.

Brown, Edgar,1997. An Experimental Bassoon. ISMA Vol. 19:Part 5(1997) p.279.

Bruijn de, A. 1978. Timbre-Classification of Complex Tones (The Relation between Subjective & Physical Parameters). Acustica Vol.40

Bulen, J.C. 'Brightness' Measures of Trombone Timbre. University of Washington, Seattle, Thesis.

Campbell,1987. Murray Campbell & Clive Greated. 1987. The Musician's Guide to Acoustics. J M Dent & Sons.

Clinch et al.1982. P.G.Clinch, G.J. Troup & L.Harris. 1982 The Importance of Vocal Tract Resonance in Clarinet and Saxophone Performance. Acustica Vol.50.

Coltman, John W.1973. Mouth Resonance Effects In The Flute. JASA Vol. 54 No.2.

Cowie, J.M.G. 1973 Polymers:Chemistry & Physics Of Modern Materials. International Textbook Co. Ltd..

Dalmont, J.P. , B. Gazengel, J. Gilbert & J. Kergomard. 1995. Some Aspects of Tuning & Clean Intonation in Reed Instruments. Applied Acoustics 46.

Dalmont, Jean-Pierre & Kees Nederveen. 1997. Why is a Saxophone Louder than a Clarinet. ISMA Vol. 19:Part 5 p.267

Farrell, K.L. D.M.A. 1988. An Analysis of the General Playing Characteristics of Six Commonly Used Alto Sax Mouthpieces. Univ. of Georgia, 1988 (Dissertation)

Fletcher, N.H. 1979. Excitation Mechanisms in Woodwind and Brass Instruments, Acustica, 43(1)

Fletcher, Neville H. & Thomas D. Rossing. 1991. The Physics of Musical Instruments. Springer-Verlag New York.

Fuks, Leonardo & Johan Sundberg. 1997. Blowing Pressures in Reed Woodwinds ISMA Vol. 19:Part 5(1997) p.273.

Fuks, Leonardo. 1997. Prediction & Measurements of Exhaled Air Effects in the Pitch of Wind Instruments. ISMA Vol.19:Part 5(1997) p.373

Ghosh, R.N.1938. Theory of the Clarinet. J.A.S.A. vol. 9, Jan. 1938

Gibson, O, Lee. 1994. Clarinet Acoustics. Indiana University Press. ISBN 0-253-32576-5.

Hall, Donald E. 1980 & 1991. Musical Acoustics (Chapter 12) Blown Pipes & Flutes Brookes/Cole Publishing Co. Pacific Grove, California, 1st ed.1980, 2nd 1991

H.J.Dane, S.G. Kruijswijk, A.J.M. Houtsma. 1990. A Quasi-stationary Model of Air Flow in the Reed Channel of Single-reed Woodwind Instruments. Acustica Vol. 70.

Idogawa, Tohru , Michiko Shimizu & Masakazu Iwaki. 1991. Acoustical Behaviors Of An Oboe & A Soprano Sax Artificially Blown. Theory of Dynamical Systems in Applied Science, Vol. 10.

Kaye and Labey. 1959. Materials - Velocity Of Sound. Longman,Green & Co.

Keefe, Douglas H. 1992. Physical Modelling of Wind Instruments. University Of Washington Music Journal, Vol.16, No.4.

Kroll, Oskar. 1968. The Clarinet. B.T.Batsford Ltd. London.

Krüger, 1997. Krüger, Walther. On The Dimensions Of The Clarinet Mouthpiece & Barrel Rohrblatt, Schorndorf, 12 (1997) Book 1

Martin, John. 1994. The Acoustics Of The Recorder. Ed.Moeck Nr. 4054, Moeck Verlag Celle.

Nederveen, C.J. 1997. Length Corrections for Woodwind Tone Holes. ISMA Vol.19:Part 5 (1997) p.461

Nederveen, Cornelis J. 1998. Acoustical Aspects of Woodwind Instruments, Revised Edition, Northern Illinois University Press, DeKalb, Illinois 60115.

Polczynski, Mark. 1997. Selecting Plastics For Woodwinds, Woodwind Quarterly No.14, 1997.

Rendall, F. Geoffrey. 1971. The Clarinet. W.W. Norton.

Scavone, Gary P. 1997. An Acoustical Analysis of Single Reed Woodwind Instruments With the Emphasis On Design & Performance Issues & Digital Waveguide Modelling Techniques. Stamford University (Dissertation)

Schumacher, R.T. 1978. Self-Sustained Oscillations of the Clarinet: An Integral Equation Approach. Acustica, vol.40, 1978.

Sharp, David B., Arnold Myers, & Murray Campbell 1997. Using Pulse Reflectometry to Compare the Evolution of the Cornet & the Trumpet in the 19th & 20th Centuries. ISMA Vol. 19:Part 5(1997) p.541

Smith, J.R. Nathalie Henrich & Joe Wolfe. 1997. The Acoustic Impedence of the Boehm Flute. ISMA Vol. 19:Part 5(1997) p.315

Smith, R.A. & D.M.A. Mercer. 1974. Possible Causes of Woodwind Tone Colour, Journal Of Sound & Vibration(1974) 32(3),347-358

Smith, R.A. & Daniell, G. J. 1976. Systematic Approach to the Correction of Intonation in Wind Instruments. Nature, Vol. 262, Aug.1976

Stewart, Stephen E. & William J. Strong. 1980. Functional Model of a Simplified Clarinet. JASA, 68(1), July, 1980

Thompson, Stephen C. 1979. The Effect of the Reed Resonance on Woodwind Tone Production. J.A.S.A. 66(5), Nov. 1979

Walstijn van, Maarten O., John S. Cullen & Murray Campbell. 1997. Modelling Viscothermal Wave Propagation in Wind Instrument Air Columns. ISMA Vol. 19:Part 5 (1997) p.413

Wehner, Walter Leroy. 1961. The Effect Of Interior Shape & Size of Clarinet Mouthpieces on Intonation & Tone Quality. University of Kansas, Ed.D..

Whelan, A. 1982. Injection Moulding Materials. Applied Science Publishers Ltd.

Wilson, Teresa D. & Douglas H. Keefe. 1998. Characterizing the Clarinet Tone: Measurements of Lyapunov Exponents, Correlation Dimension, and Unsteadiness JASA 104(1) July 1998

Wilson, Theodore A. & Gordon S. Beavers. 1974. Operating Modes of the Clarinet JASA Vol. 56 (2) Aug. 1974

Worman, Walter Elliot. 1971. Self-sustained Non-linear Oscillations of Medium Amplitude in Clarinet-like Systems. Case Western Reserve Univ. Cleveland, Ohio (Dissertation).