The Baroque Bassoon: form, construction, acoustics, and playing qualities

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Chapter 4

Acoustics of the baroque bassoon

The acoustics of wind instruments have been thoroughly dealt with in textbooks such as Campbell and Greated (1987), Backus (1977), Benade (2nd edn 1990) and Nederveen (rev. edn 1998).[1]

The following is an informal, qualitative summary that, it is hoped, might be understood by the non-physicist musician. As such it is highly simplified and ignores many of the complicating factors that occur in real instruments. However it is hoped that it may help the non-acoustician reader to clarify some of the notions of sound production in a bassoon, and may aid the comprehension of the discussion of the Poerschman bassoon in the next chapter.

4.1 Air columns, reeds and resonance

In wind instruments the primary vibrator is the body of air within the instrument; thus the object that we call the instrument is simply the container for the vibrating part. The shape of most wind instruments is long and thin (the ocarina being an exception) so this body of air is called a column. The air column is set into motion by an excitatory mechanism, usually one of several forms of reed, and it vibrates at frequencies that are determined by its shape and dimensions. That is, the dimensions of the air column determine the pitch of the sounds produced. The air column is contained in the bore of the instrument, so the bore and air column dimensions are the same and these two terms are often interchanged. Toneholes connected to the bore add further complexities to the air column's form.

There are three elementary forms of air column that can be used to make workable woodwind instruments: cylindrical open at both ends, cylindrical closed at one end, and conical closed at the apex. An air reed mechanism such as occurs at the fipple of a recorder or the embouchure of a flute is acoustically an open end, while the single reed of a clarinet or saxophone, and the double reed of oboe and bassoon, acts acoustically as a

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[1] Murray Campbell and Clive Greated, *Musician's Guide to Acoustics* (London/Melbourne: J. M. Dent and Sons, 1987).
John Backus, *The Acoustical Foundations of Music* (New York: Norton, 1977).
Arthur H. Benade, *Fundamentals of Musical Acoustics*, 2nd rev. edn (New York: Dover, 1990).
Cornelis J. Nederveen, *Acoustical Aspects of Woodwind Instruments*, rev. edn (Illinois: Northern Illinois Press, 1998).

closed end. The acoustical form of the bassoon and oboe, therefore, is a conical bore, closed at the apex.

When the player blows through a double reed (considering here the reed unattached to the bassoon), the airflow between the blades lowers the air pressure there (this is the Bernoulli effect), so that the higher pressure outside the blades forces them to shut.[2] Once shut, the air flow is cut off so there is no longer a Bernoulli force to keep them closed, and the elasticity of the blade material causes them snap open, allowing air to flow between them again, and the cycle repeats itself. Thus the action of blowing through the reed causes it to open and shut, emitting pulses of alternating high and low air pressure. If these pulses are regular the result is a pitched note. The player can affect the way the reed vibrates through the pressure of air blown through, the pressure the lips apply to the blades and the position of the lips on the blades. So he or she can adjust the pitch of this note through a wide range of frequencies, or allow the reed to vibrate in a more chaotic way; producing a more noisy sound, as when *crowing* the reed.

When coupled to the instrument (considering first the full-length instrument, as if it had no toneholes), the pulses emitted by the reed will travel down the length of the air column as a wave of alternating air pressure – a sound wave – with the bore acting as a wave guide. When a pulse reaches the end of the instrument it encounters a severe change of impedance; for example, a high pressure pulse travelling down the bore is rapidly dissipated in the wider air surrounding the instrument's end, and this causes the pulse to be reflected back up the bore. However a reversal of phase also takes place; that high-pressure pulse is reflected back as a low-pressure pulse, and vice versa, so that the reflected wave is 180 degrees out of phase with the original wave.[3] The two waves of the same frequency but travelling in opposite directions add up to create a standing wave, where node points of zero pressure fluctuation exist in fixed positions along the bore, with regions of fluctuating pressure between them. There is always a pressure node at the open end because air is free to travel in and out of the instrument's end, so there is no fluctuation of air pressure there, but instead a maximal velocity fluctuation as the air flows in and out. In the case of a reed instrument there is always a pressure antinode at the reed

[2] Benade, *Fundamentals*, pp. 363-364 and 437-439.
[3] See Wolfe, http://www.phys.unsw.edu.au/jw/flutes.v.clarinets.html#time for an explanation and animated diagrams.

end; the pressure fluctuates maximally between values above and below atmospheric, and the instrument is said to be pressure driven.[4]

The reed on its own can produce sound in a wide range of frequencies, however the standing waves in the air column cannot be established at just any frequency as another condition has to be met, once the reed is coupled to the bassoon. When a returning pulse of high pressure reaches the reed it forces the blades to open, thus the action of the reed is now coupled to the sound waves in the air column. A pressure pulse leaving the reed travels down the bore at a fixed speed – the speed of sound in air (or in this case, in slightly warm, rather humid air, so a little faster than normal: around 345 metres per second). It makes the return trip, and when it reaches the reed it forces that to open and admit another pulse, however there are only certain intervals of time for this return trip that will make the system work.

A swing makes a helpful analogy here; the child on the swing goes back and forth with the time taken for the return trip (the *cycle*) dependent on the length of the swing's ropes (the length of time for one cycle is called the *period*). Left to its own devices, the oscillations of the swing will die away as energy is lost through friction, so the dutiful parent feeds more energy into the system by pushing the swing. The parent must time his or her pushes correctly to keep the oscillations going; if he pushes too late, as the swing is already halfway on its trip away, or too early, when it is still on its way back, he will interfere with the oscillation (as well as risk a crack on the head). Rather than his efforts adding to the energy of the swing, the two will work against each other to damp out the oscillations, and if badly enough timed, will bring the swing to a standstill. The parent can tell when to push (just when the swing is starting to swing away), because the swing itself shows the way, and in the wind instrument, the wave in the air column drives the reed to open at the right time to input its energy optimally; the air column and reed are connected in a feedback loop.

Given that the length of the instrument and the speed of sound are both fixed values, there are only certain periods of time that the pulse will take to do the return trip along the bore and arrive back at the right time to open the reed. Period (measured in seconds) is the inverse of frequency (measured in cycles per second), so there are only certain frequencies

[4] An air reed instrument is open at the blowing end, so has zero pressure fluctuation and maximal velocity fluctuation there (as at the other open end); so it is said to be velocity driven.

of air column oscillation that will work optimally for that length of instrument. When the oscillations are optimal, and the air column couples with the reed to drive it (the reed) to input energy timed to sustain the oscillation, the situation is called *resonance* and the frequencies at which this happens are *resonance frequencies* of the particular air column in question.

The resonance frequencies of a perfectly conical air column (closed at its peak) form a *harmonic series* where each is a whole number multiple of the lowest resonant frequency; f, 2f, 3f, 4f, and so on. The frequency f is called the *fundamental* (also first *harmonic*) of that harmonic series, the other elements are the second harmonic, third harmonic, and so on. The value of f is that of a sound wave whose wavelength is twice as long as the cone; frequency and wavelength are inversely related so that f = speed of sound / wavelength.

In a cylindrical bore with a closed end the situation is different, there the resonance frequencies are only the odd-numbered members of a harmonic series: f, 3f, 5f, 7f, etcetera, and the wavelength of the fundamental is equal to four times the length of the cylindrical tube.

The cylindrical bore situation is the easier to explain. As before stated, the standing wave must have a pressure antinode at the reed end because it is effectively closed, and a pressure node at the open end. The distance from an antinode to a node is a quarter of the wavelength, therefore the full wavelength is four times the tube length (4L) and the frequency f is v/4L where v is the speed of sound.

Another wavelength can also fit those criteria though, one that has another node at one third of the tube length from the reed end, and another antinode at two thirds of the length. Thus it has three quarters of its wavelength fitting into the tube, so its full wavelength is 4L/3 and its frequency is 3v/4L which is 3 times the fundamental frequency f. Another waveform fits the criteria with 5/4 wavelengths fitting into the bore, so it has a frequency of 5v/4L or 5f, and so on. These waveforms and their frequencies are often called the *modes of vibration* for that air column. The first three modes are illustrated in the diagram below, taken from a textbook of the Open University.[5]

[5] *Musical Instruments 1* (Milton Keynes: The Open University, 2004), p. 29.

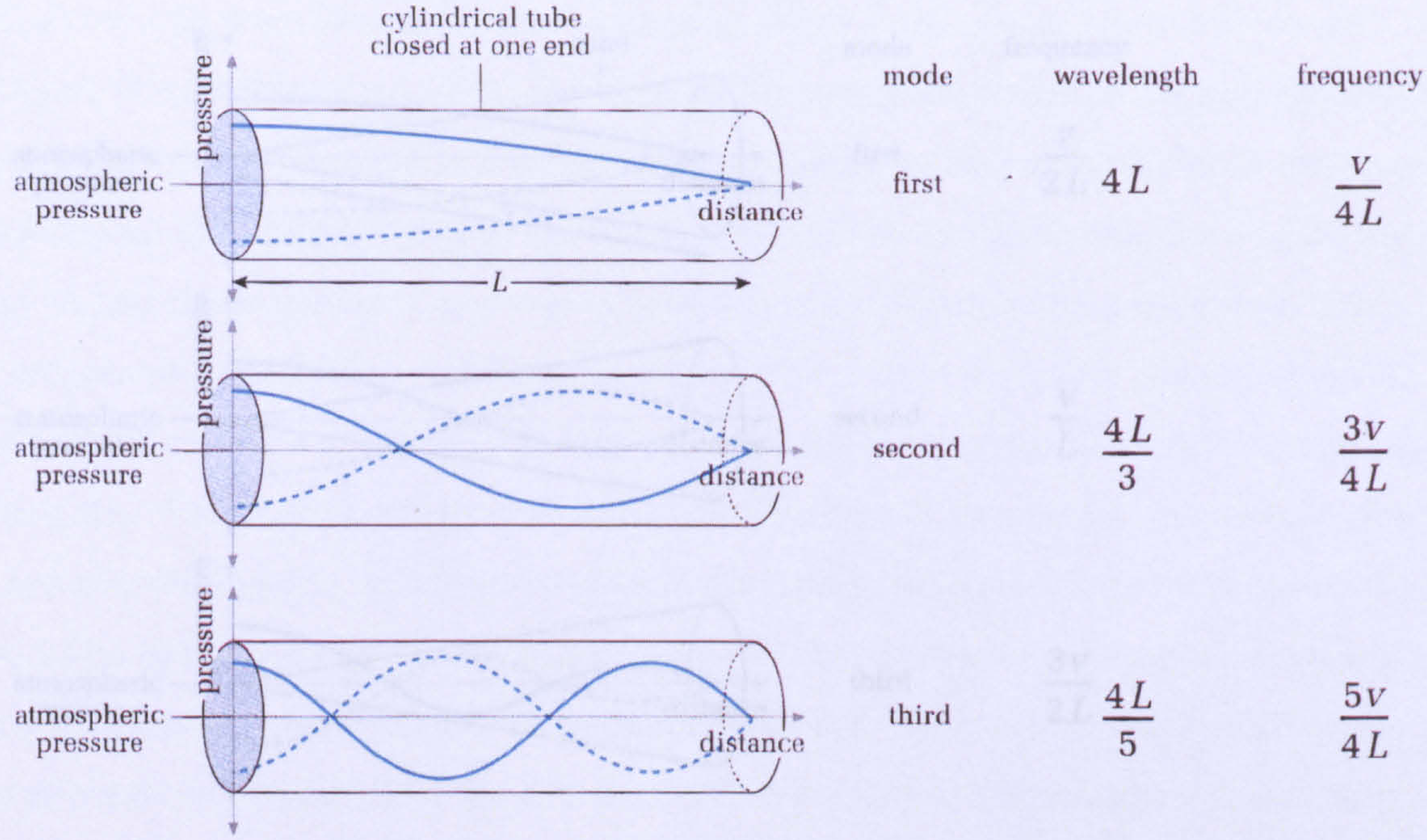

Fig 4.1.1. The first three normal modes of vibration for a cylindrical tube closed at one end, plotted in terms of pressure. The solid curve shows the pressure at one extreme of the cycle and the dashed curve shows the pressure at one half cycle later. The points where they cross are the pressure nodes and where they are farthest apart are the antinodes.

The standing waves in the conical air column must also fit the same criteria of an antinode at the reed end and a node at the open end, so it is not at first obvious why the waveforms are different from those in the cylinder, and why the resonant frequencies form a full harmonic series. The explanation is not easy and several textbooks either avoid explaining it or do not do so very clearly. A paper by Ayers, Eliason and Mahgarefteh from 1984 surveys the textbook explanations and gives several ways of understanding the situation.[6] Wolfe gives an explanation comprehensible by non-mathematicians on the useful and ever expanding University of New South Wales' musical instrument acoustics website.[7]

Perhaps the simplest way to perceive the situation is to accept that what looks, in each of the three diagrams below, like a quarter wavelength starting at the cone's apex, is actually a half wavelength with the antinode displaced to the left – so far to the left that it takes the place of the node that might otherwise be there.

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[6] Ayers, R. Dean, Lowell Eliason, and Daniel Mahgarefteh, 'The conical bore in musical acoustics', *American Journal of Physics*, 53.6 (June, 1985), 528-537.

[7] Joe Wolfe http://www.phys.unsw.edu.au/jw/pipes.html.

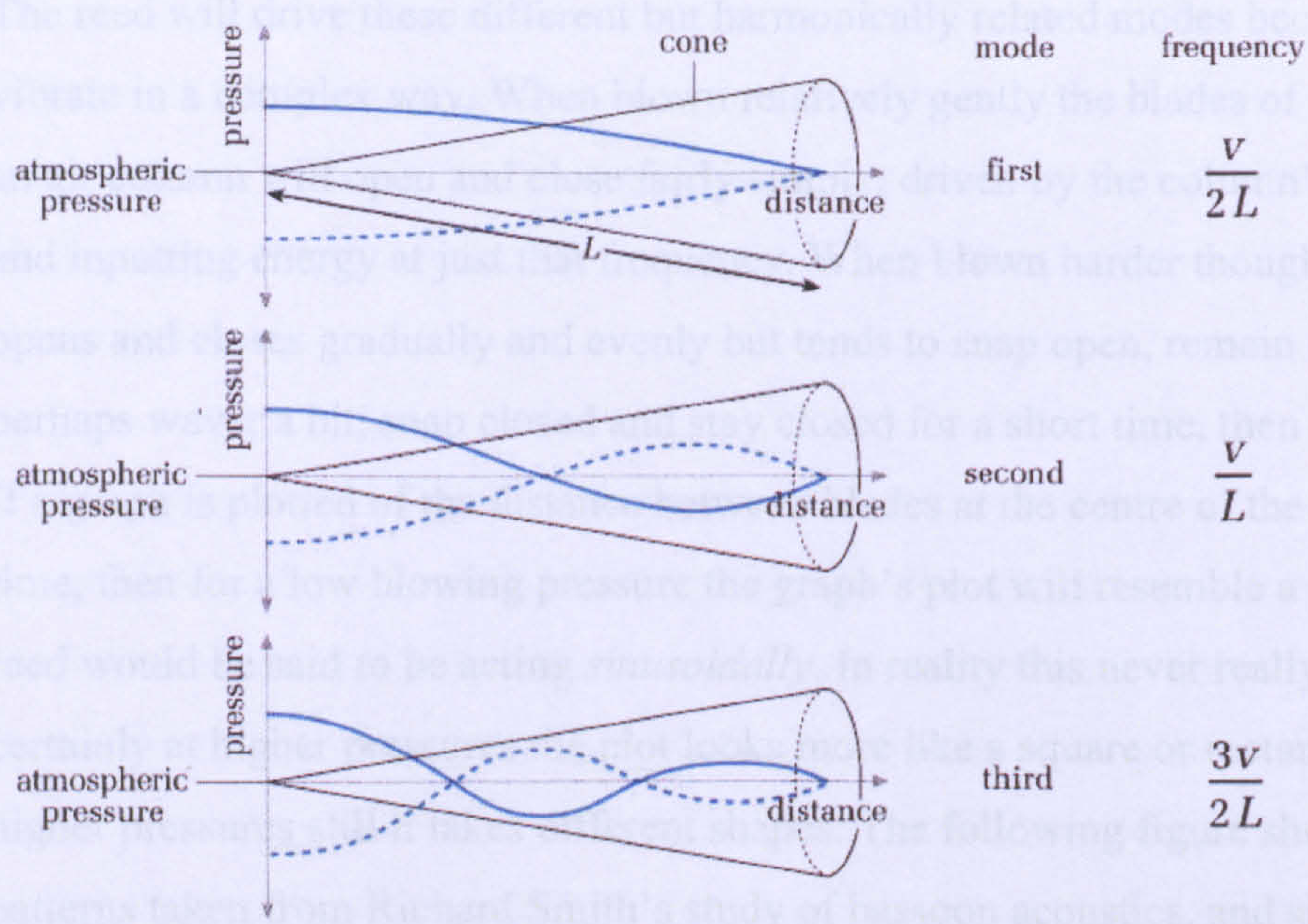


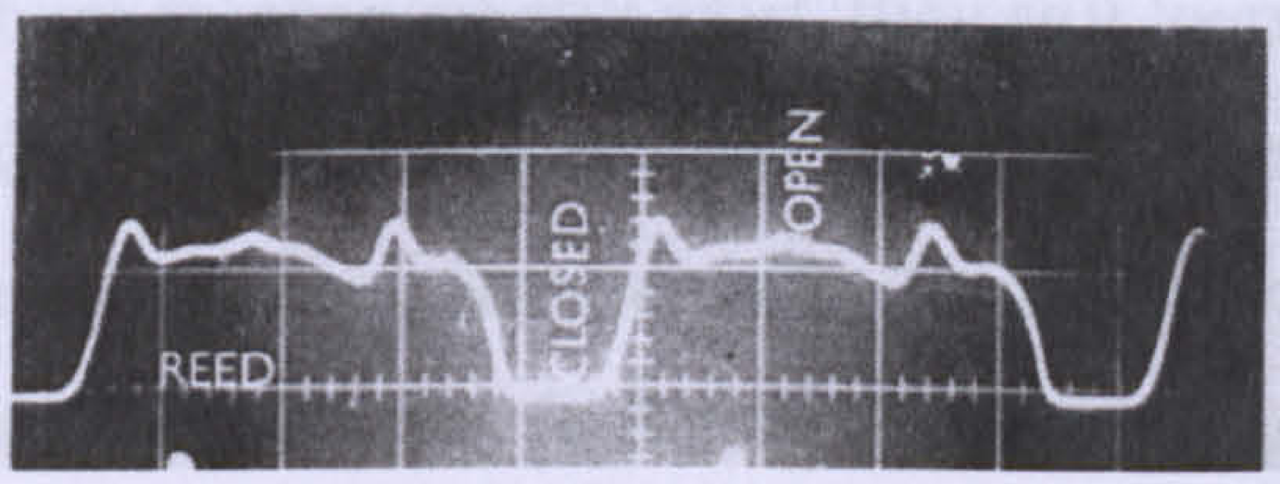
Fig 4.1.2. The first three normal modes of vibration for a cone, plotted in terms of pressure. The solid curve shows the pressure at one extreme of the cycle and the dashed curve shows the pressure at one half cycle later [8]

Note that the acoustic pressure (represented by the vertical distance between the solid and dashed blue curves) is significantly higher towards the reed than at the open end. That is because for a wave travelling in a cone, the wavefront gets spread out over a larger and larger diameter as it travels further down the bore, and as it is reflected back it is concentrated into a decreasing diameter. The wavefront is curved; it is a portion of a sphere with radius equal to the wavefront's distance from the apex of the cone, while a wave travelling in a cylindrical bore is a plain wave with a flat front and constant intensity all along the cylinder.

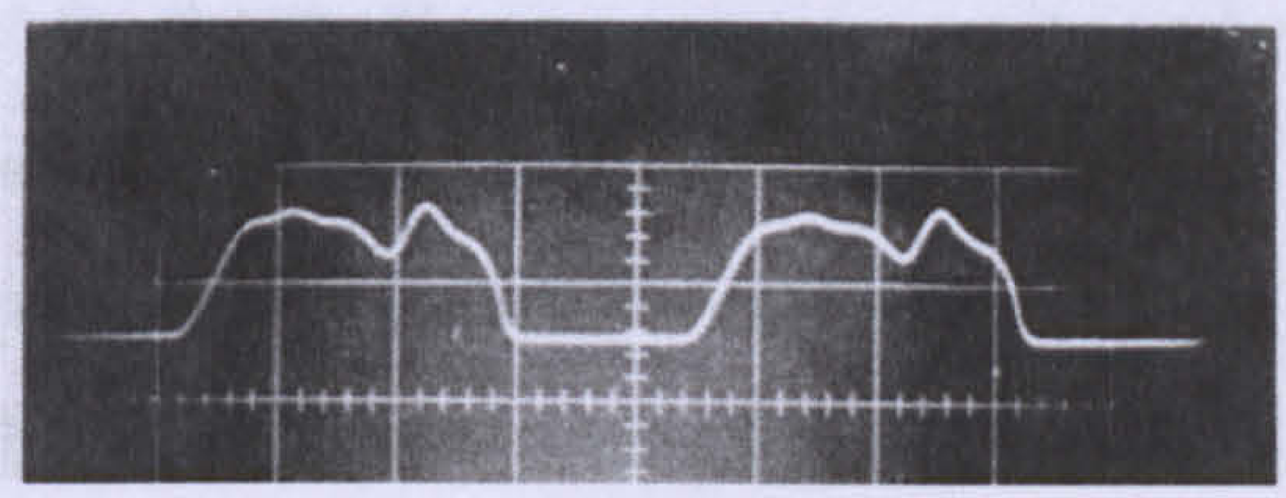
The air column can vibrate at any of these resonance frequencies, or at several at the same time to produce a complex sound constructed of several frequencies. This is musically useful since Fourier's theorem tells us that a complex but sustained, pitched sound is made up as the sum of several different frequencies, all of which are elements of the same harmonic series. That means that all of the frequencies present in a note produced by a wind instrument (or bow-driven stringed instrument) are elements of one harmonic series, that is they are *harmonically related,* and the pitch that is heard is that of the fundamental frequency of that series.[9]

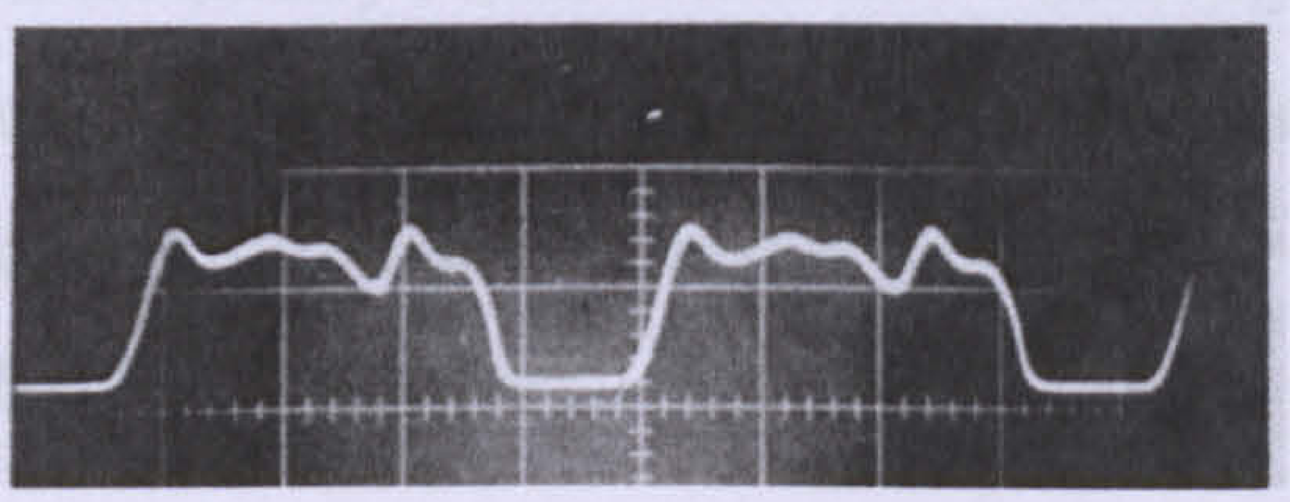
[8] *Musical Instruments 1,* p. 31.
[9] Transitory, decaying notes such as produced by plucked or hammered strings are different in this regard.

The reed will drive these different but harmonically related modes because it too can vibrate in a complex way. When blown relatively gently the blades of a reed connected to an air column will open and close fairly simply, driven by the column's fundamental mode and inputting energy at just that frequency. When blown harder though, the reed no longer opens and closes gradually and evenly but tends to snap open, remain open for a little, perhaps waver a bit, snap closed and stay closed for a short time, then snap open again.[10] If a graph is plotted of the distance between blades at the centre of the reed's tip against time, then for a low blowing pressure the graph's plot will resemble a sine wave, so the reed would be said to be acting *sinusoidally*. In reality this never really quite occurs, and certainly at higher pressures the plot looks more like a square or rectangular wave, and at higher pressures still it takes different shapes. The following figure shows oscilloscope patterns taken from Richard Smith's study of bassoon acoustics, and show tip opening against time for two cycles at each of several blowing pressures.[11] Note that even at the lower pressures the reed is open for longer than it is closed, and at the higher pressures it does not fully close at all, at least in the middle of the tip from where these graphs are plotted.



At blowing pressure 400mm water


800mm water


600mm water

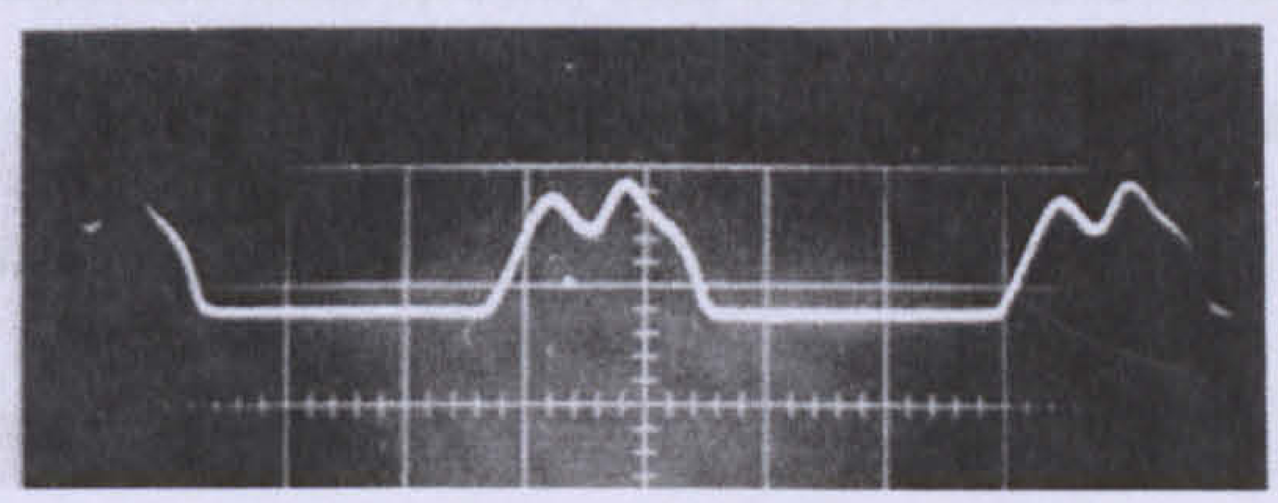

900mm water

Fig 4.1.3. Tip opening of bassoon reed through two cycles of oscillation. The x-axis (with scale marked) crosses the y-axis at the value for reed closed, so when the curve is above that axis the reed is open

The reed's waveforms are still *periodic*, that is, they repeat regularly, so by Fourier's theorum they are constructed as the sum of several frequency components (at differing amplitudes), all harmonically related to the repetition frequency. The reed may be driven by the wave in the bore to operate at the air column's fundamental resonance frequency,

[10] Acousticians like to say that it behaves *non-linearly*, or rather, that it behaves this way because of the *non-linear* nature of the Bernoulli force.

[11] Richard Smith, 'Factors Affecting the Spectrum Envelopes of Woodwind Instruments' (unpublished MPhil thesis, University of Southampton, 1972), plate 4, p. 20.

but then it (the reed) can add higher harmonics to the system. These will *resonate* (create resonance) with the higher air column modes with the result that the instrument creates a complex note, still with the pitch of the fundamental bore mode. As the reed is blown harder, a larger proportion of the total energy of the reed is fed into the higher frequency components.

A further consequence of the multiplicity of bore modes is that an *oscillatory regime* can be established that ignores the first mode altogether. The player can manipulate the way the reed vibrates with breath pressure and embouchure, and by *overblowing* can put so much of the reed's energy into the higher frequencies as to cause it to de-couple from the air column's first mode and establish a regime of harmonic oscillations based on the second bore mode. With a conical bore, the second bore mode frequency is twice that of the first mode, so the note now sounded is an octave higher than the note based on the first mode. The new regime of oscillation does not require all of the bore modes available, only the second, fourth, sixth, eighth and so on, because the new note of frequency 2f has a new harmonic series with components 2f, 2x(2f), 3x(2f), 4x(2f) etc. Since the odd numbered bore resonances still exist, they still 'compete' for the reed's co-operation, so it can be difficult to set up this new regime, and in a real instrument additional techniques such as opening an octave vent may be needed to help get it established. Overblowing can, of course, be taken further to establish a regime based on the third bore mode, creating a note of frequency 3f, an octave and a fifth higher than the first mode, and so on. The overblown note established on the second bore mode is called a *second register* note, that established on the third mode a *third register* note.[12] A first register note is sometimes also called a fundamental note.

So far the discussion has ignored many complicating factors and has been with regard to an idealised design that does not, indeed cannot exist; there cannot be a bore-with-reed-attached that forms a perfect cone. In a real bassoon the situation rapidly becomes more complex; the cone's apex is cut off and a reed substituted, which has a bore shape very different from the missing cone (though its volume may be close to that of the missing apex) and in addition to its physical volume, has an 'equivalent volume' caused by the motion of the blades when played. Only the lowest note uses the whole bore length; all others vent from toneholes of various sizes pierced at various positions along the cone.

[12] There can be confusion here as players sometimes use the word register differently, but for the purposes of this paper the term will be used only as described here.

When open, the toneholes constitute a *tonehole lattice,* and when closed they form small cavities adding to the volume of the bore at their location. So even a bore that has been reamed to a straight straight-sided cone will, as far as the standing wave is concerned, have *perturbations* or deviations from that simple shape, made from the volumes of the toneholes. As has been shown in Chapter 2, all baroque bassoons have bore shapes with discontinuities and other deviations from a straight cone, and most of them are considerably more complex, with several significant changes of taper along the bore length.[13] All this means that real instruments will have resonances that are unlikely to be in simple harmonic relationships.

Another complexity is *end correction*; the effective or acoustical length of the tube is greater than its physical length. A way to envisage this is to consider the air at the bore's open end: there is a region of air that oscillates in and out of the open end, forming a small jet as it exits, and that jet maintains its integrity for a little way beyond the end of the tube due to its inertia and that of the mass of air outside, so the effective length of the air column is a little longer than the tube itself. The additional length is about 60% of the bore radius at the exit for a thin-walled tube, but increases as the flange size (the flat surface at right angles to the bore axis) increases, up to a maximum of around 78%.[14] The additional effective length is called the end correction. In addition, the end correction effect is to some extent frequency dependent, so that the higher frequency components of a note 'experience' a longer bore; this matters more when the bore radius is larger, and can put the bore modes out of harmonic alignment.

A similar frequency-dependent effect occurs at the toneholes, especially toneholes that are small relative to the bore diameter at their location, such as those in all baroque instruments (in contrast, for example, to saxophones and the Boehm-system flute). For notes venting from a tonehole, the difference in effective bore length for the different modes can be quite marked, and manifests itself in the increased flattening effect that cross-fingerings have in the second register in comparison to the low register.[15]

[13] Even in modern bassoons the bore deviates from a straight conical form; see Burton, 'Bassoon Bore Dimensions'.

[14] Douglas Keefe, 'Woodwind Tone Hole Acoustics and the Spectrum Transformation Function' (unpublished doctoral thesis, Case Western Reserve University, 1981), pp. 345-346. The early makers were probably not considering this effect, but it is noticeable that type 1 bassoons have a particularly small flange size at the bell opening, while many type 2s, especially the German with their brass bell-crowns, have a large flange radius.

[15] Benade, *Fundamentals*, pp. 431-435.

Another important effect relating to toneholes is that of the *cutoff frequency*.[16] When one or several toneholes are open, they act to effectively shorten the air column, and thus the wavelength supported, by providing a strong reflection near the position of the first open hole (that nearest the reed). However, at higher frequencies the wave in the bore finds it harder to shift the mass of air inside the toneholes – the holes do not 'look so open' as they do to lower frequencies. At sufficiently high frequencies toneholes no longer provide a significant reflection and the wave is free to propagate down the bore.[17] The frequency at which this happens is affected by the spacing between open toneholes and their size (both diameter and length); larger holes provide better reflections so raise the frequency at which cutoff occurs, smaller or deeper holes at wider spacing lower the cutoff frequency.

At frequencies near to cutoff, where this effect begins to take hold, the resonances become irregular; as Wolfe puts it: 'Near the cut-off frequency the standing wave extends somewhat beyond the first open hole, and the extent depends on frequency. Consequently, the resonance frequencies follow no simple pattern'.[18]

Above cutoff the holes are effectively closed; 'the effective length of the bore is that of the whole bore, and so the frequencies of resonance become approximately equally spaced again, but with a narrower spacing…'[19] This narrower spacing matches that of the resonances in the same frequency range of full-bore-length notes Bb1 and C2, and the resonance strengths also match. 'In other words, for frequencies well above [cutoff], all fingerings behave approximately as though all holes were closed!'.[20]

If any of these small resonances above cutoff coincide with an harmonic frequency it is only by chance. The result is that the bore does not support the regeneration of higher modes above the cutoff frequency much at all; those high frequencies generated by the reed pass right through the bore to the open end. The higher frequencies are still present in the heard note, but they come, in manner of speaking, direct from the reed, though the qualities of their radiation are still affected by the geometry of the open end of the instrument; the bell in the case of the bassoon.

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[16] Benade, *Fundamentals*, pp. 447-462.
[17] See Joe Wolfe, 'Cutoff frequencies, crossfingering and half-holing in woodwinds', http://www.phys.unsw.edu.au/jw/cutoff.html
[18] Ibid p.2; 'Three regimes of frequency'.
[19] Ibid.
[20] Joe Wolfe and John Smith, 'Cutoff frequencies and cross fingerings in baroque, classical and modern flutes', *JASA*, 114-4, (Oct 2003) 2263-2267, p.2268. See also graph 4.6.2.

One consequence for the player is that notes above the cutoff frequency cannot normally be produced, as there is no support for them by the air column. However recent research seems to confirm that in certain circumstances the well-trained player can adjust the vocal tract to provide tuned resonance support from the other side of the reed.[21] This is not considered a normal technique for the baroque bassoon, but may in any case be what players do to help obtain the highest notes on the instrument, for which the air column gives only weak support.

It would seem at first that the effects of the bore resonances being not harmonically aligned must be catastrophic: how could a regime of oscillation be established between competing resonances? But this is not necessarily the case. Firstly, the bore resonances are not just a single frequency, but operate over a small range; that is, the air column will resonate at frequencies a little to either side of the optimum, though the resonance achieved will be a little weaker. So nearly-harmonically aligned resonances can still be helpful. Secondly, not all of the bore resonances have to be utilised for any one regime; for example, if the first and third bore resonances are nicely harmonically aligned but the second is sharp, a regime based on the first resonance can still be established. The first and third modes will co-operate together with the reed and the second mode will be ignored. However if that air column is then overblown to establish a second register note, it will be sharp of an octave above the first register. An example of this is the note F2 on the baroque bassoon, fingered 123 456 F. This is usually a good, strong note, and yet when overblown we get, not an octave higher, but F#3 (or near to it). That is because the second bore resonance for the fingering 123 456 F is sharper than the second harmonic of the first bore resonance, and yet the fundamental note, F2, still plays with good tone quality.[22]

The sound wave that comes out of the instrument is still one composed only of harmonically related components because those are produced by the reed's periodic oscillations. Any of those components that are supported by well-tuned bore resonances will receive a boost to their relative strength in the sound spectrum of the note. Some of the harmonics in the spectrum will be weak if their frequency is one that is particularly

[21] See Jer-Ming Chen, John Smith and Joe Wolfe, 'Pitch bending and glissandi on the clarinet: roles of the vocal tract and partial tone hole closure', *JASA*, 126 (2009), 1511-1520.
[22] When actually playing the F#3, the first tonehole is opened to provide a *register hole* to help establish the second register. The hole's position changes the tuning a little too, but the second register can be made to sound even without opening that hole. See discussion of F#3 in Chapter 4: Making the Poerschman Bassoon.

poorly supported by bore resonances; although produced at the reed they are subsequently damped out.

In effect the first bore mode always seems to have first call on co-operation with the reed; the fundamental note will play at, or near that frequency and any other bore resonances near enough to being harmonically aligned will help in the ease of establishing that note, and in the strength of its sound. However, strong enough higher resonances that are out of tune (out of harmonic alignment) can pull the tuning their way – the tuning of the note may be a compromise between the two. If there are strong enough resonances that are badly enough out of tune, they can fight for control of the reed to such an extent that a note cannot be established at all, or the note may oscillate from one pitch to another, or two or more notes may sound at once (in a *multiphonic*).

4.2 Manipulation of resonances

In the processes of tuning and adjusting a woodwind instrument, the maker manipulates the resonance characteristics of the air column. The structural changes he or she makes are to the dimensions and shaping of the toneholes and of the bore. Larger scale changes, such as repositioning toneholes and major bore redesign, are usually carried out at the design or prototype stages; they cannot usually be practically applied to instruments being prepared for sale.

A comprehensive exposition of the sorts of adjustments and the manner of their application is made by Herbert Myers in his Doctoral project 'The Practical Acoustics of Early Woodwind Instruments'.[23] He has a whole chapter dedicated to each of 'Tone Holes' and 'Bore Shapes'.

A general rule governs the use of localised bore modificatons, or *bore perturbations*, which, as Benade says 'was first enunciated a century ago by Lord Rayleigh'. That is:

> A localised enlargement of the cross section of an air column (a) lowers the natural frequency of any mode having a large pressure amplitude (and therefore small flow) at the position of enlargement, and (b) raises the natural frequency of any mode having a pressure node (and therefore large flow) at the position of enlargement).[24]

[23] Herbert W. Myers, 'The Practical Acoustics of Early Woodwinds' (unpublished project in partial fulfilment of Doctor of.Musical Arts, Stanford University, 1980).
[24] Benade, '*Fundamentals*', p. 474.

The converse of this rule also applies; narrowing the bore at either nodal or antinodal positions has the opposite effect to widening in the same position.

Benade explores several examples of ways to treat poor behaviour of actual instruments in his *Fundamentals...*, and in Chapter 22 he makes use of 'bore perturbation weight function curves' or 'W curves'.[25] These latter are derived from the above principle, and are a way of showing graphically the effects that changing the bore size at any position along the instrument has on the tuning of a particular mode, for a particular fingering. There is potentially a separate W graph for every note playable on the instrument.[26]

The complex shapes of the bores in many baroque period woodwinds has been taken as evidence that their makers made use of such bore-perturbation techniques. Descriptions of procedures for tuning recorders, using both tonehole and bore adjustments, have been published by several of today's recorder makers.[27]

4.3 Acoustic Impedance

The pattern of bore resonances for any fingering has a major effect on the tuning, response and stability of the note(s) played with that fingering, and somewhat on the quality of sound produced. These patterns are functions of the air column's configuration (including reed, crook and toneholes both open and closed) and are independent of the player.

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[25] Benade, '*Fundamentals*', p. 474 and following.

[26] This study could be usefully extended by constructing a full set of W curves for the reconstructed bassoon discussed in the next chapter. Benade does not explain how his were made but one way of obtaining them is to feed an elongated, flattened, oval piece of wax or plasticene along the bore while the instrument is blown in a fixed, consistent manner; usually with some artificial blowing mechanism. The wax lump serves to reduce the bore diameter at its position, and the pitch of the note being played will rise and fall as the lump passes pressure antinodes and nodes respectively. These changes are plotted on graphs, one for each note, of pitch change versus position on the bore. An initial attempt was made to carry this out on this bassoon, with the construction of an 'artificial mouth' blowing apparatus, but there turned out to be significant problems with setting up the experiment. Keeping a reed vibrating in these artificial circumstances was very problematic, and the bore modification by wax lump did not seem to change the pitch as easily or consistently as happens on air-reed instruments, so the project was shelved for another day. See Mathew Dart 'An Investigation into the Control of the Bore over the Tuning in the Baroque Flute' (unpublished research essay, London College of Furniture, 1983) and Adrian Brown, *The Recorder, A Basic Workshop Maunual* (Brighton, GB: Dolce Edition, 1989), pp.27-29 for methods and results of the process applied to flute and recorder.

[27] Tim Cranmore, *Obedience training for Recorders* (Hebden Bridge: Peacock Press, 2009), pp. 43-55.
Brown, *The Recorder,* pp.27-31.
Alec Loretto, 'Tuning recorders by modifying the bore', *FoMRHI Quarterly*, 102 (Jan 2001), C-1740.
Jan van der Heide, 'Effects applicable to the tuning of instruments with a conical bore (replaces C-457)', *FOMRHI Quarterly,* 34 (Jan 1984), C-503.
Bob Marvin, 'Untitled (tuning conical bore woodwind instruments)', *FOMRHI Quarterly,* 33 (Oct 1983), C-492.

Because values can be established objectively, and to some extent related to the playing characteristics of the instrument, bore resonances are attractive to study.

The way that acousticians analyse and quantify bore resonances is with the concept of *acoustic impedance*. Dickens, Wolfe and colleagues state:

> The acoustic behaviour of wind instruments is largely determined by their acoustic impedance spectrum measured at the embouchure or 'input' to the instrument. The acoustic impedance Z is the ratio of acoustic pressure *p* to acoustic volume flow *U* and its extrema identify the frequencies of resonances and antiresonances due to standing waves in the bore.[28]

Wolfe further explains:

> We define Z = p/U. Z usually varies strongly when you change the frequency. The acoustical impedance at a particular frequency indicates how much sound pressure is generated by a given air vibration at that frequency.[29]

Acoustic impedance is measured at a point in the bore, and the acoustic pressure p is the difference between the maximum and minimum air pressure at that point, as it fluctuates in the standing wave. The acoustic volume flow U is the volume of air flowing (back and forth) per second through the cross-sectional area at that point. When measured at the reed end of a conical bore, at a resonance frequency, we can see that pressure fluctuation is large and the volume flow is small, so therefore impedance is large. If measured at the same place for a non-resonating frequency there will be very little fluctuation in pressure and so Z will be low. So if we take a reed instrument bore (with a particular fingering pattern) and measure the acoustic impedance at the reed end over a wide range of frequencies, we will get an indication of the resonance frequencies of that bore; the impedance values will be high at the frequencies where resonance occurs.

Because the impedance is measured at the reed end, it is often called *input impedance* and a plot of input impedance versus frequency for a particular bore configuration is called an *impedance spectrum* as it shows the impedance over a range of frequencies. Each fingering pattern effectively produces a different acoustic system, and thus a different impedance spectrum, even though the physical structure of the instrument remains the same. Examples of such spectra are given and discussed below.

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[28] Paul Dickens, Ryan France, John Smith and Joe Wolfe, 'Clarinet Acoustics: Introducing a Compendium of Impedance and Sound Spectra', *Acoustics Australia,* 35.1 (April 2007) 17-24, p. 1.
[29] *What is acoustic impedance and why is it important?* http://www.phys.unsw.edu.au/jw/z.html.

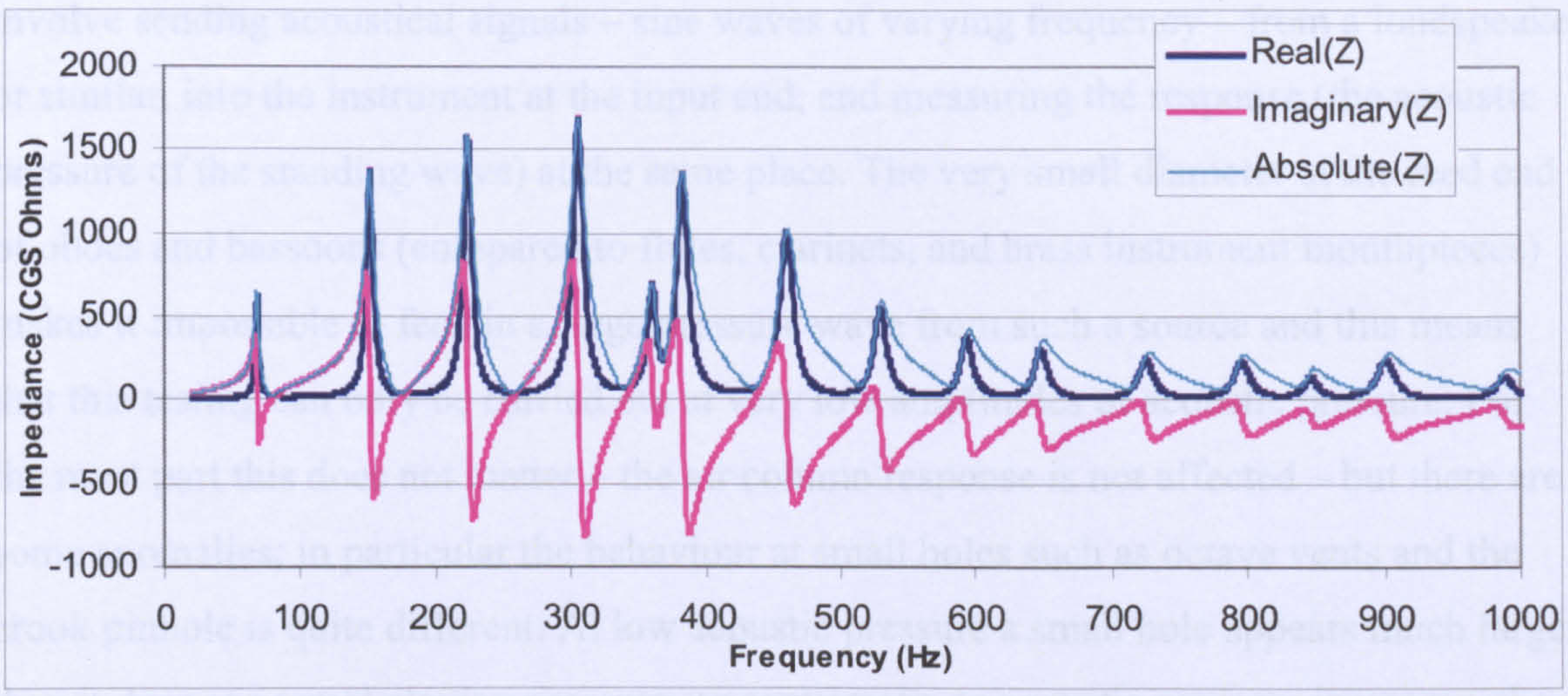
Acoustic impedance is a more complicated matter than the simple explanation so far given, and has a mathematically complex value which is made up of *real* and *imaginary* parts; the imaginary part is so called because it involves the use of the square root of −1, an imaginary number. Cronin explains it thus:

> The real part is associated with the dissipation of energy by friction inside the bore and radiation to the surroundings. It is always positive, since no energy is generated within the air column. The imaginary part (reactance) is associated with energy storage and release. In a vibrating air column, energy is stored as the potential energy of compressed air (compliance) and as the kinetic energy of moving air (inertance). If the input reactance is positive, the flow lags behind the pressure, and the air column looks like an inertance. If the reactance is negative, the flow leads the pressure, and the air column looks like a compliance. The sign of the reactance varies with frequency, and at resonant frequencies the reactance is zero.[30]

Most of the impedance graphs used in this study plot only the real part, as that gives very clear peaks of impedance at the resonant frequencies. Plots of *absolute* impedance, show more widely spread peaks and are occasionally used when found helpful. Absolute impedance is the vector sum of the real and imaginary parts: absolute $Z = \sqrt{(R^2 + X^2)}$ where R is the real part of the impedance and X is the imaginary part.

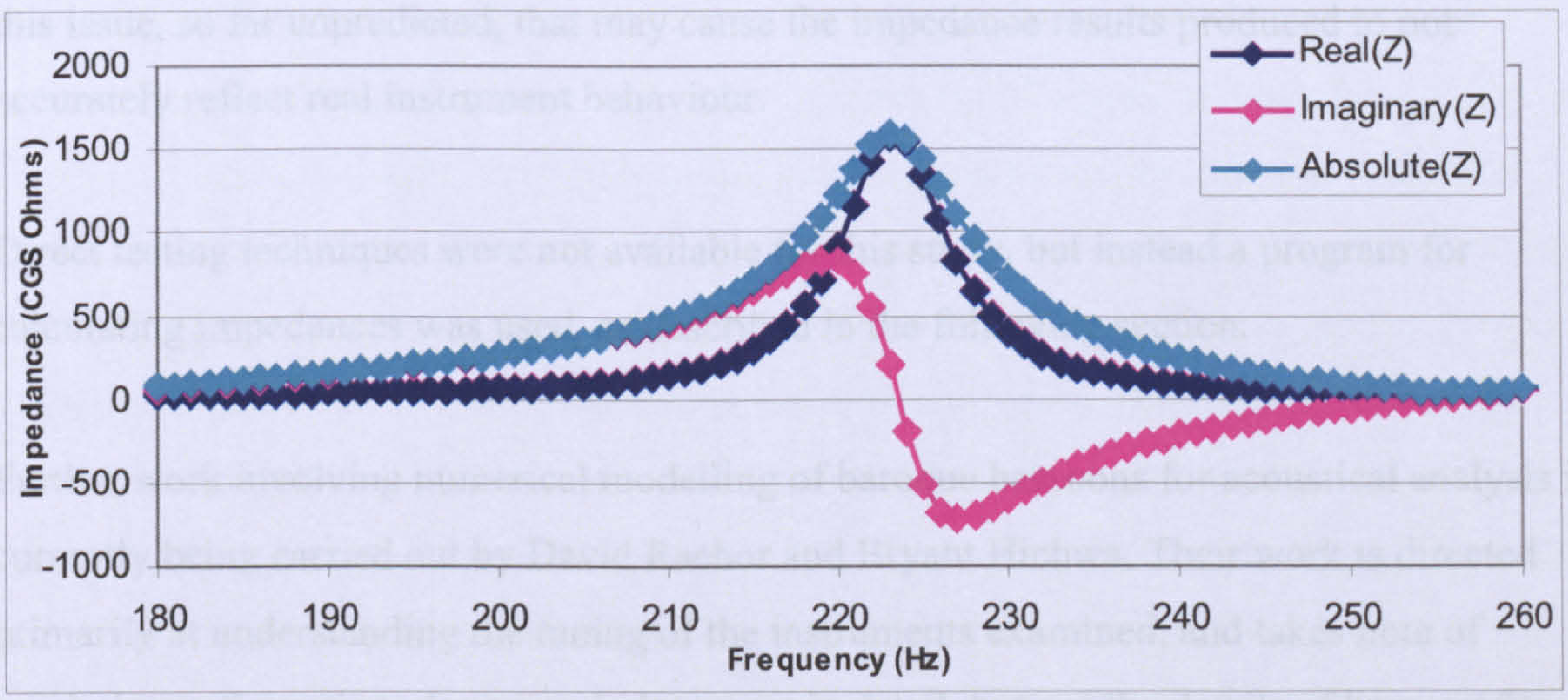
The relationship between the three can be seen in the sample graph below. This shows values for the fingering for D2: 123 456 FED on the Poerschman reconstruction, calculated using the computer program discussed in the next section. It can be seen that both Real and Absolute values are always positive; that their maxima coincide, and that those maxima occur at frequencies where the value of Imaginary Z is zero. The peaks of Real Z are symmetrical in shape and relatively narrow, but when the Imaginary part has a large positive or negative value, Absolute Z is greater than Real Z; so the peaks of Absolute Z are wider and are not symmetrical. As mentioned above, the air column will support resonance over a range of frequencies around the optimum one; the spread of the Absolute Z peaks shows that range.

[30] Robert H. Cronin, 'Understanding the Operation of Auxiliary Fingerings on the Modern Bassoon', *Journal of the International Double Reed Society*, 24 (1996), 23-30, pp. 6-8.



Graph 4.3.1. Real, Imaginary and Absolute input impedance values for Poerschman bassoon reconstruction, fingered: 123 456 FED

The impedance values are calculated here, as for all of the impedance graphs in later sections, at frequency increments of 1Hz. The graph below shows a portion of the same values 'zoomed-in' to a limited frequency range in order to show the level of detail; each data point is marked.



Graph 4.3.2. The same values as graph 4.3.1, plotted over a limited frequency range

Methods have been developed to measure the input impedance of actual instruments,[31] and also to calculate impedances from air column configuration data.[32] Direct testing methods

[31] John Backus, 'Input impedance curves for the reed woodwind instruments', *JASM,* 56.4, (October 1974) 1266-1279.
Paul Dickens, John Smith, and Joe Wolfe, 'Improved precision in measurements of acoustic impedance spectra using resonance-free calibration loads and controlled error distribution', *JASA*, 121, (2007) 1471-1481.
Dickens et al, 'Clarinet Acoustics'
Maarten van Walstijn, Murray Campbell, J.A. Kemp and David Sharp, 'Wideband measurement of the acoustic impedance of tubular objects', *Acustica*, 91.3, (2005), 590-604.

Footnote continued on following page.

involve sending acoustical signals – sine waves of varying frequency – from a loudspeaker or similar, into the instrument at the input end, and measuring the response (the acoustic pressure of the standing wave) at the same place. The very small diameter at the reed end of oboes and bassoons (compared to flutes, clarinets, and brass instrument mouthpieces) makes it impossible to feed in a large pressure wave from such a source and this means that this testing can only be carried out at very low amplitudes of acoustic pressure. For the most part this does not matter – the air column response is not affected – but there are some anomalies; in particular the behaviour at small holes such as octave vents and the crook pinhole is quite different. At low acoustic pressure a small hole appears much larger than it does at normal playing pressure, or conversely, as acoustic pressure increases, the resistance to air flow at a small hole increases to such an extent that it appears as a smaller and smaller hole. Since the methods of calculating input impedance are worked from the results of direct testing, they model behaviour at low acoustic pressure too. In the case of the program described below, the diameter values used for the pinhole, and for the amount of hole I that is open in a 'half-hole' fingering, must be estimated at considerably less than the real value to compensate for this effect. There may be other anomalies arising from this issue, so far unpredicted, that may cause the impedance results produced to not accurately reflect real instrument behaviour.

Direct testing techniques were not available for this study, but instead a program for calculating impedances was used, as described in the following section.

Further work involving numerical modelling of baroque bassoons for acoustical analysis is currently being carried out by David Rachor and Bryant Hichwa. Their work is directed primarily at understanding the tuning of the instruments examined, and takes note of tonehole configuration, design and placement in detail, but not the details of bore profile.

Maarten van Walstijn, Murray Campbell and David Sharp, 'Measurement of Input Impedance of an Acoustic Bore with Applications to Bore Reconstruction', *Proceedings of the Institute of Acoustics*, Vol 24 Part 2, Spring Conference, Salford, UK, 25-27 March 2002.
Smith, John, Claudia Fritz and Joe Wolfe, 'A new technique for the rapid measurement of the acoustic impedance of wind instruments', *Proceedings Seventh International Congress on Sound and Vibration, 4-7 July 2000, Garmisch-Partenkirchen, Germany*, Eds G. Guidati, H. Hunt, H. Heller and A. Heiss, Vol III pp. 1833 - 1840.
Comprehensive sets of input impedance plots for different kinds of flutes can be explored on the University of New South Wales website: Joe Wolfe, *Flute Acoustics*, http://www.phys.unsw.edu.au/music/flute/
[32] Plitnick and Strong, 'Numerical method for calculating input impedances of the oboe'. *JASA*, 65(3) (Mar. 1979), 816-825.
Keefe, 'Woodwind Tone Hole Acoustics'.

4.4 Computer program 'Impedps'

Extensive use has been made in this study of a computer program for calculating input impedances of reed woodwind instruments, developed by Robert H. Cronin, mechanical engineer and maker of historical reed woodwind instruments. Cronin has presented a description of the program, and examples of results obtained along with ways to interpret them in two papers; one published by the International Double Reed Society and another presented at a meeting of the Acoustical Society of America.[33]

The program is called 'Impedps' and is based on the method of Plitnick and Strong, with extensions to improve the tonehole model, include viscous and thermal boundary-layer effects, and to model the bore as a series of conic-frustra segments rather than cylindrical segments.[34]

The user makes a data file of the air column to be tested, with the bore specified as a series of conical segments (the internal shape of the reed is treated as a cone of the reed's exposed length with end diameters to give the same cross sectional areas that the reed has at each end). Tonehole data is entered in the file with parameters for diameter, length, outside diameter at hole (to give flange-effect), diameter of keypad (if any), height of pad above hole when key open, and whether the hole edges are sharp or rounded (though no provision is made for undercutting). Hole position is specified as the junction between two bore segments, so the bore must be divided appropriately. This data file is loaded into the program which, when run, calls for further input; the fingering pattern to be used, the range and increment of frequencies for which impedances are to be calculated, and two parameters of the reed; its *reed equivalent volume* (r.e.v.) and its own frequency. The r.e.v. is a value for the extra acoustic volume that a reed has when it is vibrating; that is, when in motion the reed effectively has a greater volume than its physical volume when at rest.[35]

Results are output as a text file that can be entered into a spreadsheet program (Excel in this case) to create graphs of impedance versus frequency. On these plots it is often useful

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[33] Cronin, 'Understanding', 23-30.
Robert Cronin and Douglas Keefe, 'Understanding the operation of auxiliary fingerings on conical double-reed instruments'. Notes for a talk presented at the 131st meeting of the Acoustical Society of America, Indianapolis, Indiana, 13-17 May 1996. The paper was also presented at the meeting of the Musical Acoustics Network, 20-21 June 2007, University of Edinburgh, Scotland.
[34] Plitnick and Strong, 'Numerical Method'.
[35] David H.Smith, *Reed Design for Early Woodwinds*, (Bloomington and Indianapolis: Indiana University Press, 1992) pp. 7-10.

to include vertical lines to show the frequencies of the harmonics of the note that is expected to sound when using the fingering pattern under investigation.

For the purposes of this study, the program is used rather simply as a tool for investigating and illuminating the playing characteristics of bassoons, without further questioning its veracity. No model is likely to be entirely accurate; there will be simplifications and factors overlooked, both in the program and in the input data, but the results obtained do, in many instances, seem to correlate well with the observed behaviour of the modelled instruments. In his original paper Cronin presents comparisons of measured impedances versus calculated values that agree well.[36] He shows graphs of impedance spectra for three different fingerings on a modern bassoon, where the calculated and modelled data sets are overlaid. The curves correspond well in general shape; the number and general arrangement of peaks match. Differences in height and position of the peaks are mostly within c. 100 Ohms in amplitude and c. 8 Hz in frequency. There are occasional greater errors, up to 600 Ohms, in the amplitude of some peaks. The good general correspondence suggests that errors are mostly due to inaccurate modelling, or the inability to account in the model for such as bore surface condition, porosity, and leaks at pads and joints, rather than inaccurate calculations. That is, the model is somewhat idealised; of a uniform bore surface with perfectly formed toneholes, and airtight joints and pads. He concludes that 'one may view this as a validation of the model or a confirmation of the experimental data. Either way, it gives one confidence in the results'.[37]

In use here, there are many instances where the correlation between obtained results and observed behaviour of the instruments are very strong, to the extent that the program's output can be used to explain, or at least to illuminate, many aspects of the response and tuning of the bassoons modelled. Some results are also found to accord well with theory of cutoff frequency associated with the open-tonehole lattice, and with cutoff values calculated using Benade's equation (see sections 4.1, p. 267 and 4.6, p.287). Absolute accuracy of any particular values cannot be claimed, but general relationships – the relative tunings and amplitudes between peaks in a graph, and the manner and degree in which bore, tonehole, or fingering pattern modifications affect resonances – seem to be accurately represented. Ideally these should be checked against directly tested values, but that was not possible in this study.

[36] Cronin, 'Understanding', Figs 1-3.
[37] Cronin and Keefe,'Understanding', pp. 1-2.

Footnote continued on following page.

There are certainly some anomalies that arise, though whether due to deficiencies in the entry data or in the calculations, or whether requiring some other explanation is not clear; so some matters do require further investigation.

Instrument makers may be rather disappointed to find that this program works as an analytical tool but not as a predictive one; that is, it can help to explain behaviour of an instrument but it will not explain how to fix it. That requires trial and error just as in real instrument making, although with this program it is done at the computer desk rather than at the lathe.

The program is used first to investigate some general aspects of conical bore reed instruments, looking at bore taper angles and at a compound bore made of two different tapers. Following that there is an analysis of one problematic fingering on the reconstructed Poerschman bassoon; this example is used to demonstrate how input impedance graphs can be used to illuminate some acoustical reasons for the behaviour of the instrument. Further analysis of this sort is used in Chapter 4.

4.5 Simple bore shapes and general principles

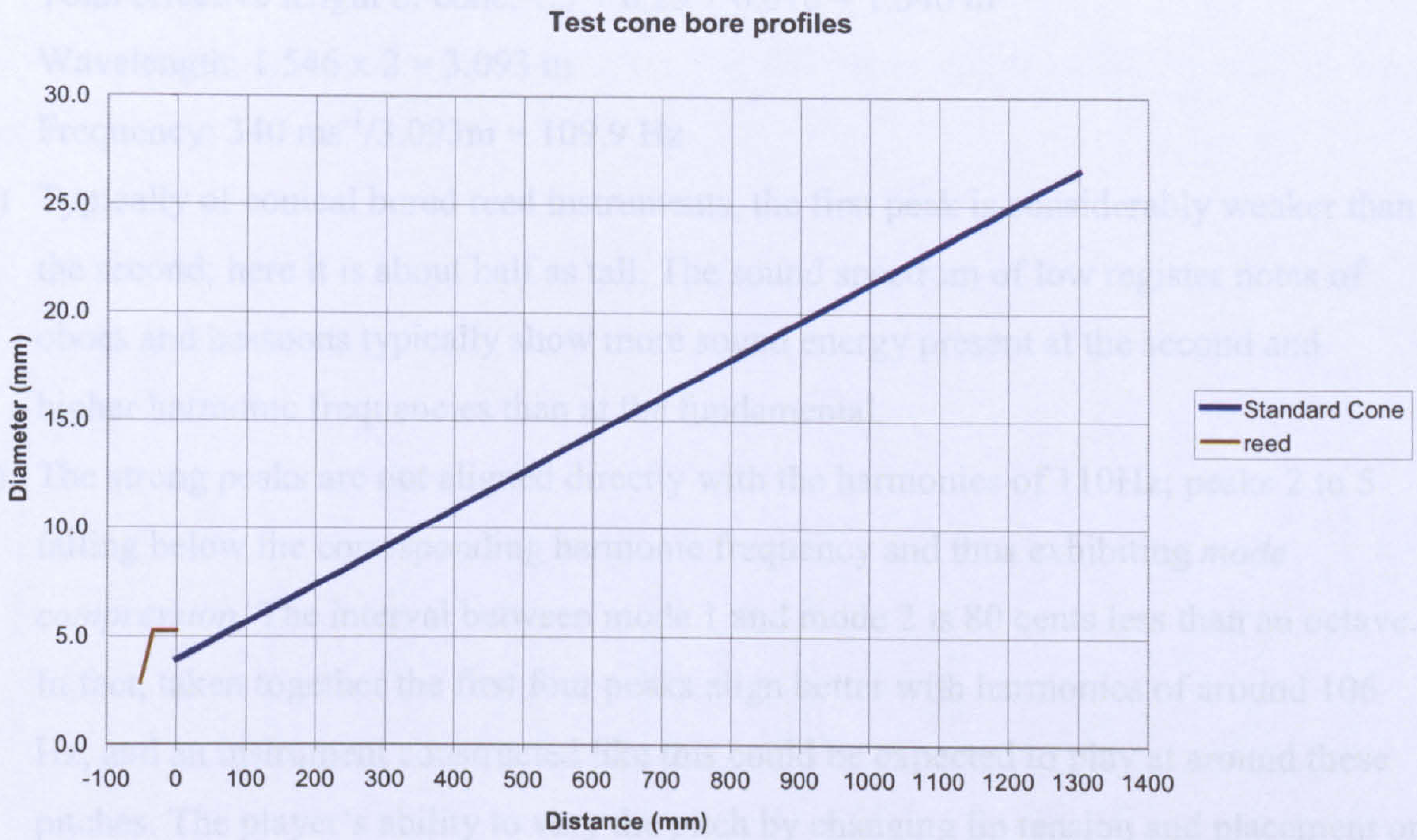
A variety of conical bore profiles were modelled; with shapes chosen to have some relationships to the design of the Poerschman bassoon discussed in the next chapter.

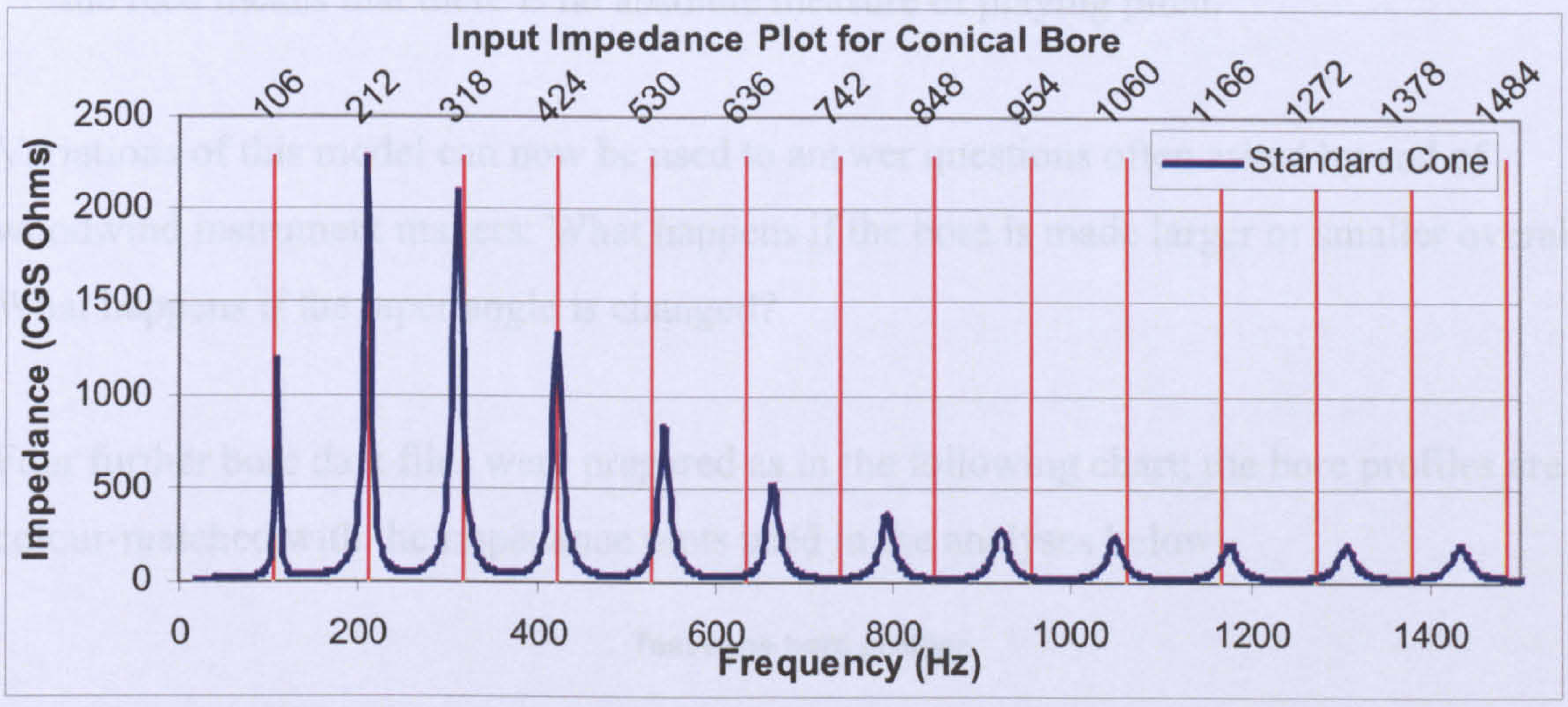
1. <u>Standard Cone</u>

   The starting point is a cone of the same taper angle as the wing joint of the Poerschman bassoon (see Chapter 5). The rate of taper is .0175; the bore diameter increases by .0175mm for every mm along the bore's length. This was modelled 1300mm long which is approximately the length of the down bore; crook + wing + boot small bore (300mm + 500mm + 500mm).

   The small end diameter is 3.85mm, typical for the small end of a baroque crook, and the resulting open-end diameter is 26.6mm.

   It was fitted with a (virtual) reed the size of a modern bassoon reed (somewhat smaller than a baroque one as the bore length is shorter than a full bassoon). Effective length (the length extending beyond the end of the crook) is 52mm, composed of cylindrical tube length 34.5 plus tapering (in bore terms) blade length of 15.5mm.





Graph 4.5.1. Bore profile and impedance curve for conical bore 1300mm long, of taper .0175, with reed attached. Vertical lines with diagonal tags show the frequencies of harmonics of the lowest peak.

Points to note:

a) The graph of input impedance shows the first peak at 110Hz (A2 at A4=440 Hz, Bb at A=415 Hz). This agrees well with the calculated frequency for the same cone if the reed were removed and the cone made complete to its apex:

Length of missing cone (from apex to 3.85mm dia.): 0.23 m

End correction at open end: 26.6 x 0.62 = .016 mm.[38]

[38] Taking flange width (i.e. the wall thickness of this tube) to be 1mm, see Keefe, 'Woodwind Tone Hole Acoustics', Fig 17 p.346.

Total effective length of cone: 1.3 + 0.23 + 0.016 = 1.546 m

Wavelength: 1.546 x 2 = 3.093 m

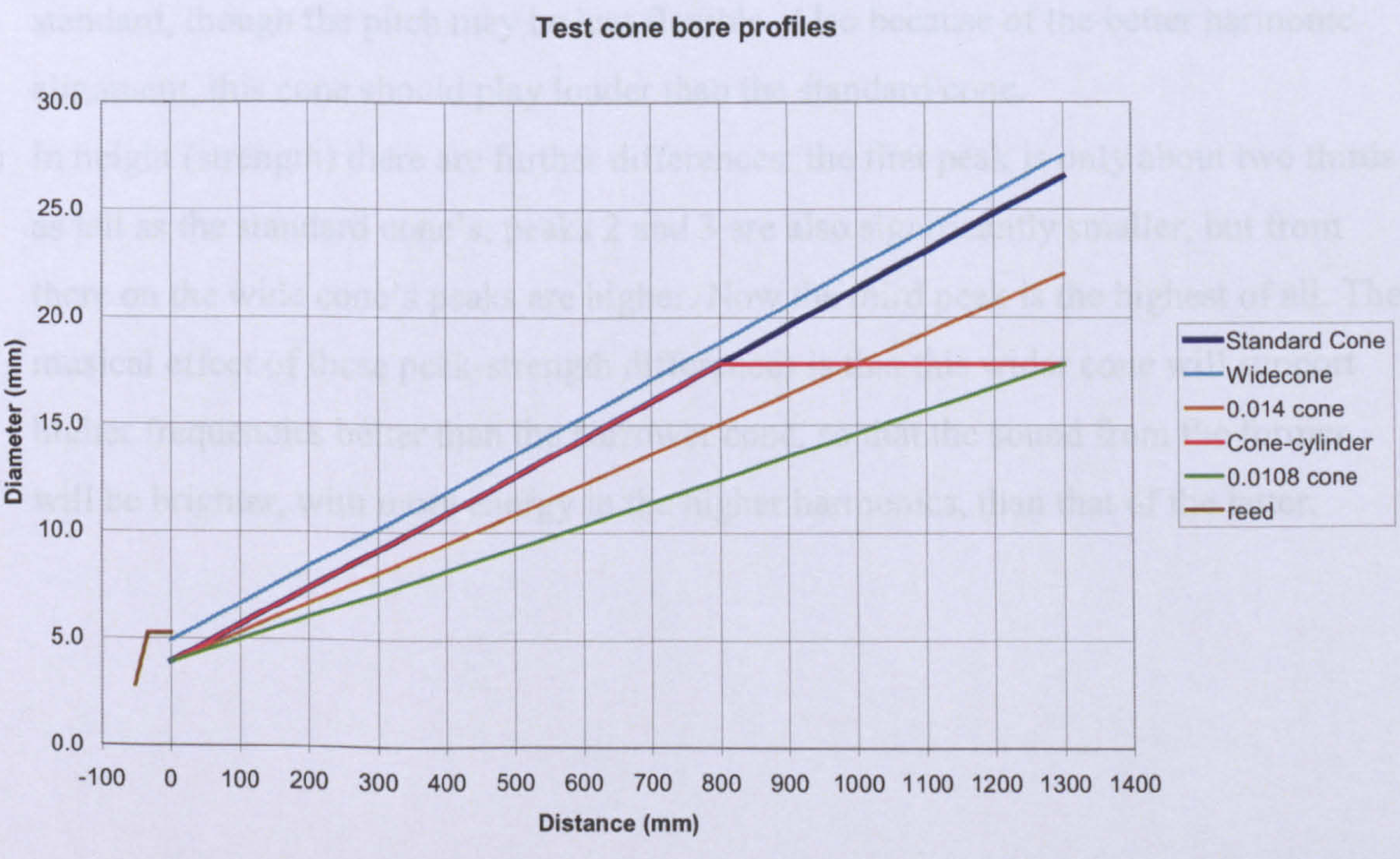
Frequency: 340 ms^{-1}/3.093m = 109.9 Hz

b) Typically of conical bored reed instruments, the first peak is considerably weaker than the second; here it is about half as tall. The sound spectrum of low register notes of oboes and bassoons typically show more sound energy present at the second and higher harmonic frequencies than at the fundamental.

c) The strong peaks are not aligned directly with the harmonics of 110Hz; peaks 2 to 5 falling below the corresponding harmonic frequency and thus exhibiting *mode compression*. The interval between mode 1 and mode 2 is 80 cents less than an octave. In fact, taken together the first four peaks align better with harmonics of around 106 Hz, and an instrument constructed like this could be expected to play at around these pitches. The player's ability to vary the pitch by changing lip tension and placement on the reed means that there is no absolute measure of playing pitch.

Variations of this model can now be used to answer questions often asked by and of woodwind instrument makers: What happens if the bore is made larger or smaller overall? What happens if the taper angle is changed?

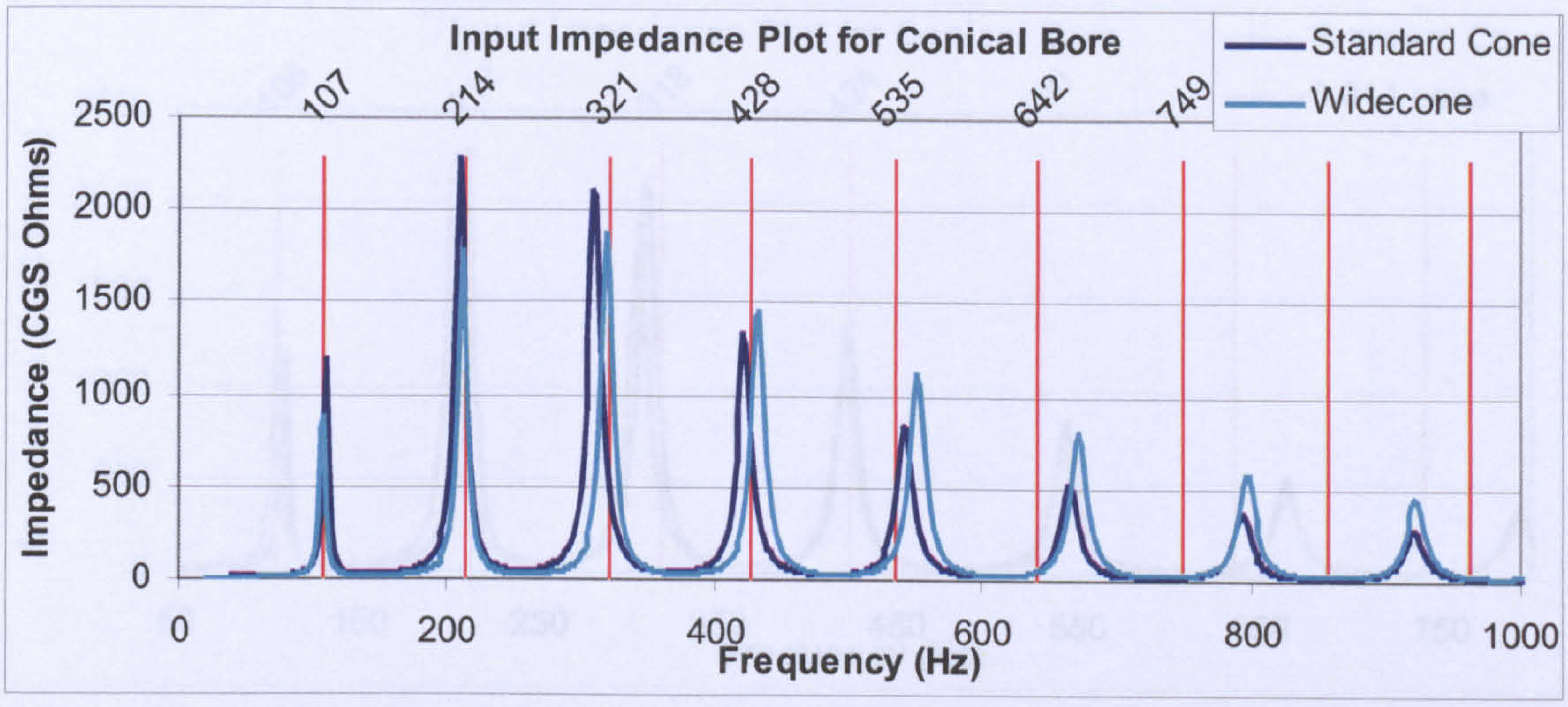
Four further bore data files were prepared as in the following chart; the bore profiles are colour-matched with the impedance plots used in the analyses below:



Graph 4.5.2. Bore profiles for conical bores tested

2. Widecone

The bore was made 1mm larger in diameter over the whole length, with the reed kept the same.



Graph 4.5.3. Impedance curves for Widecone bore versus Standard Cone

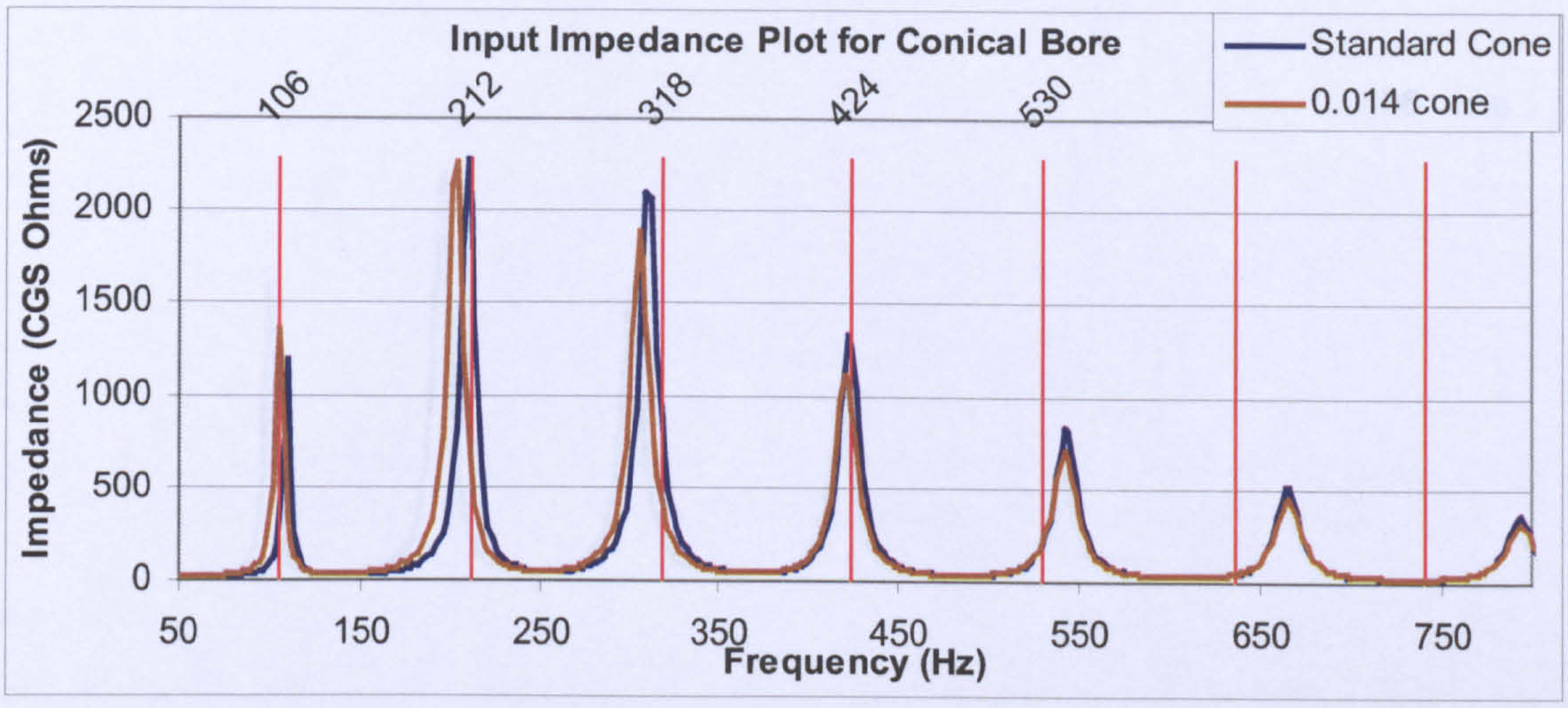
Results:

a) The fundamental has gone down in frequency to 107 Hz, a difference of 48 cents for that peak. However the next four peaks get increasingly higher in frequency than their standard cone counterparts, so that the first five peaks align reasonably well with harmonics of the fundamental of 107 Hz. The interval between peak 1 and peak 2 is just 17.5 cents less than an octave. This cone should play at much the same pitch as the standard, though the pitch may be less flexible. Also because of the better harmonic alignment, this cone should play louder than the standard cone.

b) In height (strength) there are further differences: the first peak is only about two thirds as tall as the standard cone's; peaks 2 and 3 are also significantly smaller, but from there on the wide cone's peaks are higher. Now the third peak is the highest of all. The musical effect of these peak-strength differences is that this wider cone will support higher frequencies better than the narrower cone, so that the sound from the former will be brighter, with more energy in the higher harmonics, than that of the latter.

3. Lower Taper Angle

The taper rate is reduced to .014; this is around that of the modern German bassoon.



Graph 4.5.4. Impedance curves for 0.014 taper cone versus Standard Cone

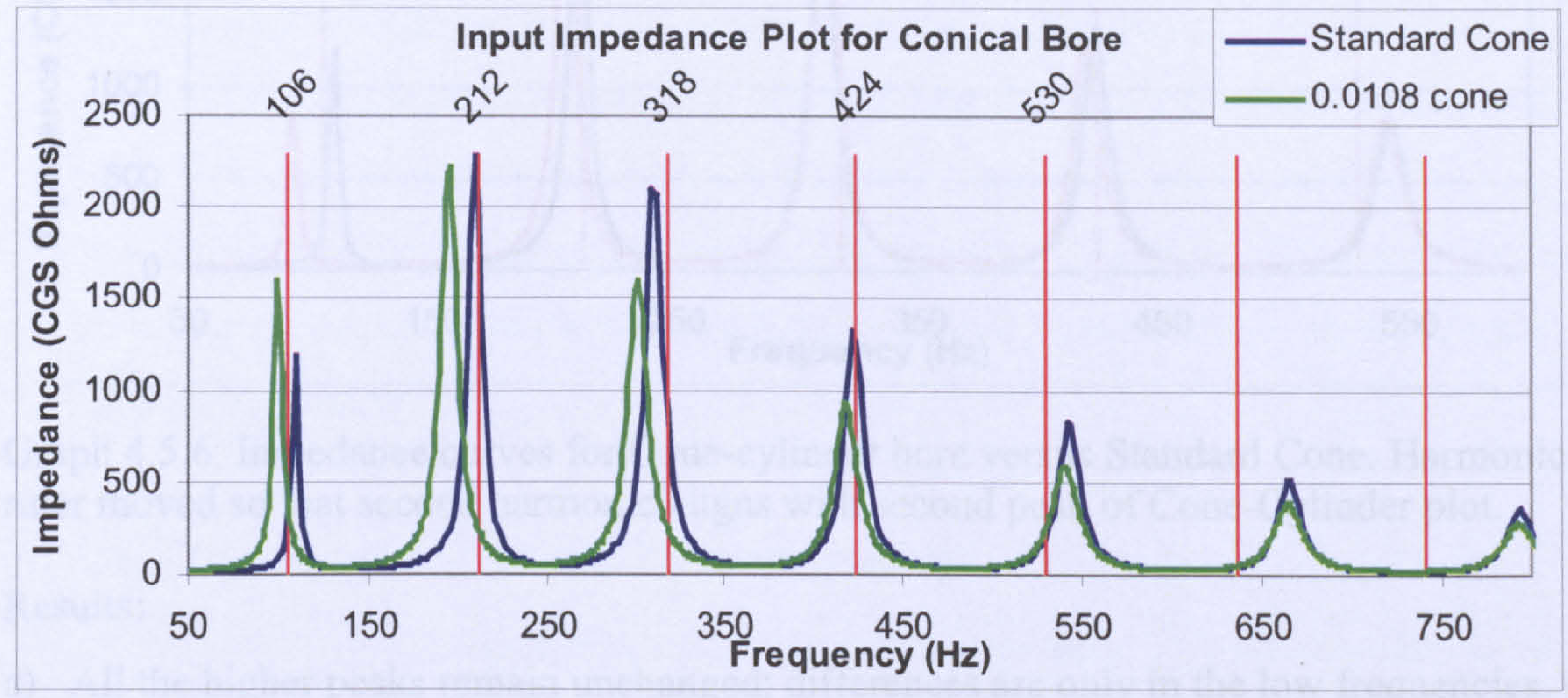
Results:

a) The first three peaks are reduced in frequency and the fourth just a little; all higher peaks remain at the same frequency. The fundamental is now at about 105.5Hz, but the first three peaks taken together align with harmonics of 102 Hz; around 75 cents flatter than the supposed playing pitch of the previous two cones. The interval between peaks 1 and 2 is around 66.5 cents less than an octave.

b) The first peak is strengthened by around 13% and the next four peaks reduced a little indicating that this cone may produce a sound with less energy in the higher partials than the standard; it should give a less bright, somewhat 'darker' sound at a slightly lower pitch.

4. Even Lower Taper Angle

A lower taper angle of .0108 was made to match the bore at number 5 below; both have the same diameters at each end.



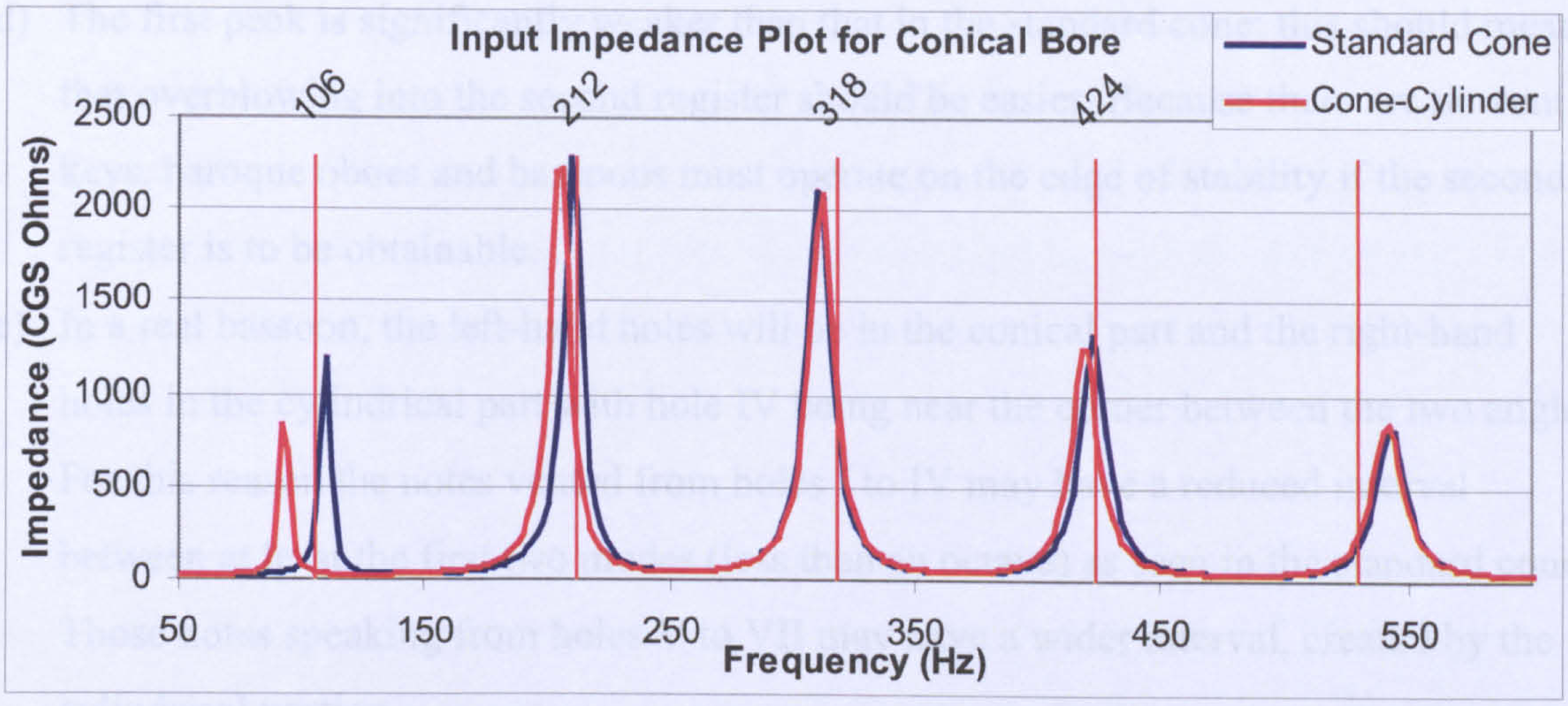
Graph 4.5.5. Impedance curves for low angle cone versus Standard Cone

Results:

a) The trends just mentioned are taken further. The fundamental frequency is now 100Hz; around 100 cents flatter than the playing pitch of the standard (a little over a semitone). The interval between peaks 1 and 2 is around 40.5 cents less than an octave.
b) Peak 1 is even stronger and peaks 3 to 6 even weaker, while peak 2 stays at about the same strength.
c) So this instrument would produce a flatter note, possibly of even darker tone quality.

5. Cone-Cylinder

This is an approximation of the kind of bore profile found particularly in German type 2c bassoons, where the wing taper is relatively steep, and the boot small bore is at zero taper angle, at least for the first half of its length. (See the Eichentopf and Poerschman bassoons in Chapter 3). The bore retains the standard taper for the first 800mm to reach a diameter of 17.85mm, it then continues at that diameter for the remaining 500mm to make the same overall length. These proportions are similar to a bassoon with conical crook plus wing and cylindrical boot small bore.



Graph 4.5.6. Impedance curves for Cone-cylinder bore versus Standard Cone. Harmonic ruler moved so that second harmonic aligns with second peak of Cone-Cylinder plot.

Results:

a) All the higher peaks remain unchanged; differences are only in the low frequencies, so the Frequency axis range is reduced here.

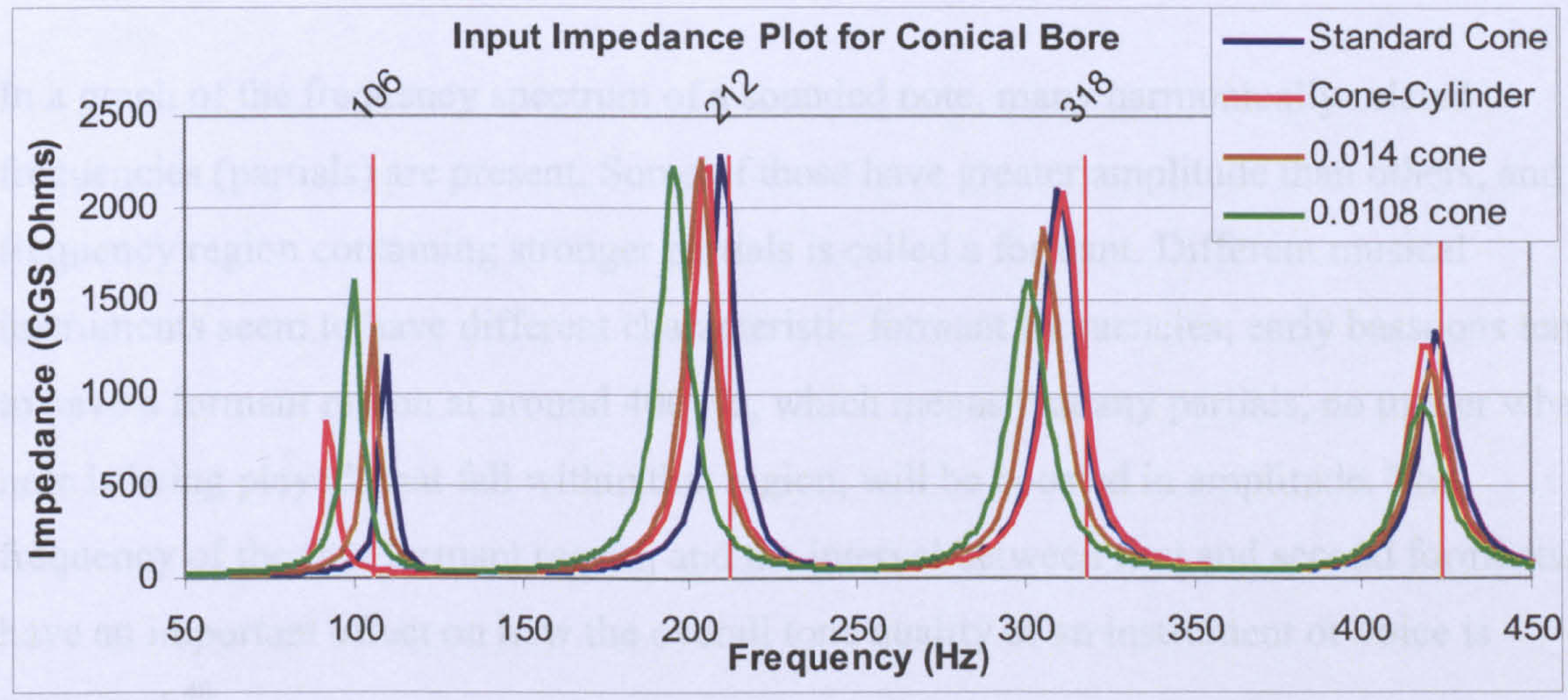
b) Peaks 1, 2 and 4 are flatter, and particularly peak1which has moved almost 300 cents, three semitones, from the original first peak to 92.5Hz (now approximately F#2 at A=440Hz or G2 at A=415Hz). This large pitch difference has been achieved without lengthening the instrument, and this is very useful to a maker trying to design a bass instrument with toneholes reachable by hand without extensive keywork. The two groups of fingerholes, one for each hand, can be brought closer together, so that there is not quite such a large distance between holes III (lowest left hand hole) and IV (highest for the right hand).

c) The interval between the first two peaks is now considerably greater than an octave; at 1380 cents it is near to an octave plus a major second. The intervals between the other strong peaks are also wider than those between corresponding harmonics; this is the mode stretching that is commonly seen in the lowest notes on bassoon and oboe. It can cause instability in the lower notes (see discussion of D2 in the next chapter), but is also put to use in the bassoon, where the fingering used for F2 is overblown to provide a good F#3. Here it is rather extreme and would have to be moderated somewhat in a real instrument; either the first resonance would have to be sharpened or the higher ones flattened. In the Poerschman and Eichentopf (and other) bassoons, a reamer is used to enlarge the boot small bore from the south end, perhaps for this purpose; it effectively shortens the cylindrical part and re-starts the conical expansion (see next chapter under discussion of G2).

d) The first peak is significantly weaker than that in the standard cone; this should mean that overblowing into the second register should be easier. Because there are no vent keys, baroque oboes and bassoons must operate on the edge of stability if the second register is to be obtainable.

e) In a real bassoon, the left-hand holes will be in the conical part and the right-hand holes in the cylindrical part with hole IV being near the corner between the two angles. For this reason the notes vented from holes I to IV may have a reduced interval between at least the first two modes (less than an octave) as seen in the standard cone. Those notes speaking from holes V to VII may have a wider interval, created by the cylindrical portion.

6. <u>The first four peaks of the four bores are compared.</u>



Graph 4.5.7. Impedance curves for four bore shapes

Concluding Notes:

a) With a lowering of taper angle the frequencies of all modes are reduced. At the same time peak 1 is strengthened and peaks 3 and above weakened. The interval between peaks 1 and 2 is gradually widened, though the lowest angled, straight cone still has an interval that is 40 cents less than an octave.

b) Converting the lower part of the bore into a cylinder has a considerably greater flattening effect on the first mode than simply reducing the taper to give the same open end diameter (the 0.0108 taper). Only the first two modes are affected; the others are unchanged in pitch or strength (peak 4 is flattened just a little). The balance of strength tips the other way; here mode 1 is reduced considerably compared to a fully-conical bore, especially the lower angled of those, while the other mode strengths are the same as for the standard cone. It is as if the strengths and tunings of the higher modes are created in the conical part of the bore (nearer the reed), while the first and to a lesser extent the second modes are modified by the cylindrical part.

c) These results show some of the ways in which a maker may manipulate pitch, register tuning, response and possibly aspects of tone character through choices of gross bore shapes. In the following chapter some more specific bore shaping is discussed.

Afterword

Richard Smith studied the sound spectra produced by conical bores of differing taper angles, blown in a consistent way using an 'artificial mouth' apparatus.[39] The range of taper angles included those typical of bassoons. He found that the pitches of formants in the spectra sharpened with increased taper angle, and the distance between formants increased.

In a graph of the frequency spectrum of a sounded note, many harmonically related frequencies (partials) are present. Some of those have greater amplitude than others, and a frequency region containing stronger partials is called a formant. Different musical instruments seem to have different characteristic formant frequencies; early bassoons tend to have a formant region at around 400 Hz, which means that any partials, no matter what note is being played, that fall within that region, will be boosted in amplitude. The frequency of the first formant region, and the interval between first and second formants, have an important effect on how the overall tone quality of an instrument or voice is perceived.[40]

There does not seem to be a direct correlation between air column resonances as shown in impedance plots, and formant frequencies. The formants that Smith found all lie higher than the frequencies discussed above, with the lowest, for the least-tapered bore, at around 500 Hz, so they do not seem to exist as a direct consequence of the strongest air column modes as modelled here.[41] It is possible that they are instead related to the radiation characteristics of the cone; getting higher pitched and more widely spread as the diameter at the open end of the cone gets larger. There is also not a general raising of resonance strengths around 400 Hz, or any other frequency, in the impedance spectra calculated for the Poerschman bassoon discussed in the following sections.

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39 Smith, 'Factors'.
40 See Benade, *Fundamentals*, pp. 374-380.
41 Smith, 'Factors', p.12.

4.6 Anatomy of a fingering: a problem note on the Poerschman bassoon

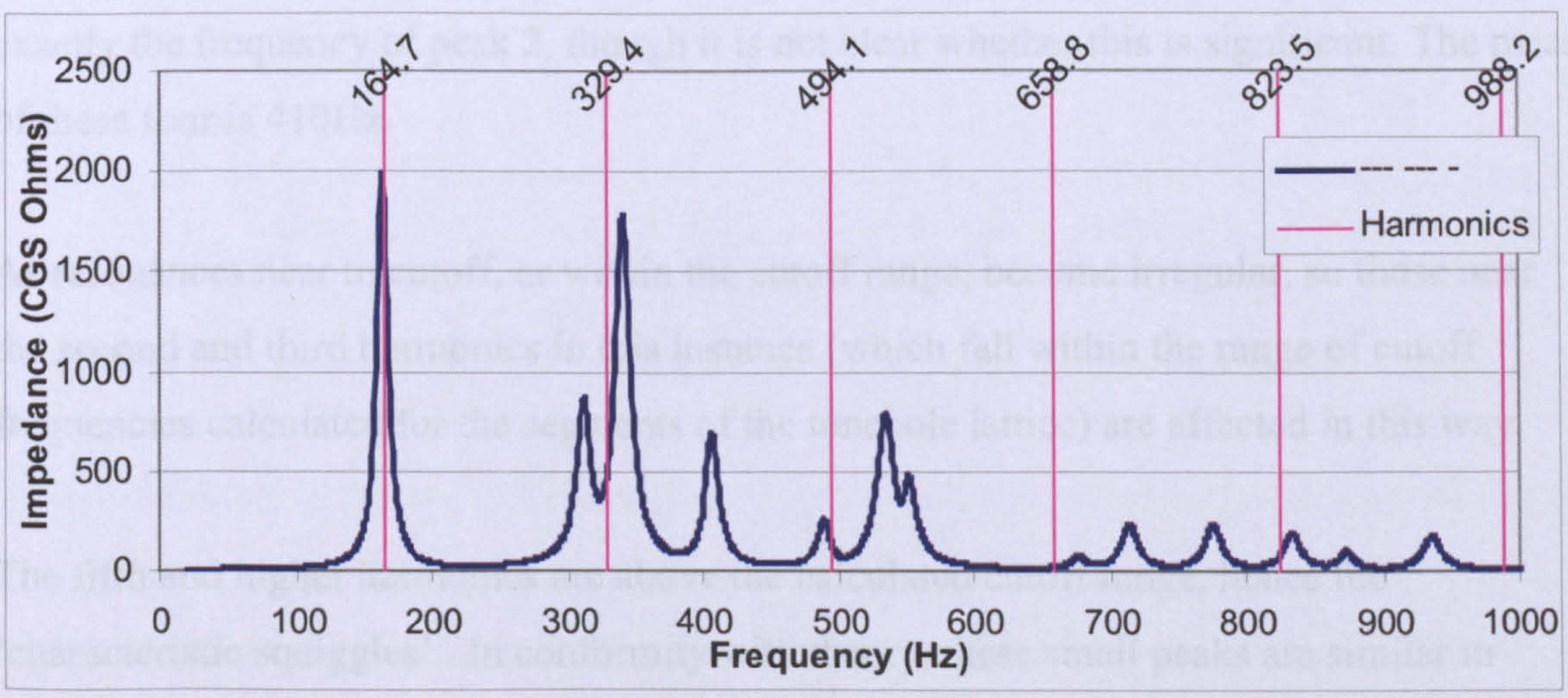
Impedance spectra can be related to an instrument's playing behaviour to aid the understanding of the qualities that the player experiences. Output from the *Impedps* program is used here to illuminate the issues behind a problematic note on the reconstructed Poerschman bassoon.

The problem

The all-fingers-off fingering (--- --- -), which is often used for F3, produces an unstable note: the pitch 'flips' back and forth between 24 cents sharp and nearly a semitone flat, although it is possible to play at the correct pitch at both dynamic extremes.

Analysis

The impedance graph for this fingering shows a strong first peak at 164Hz, just a little flat of the frequency of F3 (164.7Hz at A=415Hz). But at the second harmonic (329.4Hz) there is a pair of peaks straddling the desired frequency (the second and third peaks, 312 and 341Hz respectively). There is only a very small peak at the third harmonic, and another, poorly aligned one, at the fifth harmonic. The small peaks above the fourth harmonic are described by Cronin as 'the sum of weak reflections at the open holes and bell';[42] and by Benade as 'characteristic squiggles that an air column provided with many tone holes produces when excited above cutoff'.[43]



Graph 4.6.1. Impedance curve for the all-open fingering on the reconstructed Poerschman bassoon. Vertical lines with diagonal tags show the frequencies of the harmonics of F3 (A=415 Hz, equal temperament).

[42] Cronin, 'Understanding Auxilliary Fingerings', p.5.
[43] Benade, *Fundamentals*, p.461.

The irregular peaks around the second and third harmonics, and the small peaks above the fourth demonstrate two of the effects of tonehole lattice cutoff frequency. As stated in Section 4.1, high frequency waves in the bore have difficulty shifting the masses of air in open toneholes, so the tonehole lattice appears closed to high frequencies. The frequency at which this happens depends on the sizes (diameter and length) of the open holes, and the spacings between them. Benade gives an equation for a simplified situation where toneholes are equally spaced and equal in size:

$$f_c = 0.110(b/a) \times V/\text{sqrt}(s \times t_e)$$

Where a = bore radius, b = tonehole radius, t_e = tonehole height plus end correction of 1.5b, s = half the distance between open holes, V = speed of sound.[44]

The toneholes on this bassoon are by no means evenly spaced, and vary significantly in size, so if this formula is applied to successive segments of the lattice at each tonehole, the results range from 562Hz down to 242Hz, with an average of 402Hz. Benade states that:

> If the lattice is irregular, theory shows that: 1) if the first and second open-hole segments of the lattice (taken by themselves) have widely different cutoff frequencies, the observed value of f_c for the composite system has an intermediate value for its cutoff frequency; and 2) at the lower frequencies, the properties of the first segment still dominate the implications of f_c.[45]

The first two segments here – at toneholes I and II – have calculated f_cs of 494 and 562Hz respectively, while at the next segment it is much lower because of the small, deep hole III and the greater distance between III - IV: f_c is 272Hz. That at hole IV is 311Hz, almost exactly the frequency of peak 2, though it is not clear whether this is significant. The mean of these four is 410Hz.

As resonances near to cutoff, or within the cutoff range, become irregular, so those near the second and third harmonics in this instance (which fall within the range of cutoff frequencies calculated for the segments of the tonehole lattice) are affected in this way.

The fifth and higher harmonics are above the calculated cutoff range, hence the 'characteristic squiggles'. In conformity with theory, these small peaks are similar in strength (height) and spacing to those of full-bore-length notes (Bb1 and C2), as can be seen in the following graph, which focuses on the higher frequency range:[46]

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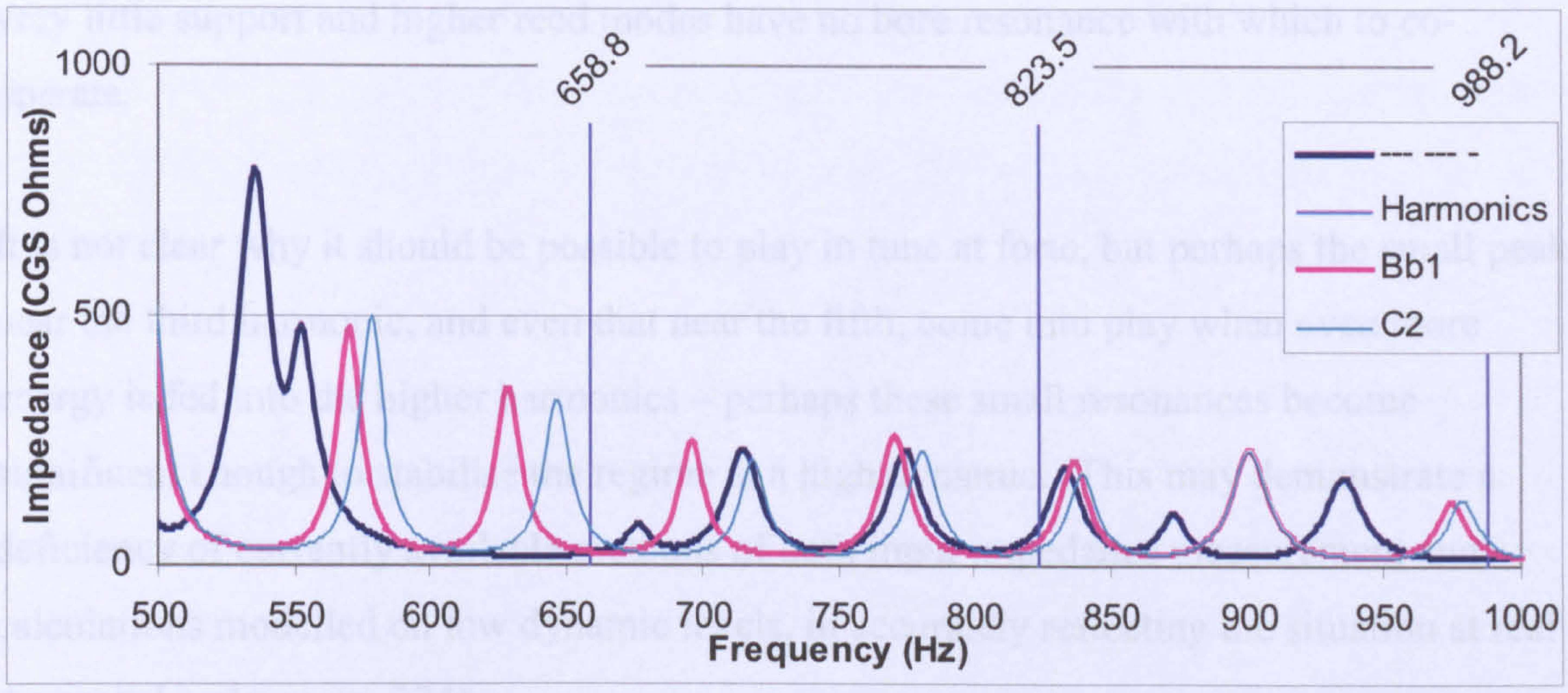
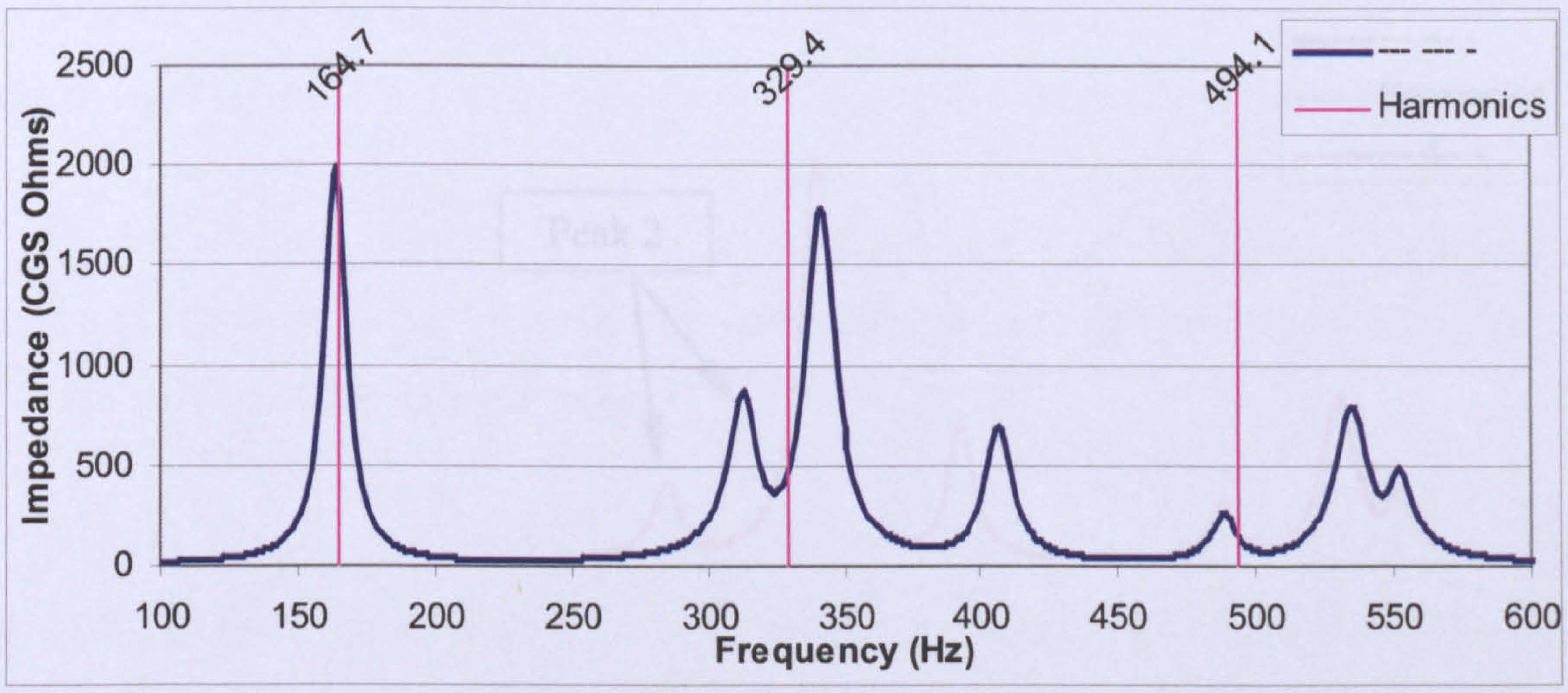
[44] Benade, *Fundamentals*, p.449.
[45] Ibid.
[46] See p. 267 and note 19.



Graph 4.6.2. Impedance curves for F3 (all open), Bb1 and C2 compared in the high frequency range

Returning to the analysis of the all-open F3 fingering; there is little significant support for harmonic frequencies above cutoff, so here the impedance graph is restricted to the lower frequency range, where the peaks of interest lie:



Graph 4.6.3. Impedance curve for all-open fingering, showing the first three harmonics

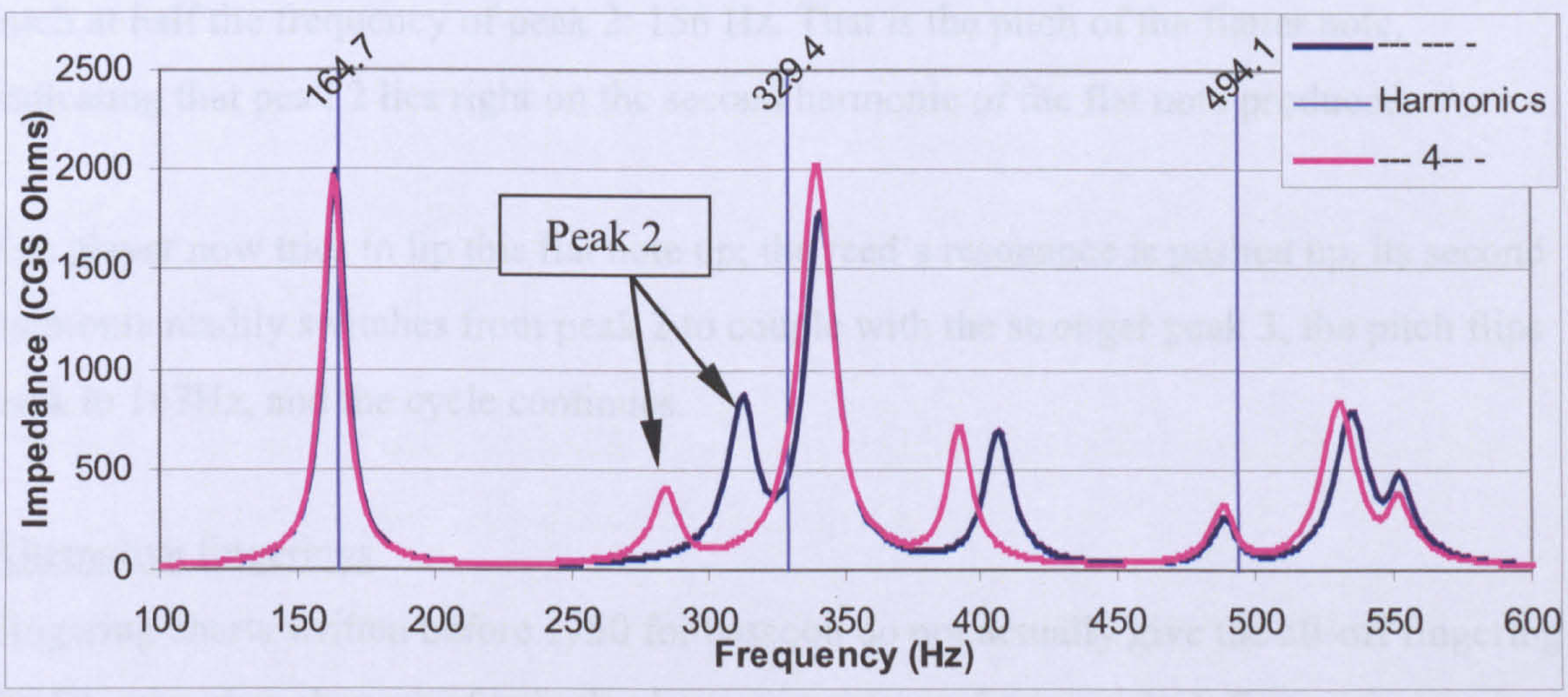
If the air column is to play at F3 it must do so only with the support of the bore resonance at the fundamental. This will work at a low dynamic level when the reed vibrates in a close to sinusoidal manner, producing just one frequency which can lock onto this one bore resonance, though the resulting note is a rather weak one.

As the dynamic is increased, the reed puts more energy into higher harmonics of its vibration frequency, and the second of these will 'hunt around' for a bore-resonance to co-operate with, finding only these two out-of-tune ones. The third harmonic finds only a very little support and higher reed modes have no bore resonance with which to co-operate.

It is not clear why it should be possible to play in tune at forte, but perhaps the small peak near the third harmonic, and even that near the fifth, come into play when even more energy is fed into the higher harmonics – perhaps these small resonances become significant enough to stabilise the regime at a high dynamic. (This may demonstrate a deficiency of currently available methods of both input impedance measurement and calculations modelled on low dynamic levels, in accurately reflecting the situation at real dynamic levels, see p. 274).

Understanding the effect

To help understand what is happening, a variant fingering which forces the system to play the higher of the out of tune notes can be analysed. It is found that by closing hole IV the higher note sounds, the lower one is no longer available and neither is the desired, in-tune F3.



Graph 4.6.4. Impedance curves for two fingerings

In the impedance graph (pink line) it is clear that the second peak has been reduced both in strength and in frequency (now 284Hz). The cutoff frequency of the lattice segment at tonehole IV matched the previous peak 2; now that hole is closed, there is a longer segment between the open holes III and V which reduces the f_c for each segment at those two holes. They are now 249 and 286Hz respectively, the latter very close to the new peak 2, (but again whether this is in itself significant, is not clear).

Peak 2 is now so low pitched that it cannot hope to co-operate with the first impedance peak in any regime. The third peak, however has been made stronger (taller), also a little flatter in pitch. It is now slightly taller than that at the fundamental and it seems that it has the strength to take over control of the system, and pull the pitch of the resulting note upwards.

This appears to explain what happens with the all-open fingering when the higher pitch is produced: the second harmonic produced by the reed finds the strong third resonance; it is strong enough to take partial control of the reed and pull the pitch upwards. The resulting playing pitch of circa 167 Hz is halfway between that of the 1st peak at 164Hz and half that of the third peak: 170.5Hz.

Now the player, faced with this sharp note, tries to *lip it down*; changing the lips' positions on the reed and thus their damping effect, increasing the reed's equivalent volume and lowering its resonant frequency to pull the pitch down. As the reed's vibrating frequency is forced down, its second harmonic decouples from the third peak resonance because that is now too high, and links instead with the second peak, providing a (relatively) stable pitch at half the frequency of peak 2: 156 Hz. That is the pitch of the flatter note, indicating that peak 2 lies right on the second harmonic of the flat note produced.

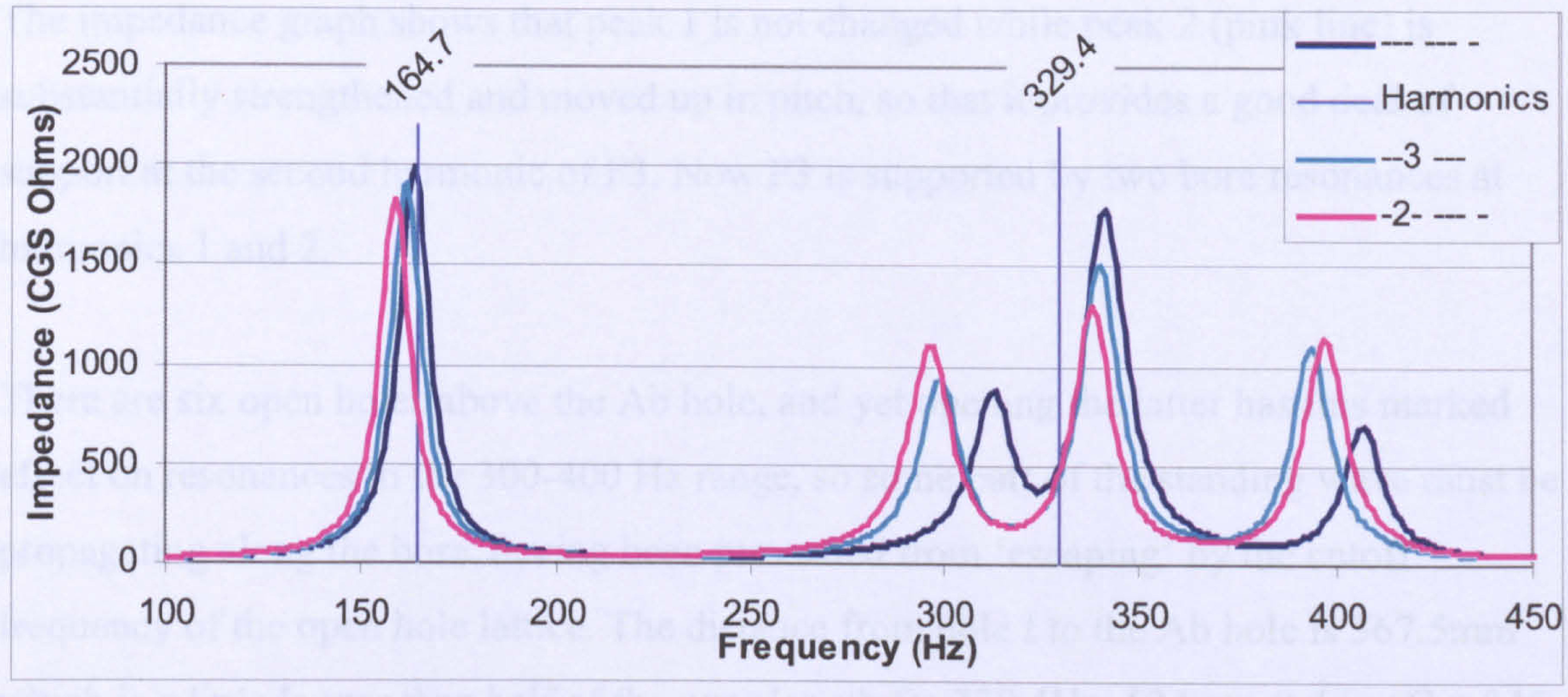
The player now tries to lip this flat note up; the reed's resonance is pushed up, its second harmonic readily switches from peak 2 to couple with the stronger peak 3, the pitch flips back to 167Hz; and the cycle continues.

<u>Alternative fingerings</u>

Fingering charts written before 1750 for bassoon do not actually give the all-off fingering for F3, even though most of today's players seem to prefer to use it. It first appears reliably dated in Diderot in 1751, then becomes common from Ozi in 1787 onwards.[47] The earlier charts all give -2- --- - (the same as for C5 on the baroque oboe), and one later one gives -3 --- -.[48] Using these fingerings on this instrument no 'flipping' is experienced, but as might be expected, both produce lower pitched notes than all-fingers-off, with -2- being flatter than --3. They are both too flat, but can be pushed up in pitch with embouchure adjustments.

[47] Paul, J.White, 'Early Bassoon Fingering Charts', *GSJ*, 43, (1990), 112-124. See also Appendix 2 and discussion of fingering charts in section 5.3.

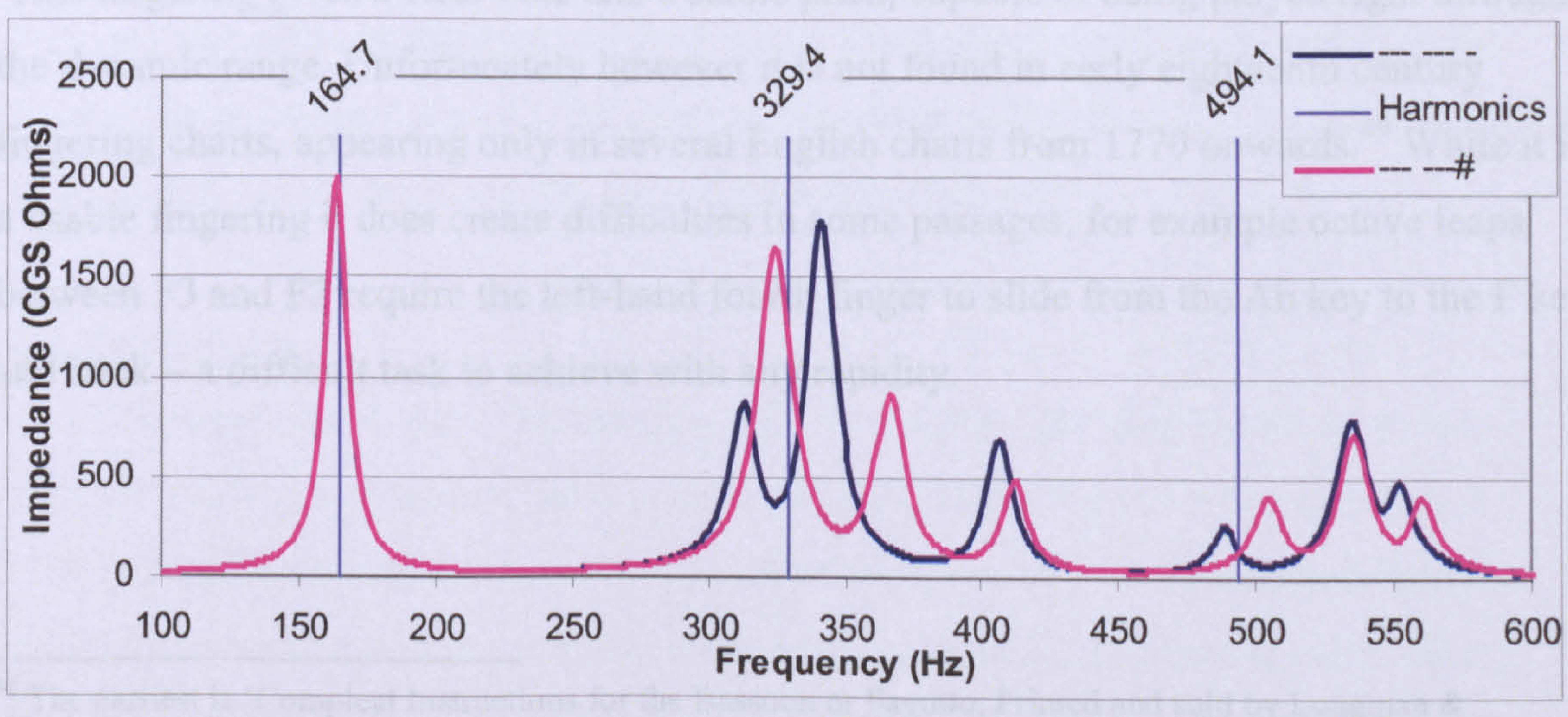
[48] Pierre Cugnier in Jean-Benjamin de Laborde, *Essai sur la musique*, (Paris: 1780).



Graph 4.6.5. Impedance curves for three fingerings

The impedance graph for these fingerings show the first peaks are flatter than F3 as expected: 161.6Hz (-33 cents) and 158.8Hz (-63 cents). No useful changes are made above 450 Hz. The second and third peaks are spaced wider apart; peaks 2 significantly flatter, peaks 3 less so. Importantly, peaks 3 are less tall, and peaks 2 taller by similar amounts, so now the peaks 3 do not have the strength to take control of the regime. The pitch produced by each fingering is that of its first peak and there is no 'flipping' to a higher pitch. The note is produced with the support only of the bore resonance at peak 1 (at all dynamic levels), so it is rather weak and muffled sounding, as well as flat. This is not a satisfactory solution to the need to play in tune.

One further fingering was found that does work: opening the G#/Ab key, the one closed-standing key, to make all the holes on the instrument open.



Graph 4.6.6. Impedance curves for two fingerings

The impedance graph shows that peak 1 is not changed while peak 2 (pink line) is substantially strengthened and moved up in pitch, so that it provides a good deal of support at the second harmonic of F3. Now F3 is supported by two bore resonances at harmonics 1 and 2.

There are six open holes above the Ab hole, and yet opening the latter has this marked effect on resonances in the 300-400 Hz range, so some part of the standing wave must be propagating along the bore, having been prevented from 'escaping' by the cutoff frequency of the open hole lattice. The distance from hole I to the Ab hole is 567.5mm which is a little longer than half of the wavelength for 329.4Hz: 524mm (taking C = 345 m/s). If there is a pressure node at hole I (it will actually be a little further along the bore due to end correction), then for a wave of that frequency propagating beyond hole I, there will be another node near to the Ab hole, and opening the hole will help that node to be established.

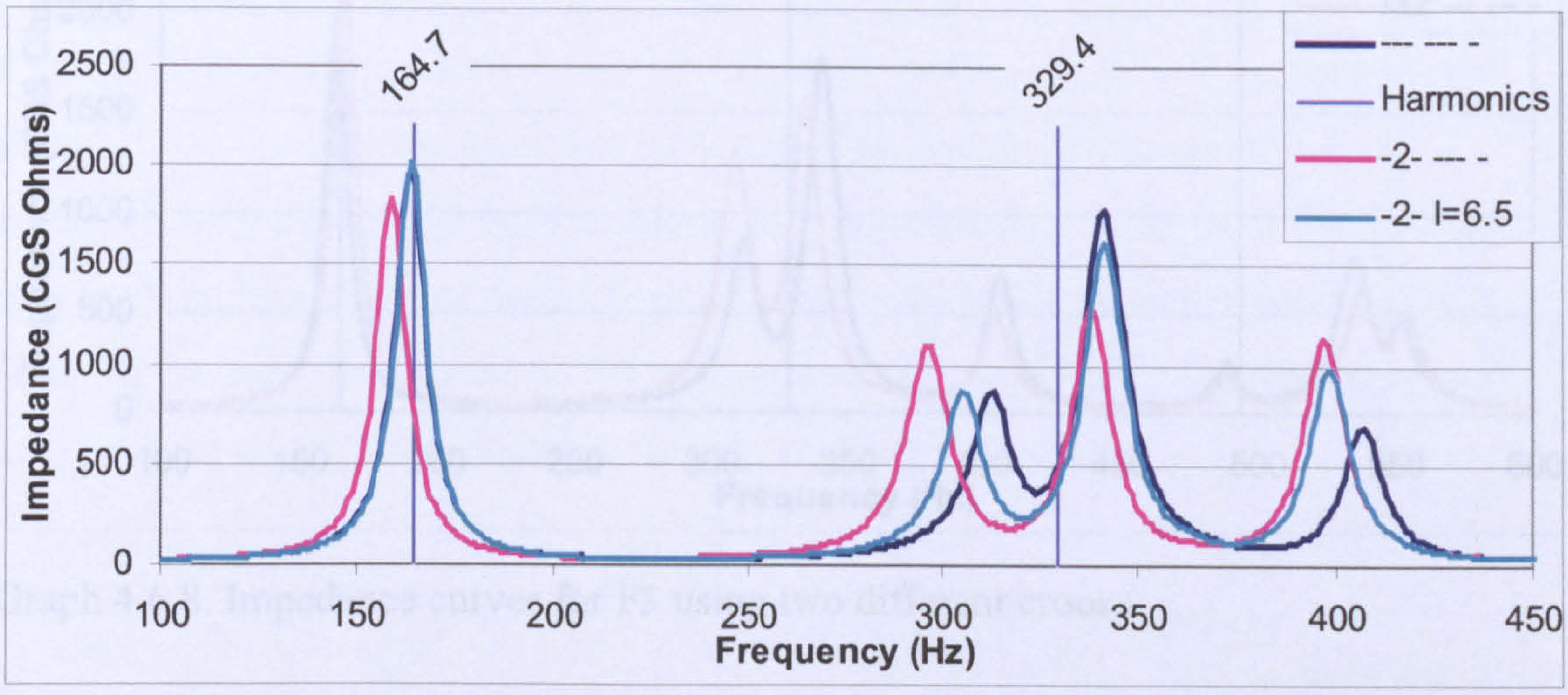
Thus the Ab hole acts as a vent for the second bore mode but, unlike a normal register vent, it does not force the note into the second register because the first mode frequency has a strong reflection at hole I and does not propagate this far down the bore. However it can act this way only if its own cutoff value is higher than 329.4Hz, otherwise it will appear closed to that wavelength even when the key is open. With a hole of 5.2 diameter and chimney of 11mm, its cutoff is c. 311Hz, but if the hole is undercut to reduce its effective length to 9mm, cutoff is raised to c. 344Hz.

This fingering gives a clear note and a stable pitch, capable of being played right through the dynamic range. Unfortunately however it is not found in early eighteenth century fingering charts, appearing only in several English charts from 1770 onwards.[49] While it is a usable fingering it does create difficulties in some passages, for example octave leaps between F3 and F2 require the left-hand fourth finger to slide from the Ab key to the F key and back – a difficult task to achieve with any rapidity.

[49] The earliest is 'Compleat Instructions for the Bassoon or Fagotto, Printed and sold by Longman & Broderip, No26 Cheapside', first published c. 1770. See Halfpenny, 'Earliest English Bassoon Tutor', p.103, and Dart, 'Early English Bassoon Fingering Charts'.

Retuning by adjusting the toneholes

Since the early fingering charts give the fingering -2- --- -, perhaps attempts should be made to make this work. In the current configuration it gives too flat a note, so hole I could be enlarged to bring the note up to pitch. Unfortunately the impedance graph does not look promising:



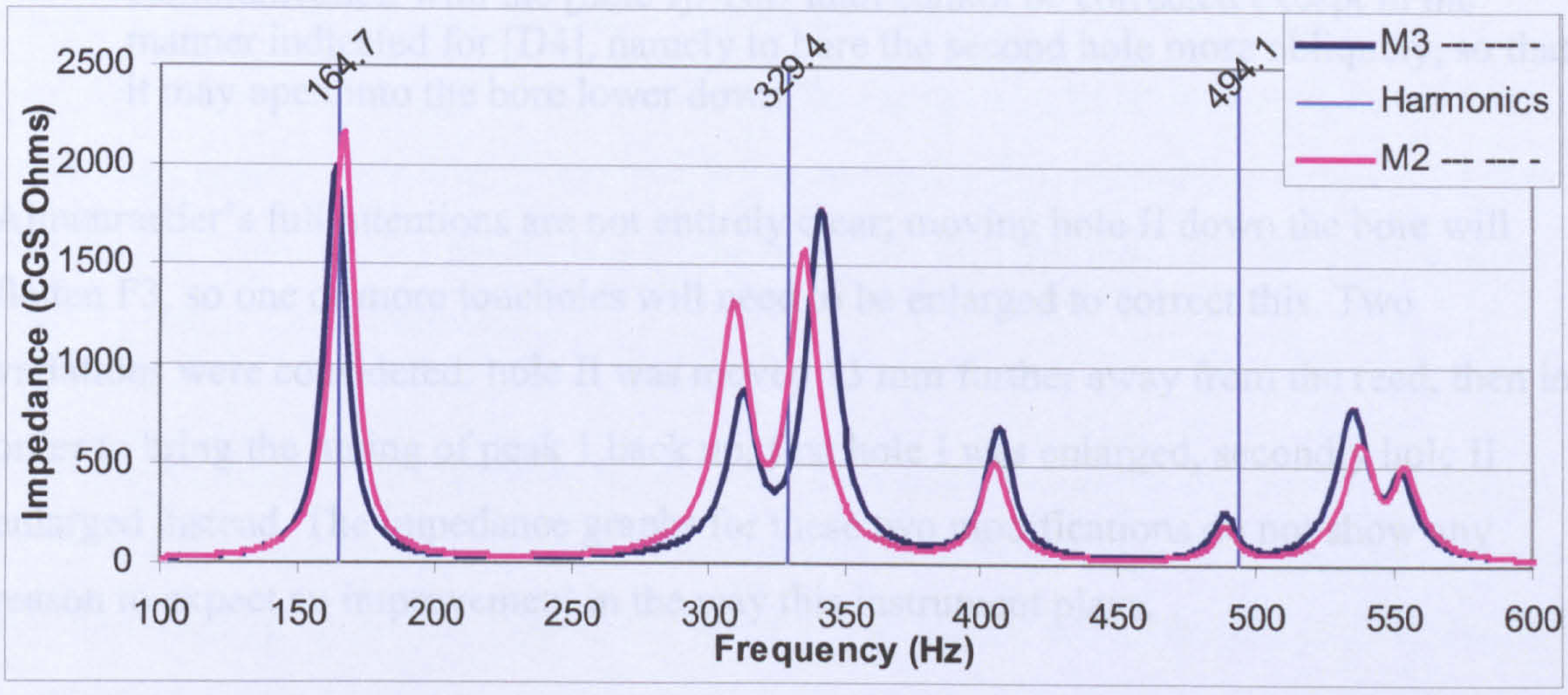
Graph 4.6.7. Impedance curves showing effect of enlarging hole I to 6.5mm

The pink line shows again the impedances for -2- --- - and the cyan line shows effects when the diameter of hole I is enlarged to 6.5mm (previously 5mm) to bring peak 1 back into tune. Now peak 2 has been sharpened, but also reduced in strength to much the same value as the all-off fingering (dark line). Peak 3 has increased in strength to almost match that of all-off fingering and the impedance values at the frequency of harmonic 2 are much the same for all three curves.

So when hole I is enlarged to sharpen -2- --- -, the situation with peaks 2 and 3 returns to (close to) that of the problematic starting point. The flatter frequency of peak 2, or the wider distance between 2 and 3, may reduce the potential for 'flipping' but there is still no good support for the regime at the second harmonic frequency.

Alternative crooks

Two different crook designs were prepared for this instrument; they are found to have different qualities and several notes behave differently between these two (see Graph 5.2.1 for bore profiles). Crook M3 was used for all of the above tests and comments but when crook M2 is used instead the problem is improved somewhat. The note is more stable; although it can still 'flip', the difference between the two pitches is less and there is less of a noticeable step between them. The pitch still feels uncertain and un-centred (there is no stable 'slot' at the desired pitch), but it is possible to play an in-tune F3. The fingering --3 is more stable and although flat, it is easy to lip up. -2- is too flat to comfortably push up.



Graph 4.6.8. Impedance curves for F3 using two different crooks

The impedance graph shows the difference; peaks 2 and 3 have been reduced in frequency and are more equal in strength. The impedance value at the frequency of harmonic 2 is significant so some support for that frequency is provided. Peak 1 is a little sharper, so a preferred playing frequency of around 166.5Hz is indicated and the second harmonic of this (333Hz) is close to the top of peak 3 also. So a sharp note is predicted, but this is not particularly apparent when playing, the small amount of lipping-down required is easily applied. It should not be surprising that a change in crook design should have a significant effect on this note as such a large proportion of the wavelength resides there. However M3 continued to be preferred for other reasons, see p. 361.

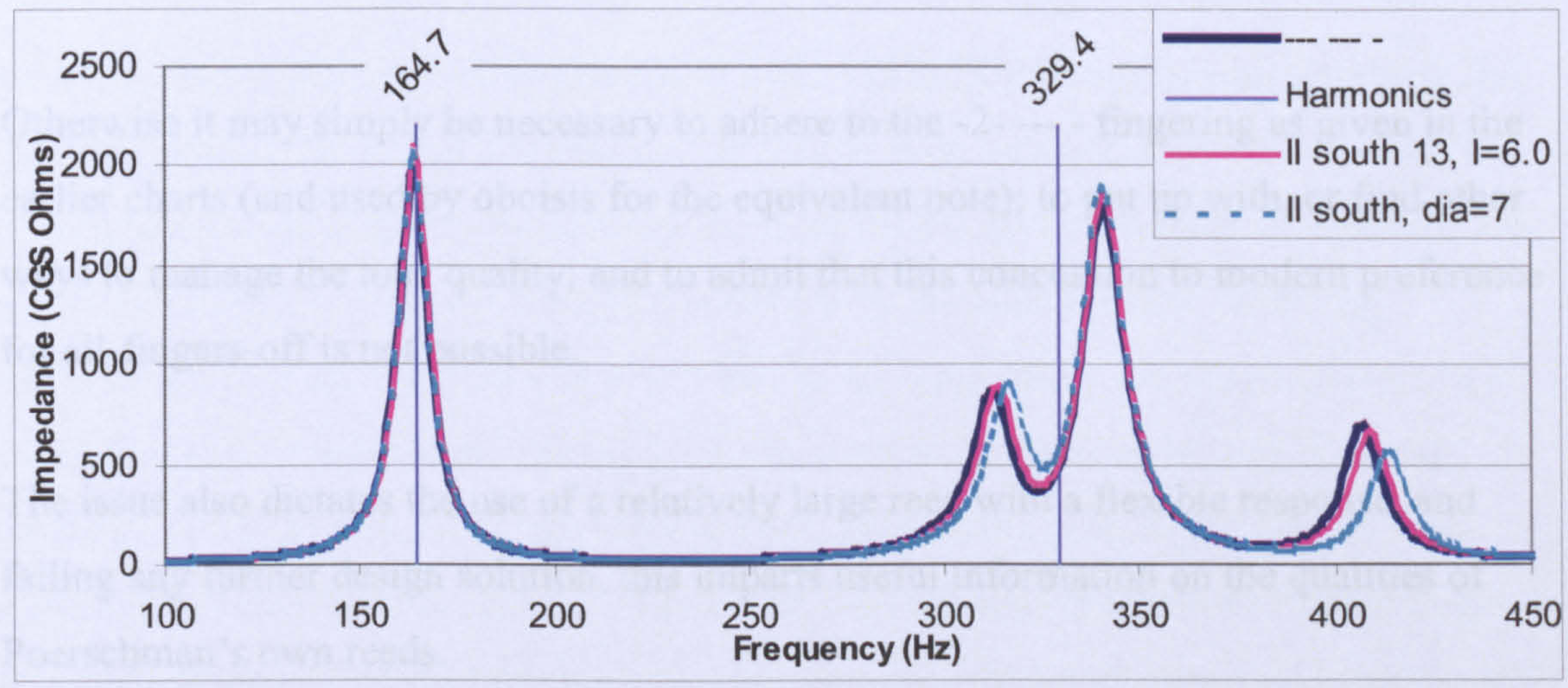
Moving toneholes

One further avenue to be pursued arises from the instructions on adjusting of bassoons by Almenraeder in his Chapter XVIII 'On various faults occasionally met with on a bassoon, and which may often be overcome with a little trouble'.[50] In Section 4 he discusses F3 with the all-fingers-off fingering and, although these directions are for a bassoon of later design, the problem identified here seems to be very much the same:

[50] Carl Almenraeder *Die Kunst des Fagottblasens,* (Mainz: Schott, 1842/43)

> The note F3 is sometimes not sufficiently certain, and by a slightly stronger embouchure can be raised as easily as it can be lowered by a light embouchure. The cause is usually that [hole II] is not bored with sufficient obliqueness downwards, or that the wood is not thick enough, thus causing too much communication with the [hole I]. This fault cannot be corrected except in the manner indicated for [D4], namely to bore the second hole more obliquely, so that it may open into the bore lower down.[51]

Almenraeder's full intentions are not entirely clear; moving hole II down the bore will flatten F3, so one or more toneholes will need to be enlarged to correct this. Two variations were considered: hole II was moved 13 mm further away from the reed, then in order to bring the tuning of peak 1 back up, first hole I was enlarged, secondly hole II enlarged instead. The impedance graphs for these two modifications do not show any reason to expect an improvement in the way this instrument plays.



Graph 4.6.9. Impedance curves: moving and enlarging toneholes

The pink line shows the effects of moving hole II 13mm south and enlarging hole I to 6mm (previously 5mm). It is very little different from the starting conditions (dark line). The cyan line shows the effect of moving hole II as before, this time enlarging hole II to 7mm (previously 5.5mm). There is a very slightly increased impedance value at the second harmonic frequency: peaks 2 and 3 are a little closer together, but peak 3 is still tall and sharp pitched. Again it seems that once peak 1 is brought back into tune by enlarging holes I or II, peaks 2 and 3 return stubbornly to their problematic positions and strengths.

[51] Tranlation by William Bailey. See Appendix 1 for the translation of the whole chapter.

Conclusions

This analysis of one note shows the sort of difficulties that can occur when a crucial harmonic frequency lies near to the cutoff frequency. F3 is the highest of the fundamental notes – those using the first resonance of their bore configuration – and its second harmonic frequency is high enough to reach into the open-hole-lattice cutoff range. The impedance graphs show that odd effects occur to resonances around this frequency range, and the fingering --- --- # shows that changing the air column well beyond the first open hole can affect these resonances.

A design solution to this problem is not obvious, though that of the crook seems likely to be critical here. Further experiments aimed at finding a new design of crook, one that has the beneficial effect on this note of M2 while not losing the other benefits of M3, should be pursued.

Otherwise it may simply be necessary to adhere to the -2- --- - fingering as given in the earlier charts (and used by oboists for the equivalent note); to put up with, or find other ways to manage the tone quality; and to admit that this concession to modern preference for all-fingers-off is not possible.

The issue also dictates the use of a relatively large reed with a flexible response, and failing any further design solution, this imparts useful information on the qualities of Poerschman's own reeds.

Chapter 5

Reconstructing the Poerschman Bassoon

In Chapter 3 many different designs were discussed in as far as they can be assessed visually and by measurements; however these assessments do not tell us how the instruments play. We do not have a database correlating aspects of design to playing characteristics of these instruments and the only way to build up such knowledge would be to thoroughly test each one. This would be a mammoth undertaking and is anyway already thwarted by several considerations: only a small percentage of the measured instruments are in good playable condition, most have at least their crooks missing, if not other damage as well, and their owners or curators are reluctant to allow any, or more than a very little playing in case further damage is caused.

An alternative to playing the originals is to make carefully considered reproductions and use them instead. Of course this route too is fraught with difficulties and drawbacks; the reproductions should ideally be accurate in all necessary details, but just what details are necessary? Bore and tonehole dimensions have been discussed (under measuring methodology) but are those all that is needed? In any case, those measurements are of an instrument in its current state, having been subjected to the ravages of time, use and handling. There is no point in reproducing a damaged instrument, so the current state needs to be extrapolated backwards to calculate the design of the instrument as it might have been when first made, and this, of course, requires some judgement and some leaps in the dark. So there can be few claims to scientific objectivity in this process, but then it is difficult to find objective criteria for assessing the playing qualities of an instrument anyway; so much is to do with how it feels to the player when used as a tool for musical expression. Nevertheless it was thought to be a worthwhile endeavour for the reasons set out under 'aims' below.

My past experience in reconstructing baroque bassoons has been of an early model, a three-keyed bassoon by J.C. Denner, Brussels M427. This is a good representative of the Type 1b design and of the first generation of German bassoons, made by perhaps the best-known woodwind maker of that generation. For the purpose of this study it was decided to take a later instrument of contrasting design and Poerschman was chosen. His bassoons are of interest for a number of reasons. Firstly, they are from Leipzig from the period when that city was particularly important for baroque music, and a large proportion of the repertoire for today's players of baroque bassoons comes from there in the Passions, Cantatas and B Minor Mass of J.S. Bach. There was also a strong link to the musical establishment of August the Strong in Dresden and because woodwind making was not much in evidence there until the next generation, it is likely that Leipzig-made woodwinds were used by the virtuoso players there. There is a large corpus of music for today's players by composers associated with the Dresden court of the time such as Lotti, Petzold, Zelenka, Heinecken, Graun, and Quantz.

Secondly, of the two known bassoon makers from Leipzig in the first half of the eighteenth century from whom bassoons survive, other current makers reproduce those of Eichentopf, so reconstructing Poerschman's bassoons will provide new information for today's players. Thirdly, Poerschman was evidently a maker of good standing; he trained the two most important makers of the next generation as well as his two sons. He was also a player of some capability, having been first bassoon in the Grosse Conzert where he would have played the latest and most fashionable music in public performances (playing new music from sight). The implications of these are that he would have had both a clear idea of desirable playing characteristics and the skills to produce a bassoon that worked the way he wanted it to. There is also the possibility that he might have wanted to experiment with design beyond what a non-performing maker might produce.

Another consideration is that, amongst the variety of pitch standards held in different cities and courts, the pitch used for chamber music in Leipzig in Bach's time was in the region of a semitone below modern concert pitch; around A=415 Hz.[1] This is the same pitch that the Denner model plays at and is, of course, the standard used today for the performance of baroque music on period instruments. This makes it easier to compare the two reproduced models and to test them in ensembles.

Aims

To illustrate the considerations required to extrapolate backwards from measurements of the surviving parts of the two bassoons to their original dimensions.

To produce a bassoon as Poerschman would have made, so as to have an instrument that is like a new one from his workshop.

To identify the specific elements of his design and the tools used, to gain some understanding of how he used them to adjust the playing characteristics.

[1] Haynes, *HoPP*, pp.231-232.

To test this instrument and see how it plays with respect to requirements and expectations of its period (as represented in repertoire and fingering charts).

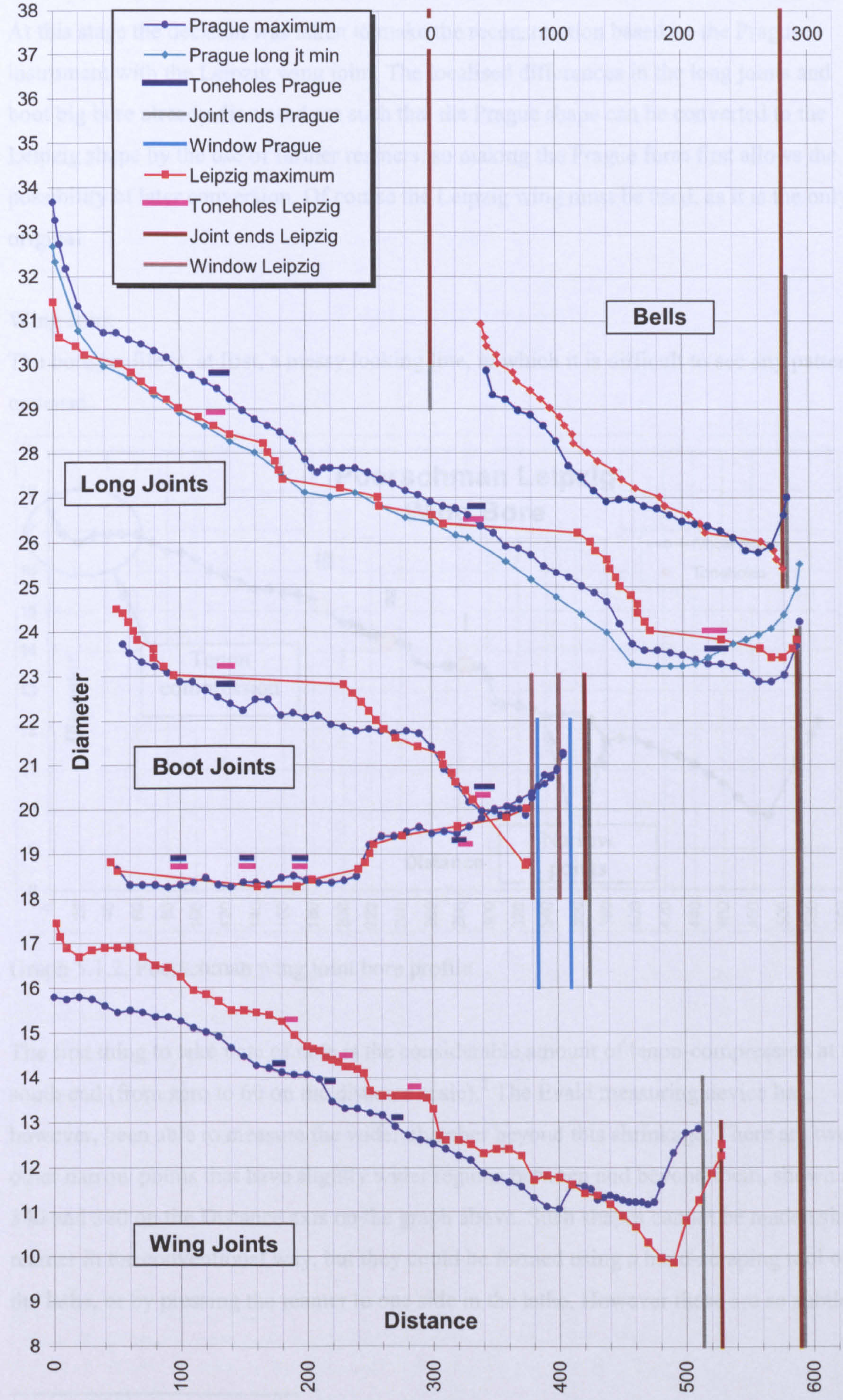
To provide the opportunity to compare characteristics with an already-prepared and familiar reproduction of a J.C. Denner bassoon; thus two German instruments from different generations and of different design styles. Since Denner was of the first German generation of baroque bassoon makers and Poerschman's successors created a quite new design, these two can be seen as representing the beginning and end of German baroque bassoon making.

5.1 Designing the reconstruction, or reconstructing the design

The condition of Poerschman's two bassoons has been discussed in Chapter 3. To summarise: the Leipzig instrument has had a complete refit of keywork sometime in the late eighteenth to early nineteenth century. It appears to have been retuned to a higher pitch by enlarging of at least some of the toneholes, but the joints do not seem to have been shortened substantially; perhaps just the long and wing joints by around 5 mm each. The Prague bassoon has not been so much altered but the original wing is missing and some of the bore, particularly in the boot joint, is in a damaged condition. This one may also have been tuned up in pitch a little, but that is by no means definite, and again joints have not been shortened.

Apart from the wings, the joints of the two bassoons match in length to within a few millimetres; the greatest difference is between the bells where the Prague bell is 4mm longer than the Leipzig (see Table 3.4.4.3.). Comparing the bores shows that they are both of much the same design; there are just two areas where the Leipzig bassoon has been reamed further than the Prague. This in turn implies that the bore of the Leipzig wing, the one original wing left, has also not been altered.

The bores of the two are plotted together in the graph below, along with tonehole positions (where they enter the bore), joint ends, and the windows in the boots. Only the maximum diameter bore measurements are shown for clarity, apart from the Prague instrument's long joint where there is a curious correspondence between the minimum diameter of that instrument and the maximum of the Leipzig long joint from 0 to 300 on the distance scale.

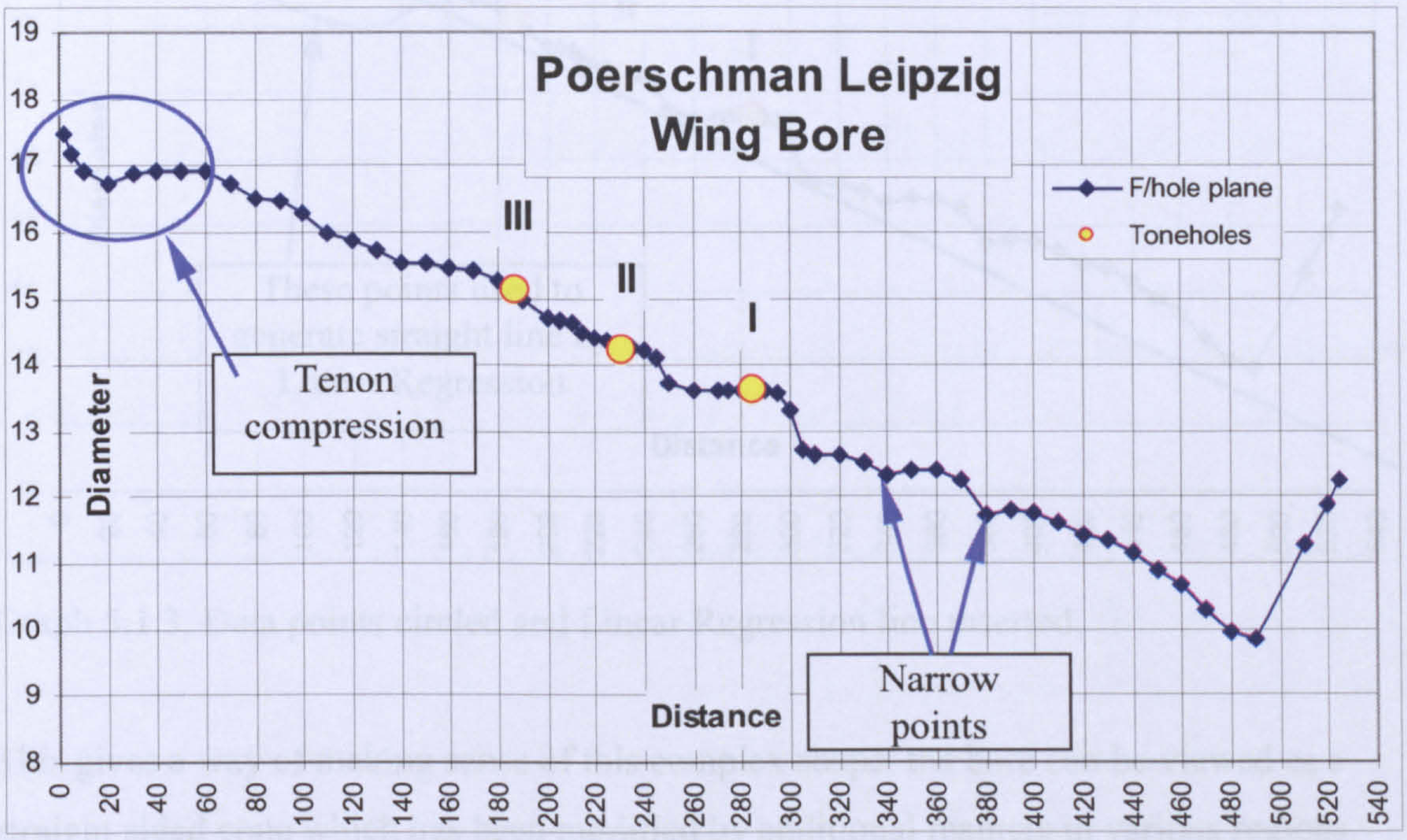


Graph 5.1.1. Poerschman bassoons in Prague and Leipzig compared

At this stage the decision was taken to make the reconstruction based on the Prague instrument with the Leipzig wing joint. The localised differences in the long joints and boot big bore already discussed are such that the Prague shape can be converted to the Leipzig shape by the use of further reamers, so making the Prague form first allows the possibility of later conversion. Of course the Leipzig wing must be used, as it is the only original.

Wing Joint

The bore profile is, at first, a messy looking line, in which it is difficult to see any pattern or sense.



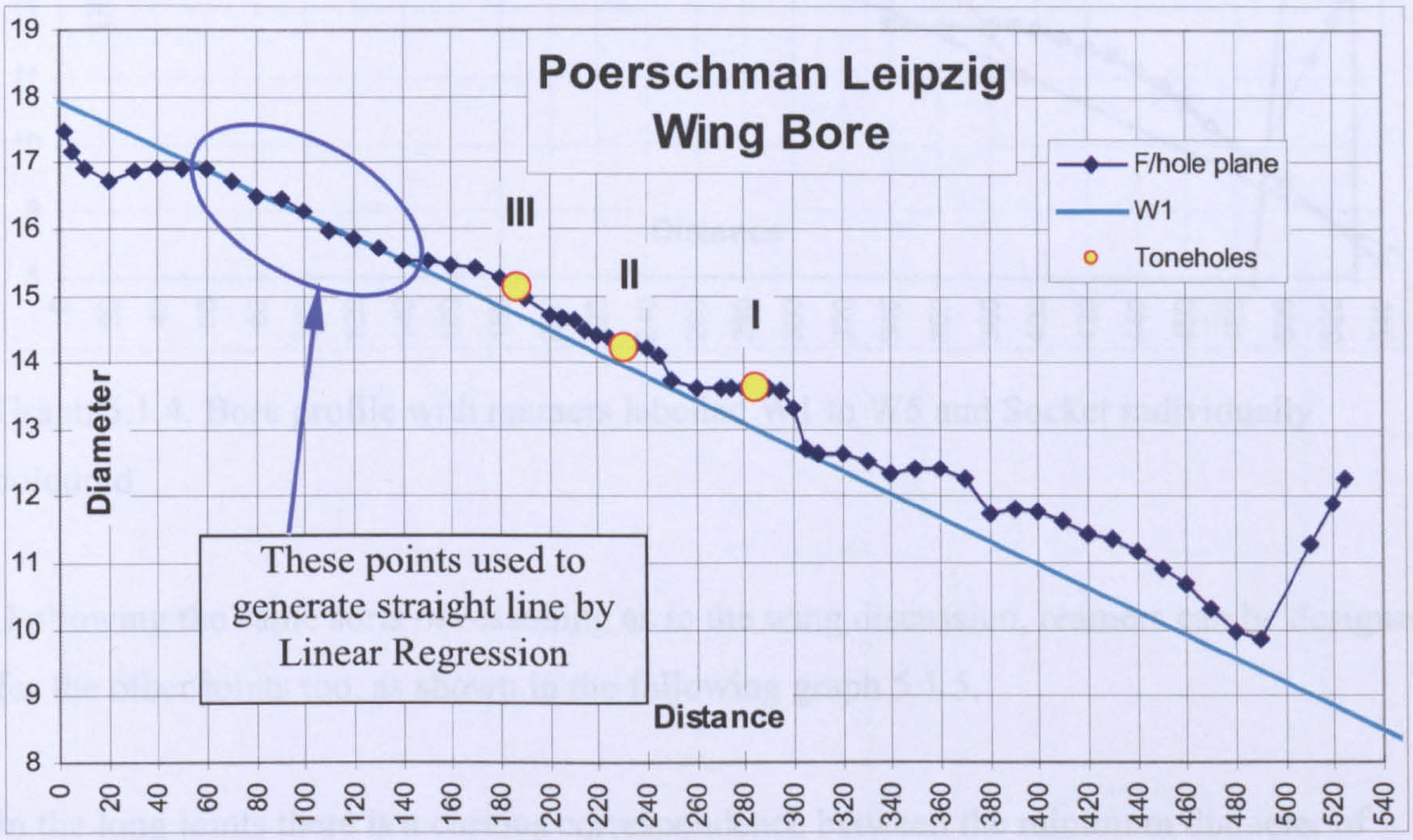
Graph 5.1.2. Poerschman wing joint bore profile

The first thing to take note of note is the considerable amount of tenon-compression at the south end (from zero to 60 on the distance scale).[2] The Evald measuring device has, however, been able to measure the wider chamber beyond this shrinkage. There are two other narrow points that have slightly wider regions between and beyond them, shown at 340 and 380 on the Distance axis on the graph above. Such shapes cannot be made using a reamer in the conventional way, but they could be formed using a hand-scraping tool off the lathe, or by pressing the reamer to one side in the lathe. However these are so subtle as

[2] See Chapter 2, section 2.3: Interpretation, where this sort of damage and its causes are discussed.

to suggest that the narrow points that bound these chambers are simply patches of dirt or old oil, or that some eccentric shrinkage or warping has taken place.

Looking next at the section next in from the shrunken tenon region, from 60 to 140 distance; the data here very closely approximates a straight line, in fact if *Linear Regression* analysis is used on these data points it gives a line right through them and touching some other points further along the bore.[3]



Graph 5.1.3. Data points circled and Linear Regression line inserted.

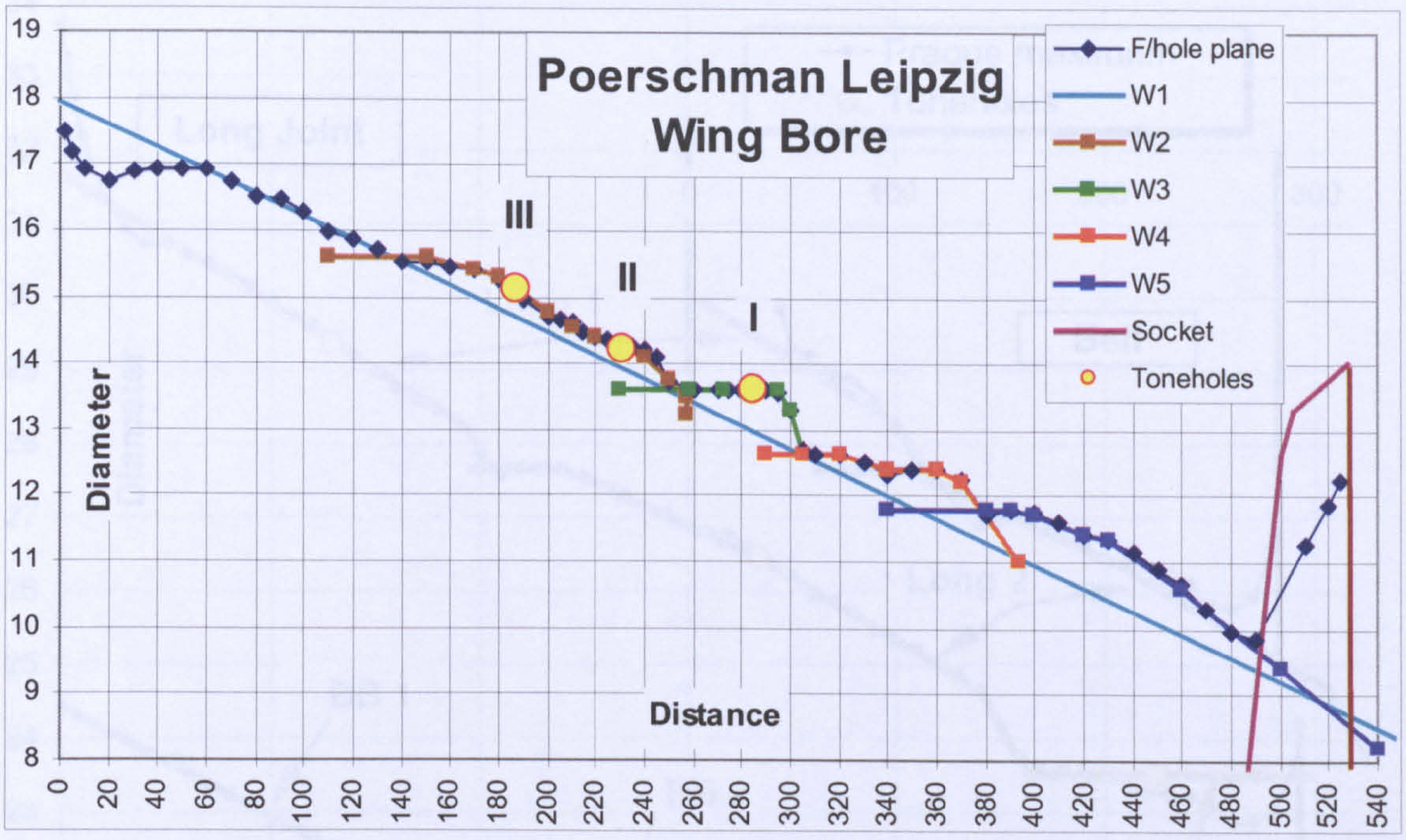
This gives a way of making sense of this complex shape; the bore can be viewed as a straight sided cone which has been modified by additional reamers in various regions. First, there is a simple solution to the reconstruction of the bore in the tenon region – as a continuation of the straight line.

Second, considering that a concave shape in the bore wall is difficult to produce on a reamer but that straight tapers and convex shapes are easier (see section on construction tools and methods), then the bore can be broken down into the separate reamers required for each convexity.

Third, a new socket for the crook is designed with the same depth but a wider opening.

[3] Linear Regression is a statistical method for finding a best-fit straight line from a collection of (x,y) values. Here the *ordinary least squares* method is used to find the line $y = A + Bx$ where:

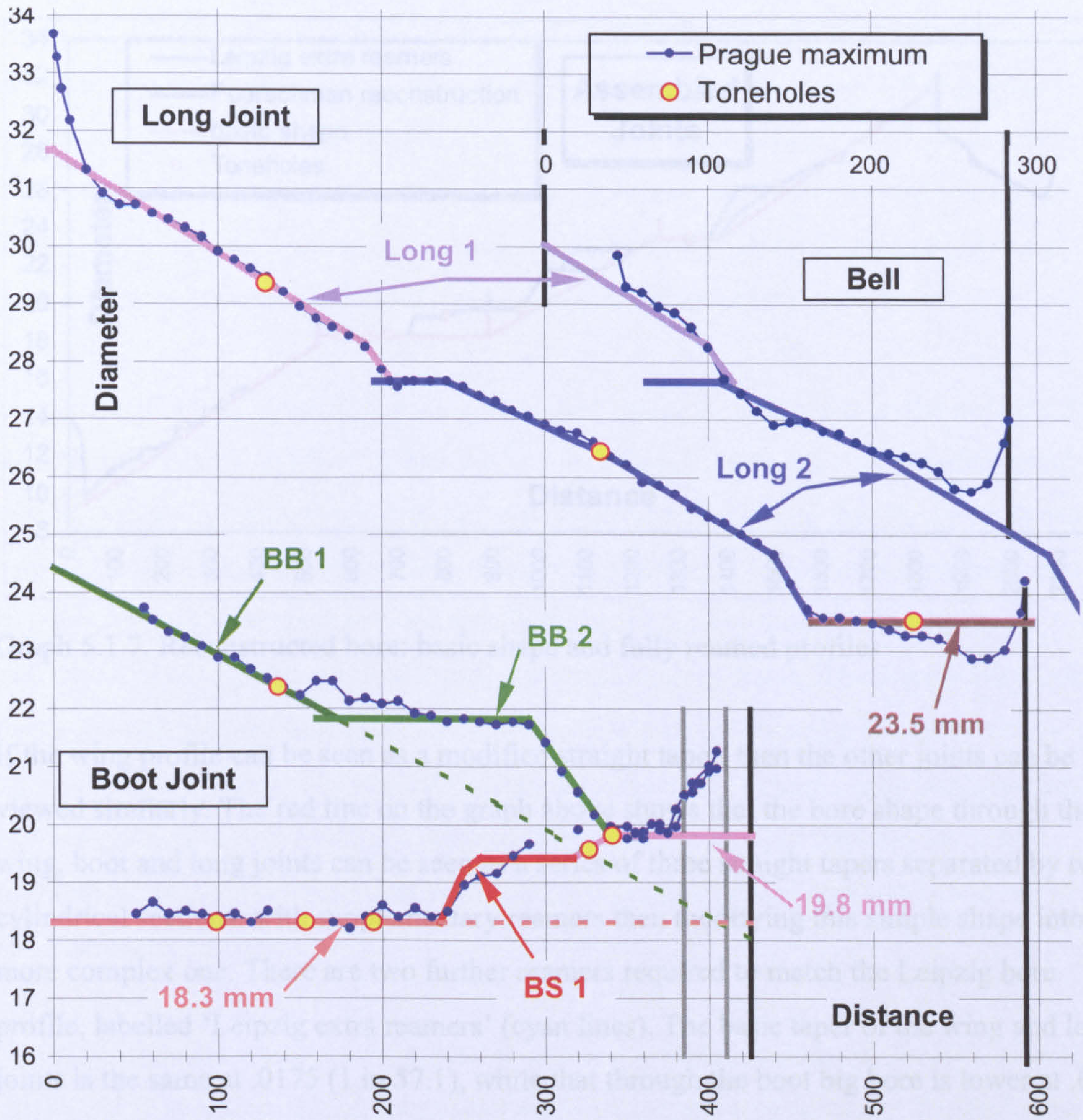
$$A = \frac{\Sigma y - (B \times \Sigma x)}{n} \text{ and } B = \frac{(n \times \Sigma xy) - (\Sigma x \times \Sigma y)}{(n \times \Sigma x^2) - (\Sigma x)^2}$$



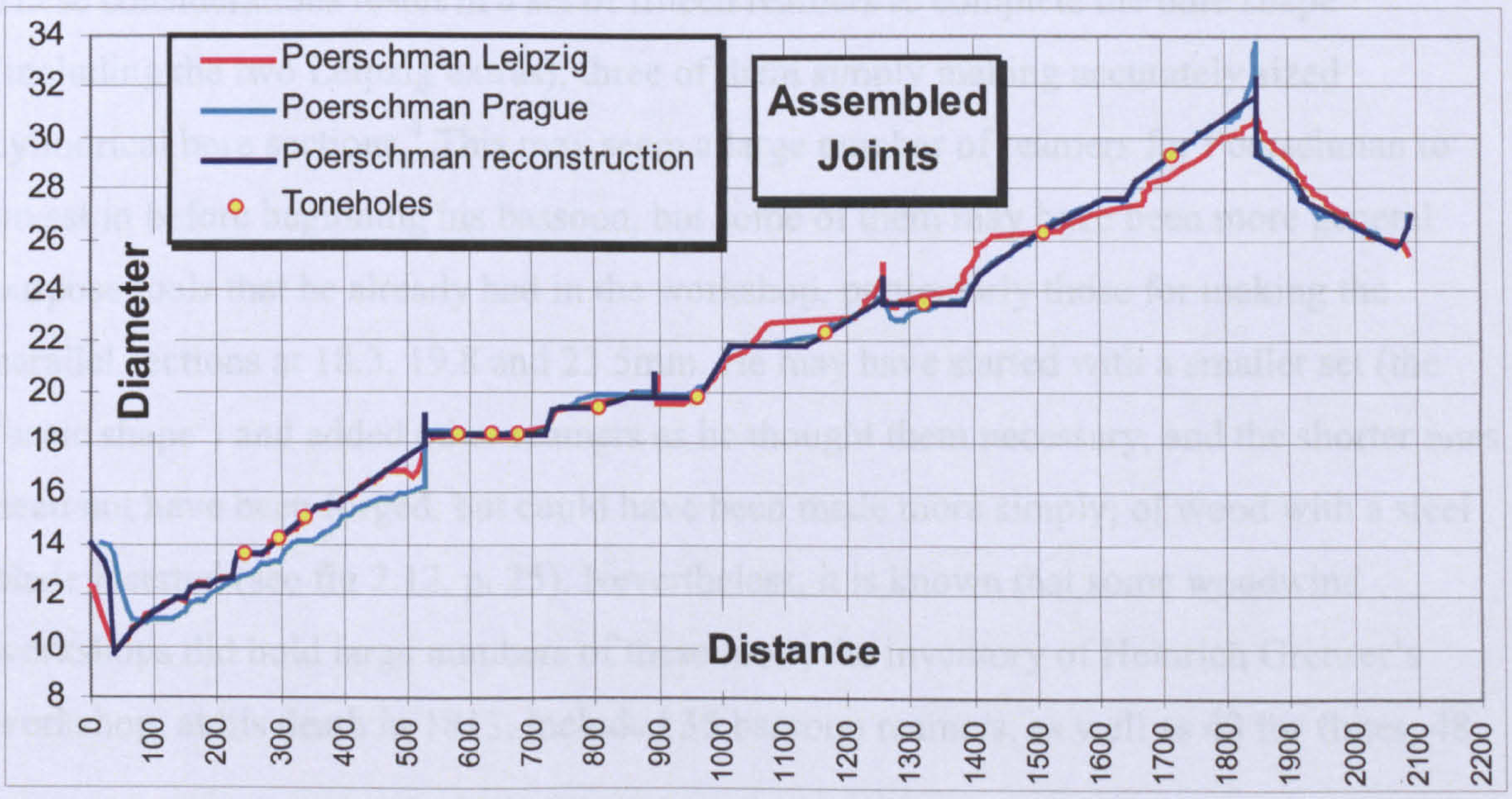
Graph 5.1.4. Bore profile with reamers labelled W1 to W5 and Socket individually coloured

Following the same sorts of reasoning as in the wing discussion, reamers can be designed for the other joints too, as shown in the following graph 5.1.5.

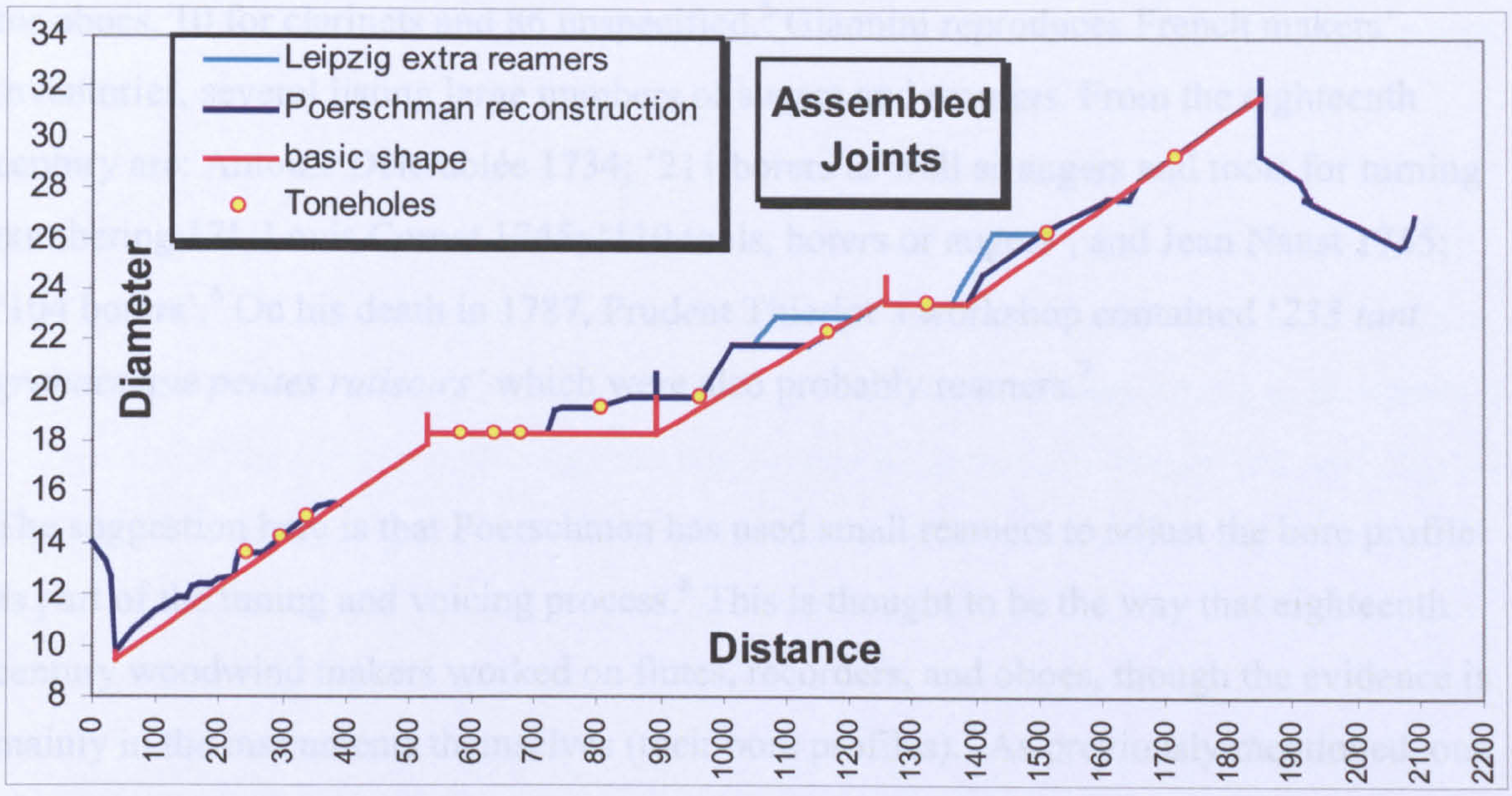
In the long joints there is a curious correspondence between the minimum diameter of Prague and the maximum of Leipzig from 0 to 300 on the distance scale. The Leipzig joint has little difference between the maximum and minimum diameters, which should indicate that it is not much shrunken from its original dimensions, while the Prague joint is quite oval. Either the boxwood Leipzig joint has, unusually, shrunk by the same amount in both axes or the Prague joint was made larger in the first place and has distorted into an oval with the minimum axis shrinking to match the smaller Leipzig bore. In the boot joint the two bassoons match closely, so the boxwood here has not shrunk any further than the maple, making it harder to argue that it has in the long joint. The decision was made to match the Prague maximum axis with two reamers L1 and L2, and those are also used for the bell joint. There is also considerable distortion at the south end of the Prague joint, where the maximum and minimum axes change places. This was interpreted as having originally been a cylindrical section to be made initially at 23.5mm in diameter (matching the boot bore where they meet) but with the possibility of expanding later if necessary.



Graph 5.1.5. Reamer profiles: BS1, BB1, BB2, Long 1, Long 2



Graph 5.1.6. The complete reconstructed bore versus original bores



Graph 5.1.7. Reconstructed bore: basic shape and fully reamed profiles

If the wing profile can be seen as a modified straight taper, then the other joints can be viewed similarly. The red line on the graph above shows that the bore shape through the wing, boot and long joints can be seen as a series of three straight tapers separated by two cylindrical sections, with supplementary reamers then modifying this simple shape into a more complex one. There are two further reamers required to match the Leipzig bore profile, labelled 'Leipzig extra reamers' (cyan lines). The basic taper of the wing and long joints is the same at .0175 (1 in 57.1), while that through the boot big bore is lower at .015 (1 in 66.7).

These considerations result in a set of fifteen reamers to complete the bore shape (including the two Leipzig extras); three of them simply making accurately sized cylindrical bore sections.[4] This may seem a large number of reamers for Poerschman to invest in before beginning his bassoon, but some of them may have been more general purpose tools that he already had in the workshop, particularly those for making the parallel sections at 18.3, 19.8 and 23.5mm. He may have started with a smaller set (the 'basic shape') and added other reamers as he thought them necessary, and the shorter ones need not have been forged, but could have been made more simply; of wood with a steel blade inserted (see fig 2.12, p. 25). Nevertheless, it is known that some woodwind workshops did hold large numbers of these tools; the inventory of Heinrich Grenser's workshop, at his death in 1813, included 35 bassoon reamers, as well as 43 for flutes, 48

[4] In this study, both W1 and BB1 were made in two sections for ease of construction and use.

for oboes, 10 for clarinets and 86 unspecified.[5] Giannini reproduces French makers' inventories, several listing large numbers of augers and reamers. From the eighteenth century are: Antoine Delerablée 1734; '211 borers as well as augers and tools for turning numbering 17', Louis Cornet 1745; '110 tools, borers or augers', and Jean Naust 1765; '104 borers'.[6] On his death in 1787, Prudent Thieriot's workshop contained '*233 tant grandes que petites rutisoirs*' which were also probably reamers.[7]

The suggestion here is that Poerschman has used small reamers to adjust the bore profile as part of the tuning and voicing process.[8] This is thought to be the way that eighteenth century woodwind makers worked on flutes, recorders, and oboes, though the evidence is mainly in the instruments themselves (their bore profiles).[9] As previously mentioned, one of the aims of this experiment is to identify the purposes and manner of use of these auxiliary reamers. There are two written historical sources that will help with this; Carl Golde on tuning oboes and Carl Almenraeder on adjusting bassoons. These are the only known sources written by historical instrument makers that describe bore modifications to be used in the process of tuning a woodwind instrument. Though both are from the nineteenth century, they both deal with conical bore, double reed instruments so are of particular interest here.

The Almenraeder text comes from his *Die Kunst des Fagottblasens* of 1842/43, so is from considerably later than the period considered here, but the comments are, for the most part, general enough to be likely to apply to bassoons generally.[10] A translation of Chapter XVIII: 'On various faults occasionally met with on a bassoon, which may often be overcome with little trouble' is given in Appendix 1. Though there is much of interest, the instructions regarding bore modifications do not correspond directly to the reamers identified for the Poerschman design.

In paragraph 2 he advises widening the whole of the wing bore in order to remedy a sharp C4 causing a wide C3-C4 octave. This seems to imply a rather simpler wing bore profile

[5] Waterhouse, *NLI*, p. 145.
[6] Giannini, *Great Flute Makers*, her translations, pp. 12, 49 and 29 respectively.
[7] Jean Jeltsch, 'Prudent a Paris: Vie et Carriérre d'un Maître Faisseur d'Instruments à Vent, in *Nouveaux timbres, nouvelle sensibilité au XVIIIe siècle. Première partie*, ed. Florence Gétreau, (Paris: Editions Klincksieck, 1998), pp. 128-152 (pp.141-2 and 151).
[8] 'Voicing' is used here to refer to the adjusting of response and tone quality of particular notes, and of the instrument as a whole.
[9] For an account of tuning by bore adjustments in baroque recorders see Cranmore, *Obedience training for Recorders*, pp. 43-55, also Brown, *The Recorder*, pp.27-31.
[10] Almenrader, Chapter XVIII.

than the Poerschman has, though all of the five reamers could be inserted deeper to widen the whole bore.

In paragraph 3 he discusses a similar situation with regard to the octave G2-G3, with G3 being too sharp. Here he suggests that the bore at the south end of the wing joint 'up to a bit beyond its tenon' should be reamed out. In the Poerschman design there is no auxiliary reamer identified for this region, but the work could be done with reamer W1, and it gives an indication of a tuning problem that may be caused by the tenon becoming compressed. There is an interesting comparison to be made here with the Golde text - Golde proposes the same area is reamed to correct a wide octave on the note fingered 123 --- (he discusses G4/G5 on the oboe, corresponding to C3/C4 on the bassoon). This will be further discussed below. Almenraeder goes on to say that if this (reaming south end of wing) is not sufficient to correct the G2-G3 octave, the bore should be widened where hole VII enters the bore. Graph 5.1.7 above shows that on the Poerschman design, hole VII lies right on the basic shape; reamer BB2 enlarges the bore downstream of it while BS1 plus the 19.8mm reamer act on the bore immediately upstream. Neither touches hole VII itself.

In paragraph 5 he suggests that the whole of the boot small bore can be enlarged to correct a croaking or rattling (*Schnarren*) of the second register notes A3, Bb3, and C4. Graph 5.1.5 shows that in the Poerschman the 18.3mm reamer would have to be replaced by a larger one, then the 19.8 reamer could be put in further from the south end to widen the area formed initially by BS1. Such a croaking on those notes has not been experienced on A3 or Bb3 but there is a common problem with C4 on early bassoons (baroque and classical) which may be being referred to here. C4 can frequently be difficult to produce cleanly and often degenerates into a multiphonic combining C3 and C4. This is discussed in section 5.3.

The second source is a text by Dresden oboe maker Carl Golde that gives instructions for such methods applied to the oboe.[11] Golde died in 1873, but writers agree that the methods he describes would apply to earlier, baroque period oboes too, and are the sort of knowledge that would be passed from master to apprentice since that earlier period.[12] The

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[11] The notes are translated in Appendix 1 to: Karp, 'Woodwind Instrument Bore Measurement', pp.19-21. There is a transcription of the same translation with interpretation and added material at: Marc Ecochard, 'Tuning the Hautboy, A perspective on original tuning and modern adaptations', transl. Jem Berry, http://www.grandhautbois-flutes.com/c_publications/download.php?num=17&affiche=1

[12] Ecochard, 'Tuning', p.3, and Haynes, *TEO*, p.90. Golde may be descended, in workshop/apprenticeship terms, from Poerschman, either via: Poerschman – Grundmann – Floth – Bormann – Golde,

makers of the eighteenth century nearly all made both oboes and bassoons, and would no doubt have applied techniques of adjusting playing characteristics learned on one, to the other, so bassoon makers can learn from these oboe-centric instructions. As they are both double-reed, conical bore instruments, the acoustics are very similar, and the baroque models of each are constructed with analogous joints for left and right hand. However the proportions of each are not entirely analogous; for example the bassoon's crook makes up a larger proportion of the bore than does the oboe's staple (the crook's length can be more than two-thirds the length of the wing), and the toneholes are more clustered on the bassoon compared to the relatively evenly-spaced oboe holes.

Whereas Almenraeder's instructions are aimed at correcting faults that may develop in a bassoon, Golde's instructions relate to the final stages of making an oboe. The implication is that the oboe is first prepared with a basic set of reamers and the toneholes drilled a little undersize, then tuning and voicing proceeds by working on both the toneholes and the bore together. Advice is given for adjusting specific notes by enlarging and undercutting toneholes, and by extra 'after-reaming' of specific sections of the bore using convex or 'arched reamers' ('*nachbohren mit gewölbtem Bohrer*').[13] Tuning and voicing (refining of response characteristics) are treated as two sides of the same coin. As Ecochard puts it, 'good tuning and good tone are reached at the same time'.[14] This can become a complex process – any action carried out to one purpose will have effects on other notes too; there are many inter-related effects having to be juggled.

The whole of Golde's text will not be related here, but some of the bore adjustments suggested seem to correlate directly with the auxiliary reaming found on the Poerschman bassoon, so those are discussed. The following quotes (indented) are all taken from the Karp translation, although there are one or two suggestions for slightly different interpretations of the original text.

> The middle D [fingered ~~1~~23 456, corresponding to G3 on the bassoon] can be sharpened by very slightly chambering between the C hole [hole I] and just below the narrowest part of the bore.

The Poerschman reamers W4 and W5 act in the corresponding region of the wing joint.

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or: Poerschman – C.A. Grenser – J.H. Grenser – Wiesner – Golde, see *NLI*, p.140.

[13] Ibid., p.2. The full German text is also given on pp.12-14.

[14] Ecochard, 'Tuning the Hautboy', p.2.

> If the A [fingered 12- ---, corresponding to D on the bassoon, octave not specified] remains slightly flat a small chamber must be made between its hole [III] and the B hole [II].

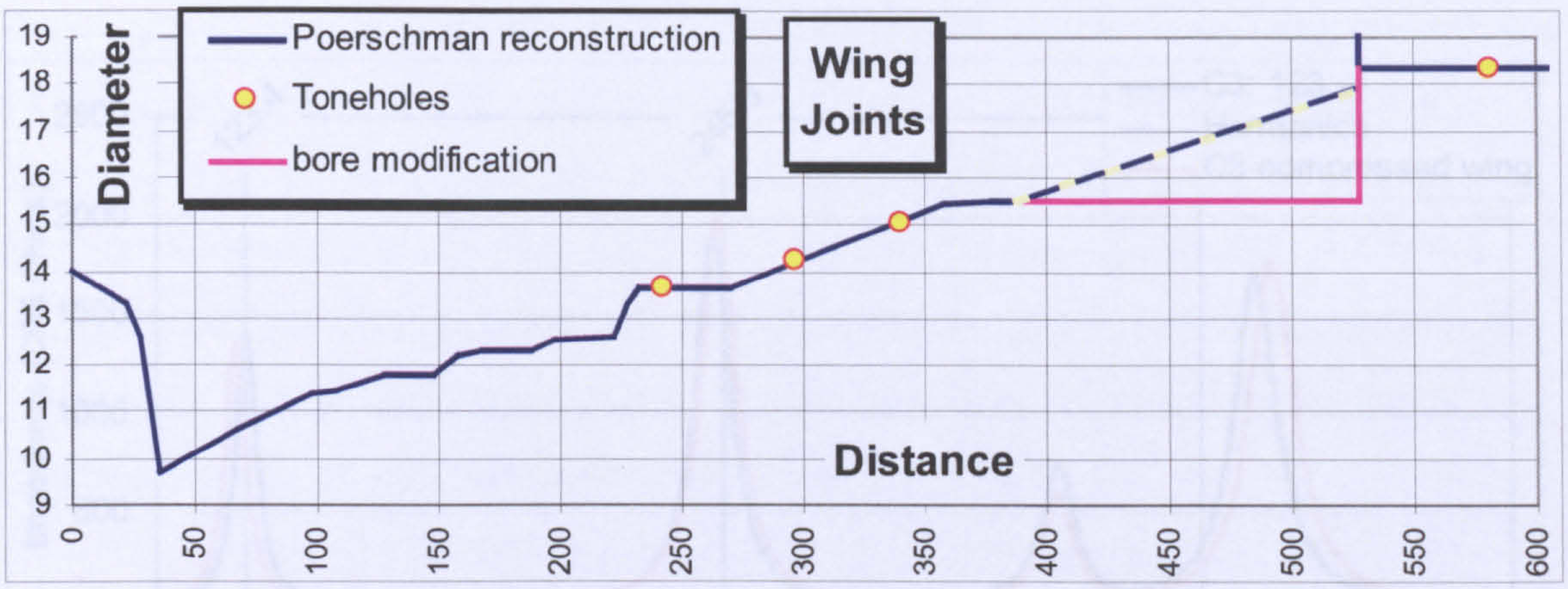
Reamer W2 acts from below III to above II, so rather exceeds this specification, but it removes such a small amount of material in the original that it would be surprising if it had much effect. It is available to be put in more deeply if that is thought useful though.

> If the middle C and D [corresponding to F3 and G3 on the bassoon] are too flat, the narrowest part of the bore can be enlarged through the reed socket with the long reamer.

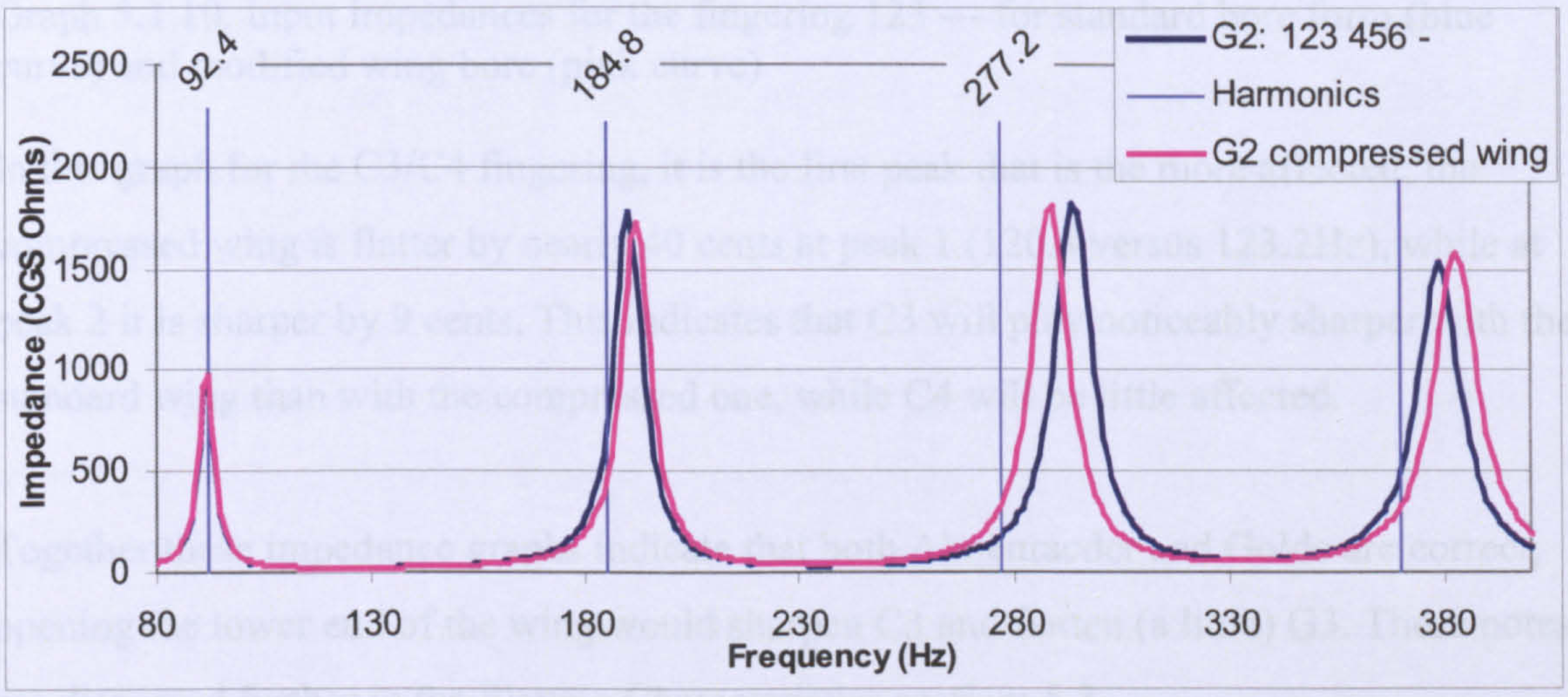
Golde refers to the very sensitive part of the bore which, in most baroque oboes and some bassoons, consists of a short cylindrical section, though in the Poerschmans it does not. Reamer W5 has the effect of widening the throat a little, at the same time as chambering below the throat. Either W5 or W1 could be used through the crook socket to further open the throat, but there is a warning from Almenraeder that this must not be overdone; he says in §6 that if the throat becomes too wide (through rot or wear), the high notes G4, A4 and Bb4 become difficult and imprecise (*unrein*, literaly: impure or unclean).

> If the low G [123 --- corresponding to C3 on bassoon] is too flat its hole can be conically undercut, or the upper end of the lower joint bore can be gently widened from above, or the upper joint can be slightly chambered from its lower end up to just below the A hole [III].

The reamer W1 shapes the bore in this region and if necessary (if C3 is found to be flat), it could be put in more deeply to expand the wing bore from the tenon end nearly to hole III. This is the same region that Almenraeder says can be widened to flatten G3, so here is another tuning problem that might occur as a consequence of wing tenon compression; both G3 may be sharp and C3 flat. Input impedance calculations show that both of these claims may be correct; the *Impedps* software was used to calculate impedances for these two fingerings (see sections 4.4 and 4.6), for both the reconstructed Poerschman bore profile and then with the wing profile modified with a severe reduction of diameter at the south end; an exaggerated version of tenon compression.

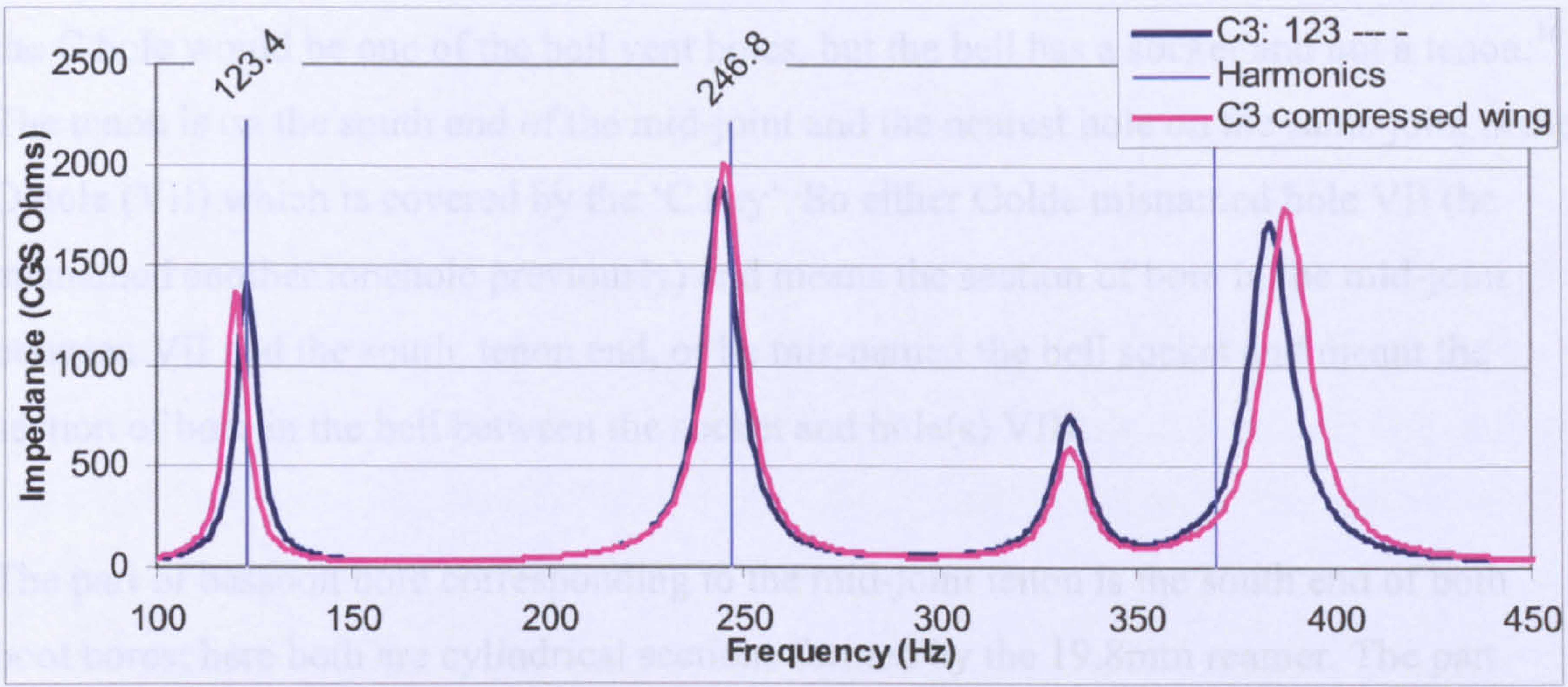


Graph 5.1.8. Reconstructed wing bore profile and modified south end profile



Graph 5.1.9. Input impedances for the fingering 123 456- for standard bore form (blue curve) and with the modified wing bore (pink curve)

This graph shows that for the G2/G3 fingering, the first impedance peak is the same for both bore versions, sitting just a little flat of G2 (92.4Hz). The second peaks are both a little sharp of the second harmonic, but that of the compressed wing is sharper still; the difference is around 18 cents. There is the same relationship at the fourth peaks; the modified wing's value is 18 cents sharper than that of the standard wing. So the overblown note G3, for which 184.8Hz is the first harmonic and 369.7Hz is the second, will play a little flatter with the standard wing than with the compressed one (though apparently still too sharp of the desired frequency), while G2 (92.4 Hz) will probably not be affected at all. The third peak, meanwhile, is significantly sharper with the fully reamed profile, so much so that it is not in harmonic relationship with the other impedance peaks, and this is significant in allowing G3 to be sounded (by overblowing) without leaking hole I; this is discussed in the Results section below.



Graph 5.1.10. Input impedances for the fingering 123 --- for standard bore form (blue curve) and modified wing bore (pink curve)

In this graph for the C3/C4 fingering, it is the first peak that is the more affected; the compressed wing is flatter by nearly 40 cents at peak 1 (120.4 versus 123.2Hz), while at peak 2 it is sharper by 9 cents. This indicates that C3 will play noticeably sharper with the standard wing than with the compressed one, while C4 will be little affected.

Together these impedance graphs indicate that both Almenraeder and Golde are correct; opening the lower end of the wing would sharpen C3 and flatten (a little) G3. These notes are discussed further in the Playing Characteristics section: 5.3.

> The third very short lower joint reamer must fit into the lower joint up to its tang (*muß ins Unterstück bis ans erste an der Angel hinein*). This gives body to the lower and middle registers and greatly improves the speech of the high C [F4 on bassoon].

By '*Unterstück*' is meant the oboe's middle joint, which holds fingerholes IV to VII. It is not possible to be sure how far up Golde's 'third reamer' reached, but in many oboes an enlarged section (chamber) can be seen in the region from the south end of the mid joint up to halfway between the Eb hole and hole VI; a good example is MI 90 in Nuremberg, made by J. Denner.[15] In that case, this correlates to the region here reamed out by BS1, from the bottom of the boot up towards hole VI in the small bore (see Graph 5.1.5 above)

> If the low C and D [F2 and G2 on bassoon] of an oboe or English Horn are too flat and too hard-blowing one may chamber slightly only from the tenon to the C hole.

[15] Kirnbauer, *Verzeichnis*, pp.130-131, where bore graphs are given.

The meaning here is unclear; the passage comes just after another mentioning the bell, and the C hole would be one of the bell vent holes, but the bell has a socket and not a tenon.[16] The tenon is on the south end of the mid-joint and the nearest hole on the same joint is the D hole (VII) which is covered by the 'C key'. So either Golde misnamed hole VII (he misnamed another tonehole previously) and means the section of bore in the mid-joint between VII and the south, tenon end, or he mis-named the bell socket and meant the section of bore in the bell between the socket and hole(s) VIII.

The part of bassoon bore corresponding to the mid-joint tenon is the south end of both boot bores; here both are cylindrical sections formed by the 19.8mm reamer. The part corresponding to the oboe's upper bell bore is that formed by reamer BB2. On most baroque oboes the bore adjacent to the bell socket is significantly larger than at the end of the middle joint tenon; that is, there is a step up in size by around two millimetres from middle joint to bell (even taking tenon compression into account). On the bassoon the corresponding section is between VII and VIII, and on the Poerschman bassoons the reamer BB2 expands the bore rather sharply just beyond hole VII to correspond to that step. This is one of the regions that are expanded further in the Leipzig bassoon.

A point that Golde makes right at the beginning is also apposite to bassoon bore design; he says that the bore in the top and middle joints (corresponding to the wing and boot small bore) should be '*sakig oder gewölbt*' meaning bulging (like a full sack), arched or convex.[17] This is needed, he says, to 'ease the speech of the upper and lower registers and the beauty of the middle register depends on it'. Oboes which do not have this arched profile (presumably with a straight taper instead) have a 'thin, nasal tone, as that of French and Viennese oboes'.

In the bassoons measured, an arched profile in the wing is common, but not so much in the boot small bore, though Jakob Denner (Linz) and Deper are good examples having both. However most of the bassoons have an arched shape over the down-bore as a whole, as the wing is nearly always steeper than the boot small bore. The Type 2c (German)

[16] Golde's oboe has a low B key that would have covered one of the pair of bell vent holes to produce that note. The hole under the key might then be called the C hole as it is the primary vent for low C4, but really both bell holes are the vents for C, as is more clear on earlier, baroque period oboes when both bell vents are permanently open.
[17] Karp translates this as 'sword shaped' in 'a reluctant concession to common usage'; that is a term sometimes used to describe the type of profile where the bore expands at a relatively steep taper from the small end, then taper rate decreases with distance from that end – resulting in a quasi-parabolic shape.

bassoons are rather different though; the Wietfelts, Scherers and Rottenburgh all have two arched shapes in their wing profiles, one from the throat (narrowest part of the bore) to the fingerhole region, then another from hole III to the south end, followed by a cylindrical boot bore section. The Poerschman and Eichentopf just have the upper of those two arches extending only to the first fingerhole, and are essentially straight tapered for the remainder of the wing, up to the cylindrical section in the boot small bore. The shape specified by Golde does appear in later bassoons by Sattler and Poerschman's descendants Grundmann and Floth, who worked closer to Golde's time; these can be seen in Chapter 2, Graphs 2.6.26 – 28.

As shown in the previous chapter, this arched or parabolic bore shape causes the interval between the first and second resonance frequencies (of a note using the whole of the bore section in question) to be widened compared to those in a straight-tapered bore. Having the interval between the first two resonances wider than an octave for at least the lower notes (those using most or all the bore length) seems to be a desirable or necessary attribute; it still pertains to modern bassoons and oboes, but whether that is what causes the good qualities Golde links to an arched bore profile is not entirely clear.[18]

Golde's instructions on bore and tonehole adjustments give an impression of the complex understanding that a woodwind maker must have of the workings of the instrument. Since any action carried out to one purpose will have effects on other notes too, the maker must have a variety of techniques to separate out the many inter-related effects that have to be juggled. Arthur Benade introduced a twentieth-century acoustician's view of the same processes with his discussion of the use of 'W curves' (see under Acoustics). Benade describes the process of making localised changes in the bore of his bassoon, guided by his W curves, to improve tuning and response of three notes. He too gives a good impression of the complicated, interlinking nature of tuning issues; he likens the process of tuning a wind instrument to 'a game that is very similar to diagramless crossword puzzle in three dimensions'.[19]

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[18] U.S. Patent No. 3,161,102, Dec. 1964 by John de Lancie and Hans Moennig advocates modifying the straight-tapered bore of modern oboes into, effectively, an arched shape, by reducing the taper angle of the mid-joint and creating a step up in diameter where the top joint joins the mid. The claim is that this improves the tuning of the octaves between the lowest notes (Eb4 down to Bb3) and their overblown counterparts, and improves the tone quality and stability of the low range notes. See also note 32, section 5.3.
[19] Benade, *Fundamentals*, p.480.

5.2 Setting up and testing the reconstruction

Crook design

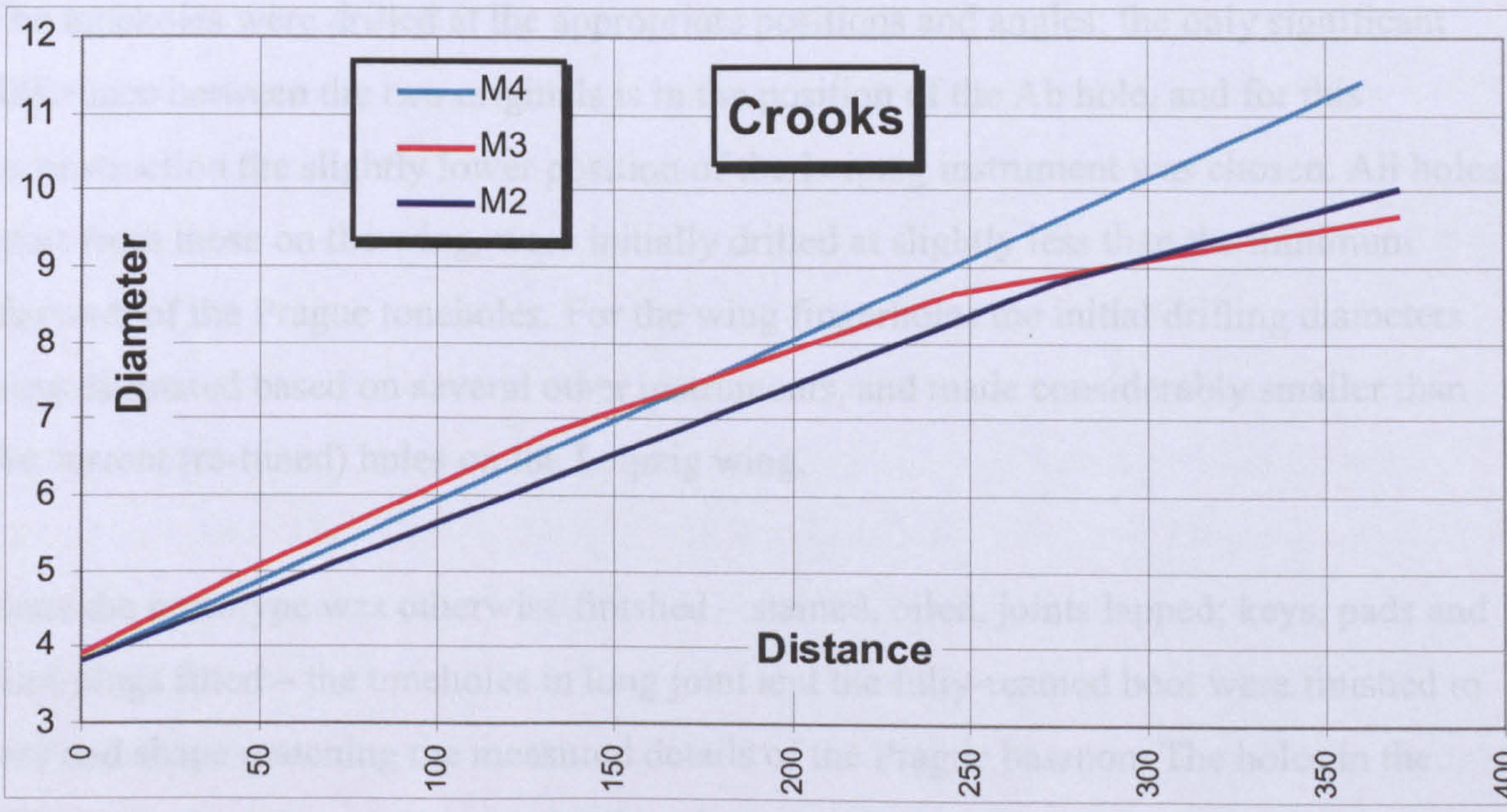
Preliminary calculations were made to establish an appropriate crook length assuming a playing pitch of A=415Hz. These indicated that a rather long crook would be needed; in the order of 370mm. This was convenient because it is the length of crook used for the Denner reproduction. It was surprising though, as it was already known that various makers' reproductions of the Eichentopf bassoons all used crooks of around 340mm length; it had been thought that this might be a feature that distinguished Denner type from Leipzig designs.

Four crooks of three different designs were prepared; all were made of 0.7mm brass sheet, their bore profiles are shown in Graph 5.1.8 below.

M2 is the design used for the Denner model; 370mm long, small end inside diameter (i.d.) is 3.8mm, expanding by the main taper of .0182 for 274mm, then by a lower taper of .0125 for 96mm to large end i.d. of 10.0mm.

M3 is also 370mm long, starting at 3.9mm i.d. and expanding in a more arched profile to a big end diameter of 9.7mm.

M4 is based on the original crooks associated with the G. Wietfelt and Scherer instruments. It has one straight taper of .021 (1 in 47.3), from 3.8mm i.d. at the small end. One was made 360mm long with a big end i.d. of 11.4mm, and another 350mm long, big end i.d. 11.2mm.



Graph 5.2.1. Crook designs for Poerschman reproduction.

All three crooks have a pinhole of 0.7 mm diameter drilled at 40 mm from the big end; insertion into the wing joint is 28mm, so the pinhole is 12mm above the top of the wing. See discussion below under Results.

Reeds

Two contrasting reed styles were used. Although they are of considerably different lengths, they both can be used to play the instrument at A=415 Hz.

1) Made by J. Kopp; short scrape baroque model. Length 70mm, blade length (tip to first wire) 36mm, scrape length 23mm, tip width 18mm.
2) Unknown maker; conventional (modern) scrape. Length 62mm, blade length 33mm, scrape length 29mm, tip width19mm.

Bore

Two each of wing and boot joints were prepared; one of each was made fully reamed, that is, with all the reamers used, to produce the bore profile shown by the dark blue line in Graph 5.1.7 above. The other pair were reamed just to the simple shape shown by the red line in the same graph, so the wing was a single truncated cone of .0175 taper (1 in 57.14), the boot small bore cylindrical at 18.3mm diameter all the way through, the boot big bore a single cone of .015 taper (1 in 66.7). Only one of each of bell and long joint were made, both fully reamed to the Prague profile.

Toneholes

The toneholes were drilled at the appropriate positions and angles; the only significant difference between the two originals is in the position of the Ab hole, and for this reconstruction the slightly lower position of the Leipzig instrument was chosen. All holes, apart from those on the wing, were initially drilled at slightly less than the minimum diameter of the Prague toneholes. For the wing fingerholes the initial drilling diameters were estimated based on several other instruments, and made considerably smaller than the current (re-tuned) holes on the Leipzig wing.

Once the prototype was otherwise finished – stained, oiled, joints lapped; keys, pads and boot plugs fitted – the toneholes in long joint and the fully-reamed boot were finished to size and shape matching the measured details of the Prague bassoon. The holes in the fully-reamed wing were then gradually enlarged and shaped in the normal tuning process.

The sizes and shapes of the tuned boot and wing toneholes were then duplicated on the simple-bore (under-reamed) wing and boot, so that the only difference between those two pairs of joints was the bore profile.

Testing

The instrument was tested in the ways normally used when making and tuning a bassoon; rather than attempting a scientifically rigorous evaluation of qualities, it was treated as an instrument being prepared for use in performance. In addition to testing in the workshop, it was used in orchestral performances and in a chamber group, playing continuo alongside a harpsichord, and obbligato parts with a pair of oboes alternating with recorders.

Five professional players of baroque bassoon were invited to try the instrument and give their comments. Two of the players were particularly experienced with the Denner reproduction model bassoon, the other three with reproductions of Eichentopf and Scherer bassoons. They tried both the fully reamed bassoon and the simple-bore wing joint set on the fully reamed other joints, without initially being told which was which.

Results

A description and analysis of the tuning, response and the fingerings required is given in a note-by-note format later in section 5.3. First some more general comments on set-up and test results.

Crooks

Initial tuning and setup was carried out using crook M2; tuning and response was satisfactory, that is, all notes could be sounded easily and clearly, and played in tune. However there was a feeling of restricted power of tone available, particularly from C4 upwards.

M3 was found to work better in that a more generally satisfactory response was found; a greater power of tone was possible while still allowing a reasonable pianissimo and a graded crescendo-diminuendo. Tuning was also satisfactory and high range notes (E4 and above) were easier to produce, with A4 and even Bb4 possible.

M4 also produced a good, powerful tone, but some tuning became unacceptable, in particular C4 became unusably sharp, with C3 only slightly less so. A4 would not sound. There were some good qualities in tone production though, and it was thought that this was worthy of further investigation for which the bassoon would have to be retuned (hole IV at least, would have to be made significantly smaller). This is a project for the future.

So for the purposes of most of the tests and the following analysis, crook M3 was used, although occasional references are made to the different effects of M2.

A pinhole was used in all three crooks, as specified above. Experiments were tried with it closed, but it was found to be necessary for secure playing of several notes; these effects are discussed in appropriate parts of the following section. It is common practise for modern makers of reproduction baroque instruments to include a pinhole, despite the fact that most original crooks from the period do not have them and that clear evidence for their use does not exist from before 1774. The improvement in facility of the notes from C4 to E4 inclusive is so marked, and the difficulties of playing without one so ubiquitous, that qualms regarding authenticity in this matter are laid aside. The earliest clear evidence is in the painting of Felix Reiner, dated 1774.[20] This shows a key mounted on the wing joint to cover the pinhole, to be operated by the left thumb. The earliest written evidence is in the method of Pierre Cugnier, where he states:

> A hole is pierced in the crook, locating it about an inch above the ferrule of the wing joint, into which the crook fits. Others place it higher, but it is better at the location just mentioned, because it can be closed, if you wish, with a key placed on the wing joint, that covers this hole and is opened or closed with the left thumb. This hole makes it easier to play the notes C, D, E of the third octave, that sound through the holes numbered 1, 2, 3 [sic]. Without it the C is difficult, as are the other two tones; but it is necessary that the hole does not exceed the size of a small needle, otherwise too much wind would be lost, and would harm the low notes, especially when they must be played softly.[21]

Of the crooks measured in this study only that of the Scherer in New York has a pinhole and that may not be original. The difficulties experienced by current players when attempting to manage without the hole may indicate that the setups in use – crook design and reed construction – and perhaps other aspects of playing technique, are not quite correct for managing these instruments. However it may instead be the case that eighteenth century players had to contend with the same difficulties until the discovery was made. The two sources mentioned indicate an established use of the pinhole to the extent that a key had also been invented to close it for notes where it is not helpful, which

[20] *Bildnis des Fagottisten Felix Reiner*, Peter Jakob Horemans, Munich 1774, Leihgabe der Bayerischen Staatsgemäldesammlungen, Inv. Nr. 4331, (Bayerischen Nationalmuseum, Munich).
[21] Pierre Cugnier, 'Basson', in *Essai sur la musique*, Jean-Benjamin de Laborde, (Paris: 1780), pp. 323-343; my translation here and below.

would imply that the use of the open hole had been established some time beforehand. Almenraeder wrote about a non-key-operated pinhole in 1842:

> On a well-bored bassoon where the bores of all the pieces fit exactly to each other and the wing and boot small bore are particularly accurately reamed, one can close the pinhole after a time when the instrument has been much used, if it is otherwise in good condition. The slurs for which this hole really exists are not impaired, and all the notes of the instrument gain in fullness as well as in delicacy (*gewinnen dabei an Fülle, wie an Zartheit*). On new bassoons I have not, at first, been able to dispense with this hole, but after several years I have found it no longer necessary on my instruments.[22]

This prototype has not yet reached that exalted state, or perhaps the ideal setup has not yet been found, so the pinhole is kept open. It is essential in helping C#4 to speak, and greatly beneficial for C4, D4 and Eb4.

Wing joint auxiliary reaming

It has to be said that after all of the above analysis, these reamers seem to make only a very subtle difference. Using the simple cone wing assembled with the fully reamed boot, long and bell joints produces a perfectly acceptable instrument that can be played in tune, with pleasing tonal qualities and reasonable balance in tone and tuning. One of the professional players preferred it to the fully reamed wing.

So the auxiliary reaming is certainly not necessary for tuning, but that is not to say that it does not provide some benefits. The other four players did find some preferable qualities when using the fully reamed wing; no method for demonstrating these objectively was found, but the players' subjective appreciation of the differences included the following comments: The instrument is 'more responsive', 'feels more resonant', tonal qualities are 'more flexible – you can do more with it'. The tone quality of especially the range G3 to D4, seems 'better focused', with less extraneous noise, more 'rounded' and 'better projecting', with something of a 'more vocal, singing quality'. The notes in the octave G2 to G3 feel more secure in both tuning and tonal character. In comparison the simple wing feels a little more raw; the tone quality somewhat crude. Again these differences are subtle and difficult to pin down, but all of the players noticed some differences immediately they tried the two wing joints – they could easily tell them apart. Some more specific points regarding the auxiliary reamers and their possible uses are made in the following note-by-note discussion.

[22] Almenrader, Chapter XVIII, § 7; see Appendix 1.

`5.3 Playing characteristics of the Poerschman reconstruction

The playing behaviour of the reconstructed Poerschman model bassoon is discussed note-by-note from the bottom up, including fingerings used and comments on the tuning, response and other characteristics. The set-up described for the most part is using the reeds previously mentioned, crook M3 and the fully reamed joints. The auxiliary reamers and their possible uses are mentioned where appropriate.

The fingerings used on the instrument are given for each note as it is discussed, and references made to those given in fingering charts of the period. The surviving early fingering charts for bassoon have been surveyed and discussed by Paul White.[24] They are rather thin on the ground for the period of interest here, but those that there are, are collated in Appendix 2. There is only one chart for a three-keyed instrument and ten for four keyed bassoons, running right up to 1795. One five-keyed chart is included because of its relatively early date (Hotteterre/Bailleux c.1765).

Fingering charts are both descriptive and prescriptive; they show how to operate a baroque bassoon and also how the instrument should work. That is, the fingerings given should work on an appropriate instrument and if they do not there may be something wrong with the setup (reed and/or crook), or with the reconstructed instrument's design. However there is a question over how seriously fingering charts can be taken. Those for baroque bassoon mostly appear in encyclopaedias, collations of instructions for various instruments, or small tutors aimed at beginning amateurs. There is no carefully considered and thoroughly worked tutor of the scale of Quantz's '*Versuch...*' for the flute until Ozi's work of 1787.[25] The impression from the early charts is that, in the main, they present just the simplest of fingerings, without any indication that alternatives are possible; they also do not make the enharmonic distinctions that are found in flute charts from Hotteterre onwards.[26] However it seems unlikely that professional players would not have discovered and subsequently used alternative fingerings that broaden the possibilities of the instrument by either making playing easier, improving tone quality, or making new high notes playable. Cugnier hints at this in his method published in 1780; his fingering chart

[24] White, 'Early Bassoon Fingering Charts', pp 112-124. White gives a 'standard' fingering for notes up to F4 and notates the exceptions. This is the standard occasionally referred to below.
[25] Quantz, Johann Joachim, *Versuch einer Anweisung die Flöte traversiere zu spielen*, [1752] trans. by E.R. Reilly (London: Faber and Faber, 1971). Ozi, *Méthode Nouvelle.*
[26] Jacques Hotetterre, *Principles of the Flute, Recorder & Oboe*, (1707) trans. and ed. by David Lasocki (London: Barrie & Jenkins, 1978)

for a 5-keyed instrument is impressive as it ranges from A1 to F5, though with just one fingering per note and the comment that:

> There are other fingerings to make several notes in different ways according to the passages where they are used, it would be too long to show here, we had to leave them out to give the simplest and most known tablature; it is the Masters who will choose to teach these different fingerings.

He previously advised that 'it is necessary to choose a skilled master, who knows the fingerings, and can teach them, [and] to practice them until they become habitual'.[27]

So it is an open question as to how well the simpler charts represent the practice of professional players, and in effect, whether we should allow ourselves to use fingerings not presented in the charts.[28]

In references to note pitches made below, the frequencies cited are for equal tempered intervals calculated from A = 415Hz. In actual use the bassoon, being a not-entirely-fixed-pitch instrument, will need to play with justly tuned intervals at times, so at pitches differing from these. Quantz advises that in order to be able to play in tune, the flute player must make pitch distinctions between enharmonic note pairs of one ninth of a tone; around 22 cents.[29] In the more extreme *quarter-comma meantone*, which may also be encountered by the baroque bassoon player, the difference is close to 41 cents.

As noted above, the surviving bassoon charts of this period do not give the alternative fingerings for enharmonic pairs that are so diligently laid-out for flute players by Quantz, Tromlitz, and Hotteterre. Lacking them, the bassoonist must be able to make such distinctions by embouchure and breath control, and the instrument will need to be capable of such flexibility. However there are some places where the player can borrow, if not the exact fingering, then ideas from these flute works by which he/she can adapt the given bassoon fingerings. Some comments are made on these in the note-by-note discussion following.

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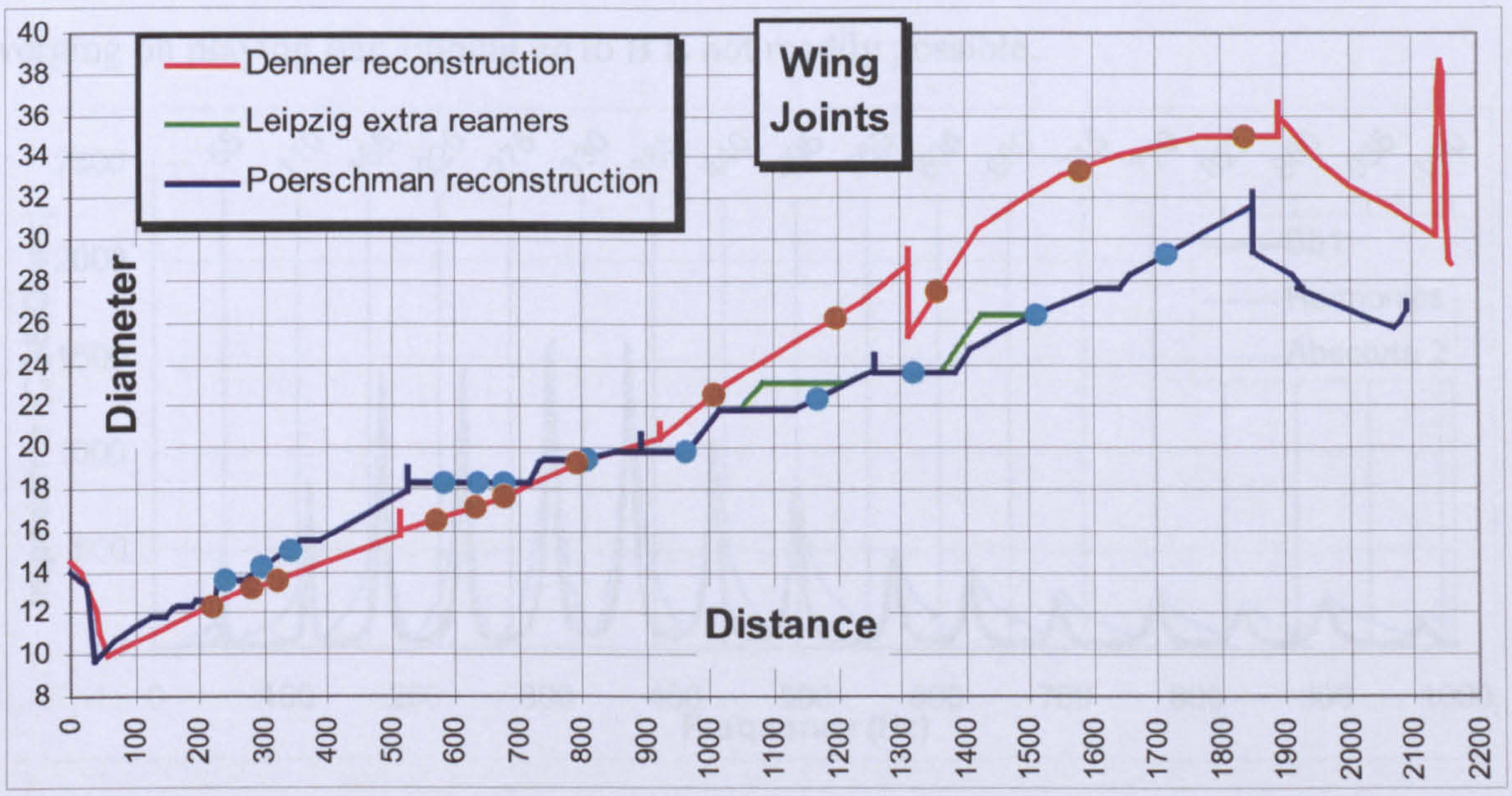
[27] Pierre Cugnier in Delaborde *Essai* pp. 342 and 335.
[28] By 1803 the question was no longer open, at least for Ozi. After presenting a chart containing only one fingering for almost every pitch, on page 5 he gives seven examples of corrective fingerings; Fröhlich gave even more in 1811. See White, 'Early Bassoon Fingering Charts', pp. 100-102 and 104-106.
[29] Quantz, *Versuch*, Chapter III, para. 8. He divides the whole tone into one major and one minor semitone. The minor semitone is 4 commas, and is found between two notes on the same line, with one moderated by flat or sharp, e.g. between E and Eb, or F and F#; the major semitone of 5 commas exists between e.g. F# and G or G and Ab. The difference, e.g. between G# and Ab, is one ninth of a tone; 200/9 = 22.2 cents.

Because the toneholes must be placed even less optimally, with regard to acoustic considerations, than those of the smaller woodwinds, tuning the instrument can pose greater difficulties, so a degree of flexibility in the tuning may be necessary. This leaves the bassoon player with more work to do to play in tune, as Cugnier confirms (although in this passage he drifts from the issue of tuning to that of strength-of-tone):

> Some care is taken to make the bassoon in the most correct proportions, as well as for the selection of the reed and the crook, [yet] it is hardly possible to find an instrument that bears all the tones and semi-tones just and fixed as they are located on the monochord; there are always some notes that are a bit stronger or a little weak: the ear must guide the mouth to give a little more strength to the notes that are weak, and on the contrary to decrease those which are a little stronger.[30]

The behaviour of the reconstructed Poerschman design is contrasted with that of the J.C. Denner. The bores of the two are compared in the graph below, where it can be seen that there are significant differences in profile, tonehole placement and overall length. Crooks used on each are the same lengths; the Denner uses M2 as shown in Graph 5.2.1, p. 314.



Graph 5.3.1. Bore profiles of reconstructed Denner and Poerschman bassoons, with toneholes marked where they enter the bore

In the analyses of the instruments' behaviour, extensive use is made of impedance graphs calculated with the *Impedps* software written by Robert Cronin. These are described in

[30] Cugnier p.335.

Chapter 4 and hints for understanding them are given there. For the most part, only the 'real' part of impedance is shown, as that gives greater clarity in more precise-looking graphs. But occasionally, 'absolute' impedance is graphed when the wider peaks help to support the argument (see pp. 272-273).

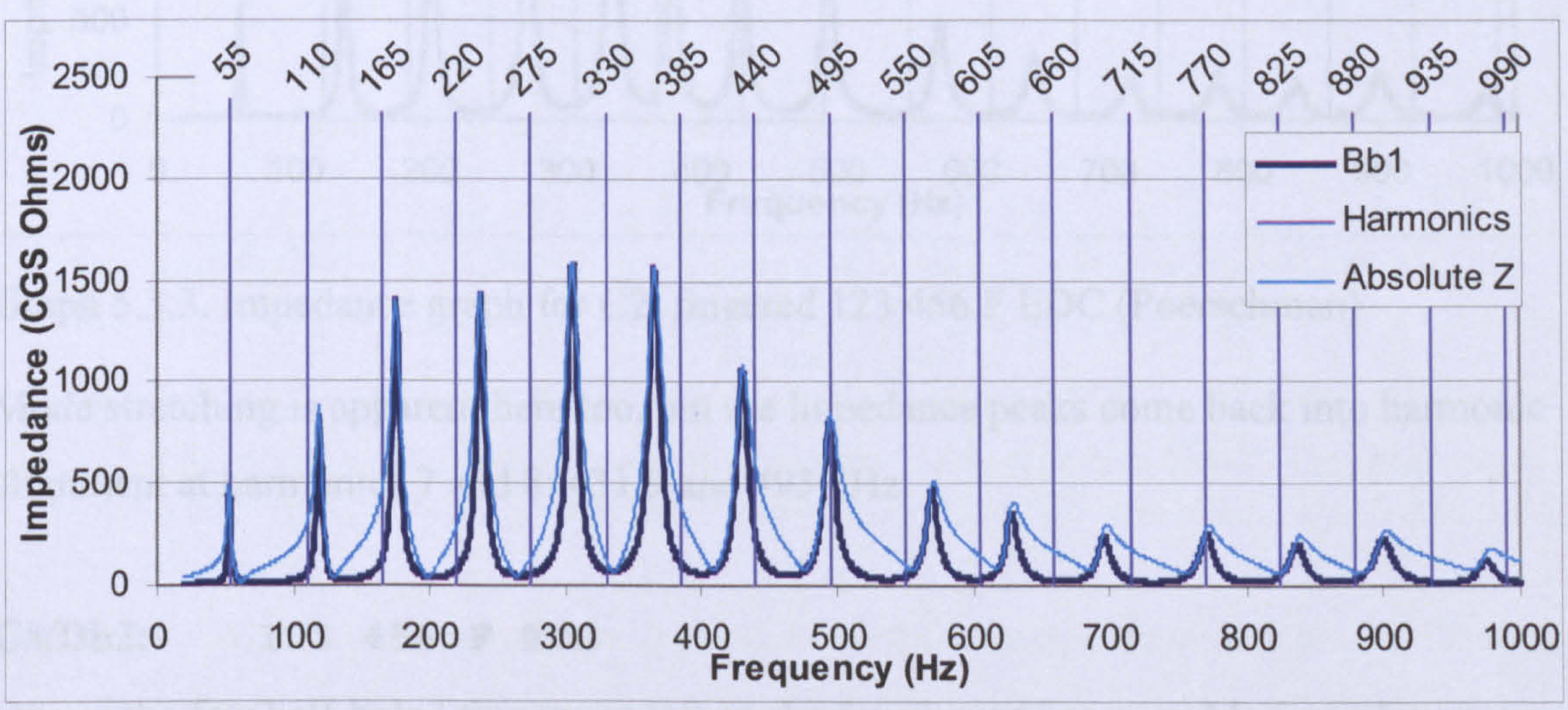
Unless otherwise stated, all graphs and remarks apply to the Poerschman reproduction.

Low Range

For the most part the low range (Bb1 to F2) should be straightforward to tune and voice. The fingerings used for each are needed for just the one note and not expected to overblow to the next octave. However some of the notes are produced with cross fingerings or half-holing (or both) so may require some compromises in tonehole dimensions.

Bb1 fingering: `123 456 F EDCBb`

On some instruments, including the Denner, this fingering gives a pitch somewhere between Bb and B when the embouchure used is the same as for an in-tune C2. This gives the possibility of lipping down to Bb or up to B, as is shown on three fingering charts from the period covered by this study.[31] On the Poerschman though, it is definitely Bb, even verging on playing flat; lipping up to B is not readily possible.



Graph 5.3.2. Input impedance curve for Bb1, real (dark line) and absolute impedances shown.

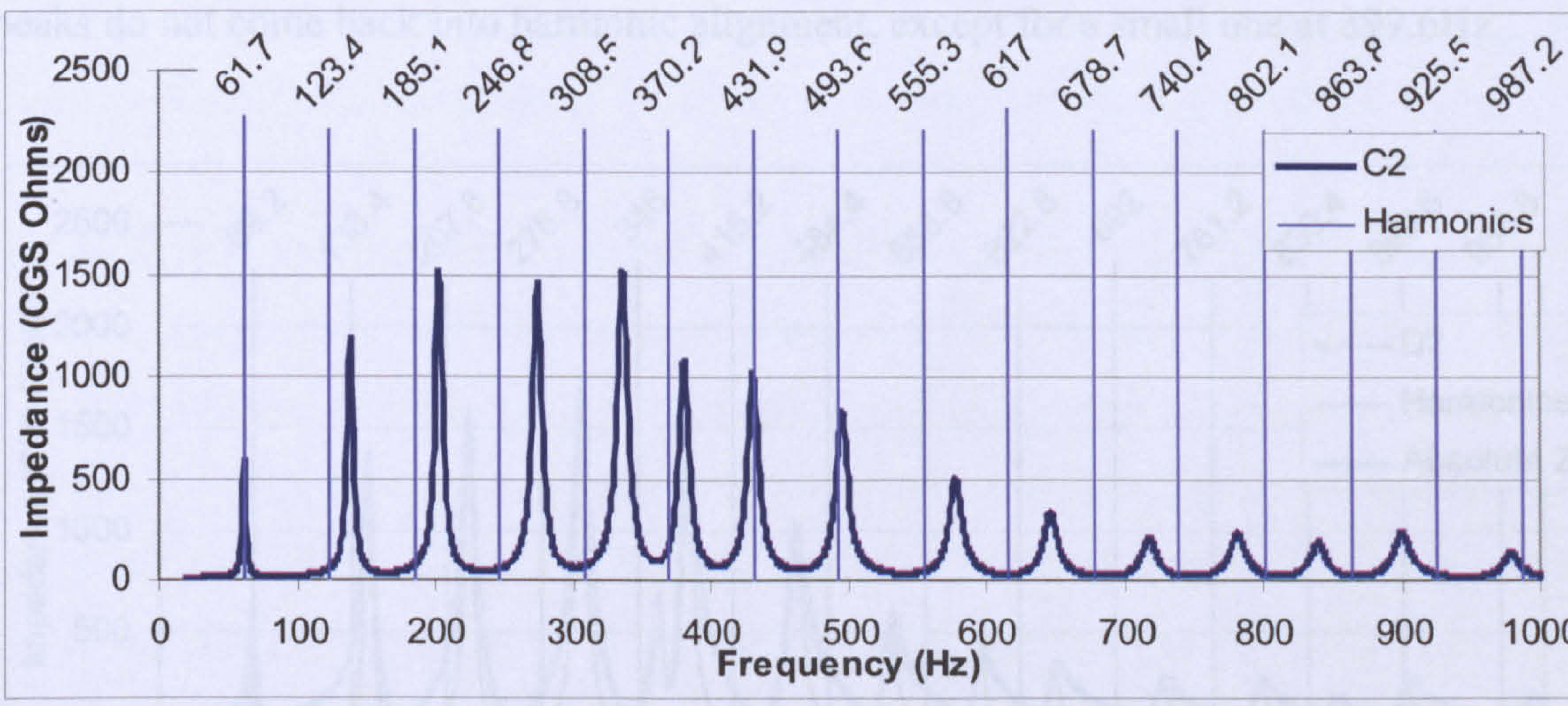
This graph of the input impedances for the low Bb fingering shows the sort of pattern seen in the previous section for the 'cone-cylinder' bore, with a wider-than-octave interval

[31] Those are; Musica Bellicosa, London 1734; Diderot, Paris 1751 and Apollo's Cabinet, Liverpool 1756. In practice, B natural is rarely called for.

between the first two impedance peaks and subsequent peaks increasingly sharp of their corresponding harmonics; this is referred to as 'mode stretching'.[32] The first peak is a little flat of Bb1 (55Hz) but the sharper subsequent peaks pull the sounding pitch up a little. However, only those peaks with some overlap of the harmonic frequencies can participate in the Bb regime, so the fourth, fifth and sixth do not play a part. At 440 and 495 Hz, peaks have got so sharp that they start to align with the next harmonic up, so peaks 7 and 8 align with harmonics 8 and 9. There is another little peak aligned at 770Hz. All of these help to establish an oscillatory regime with a fundamental frequency of 55Hz or thereabouts.

C2: `123 456 F EDC`

This is a good, strong note on both bassoons; full and rich toned on the Denner, marginally less robust on the Poerschman.



Graph 5.3.3. Impedance graph for C2, fingered 123 456 F EDC (Poerschman)

Mode stretching is apparent here too, but the impedance peaks come back into harmonic alignment at harmonics 7 and 8; 431.9 and 493.6Hz.

C#/Db2: `123 456 F EDC`

One of the few half-holed fingerings left on the four-keyed bassoon. Modern players are often uncomfortable with half-holing because of the uncertainty of pitch, depending on just how much of the hole is left open. However there is no choice for this note and in fact it is usually reasonably effective. On the Denner the note is quite secure and easy to find,

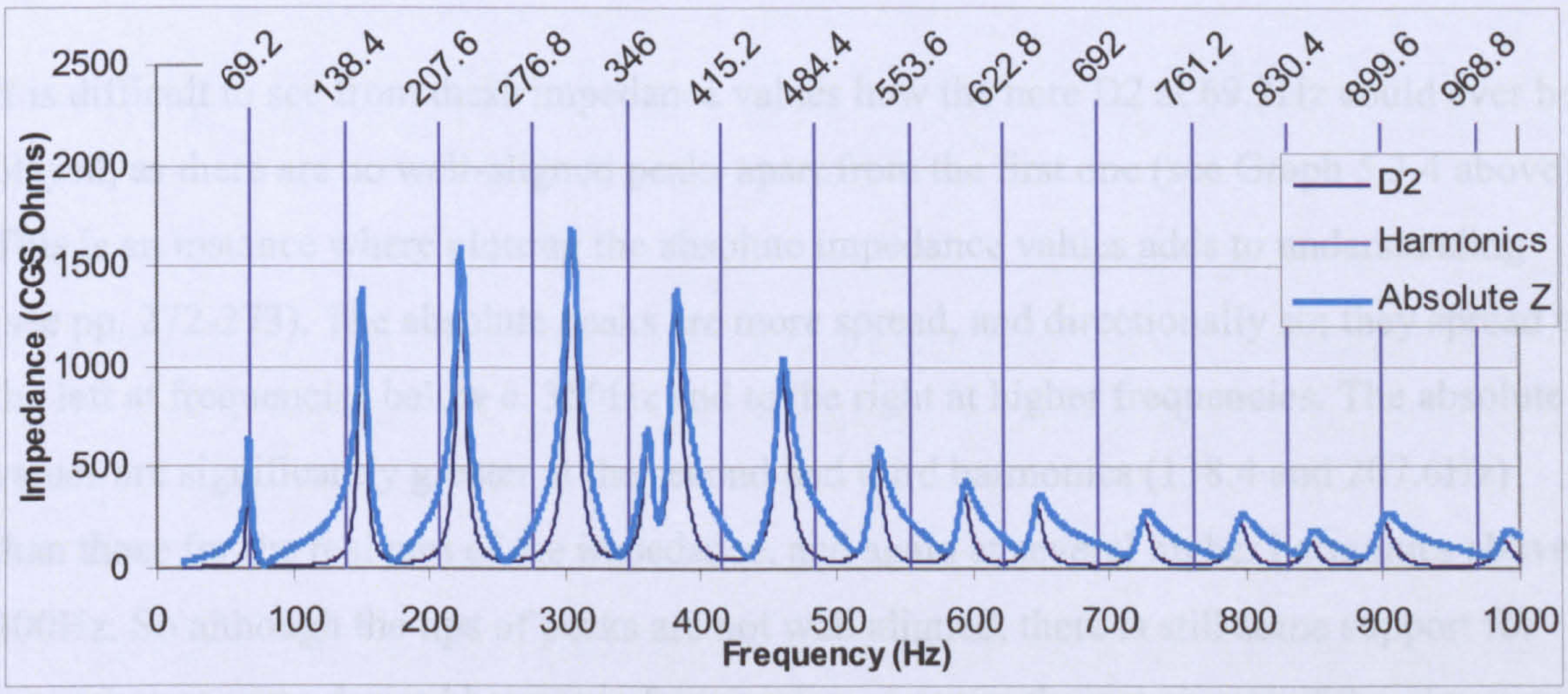
[32] The phenomenon is demonstrated and discussed in Backus, 'Input impedance curves', pp.1270-1273, and by the same author in *Acoustical Foundations*, pp. 236-9. On p. 243 of the latter he says: 'Whether the "stretch" in the bassoon and the "compression" in the clarinet are essential to their proper playing or whether they are fortuitous has not yet been determined'.

but on the Poerschman it is rather trickier and takes a little more practice to place accurately. The half-holing permits enough flexibility to allow for different pitches for C# and Db.

D2: `123 456 F ED`

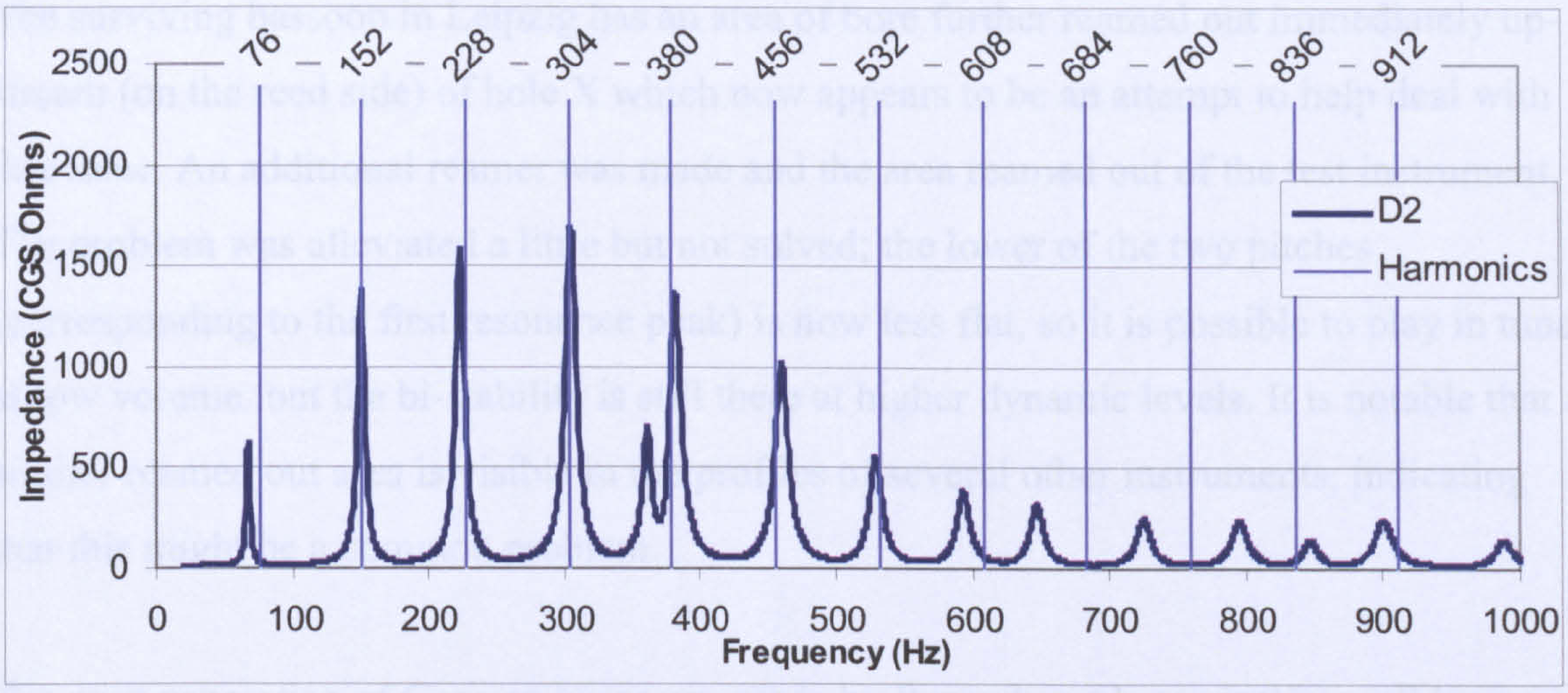
On the Poerschman this note is tricky and unstable. Small reeds particularly exacerbate this, causing a bi-stable situation between a too-flat note and a too-sharp one, and at times both pitches play simultaneously. The higher of the two pitches is around Eb2, and the note sometimes jumps up to Eb3.

On the impedance graph 5.3.4 below it can be seen that mode stretching is the cause of this instability. While the first peak is at the appropriate frequency for D2 (69.2Hz), other peaks are off-alignment with the harmonics of that frequency and this time the higher peaks do not come back into harmonic alignment, except for a small one at 899.6Hz.



Graph 5.3.4. Impedance graph for D2 (69.2Hz): the thin, dark line shows the 'real' part of the impedance; the cyan line shows the wider-spread peaks of 'absolute' impedance values

Importantly this time, the second to sixth peaks (not counting the small peak at 360Hz) <u>are</u> harmonically aligned, but to a fundamental of 76Hz (shown on graph 5.3.5 below). So these resonances will co-operate together to support a regime with a fundamental of 76 Hz; a little sharp of Eb2. Because there is no peak actually at 76Hz, the system will easily overblow to the pitch of the second impedance peak at 152Hz; sharp of Eb3.



Graph 5.3.5. Impedance graph for D2, fingered 123 456 F ED. Harmonics of 76Hz shown.

The small peak at 360Hz appears to be an irregularity caused by the cutoff frequency of the open tonehole lattice for this fingering: holes X-XI. It lies near the calculated f_c for this lattice of 376Hz (average for the two open holes using Benade's equation, see p. 287), and thus accords with theory on cutoff frequency discussed in sections 4.1 and 4.6.

It is difficult to see from these impedance values how the note D2 at 69.2Hz could ever be played, as there are no well-aligned peaks apart from the first one (see Graph 5.3.4 above). This is an instance where plotting the absolute impedance values adds to understanding (see pp. 272-273). The absolute peaks are more spread, and directionally so; they spread to the left at frequencies below c. 350Hz and to the right at higher frequencies. The absolute values are significantly greater at the second and third harmonics (138.4 and 207.6Hz) than those for the real part of the impedance, and again at several higher harmonics above 400Hz. So although the tips of peaks are not well aligned, there is still some support for resonance at some desired harmonic frequencies – apparently just enough if the player can adjust the reed's response accurately enough with his/her embouchure.

Larger (wider) reeds help the situation; they have what musicians call a more flexible response, which means that they can be more readily manipulated with the player's embouchure and breath control so that, in this case, they may be driven to vibrate at 69.2Hz despite the poor support from bore resonances. However, especially with smaller reeds, it remains an unreliable note. This is a serious problem when playing in D major, when the continuo is often required to make a strong ending on D2.

The surviving bassoon in Leipzig has an area of bore further reamed out immediately up-stream (on the reed side) of hole X which now appears to be an attempt to help deal with this issue. An additional reamer was made and the area reamed out of the test instrument. The problem was alleviated a little but not solved; the lower of the two pitches (corresponding to the first resonance peak) is now less flat, so it is possible to play in tune at low volume. but the bi-stability is still there at higher dynamic levels. It is notable that a similar reamed out area is visible in the profiles of several other instruments, indicating that this might be a common problem.

The next generation of German bassoons, made by Poerschman's apprentices, all have a small hole in the bell, the purpose of which is somewhat obscure. In later designs it was enlarged and provided with an open-standing key, to produce B when open and Bb when closed. Almenraeder referred to the earlier, small hole when discussing this development:

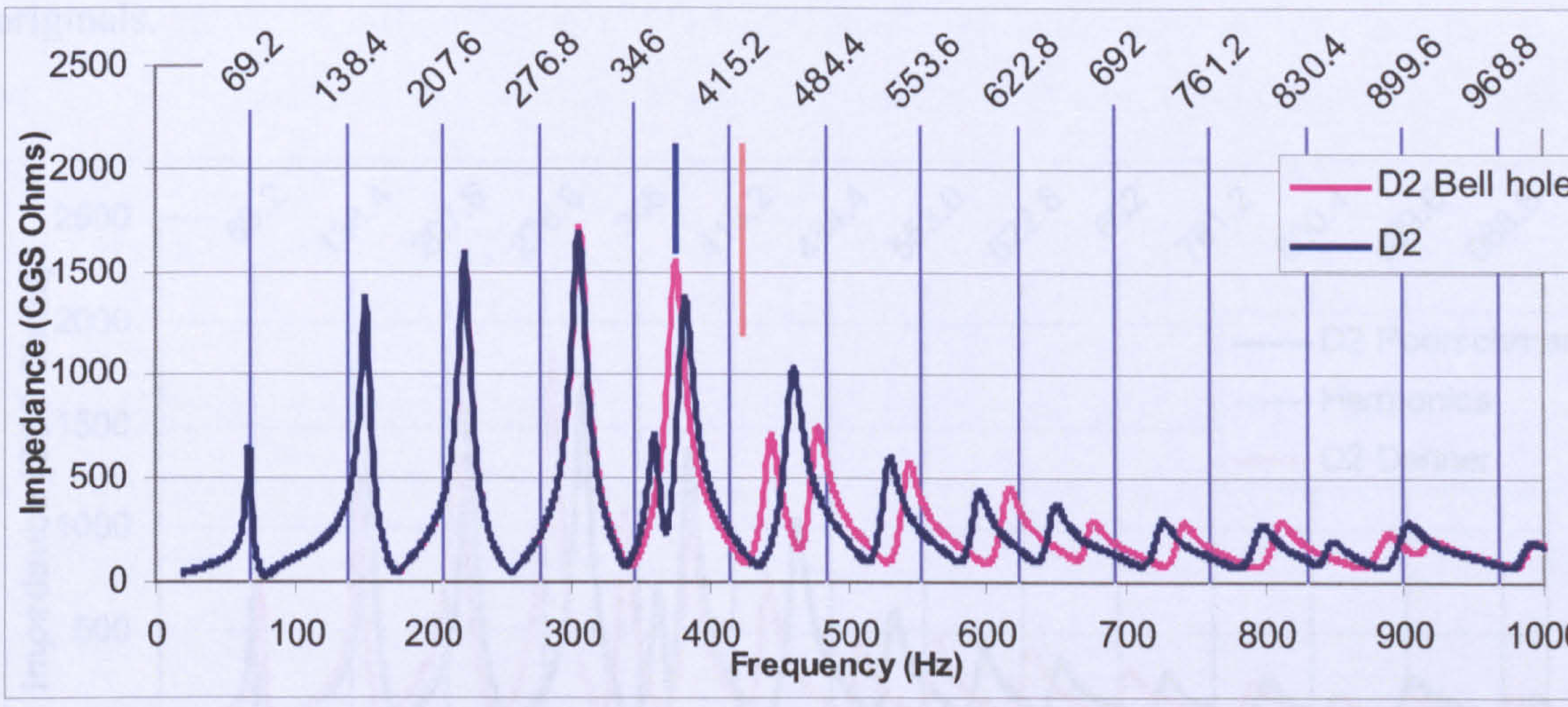
> take, for example, the small hole on the bell joint, from which B1 sounds; it was drilled on earlier bassoons so that it might make C2 sound more powerfully, and in this it was somewhat successful. It carried with it, however, the disadvantage that the Bb1 became much weaker and somewhat too high.... The large keyed hole on the bell now helps not only the C2, but also C#2 and <u>especially the usually bad D2</u>, to become more powerful tones' (my emphasis).[33]

A small hole was tried on the test instrument: a hole 5mm diameter was drilled 150mm down from the top of the bell. The result was a pleasing improvement in the stability of the D; it is now possible to play the note both strongly and softly, with a good definition of pitch and satisfactory tone.

The impedance graph for this shows that drilling the hole has no effect at all on impedance at frequencies below 340Hz; above that the peaks are realigned. Again this is in accordance with cutoff theory: drilling the bell hole has changed the open-hole lattice and raised the mean cutoff frequency to 425Hz. The previous odd peak at 360Hz has been removed (see above) and the fifth peak is now in a regular progression with the first four. There is a new irregularity between 400-450Hz – near the new cutoff. Above that, the peaks again form a regular progression, though the spacing between adjacent peaks is narrower than at the lower frequencies. It has to be said that the increase in support for harmonics of D2 is rather subtle, nevertheless three more harmonics: 7, 8 and 9 (484.4, 553.6 and 622.8Hz) are better supported, and there is a very small increase at the next

[33] Carl Almenräder, 'Bemerkungen über Blasinstrumente mit Tonlöchern; in besondere die Doppellöcher am Fagott betreffend', *Cäcilia* 19 (1837), 77-87 (pp. 84-5). Translation by J. Kopp, private correspondance.

three harmonics too. This appears to be enough to cause a noticeable effect in practice.[34] Playing qualities of C2 and Bb1 do not seem to be adversely affected.

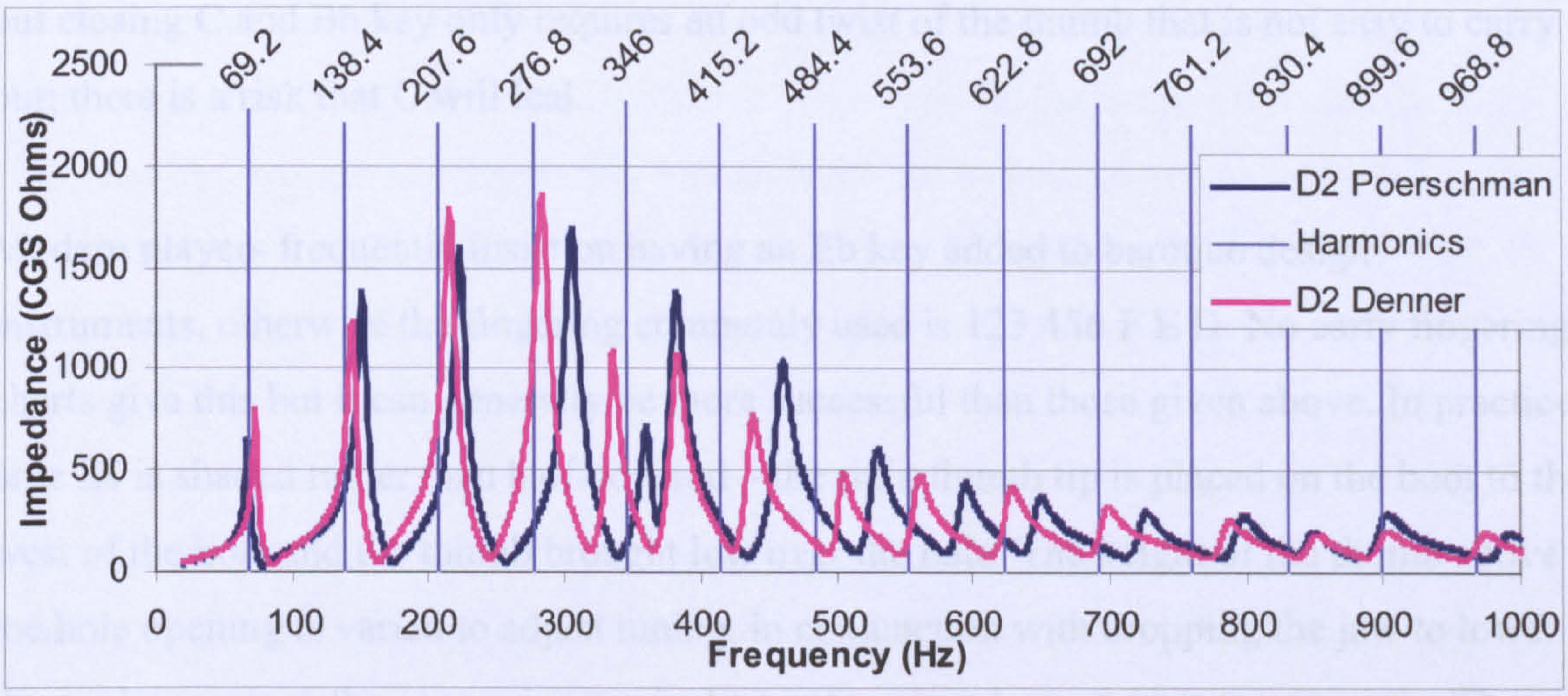


Graph 5.3.6. Absolute impedance values for D2, with and without bell hole. Vertical markers show the mean cutoff frequency before (blue) and after (pink) drilling the hole.

In contrast, on the Denner bassoon D2 is a good, stable and reliable note, though a little softer than C2. In the graph below comparing the impedances for the same note on the two bassoons it can be seen that the Denner has several more well- or closely-aligned peaks; at harmonics 1, 2, 3, 4, 8, 9 10, and 13. There is a smaller degree of mode stretching evident in the Denner, possibly because the bore taper is closer to a straight cone; there is only a small reduction in taper angle as the bore progresses from wing to boot, in contrast to the greater change in the Poerschman. The model of the cone-cylinder bore discussed in 4.5.5 above shows that the reduction in taper causes the impedance peaks to be more widely separated. This smaller degree of mode stretching is common to all of the low notes of the Denner (though not printed here). All of the peaks are a little sharp-pitched in the graph but in practice the note is easily played in tune. This is possibly because the embouchure formation required to make the system work at such a low pitch is a relaxed one, with low blowing pressure and increased lip damping that increase the reed's equivalent volume and lower its resonance; so the embouchure for such low notes has some lipping-down built-in.[35] The impedance graphs for each of the low-range notes on the Denner show sharp-pitched resonances, and yet these are stable and well-tuned notes on that instrument. This may be an indication that these resonances need to be tuned sharp, and the relaxed

[34] Only one baroque period bassoon with a bell hole that might be original is known of; that is the J.H. Rottenburgh in Brugges. The hole is rather large (c. 8mm) and is fitted with a wooden peg so that it can be closed if desired; its intention has been interpreted as to allow a choice between Bb or B for the lowest note. A bell hole has been added to the J. Denner bassoon in Rheinfelden.

embouchure used for a healthy low range, so perhaps the tuning of the Poerschman could be altered accordingly, with larger toneholes in the long joint. For the purposes of this study though, the tonehole sizes were retained as they were, matching those on the originals.



Graph 5.3.7. Impedance graph for D2 on Poerschman and Denner bassoons. Absolute impedances shown.

Eb2: `123 456 F ED`

This note is quite frequently required of the early eighteenth century bassoon player despite being a difficult one to place securely. An exposed, soft ending of an Eb major continuo line can be very troubling, and yet a dedicated tonehole and key was not added until around 1760.

Several particularly demanding passages with Eb occur in the opening chorus of Bach's St John's Passion:

Fig 5.3.1. Bars 33-34 and 58-60 of the first chorus in J.S. Bach's St John's Passion, marked '*Violoncelli e Bassoni col Bassono grosso*'

[35] See Smith, *Reed Design for Early Woodwinds*, pp. 42-43 for discussion of embouchure in these terms.

The early fingering charts give either 123 456 F EB or 123 456 F ECB; both cross fingerings with holes beyond the E vent (IX) closed.[36] However the former does not usually bring the pitch down far enough as it leaves both X and IX open, while the latter is difficult to perform due to the geometry between the key and hole X and the way the thumb can move. Closing C and the D key, or C and both D and Bb keys is easy enough, but closing C and Bb key only requires an odd twist of the thumb that is not easy to carry out; there is a risk that C will leak.

Modern players frequently insist on having an Eb key added to baroque design instruments, otherwise the fingering commonly used is 123 456 F ~~E~~ D. No early fingering charts give this but it can generally be more successful than those given above. In practice hole IX is shaded rather than half-covered – the right thumb tip is placed on the boot to the west of the hole and the thumb brought low over the hole. The height of the thumb above the hole opening is varied to adjust tuning, in conjunction with dropping the jaw to lower the reed resonance (by increasing equivalent volume) and mouth/throat resonance. Thus the tuning is flexible enough for the fingering to serve for either Eb or D#. On this instrument that fingering gives a surprisingly positive result; it is possible to be confident of hitting the note accurately (considerably more so than on the Denner), and of producing a full, rich tone. The early-chart fingerings also almost work but are not as easy to use as this one. In comparison with the Denner, it seems that a good D2 has been traded for a good Eb2.

E2: `123 456 F E`

Good, strong tone on both instruments.

F2: `123 456 F`

Good, strong tone on both instruments. On the Poerschman it verges on playing flat and the thumb must be kept well clear of hole VIII (E), as any shading flattens the note significantly. That hole is a little narrower and has a longer chimney on the Poerschman, which is also partly why the cross fingering effect is so strong in the Eb2 fingering discussed above.

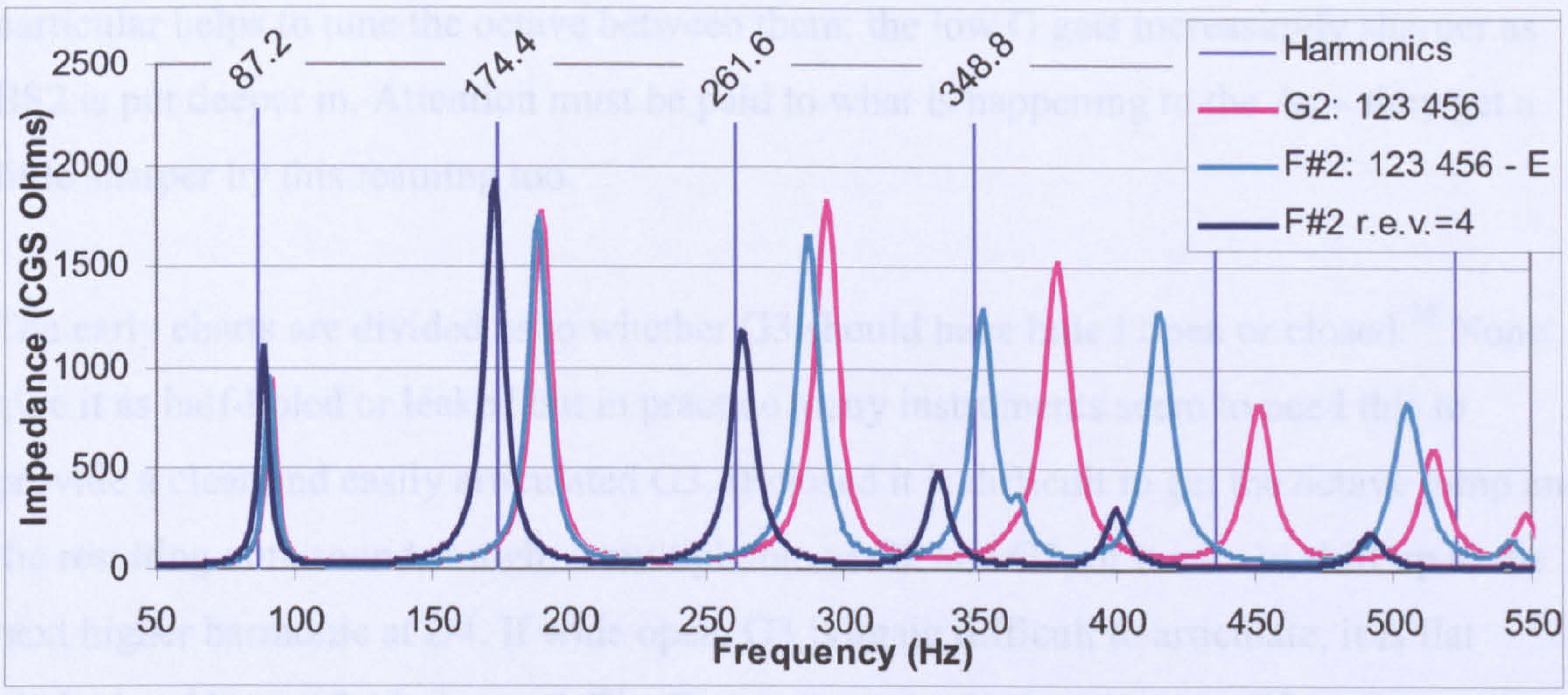
[36] Somewhat bizarrely, White gives his standard fingering as 123 456 F EDBb, which is impossible to achieve; it is not possible to close both the D and Bb keys while leaving the hole X which lies between them open.

This is the first fingering required to overblow; in this case not to the octave but to an octave plus a semitone. The overblowing is helped by opening hole I as a vent; this is discussed under F#3.

F#2: `123 456 - E`

Another cross fingering; leaving hole VII open while closing VIII. This is the only fingering given in early charts until a dedicated key was added in the nineteenth century. The cross-fingering is not adequate (on most or all early bassoons) to get the pitch down far enough because VII is relatively large and the bore expands rapidly between VII and the next open hole VIII. But closing IX (the D key) as well causes a problematic clash of resonances and not a useable note. So the note must be lipped down by lowering the jaw, relaxing the embouchure and increasing lip damping. This is something players of modern instruments new to the early bassoon often find difficult – simply closing VIII while holding a constant embouchure formation will not produce much if any drop in pitch from G2, but when the jaw is lowered the note finds another 'slot'; a stable position at the correct pitch. Closing the Bb key can help to stabilise the note at this lower pitch.

This situation too can be illustrated by an impedance graph. The 'Impedps' software requires the entry of a factor for 'reed equivalent volume' (r.e.v.), which is the extra acoustic volume that a vibrating reed has in addition to its physical, relaxed state volume. In practice, relaxing the embouchure by dropping the jaw while blowing has the effect of lowering reed resonance and increasing the r.e.v. In the graph below the pink curve shows impedances for the G2 fingering, and the cyan curve those for the F# fingering with the same r.e.v (a value of 1.4ml is used throughout these tests unless otherwise stated). The third and higher peaks for F# are reduced in frequency but the first two peaks are little changed from their G2 values. The dark line shows the F# fingering with r.e.v. significantly increased and now the first three peaks align very well with the first three harmonics of F#2, so the note is readily lipped down into a clear 'slot' at a good pitch. The higher frequency peaks drop off rapidly in height on the graph, and this is manifested in practice as a somewhat 'dark' tone quality, with few high partials present.



Graph 5.3.8. Impedance graph for G2 and F#2 fingerings on Poerschman bassoon

Importantly there is a good octave relationship with the second register F#3 using the same fingering overblown, with or without hole I leaked. This is further discussed under F#3. The pitch flexibility of these fingerings make them also useable for a meantone-tuned Gb2 and Gb3, on the rare occasions when those are encountered.

G2 and G3: `123 456 and 1̶23 456`

It is from this point that fingerings are expected to provide two octaves, so from here on tuning the instrument becomes more complex; the first open hole is the primary vent for two notes an octave apart. From here on, both octaves of each note will be discussed together.

As the lowest of these two-octave fingerings, G2/G3 is pivotal in the setting up of the instrument; G2 must play in tune at the desired pitch and G3 should be an accurate octave above it, to provide references to which other notes in both octaves are tuned. In preparation for tuning these notes, Almenraeder states:

> For this octave it is necessary to remark that the Bb, B, C, D, E and F, which lie below G2, must be exactly in tune because otherwise it is impossible to get the octave G2 to G3 pure.[37]

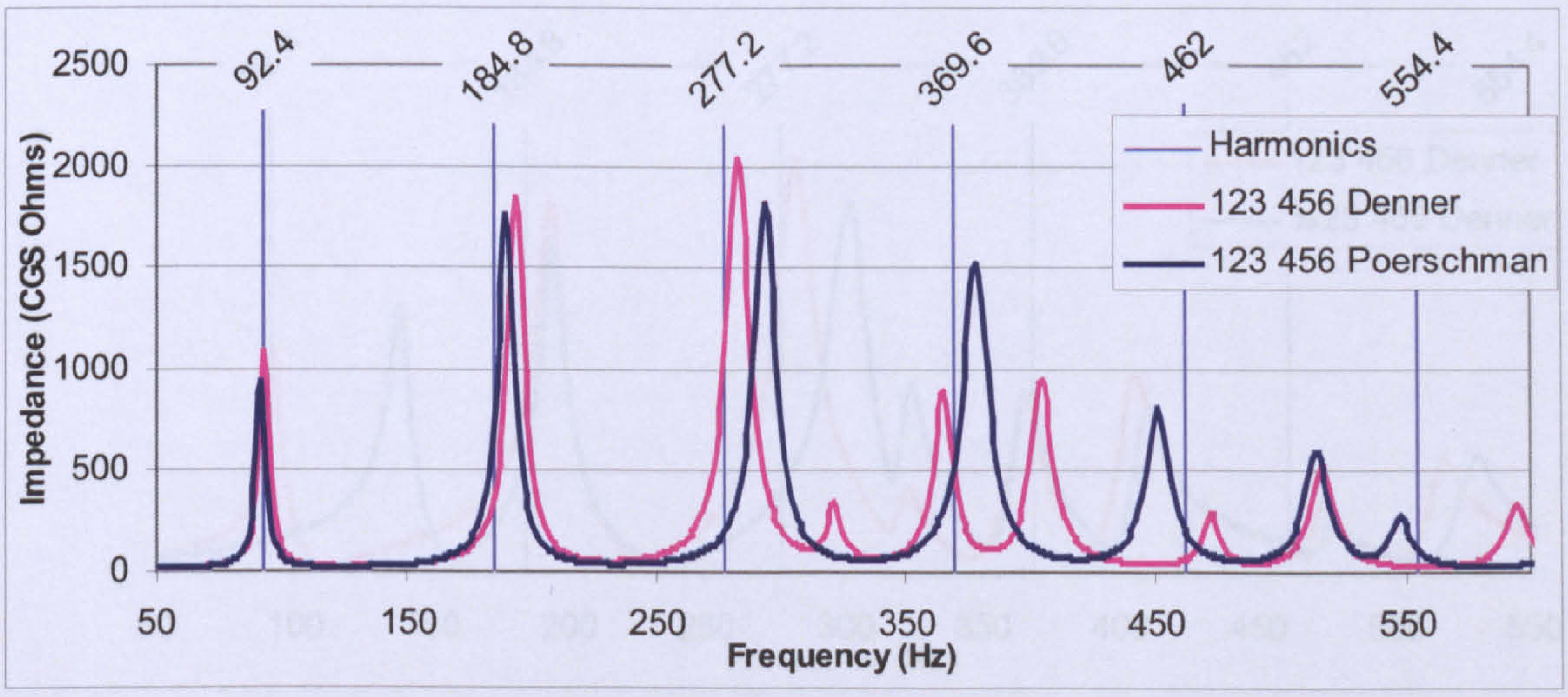
On the experimental boot joint with simple reaming both Gs play flat; G2 by around 35 cents and G3 by around 20 cents. The 19.8 cylindrical reamer enlarges the south ends of both boot bores, immediately up-stream of the G vent hole (VII) and BS2 opens the small bore further northwards. Both of these serve to raise the pitch of the Gs, and BS2 in

[37] See Appendix 1 §3.

particular helps to tune the octave between them; the low G gets increasingly sharper as BS2 is put deeper in. Attention must be paid to what is happening to the As – they get a little sharper by this reaming too.

The early charts are divided as to whether G3 should have hole I open or closed.[38] None give it as half-holed or leaked but in practice many instruments seem to need this to provide a clear and easily articulated G3. If closed it is difficult to get the octave jump and the resulting note sounds rough; a multiphonic of G2 and G3, or it tries to shift up to the next higher harmonic at D4. If wide open, G3 is again difficult to articulate, it is flat pitched and has a 'flabby' sound. The Denner operates in that manner; G3 is clear and well matched to G2 in sonority and pitch but only if I is leaked. The Poerschman, though, can operate with I fully closed; leaking it makes little or no difference. G3 can be articulated cleanly, and octave jumps to and from G2 can be easily made without changing fingering. As on the Denner, fully opening I does not work at all. On both there is a well-tuned octave between G2 and G3.

The impedance graphs for these fingerings illustrate why there is this difference between the two instruments.



Graph 5.3.9. Impedance graph for G2 fingering, Denner versus Poerschman

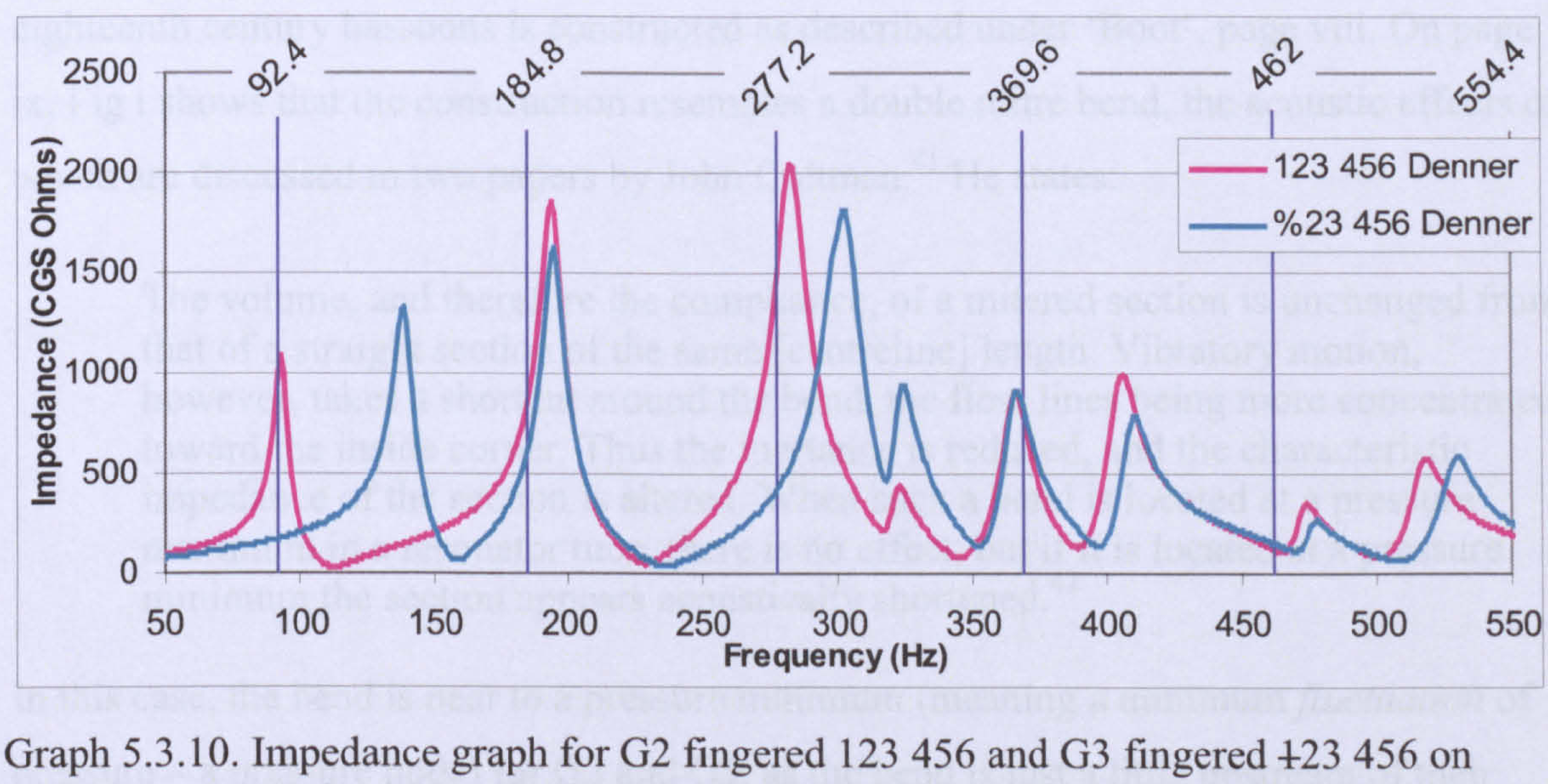
In the graph above, the first peaks for both instruments are well tuned to G2 at 92.4 Hz; Denner's is a little taller than Poerschman's. At the third peak, Denner is again taller than Poerschman and also better tuned to the third harmonic – there is a relatively high

[38] White's 'standard' has it closed as do as do five of the early charts. Prelleur, Berlin, Diderot. Tans'ur and later English charts give it open. English bassoons contemporary with those later charts have their hole I made particularly small.

impedance value at that frequency (277.2Hz) so that mode is well supported. The Poerschman peak is significantly sharper in pitch so there is very little support for the third harmonic. They both provide about the same small amount of support for the fourth harmonic (369.6Hz), despite their differently positioned and sized peaks. All of these provide good support for an oscillatory regime based on a fundamental of 92.4Hz, so G2 is a good strong note on both instruments.

In order to switch up the octave to G3 a new regime must be established on 184.8Hz and vibration modes at the odd numbered harmonics of G2 will have no place in that, so in the Denner, the well supported first and third harmonics will prevent this new regime from being established. In the case of the Poerschman, the lack of support for harmonic 3 and the smaller peak at 92.4Hz mean that there is less to prevent the change, so the player changes embouchure to set a higher reed-resonance and the octave jump is easily made.

When hole I is leaked on the Denner it is being used as a 'register vent', the operation of these is fully discussed by Benade.[39] In the graph below the cyan line shows the resonances for Ɨ23 456 (shown as %23 456 in the key).



Graph 5.3.10. Impedance graph for G2 fingered 123 456 and G3 fingered Ɨ23 456 on Denner bassoon; absolute Z shown

Leaking Hole I has re-tuned the first and third peaks, making them significantly sharper and no longer in any harmonic relationship. The peaks at harmonics 2 and 4 are little changed, leaving them to become the fundamental and second harmonics of a new regime playing at 184.8Hz.

This explanation is somewhat spoiled by peak 2 being noticeably sharp of harmonic 2; indicating that the note G3 should play sharp, when in practice this is not the case. The leftwards spread of the Absolute Z curve shows a little more support at 184.8Hz than the Real Z curve (graph 5.3.10), but this is still not enough to explain the real instrument's playing behaviour. There is still some 'mode stretching' this far up the instrument's range; a similar condition, though less extreme, appears in the G2 Poerschman graph, and Cronin also observes it in his modelling of a 'modern German' bassoon (model unspecified).[40]

It is conceivable that this is a sign of error in the modelling of the U-bend. The joint between the up and down bores is, for the purpose of the model used in *Impedps*, simply taken as the point where each meets the plug face. As discussed in section 2.2 p. 24, this generates an error in the total length of the bore centreline, consisting of:
Mean bore diameter at window + septum thickness – window height. In this case those values are: 21.8 + 4.2 – 21.0 = 3mm, so the bore has been modelled as 3mm too short.

However the turn-around in the bores is not constructed as a smoothly bowed tube of the sort found in brass instruments, and as fitted to modern bassoons. Instead, this part of eighteenth century bassoons is constructed as described under 'Boot', page viii. On page ix, Fig i shows that the construction resembles a double mitre bend, the acoustic effects of which are discussed in two papers by John Coltman.[41] He states:

> The volume, and therefore the compliance, of a mitered section is unchanged from that of a straight section of the same [centreline] length. Vibratory motion, however, takes a shortcut around the bend, the flow lines being more concentrated toward the inside corner. Thus the inertance is reduced, and the characteristic impedance of the section is altered. When such a bend is located at a pressure maximum in a resonator tube, there is no effect, but if it is located at a pressure minimum the section appears acoustically shortened.[42]

In this case, the bend is near to a pressure minimum (meaning a minimum *fluctuation* of pressure – a pressure node) for G2 and G3, as the bend is just a little upstream of their primary vent, hole VIII. Therefore, for these notes the bend construction produces an

[39] Benade, *Fundamental,* pp.455-460.
[40] Cronin, 'Understanding', p. 20.
[41] John W. Coltman, 'Acoustic properties of miter bends', 2006, https://ccrma.stanford.edu/marl/Coltman/documents/Coltman-1.44.pdf
John W. Coltman, 'Compensating for miter bends in cylindrical tubing', *JASA*, (May 2007 121-5 Pt1), pp. 2497-8.
[42] Coltman 'Compensating', p. 2497.

effective shortening of the bore compared to the length of the bore centreline, for which Coltman derives a quantity of 0.79 x bore diameter.[43] Here the bore is 19.8mm, so the acoustic shortening is 15.6mm, however the length has been modelled 3mm too short already, so the net error is 12.6mm. If the model is corrected for this, the resonances of the two Gs will, of course, be sharpened further still (by a small amount). So the mode stretching and sharp-pitched second resonance peak do not appear to have been caused by this effect, nor by this particular inaccuracy in the model. This is an area where Acoustic Pulse Reflectometry would prove useful; the technique could be used to obtain the effective acoustic length, and the effective diameter(s) around the bend so that bore model can be corrected.

G#/Ab 2and 3: `123 456 #`

The original Denner on which the reconstruction used here is based (Brussels M427) is a three-keyed bassoon, as are three of those with the JC Denner stamp, so on them there is no dedicated tonehole for this note. The apparent reluctance on the part of Denner and other makers of type 1b bassoons to add this key is somewhat mysterious. The equivalent key (for Eb) is always present on the oboes and transverse flutes of the time, even by the same makers. However, while those smaller instruments end a little way beyond their Eb keys, the bassoon has its extension bore, so there should be enough bore length, and further toneholes, to allow a cross-fingering to be used to lower the five-finger note by a semitone. In practice it is not that simple; fingering 123 45- F produces a burbling note that does not settle on any pitch. 123 45- E leaves both VI and VII open so there is not enough flattening effect. The one fingering chart for three-keyed bassoon shows half-holing VI for both octaves (I is closed for both too).[44] In practice if either E or the D key is also closed there is a more positive locking-into pitch, and in fact this is quite effective, but still somewhat awkward in fast passages. Herbert Myers has discussed the production of this note in earlier double reed instruments – shawm and curtal – and noted that on some originals of those (but not always on 'reproductions' made to play at lower pitches), the fingering 123 45- has a bi-stable nature allowing either the A or Ab to be played depending on embouchure formation, much as in the case of F#2 discussed above.[45] This effect is somewhat evident on this Denner reconstruction, though the closing of either E or

[43] Coltman, 'Acoustic properties', p.4.
[44] Majer, J. F., *Museum Musicum Theoretico Practicum*, (Nürnberg: 1732; facs. Schwäbisch Hall, 1954).
[45] Herbert W. Myers, 'Bi-stability in Shawm and Dulcian Notes', paper presented to the Musical Acoustics Network Summer Meeting, June 2007. See also Smith, *Reed Design*, pp.30-31.

D also helps, so with a drop of the jaw (and thus increase in reed's equivalent volume) the half-holing can be dispensed with. The fingerings then are:

G#/Ab2: `123 45- E` **G#/Ab3:** `123 45- D`

Once the fourth key is added this becomes, on the face of it, another simple-fingered note, since there is a dedicated (key operated) hole for the primary vent and all holes further down the bore are left open too. So it might be thought that it should be a straightforward matter to tune, but it is rarely so; the position and size of the hole seems to have been a matter of experiment from the time it was first applied until the modern system.[46]

Despite both that the hole can in theory be placed anywhere between VI and VII thanks to the key, and that it is angled downwards (away from the reed end), on baroque bassoons it is still the smallest hole on the instrument; on the Poerschman it is 4.9mm in diameter. The resulting tone of Ab2 on the Poerschman played with the simple fingering (which is the only option given in all of the early charts), is somewhat muffled, but it is positively located at appropriate pitch, while being flexible enough to be useable for both G# and Ab. Closing both D and C together focuses the tone somewhat so that it matches better the other simple-fingered notes in the low register.

Ab3 is more of a problem; again the early charts only give the simple fingering, with hole I closed in all but the latest three charts for 4-keyed bassoon (all of those last three from England).[47] On this instrument the note is weaker than Ab2 and occasionally difficult to place; in certain passages it will 'squeak' up to E4. Again closing D and C together improves the note. Closing the D key alone considerably strengthens the tone and raises the pitch; it is suitable for a mean-toned Ab but too sharp for G#, so that C must be closed too bring the pitch down. Both fingerings correct the tendency to squeak.

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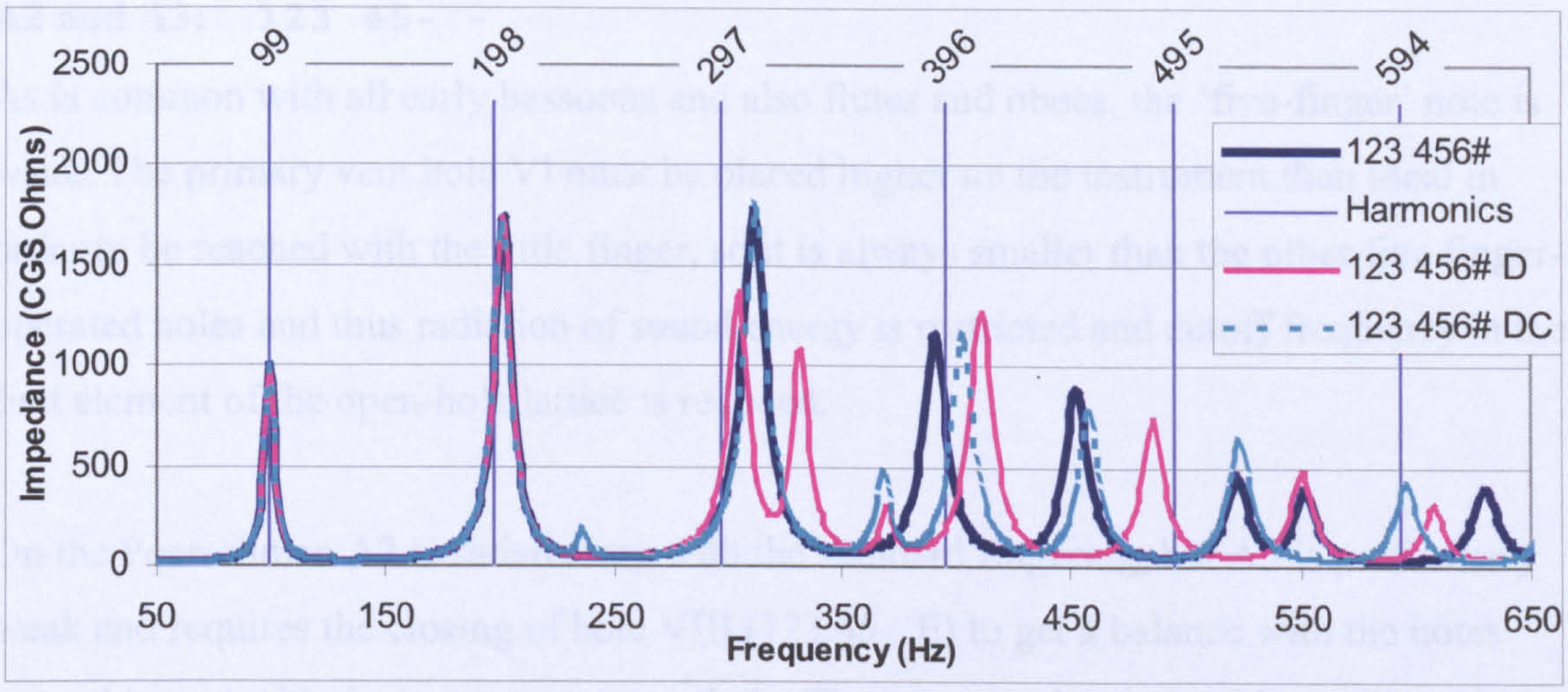
[46] James B. Kopp, 'An Acoustical Challenge for Bassoon Makers: The Story of A-flat', in *Celebrating Double Reeds: A Festschrift for William Waterhouse and Philip Bate*, ed. by Terry B. Ewell (U.S.A: The International Double Reed Society, 2009), 197-212.

[47] W. Tans'ur 1767, Longman & Broderip c.1770, Preston & Son c. 1790. English bassoons from c. 1770 on often had a very small hole I along with other design changes intended to brighten the tone quality overall. See Halfpenny, 'The Evolution of the Bassoon in England'.



Graph 5.3.11. Impedance graph for Ab 2 and 3 fingerings on Poerschman

The simple 123 456# fingering is shown by the dark line (it is concealed by the cyan and pink lines at the first two peaks where all three coincide; the auxiliary fingerings only have an effect above 270 Hz).

The very strong peak 3 is what causes the fingering to squeak. The frequency of this peak is 313Hz, close to E4 (310.9Hz), and as it is the strongest resonance, when the player aims for the second octave, it is easy to overshoot and land here instead. Closing the D key (pink line) breaks this peak into two at reduced strengths, thus ameliorating the tendency to squeak. But now the peak at harmonic 4 (396 Hz) has moved to being significantly sharp. This is harmonic 2 of Ab3 and that note sounds sharp with the 123 456# D fingering. Closing C as well (cyan line) brings that peak down in frequency and adds another small peak at harmonic 6 (594Hz). The strong third peak has been reinstated, but nevertheless the resonances at the second, fourth and sixth harmonics of Ab2 now co-operate to produce a better in tune Ab3, with a stronger tone than either of the other two fingerings produce.

For Ab2, the played note's pitch does not change so much with these auxiliaries but the tone quality does. Both auxiliary fingerings brighten and increase the strength of tone; it is not obvious from the graph why this should be, but the pink line (closing D) shows a little more support at harmonic 3, and some at harmonic 5. The cyan line (closing D and C) returns the support at harmonic 4 and adds a little at harmonic 6. These small supportive peaks at higher harmonics explain the brighter sounding note.

A2 and A3: `123 45- -`

As is common with all early bassoons and also flutes and oboes, the 'five-finger' note is weak. The primary vent hole VI must be placed higher up the instrument than ideal in order to be reached with the little finger, so it is always smaller than the other five finger-operated holes and thus radiation of sound energy is restricted and cutoff frequency in the first element of the open-hole lattice is reduced.

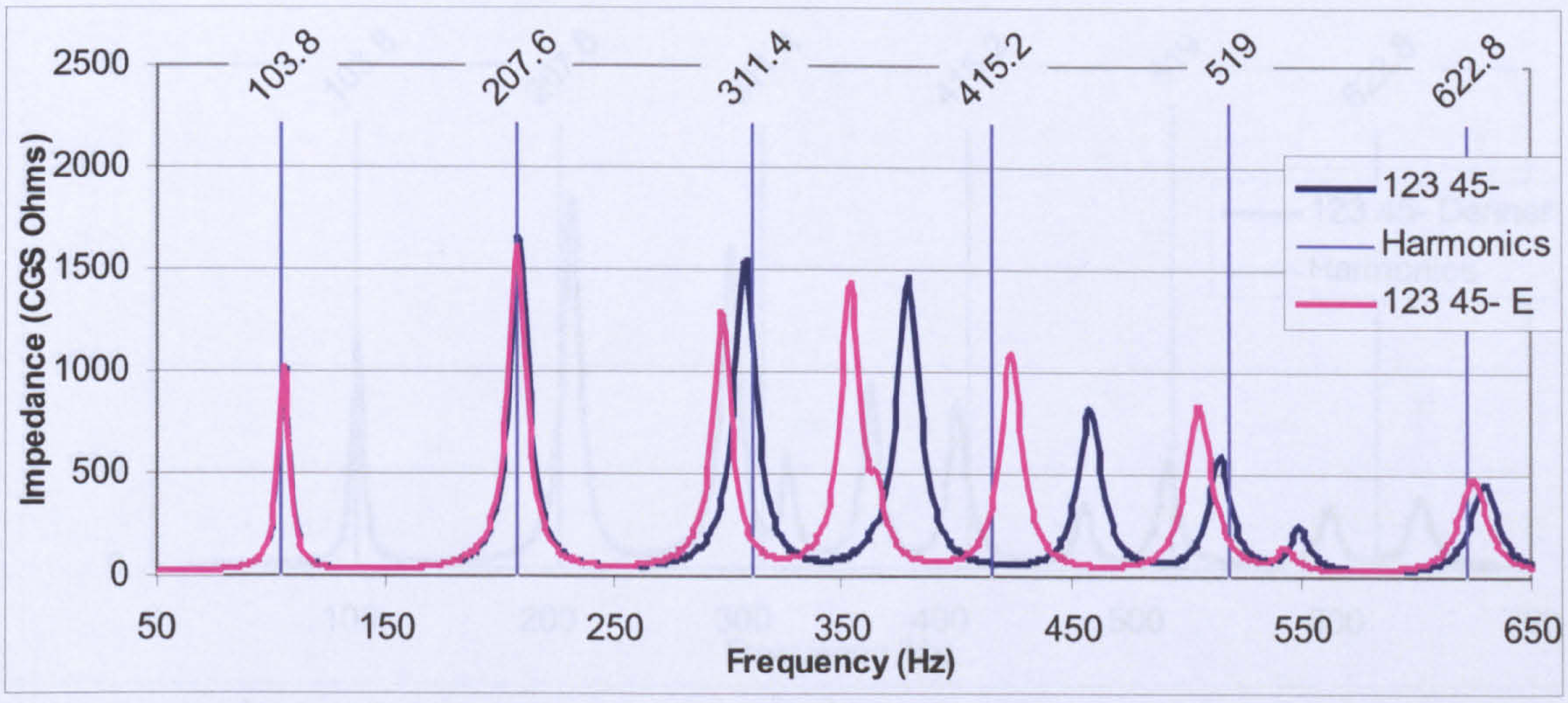
On the Poerschman A2 is satisfactory with the standard fingering, but A3 is particularly weak and requires the closing of hole VIII (123 45- E) to get a balance with the notes around it, and with the instrument as a whole. There is a tendency for this auxiliary fingering to result in rather too strident a tone, and the pitch rises too so care must be taken not to enlarge VI too much. This becomes a three-way balance; the simple fingering is used for A2 so VI must be opened out enough to give a reasonably clear tone at the right pitch. The same fingering will also be used for A3 in fast passagework so must produce a passable tone and pitch there too, but the auxiliary fingering will always be used in slower passages so VI must not be so large that this is too sharp or too strident.

This weak note seems to be an issue with other designs of early bassoon; Cronin describes it and analyses the acoustics with reference to his reconstruction of a bassoon by Eichentopf[48] and Ross recommends closing E in her published fingering chart for her reconstruction of an Eichentopf bassoon.[49] It is one of the most significant differences from the Denner design; on that instrument, closing E does change A3 but it is not necessary; both As play reasonably well with the simple fingering. The early charts right through to the more sophisticated tutors of the nineteenth century only show the simple fingering for both octaves, and give no indication that there should be a problem here. Cugnier mentions a tuning problem, but stops short of providing a solution:

> For example it is rare that the two As an octave apart, fingered by closing the holes 1, 2, 3, 4, 5, are exactly in tune ... when one only uses the same fingering shown in the tablature as we saw above. There are special fingerings to correct this defect, there are also several ways to finger other notes, according to the passages where they are used. ... It is necessary to choose a skilled master, who knows the fingerings, and can teach them.[50]

[48] Cronin and Keefe, 'Understanding'.
[49] http://www.leslieross.net/images/charts/fingeringEICH.pdf
[50] Cugnier, B*asson*, p. 335.

In impedance terms this is a similar situation to G3 discussed above, but this time it is the Poerschman with the problem. Also this time there is not a conveniently placed tonehole to open for an octave vent, so switching between octaves must be achieved through embouchure and breath control alone.



Graph 5.3.12. Impedance graphs for two fingerings of A on the Poerschman bassoon

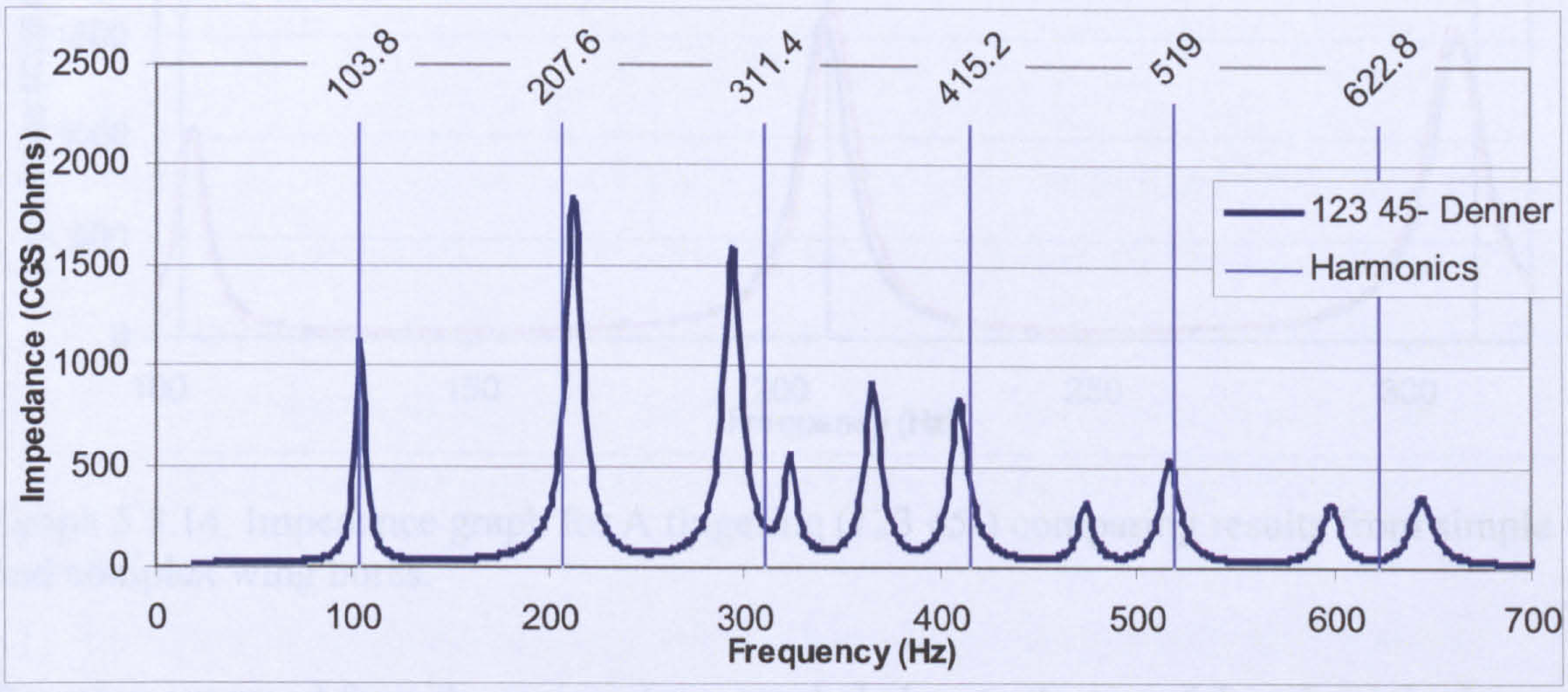
The graph above shows the simple fingering as the dark line; peaks 1,2 and 3 each align well with the first three harmonics of A2, there is also a small peak at harmonic 5 and a partially aligned peak at harmonic 6, so this should be a good strong note, and A2 does work quite well.[51]

However, the strong support at harmonics 3 and 5 are a problem for overblowing to A3, when the even numbered harmonics of A2 must become the harmonic series of A3. In that case the presence of strong bore resonances at A2's odd numbered harmonics will interfere with the switch up the octave and weaken the production of A3.
When the right thumb hole (E) is closed as shown with the pink line, the first two resonance peaks are not affected but the others are all retuned. There is now little support at harmonics 3 and 5; they both lie near impedance minima, while there is some support at harmonic 4 (415.2 Hz) and the small peak at harmonic 6 (622.8Hz) is even better aligned. So the strengths of resonances at the odd harmonics (apart from 1) are reduced and at the even harmonics they are increased, meaning that a strong oscillating regime based on harmonic 2, the frequency of A3, can easily be set going.

[51] The tonehole is the longest and second smallest on the instrument so although the bore resonances may be good, radiation of sound energy through this vent is still restricted.

A2 will also work with this fingering but it sounds rather different with more sound energy in the even harmonics than in the odd ones.

The impedance graph for the simple fingering of A on the Denner bassoon shows why the auxiliary fingering is unnecessary:

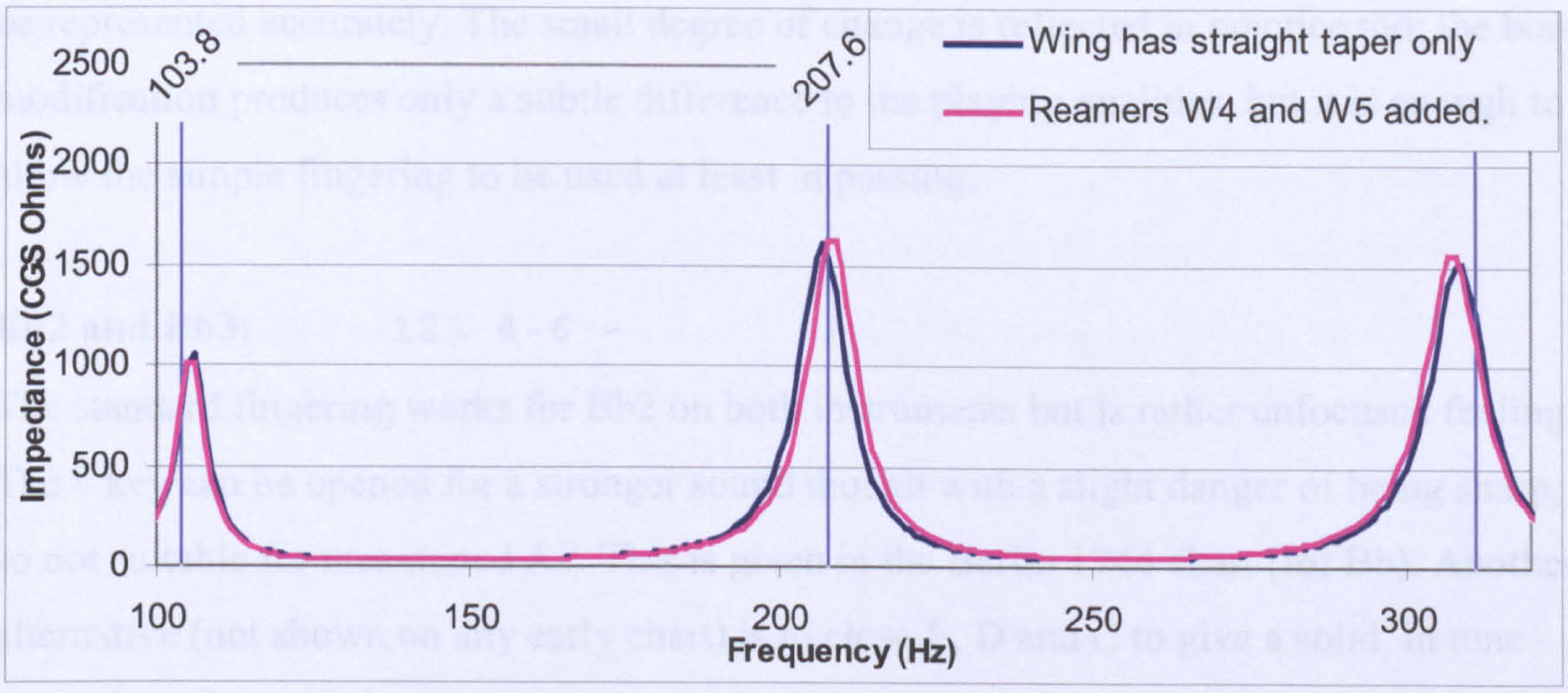


Graph 5.3.13. Impedance graph for A2 and 3 on the Denner bassoon

Here harmonic 3 lies at an impedance minimum, while small but approximately equal amounts of support exist at harmonics 4 and 5, so both octaves can work with this fingering.

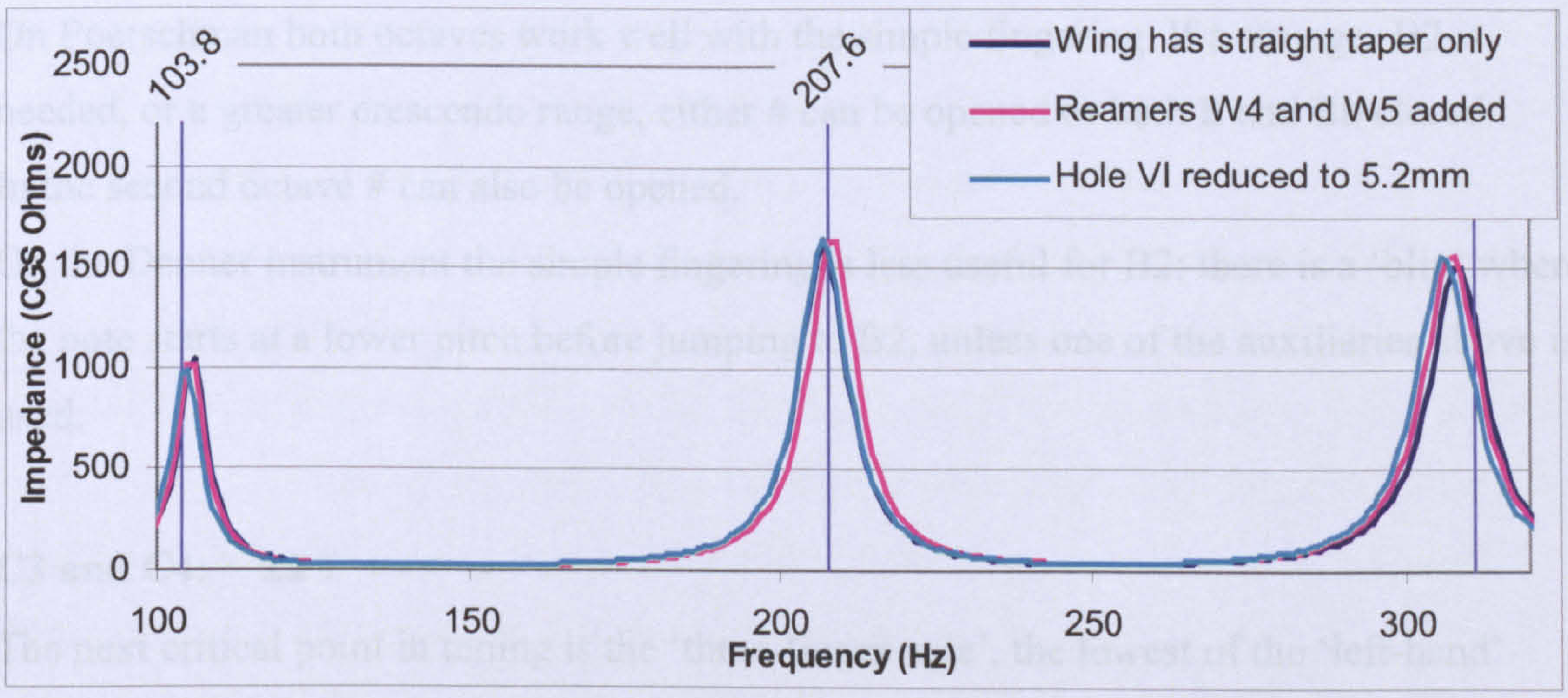
There is some evidence that Poerschman has tried some bore adjustments to improve this situation. Reducing the size of VIII improves A3 (with simple fingering) somewhat, but of course then F2 becomes too flat, so perhaps the large chamber reamed out up-stream from VIII is there to sharpen F2 while keeping the diameter of VIII to a minimum. On the Leipzig instrument this reaming is made even larger than it is on the Prague instrument, (enough to sharpen F2 by a further 15 cents according to Impedps calculations). The Denner has a much steeper and larger diameter bore through this section, which perhaps has a similar sharpening effect on F2, and hole VIII is significantly further away from the reed on this bassoon than on the Poerschman (see graph 5.3.1).

Reaming higher up the bore can also have an effect: as discussed in section 4.2, widening the bore at a pressure node will sharpen the note while reaming at a pressure antinode will flatten it. The auxiliary reamers used in the wing joint were discussed earlier, and it turns out that some of that work applies to this problem. Both of the reamers W5 and W4 (together) affect the tuning of the resonances of A. The impedance graph below shows how:



Graph 5.3.14. Impedance graph for A fingering (123 45-) comparing results from simple and complex wing bores.

Reaming out wood from the region above tonehole I up to the top of the wing joint has sharpened the second resonance of A (by 12.5 cents) and slightly flattened the third resonance. As both of the first two resonances are now sharp, the primary vent for this note, tonehole VI, can be reduced in size from 5.5 to 5.2mm. This further flattens the third peak, so will further weaken the support at harmonic 3 as desired while bringing peaks 1 and 2 into tune. (It also increases support at harmonic 6, though not shown on this graph).



Graph 5.3.15. Impedance graph for A fingering, with hole VI resized

In practice, A3 is somewhat more secure with the fully reamed wing; in particular it is possible to make a greater crescendo. When using the simple cone wing, the note flattens and gets weaker at forte.

These changes in impedance are of very fine degree, and absolute accuracy of the calculated values cannot be claimed, nevertheless the general tendencies indicated should be represented accurately. The small degree of change is reflected in practice too; the bore modification produces only a subtle difference to the playing qualities, but it is enough to allow the simple fingering to be used at least in passing.

Bb2 and Bb3: `123 4-6 -`

The standard fingering works for Bb2 on both instruments but is rather unfocused feeling. The # key can be opened for a stronger sound though with a slight danger of being sharp, so not suitable for meantoned A#. This is given in the Berlin 1744 chart (for Bb). Another alternative (not shown on any early chart) is to close E, D and C to give a solid, in tune note of good, focused tone on the Denner but of rather 'hard' tone quality on the Poerschman.

123 45- # gives a good strong, clear, well pitched note on the Poerschman – good for starting and ending passages written in Bb major. This also does not appear in any early chart though.

For Bb3 the standard fingering works well, as given in all the early charts, and is flexible enough to be used for both enharmonics.

B2 and 3: `123 4-- -`

On Poerschman both octaves work well with the simple fingering. If a stronger B2 is needed, or a greater crescendo range, either # can be opened or both E and Bb closed.

In the second octave # can also be opened.

On the Denner instrument the simple fingering is less useful for B2; there is a 'blip' where the note starts at a lower pitch before jumping to B2, unless one of the auxiliaries above is used.

C3 and C4: `123 --- -`

The next critical point in tuning is the 'three-finger note', the lowest of the 'left-hand' notes, but here there is often trouble on the bassoon. The primary vent is at the top of the boot section, a long way from the group of left-hand fingerholes; because of this it is placed lower down the bore than might be desired acoustically and so it can be difficult to get a well tuned octave at the desired pitch. The octave tends to be wide with either C3 flat or C4 sharp.

In addition to this, C4 on many instruments is difficult to produce cleanly, it often 'breaks'; burbling between C3 and C4 and jumping to G4. In order to stabilise it with the embouchure a higher reed resonance is set, but the note then stabilises at too high a pitch. This can be quite a chronic problem for modern players of both baroque and classical bassoons and yet there is no indication in the early charts or playing instructions that there was an issue.[52] This leads to the suspicion that we today are doing something wrong in the way we set up the instruments – in reed or perhaps crook designs. It might be the '*Schnarren*' that Almenraeder refers to in §5, though he says that can also affect the A3 and Bb3 too, and that has not been experienced in this or other bassoons.

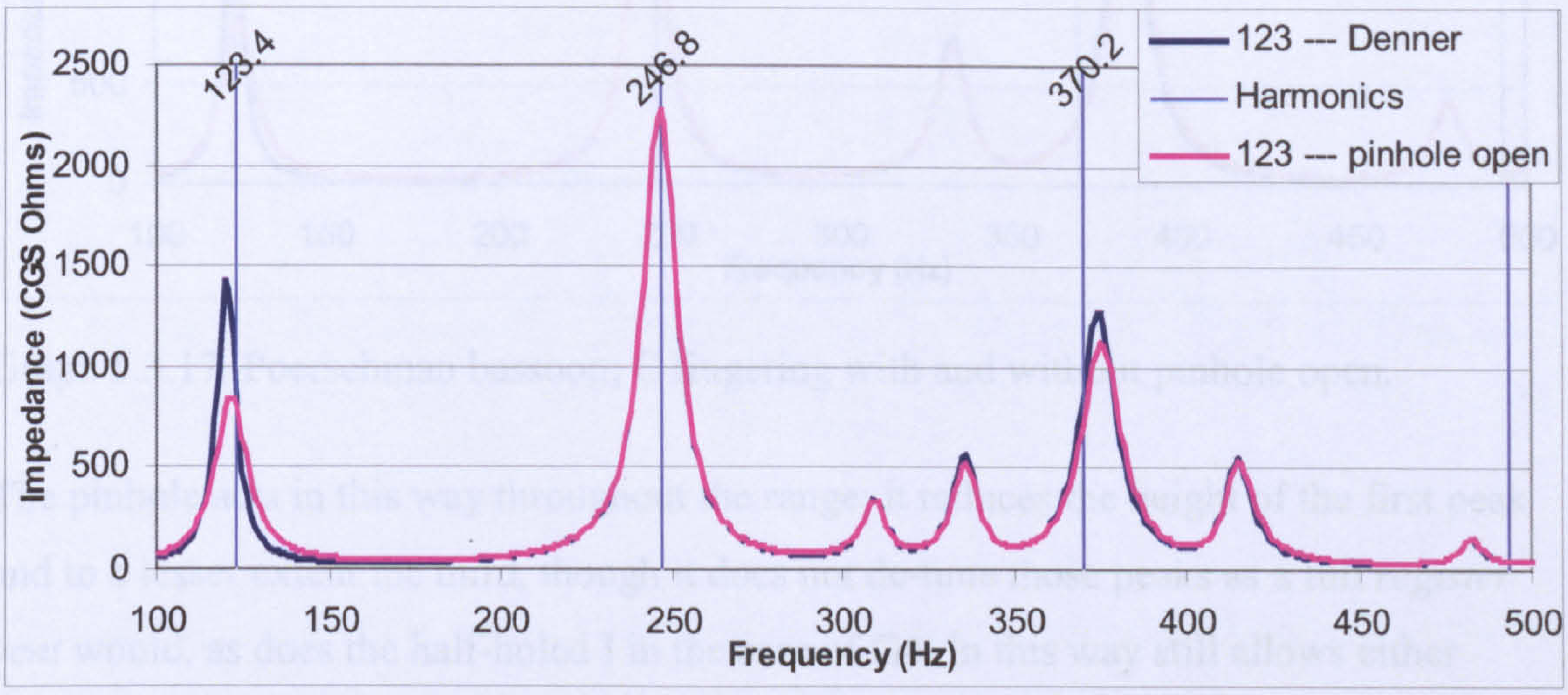
A technique commonly used by modern makers to mitigate the problem is to introduce a 'pinhole' in the crook – a small hole, in this case of 0.7mm diameter, drilled towards the big end of the crook.[53] Reed design certainly does have an effect too; on the Denner instrument one factor is that the reed must have sufficient cross-sectional area in the throat region. On this instrument, provided the pinhole is present the problem is not prominent; there is no difficulty selecting the octave of C or switching up or down between them using simple embouchure technique.

The pitch of C3 is high enough that its fourth harmonic lies above the cutoff frequency range, so there is no bore resonance support there. In fact the cutoff range starts to impinge below the third harmonic, creating the small intermediate peaks seen between harmonics 2 and 3 in the graphs below. The third impedance peak for this fingering can still play a part in the functioning of the note, and is also put to use at the top of the instrument's range for the third register note G4. However, if well aligned with the third harmonic of C3 it can interfere with production of the second octave C4, preventing the regime shifting to the even harmonics, in the same manner that the third peak of the G2 fingering interfered with overblowing to G3 discussed above. For this note, though, there is no fingerhole that can be leaked as a register vent, and in addition there is no resonance support at the fourth harmonic, so C4 has to rely on just one bore resonance.

On the Denner this third tall peak (the two small intermediate peaks are ignored in this discussion), though a little sharp, is quite well aligned with the third harmonic and

[52] That is, until Cugnier's comments on the pinhole discussed on pp.317-318. On a classical model with high c wing key, that can instead be opened to assist the note, but still this is not shown in historical charts.
[53] See pp 317-318. Evidence for its use in the baroque period does not seem to exist. See also Almenraeder's comments in Appendix 1 §7.

provides some support for resonance at that frequency. When the pinhole is opened in the Denner crook little is changed except for a reduction in the strength of both first and third peaks, leaving the second even more prominent. It would appear that this change is enough to effect the increased security of C4 experienced by the player, while still allowing C3 to be produced satisfactorily.

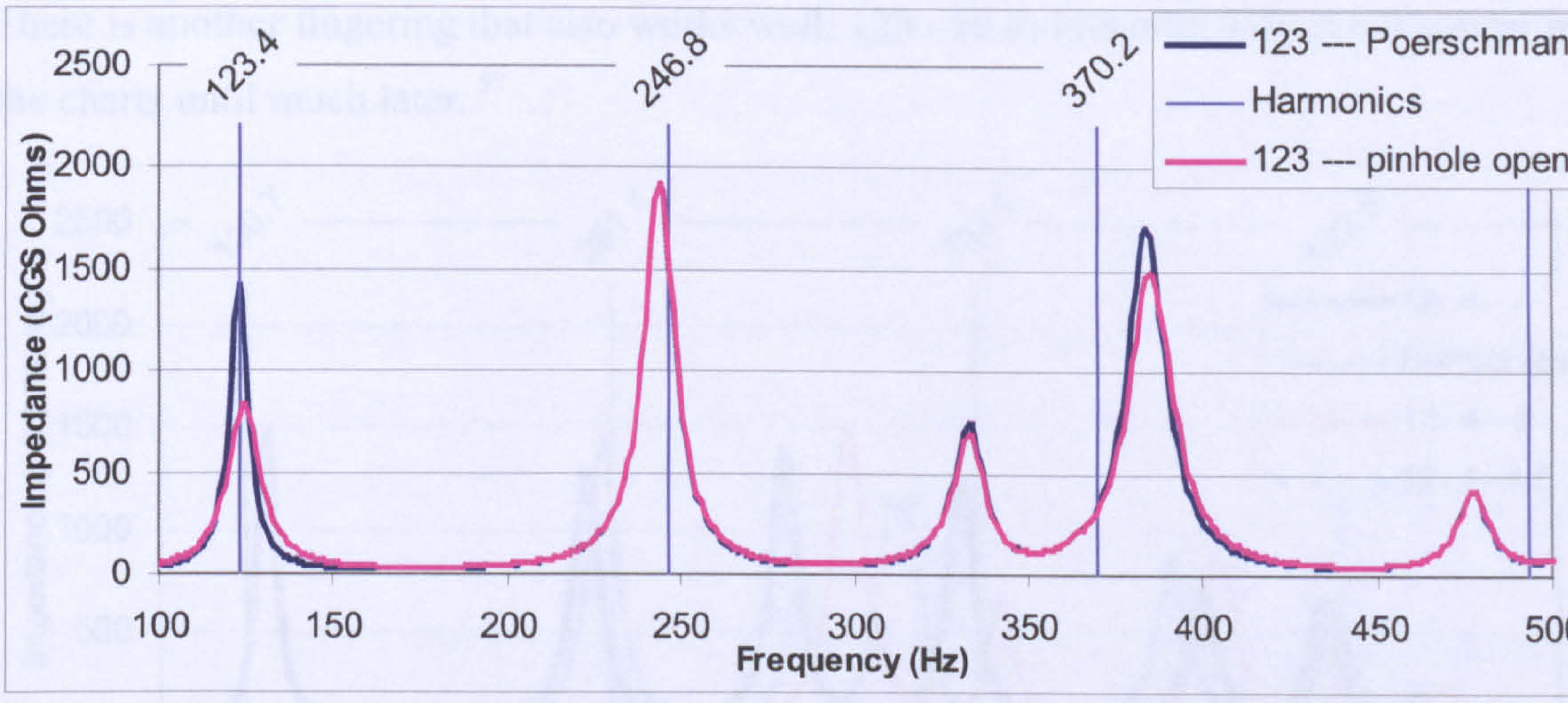


Graph 5.3.16. Denner bassoon; C fingering with and without pinhole open.

On the Poerschman the tall peak near the third harmonic, though stronger (than that on the Denner), is significantly sharper and provides less support at the harmonic frequency.[54] But this time the second peak is not so strong; in fact the impedance values at the first two harmonics are nearly equal (c. 1500 Ohms), so for a different reason it is still a little difficult to shift up to the second register. The reduction in strength of the first peak caused by the open pinhole is therefore still useful in making overblowing easier.[55]

[54] Of course this means that it is a little sharp for its other task – that of providing the fundamental for the third register note G4, which is why more holes need to be closed for that note, see G4 discussion.

[55] The pinhole is actually open for all notes, but the author of the software recommends modelling it closed for most purposes. The small impedance peak at harmonic 1 when it is open, does confirm that these bassoons operate 'on the edge of stability' as Jem Berry described the baroque oboe – necessarily so to allow overblowing without controllable octave vents.



Graph 5.3.17. Poerschman bassoon; C fingering with and without pinhole open.

The pinhole acts in this way throughout the range; it reduces the height of the first peak and to a lesser extent the third, though it does not de-tune those peaks as a full *register vent* would, as does the half-holed I in the case of G4. In this way still allows either register to be played, while easing the production of the second register, allowing that to be produced with less change in embouchure and breath pressure. A musician would say that it improves the response of the second register. However it may make production of the third register more difficult because of the reduction in strength of the third peak.

The above two graphs also show that the interval between peaks 1 and 2 is wider on the Denner than the Poerschman. This is reflected in the way the two play: C3 on the Denner can be flat and needs lipping up a little; if the tonehole (III) is enlarged, C4 becomes too sharp and that is more difficult to correct while playing than the flat C3. On the Poerschman the octave is more accurate.

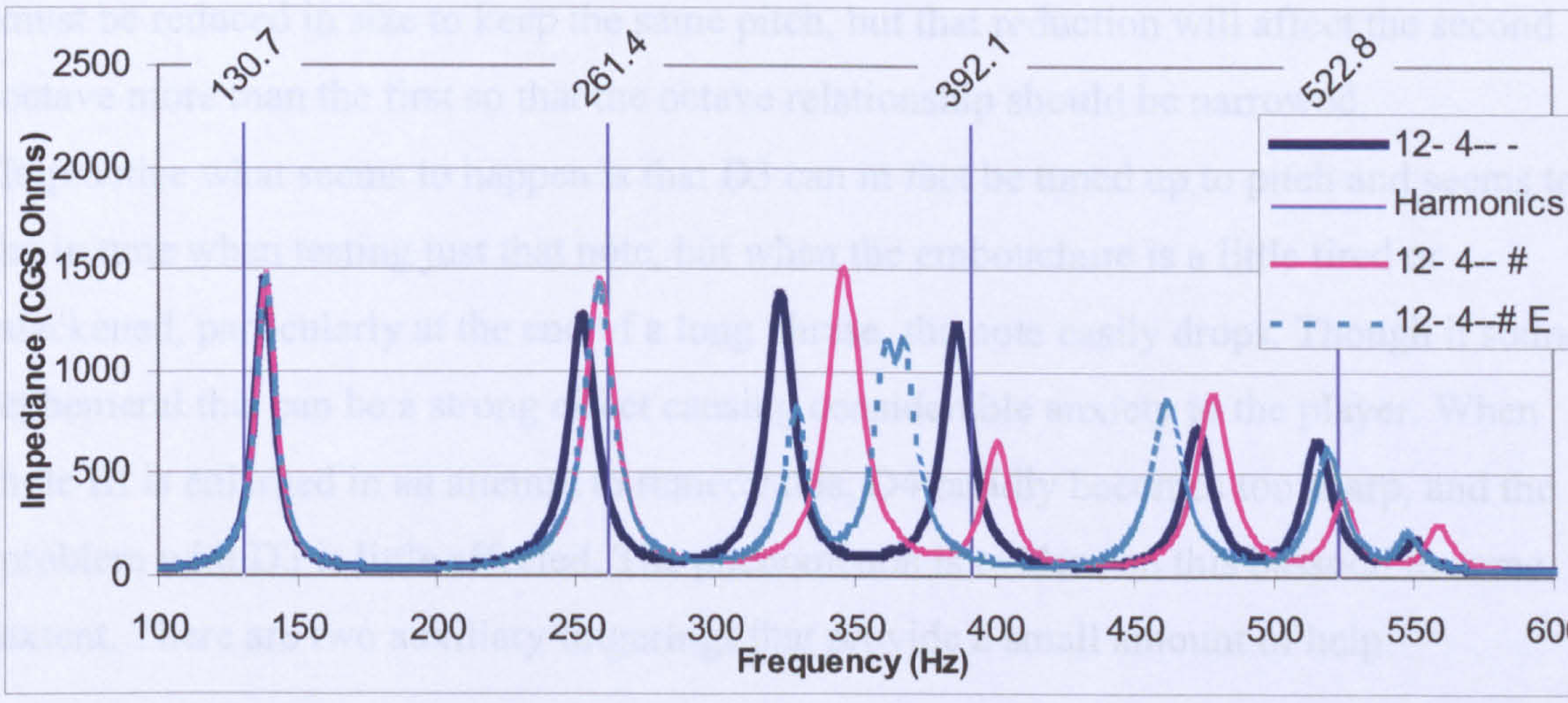
C#/Db3 and 4: 12- 4-- -

The cross-fingering effect here is sufficient to produce a good semitone below D3, with the expected slight muffling of the sound.

In the second octave, C#4 is again well tuned but can be difficult to produce; it feels stiff and unresponsive, and can crack down to the low octave or simply not speak at all in rapid passages. Opening # helps and closing E improves it further. 12- 4--# is shown in three of the early charts.[56] The pinhole is absolutely necessary here; without it C#4 does not speak at all.

[56] Musica Bellicosa, Prelleur and Diderot.

There is another fingering that also works well: 123 –56 F; however it does not appear in the charts until much later.[57]



Graph 5.3.18. C#/Db 3 and 4 fingerings

The standard fingering is shown by the dark line; although its first peak (obscured behind the pink and cyan lines) is sharp of the desired frequency, the C#3 plays in tune, perhaps because the peaks near harmonics 2 and 3 are flat. Perhaps it is the tension between these that causes the note to be a little unstable.

Strong support at harmonic 3 is good for C#3 but causes difficulty in overblowing to C#4. Opening # (pink line) gets peak 2 better aligned with harmonic 2 and reduces the support at harmonic 3, while continuing to provide a little at harmonic 4 which is good for both octaves.

Closing E in addition (dotted cyan line) keeps the improved peak 2, reduces further the support at harmonic 3 and increases support at harmonic 4. All of these are better for a well-tuned and responsive C#4 as that will use the second and fourth harmonics of C#3 to become its first and second harmonics.

The impedances shown are with the pinhole closed and the first two peaks are of equal tallness, which again causes difficulty in forcing a regime based on the second peak for C#4. When the pinhole is opened the first peak drops to about 900 Ohms while the other peaks are essentially unaffected, thus the second is now the stronger and can more easily take control if the embouchure and blowing pressure are set to favour higher frequencies.

D3 and D4: 12- --- -

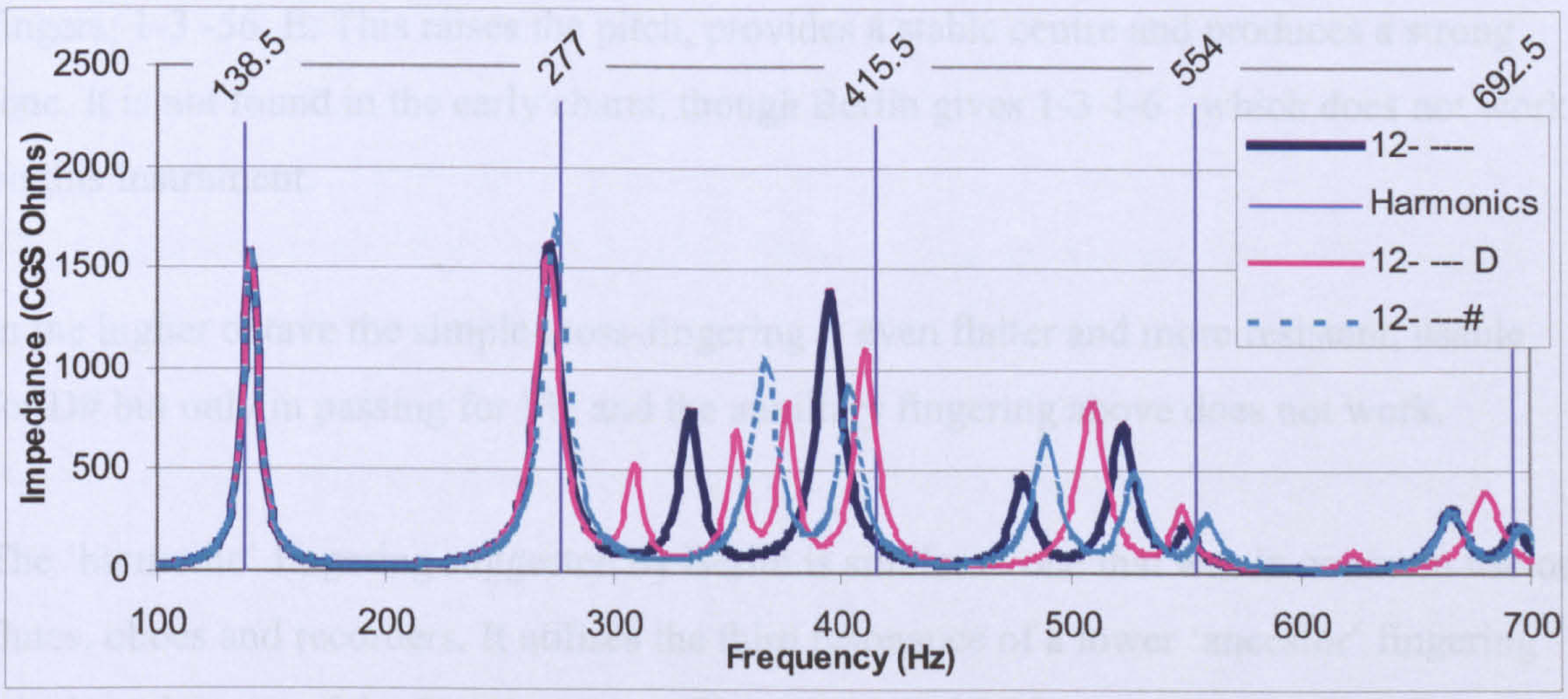
A common problem for early bassoons is that D3 plays flat while D4 is sharp. This is curiously counter to usual rules of thumb and of acoustics of woodwind instruments: hole

[57] The only chart in White's study with this fingering is by C.F. Eley, London 1828.

III is necessarily placed higher up the bore (closer to the reed) than might be desired, so that it can be reached by the left hand third finger. Moving a hole northwards means that it must be reduced in size to keep the same pitch, but that reduction will affect the second octave more than the first so that the octave relationship should be narrowed.

In practice what seems to happen is that D3 can in fact be tuned up to pitch and seems to be in tune when testing just that note, but when the embouchure is a little tired or slackened, particularly at the end of a long phrase, the note easily drops. Though it sounds ephemeral this can be a strong effect causing considerable anxiety to the player. When hole III is enlarged in an attempt to remedy this, D4 rapidly becomes too sharp, and the problem with D3 is little affected. The phenomenon is evident on this bassoon to some extent. There are two auxiliary fingerings that provide a small amount of help.

Closing the D key does not produce much obvious sharpening of D3 when directly testing the note, but does help support the pitch in circumstances as described above. There is a slight change in tone to a 'darker' quality (less sound energy in the higher partials).



Graph 5.3.19. Three fingerings for D3

The impedance graph shows (pink line) a new peak supporting resonance at the third harmonic, while small peaks at higher harmonics are shifted away to remove support for them. This is good for the tuning of D3 but makes production of D4 less positive, it can 'crack' or produce both octaves together in a multiphonic.

Alternatively, opening the # key (cyan line) raises the pitch of D3 a little and brightens the tone by raising the pitch and strength of peak two without changing the small support at the harmonics 4 and 5.

For D4, the simple fingering (blue line) is good, and selecting/switching octaves is not a problem. The pinhole must be open and it again serves to reduce the height of peak 1 from that shown in the graph.
There are small well-aligned peaks right up to harmonic 6 (832Hz) and both D3 and D4 are strong, clear notes, to the extent that getting a balance in dynamic and tone quality with the notes either side requires care from the player.

Eb3: `1-3 --- -`

Eb4: `1-3 --- - and 12- 456 (E)`

The early charts give 1-3 --- - for both octaves; the Berlin 1744 chart is the first to give the alternative of 12- 456 - for Eb/D# 4, and is the only one in the time frame of this study, though that fingering becomes common in later charts.

The cross-fingering effect is very strong and the resulting pitch in the first octave is a better D# than Eb; it does not have a clear pitch centre and is somewhat weak sounding and resistant to play. A commonly used auxiliary fingering is to add some right-hand fingers; 1-3 -56 E. This raises the pitch, provides a stable centre and produces a strong tone. It is not found in the early charts, though Berlin gives 1-3 4-6 - which does not work on this instrument.

In the higher octave the simple cross-fingering is even flatter and more resistant, usable for D# but only in passing for Eb, and the auxiliary fingering above does not work.

The 'harmonic' fingering suggested by Berlin is similar to one that was in common use on flutes, oboes and recorders. It utilises the third resonance of a lower 'ancestor' fingering which in the case of the flute is the low Eb4 fingered 123 456 #, to produce Bb6 in the second octave with fingering 123 –56 #. There the resonances are harmonically aligned so the third resonance coincides with the third harmonic of Eb, an octave and a fifth above the fundamental. The fourth fingerhole falls in just the right place – at one third of the sounding length – so that when opened it forces a pressure node and breaks the half-wavelength into thirds, to produce a new regime of vibration based on the third harmonic of the ancestor regime.

In the bassoon the ancestor fingering is G2 (123 456 -). The bore resonances are not so well aligned with the harmonics as on the flute; the third resonance is well sharp of D4

and closer to Eb4. In addition, hole III is placed high so that opening it not only forces the regime to sound on the third resonance, but also pulls the note a little sharper still.
In practice on this instrument the note can be a little too sharp, so VIII can be closed to lower it, resulting in the fingering; 12- 456 E. On the Denner the latter is unnecessary.
Fingering charts for the transverse flute from Quantz onwards often give distinct fingerings for the enharmonic pairs so that 1-3 --- is given for A# while 12- 456# is given for Bb. Here too, the two fingerings can be used to make the enharmonic pitch distinction of non-equal temperaments, and the difference in tone qualities can also be utilised. However Berlin, in giving his two alternatives, does not specify that purpose for them.

E3 and E4: 1-- --- -

The simple fingering is good for E3 on both instruments, though the Poerschman can benefit from having the tone brightened a little by any of the following auxiliaries:
1-- ---#, 1-- --- E, 1-- -56 E.
For the second octave (E4) all of the early charts give the same simple fingering as for E3. On the Denner instrument this works with reasonable security and facility, however on the Poerschman it speaks only with some reluctance and the pitch is unstable. Opening # helps both to stabilise the pitch and make speaking easier by sharpening and strengthening the second resonance of this fingering.
Only the Berlin chart offers an alternative fingering: the recorder-style 12- 45- - which also works here. It is a third register note that uses the third resonance of the A2 fingering 123 45- -, with III opened as a vent, to produce E4 as the third harmonic of A2. Hole III is well placed as a vent for this shorter fingering, so does not alter the pitch of the third resonance.

However most modern players use a harmonic fingering first given by Ozi in 1787 for a 7-keyed bassoon; 1-- 456- or a modification; 1-3 456- which does not make an appearance in the charts until Fröhlich's of 1811, then effectively continues through to the modern instrument.[58] The latter does work on this instrument (and the Denner too). It is again using the sharpened third resonance of the G2 fingering as for Eb described above. Since II is used instead of III for the vent, even higher up the bore, the pitch is pulled up even further to reach E4. When both II and III are open (1-- 456-) the pitch is even sharper, too much so on this instrument.

With these notes and the following F4, modern playing diverges from early eighteenth century technique, at least as indicated by the early charts. Many modern players seem unaware that they might expect to be able to use simple fingerings for the notes Eb4 to F4, however the ubiquity of the simple fingerings in the charts does indicate that at least earlier designed instruments should work using them, and the Denner bears that out (see comments on fingering charts at the start of this section). Having said that, this Poerschman instrument requires the harmonic fingerings, at least as it is currently set up, so seems to already have half a foot in the next generation.

F3: `-2- --- - or --3 --- - or --- ---#`

The outcome of various trials is that the fingering -2- --- is now used, as given in most of the relevant charts.[59] The rather more convenient --- --- - is not useable due to the bi-stabile pitch as comprehensively discussed in the acoustics section.

This is something of a cross-fingering although not flattening an actual used note, so it gives a slightly veiled, dark tone and a stiff response. It can be brightened somewhat by opening # or by using the alternative --3 --- - (as given by De LaBorde in 1780). The other alternative is --- --- # which works well with strong tone and easy articulation. It is good for trills on E4 and convenient in passages when # is being held open for other notes but not, for example, in octave leaps from F2. The consequence of accidentally not opening # is a dreadfully sharp note.

Benade discusses adjusting his bassoon's F3, which he says has its second resonance placed too high, sharp of the second harmonic.[60] That is similar to this situation, except that here there is a double peak around the second harmonic, the strongest of which is too sharp. If that double peak could be brought down in frequency, the higher of the pair would be better placed to support F3 at a stable pitch. Benade found that reaming the wing bore around midway between the narrowest point and hole I raised the first resonance and slightly lowered the second. The Poerschman reamers W4 and W5 both work in this region and the following impedance graph shows how they should help, and that using W3 as well also helps, up to a point.

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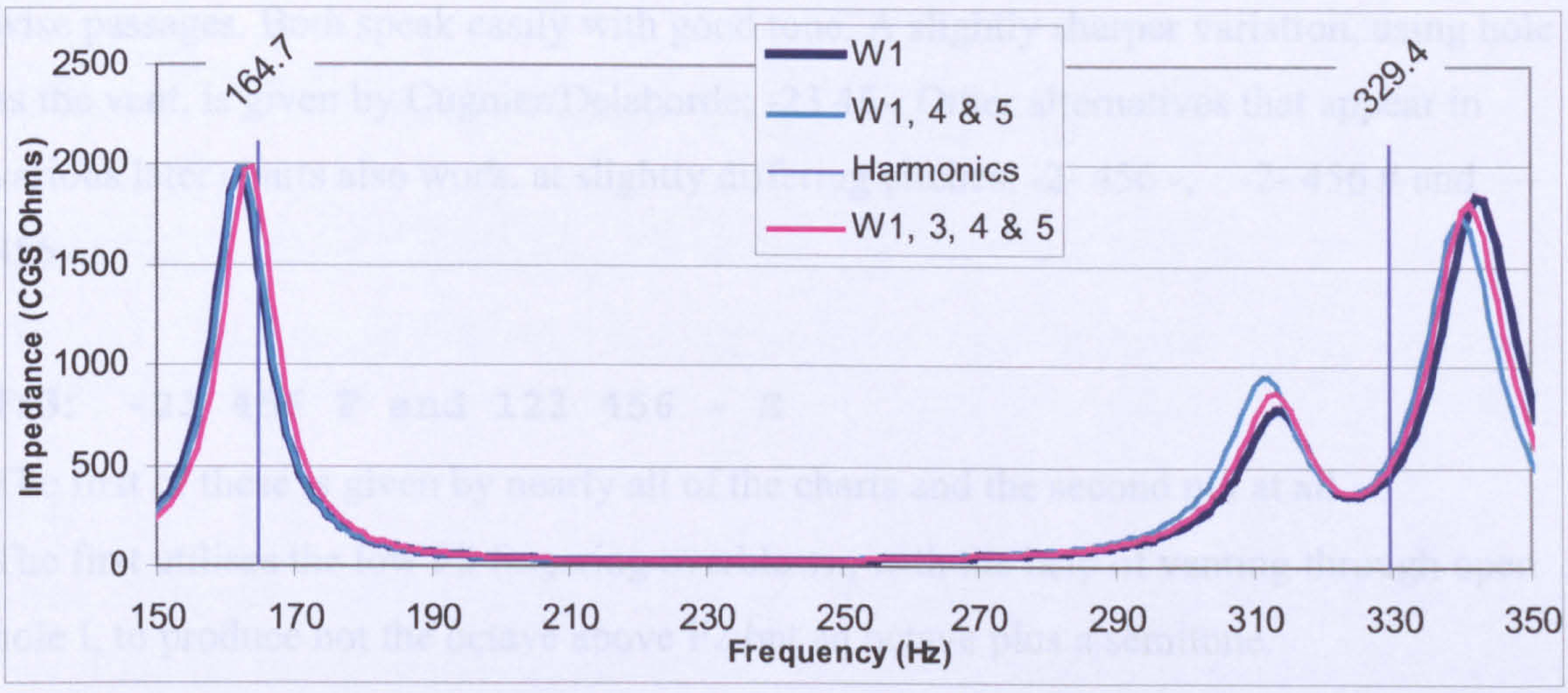
[58] Josepf Fröhlich, *Vollständige theoretisch-praktische Musikschule* (Bonn, 1810-11).
[59] The exceptions are Prelleur and Diderot – the two French charts in this group.
[60] Benade, *Fundamentals*, pp.477-478.



Graph 5.3.20. Impedance curves for fingering --- --- -; effects of auxiliary reaming

The dark line shows the situation with the simple wing, reamed with W1 only; peak 1 is obscured by the cyan line beacause adding reamers W4&5 does not affect that peak. But at the second harmonic (329.4Hz) they act to bring down the frequency of both peaks, and reduce the strength of the higher peak. The difference in pitch for the third peak is around 14 cents, (there was not much difference between using W5 on its own and 4+5 together). Now adding reamer W3 as well, shown by the pink line, undoes some of that good effect, raising the third peak back up a bit; the difference from W1 alone is only around 8 cents. But peak 1 has been sharpened a useful amount; around 16 cents, bringing almost into tune with the first harmonic. The effects here are subtle and peak 3 is still too sharp, but the situation is improved somewhat, in line with Benade's experience. In practice, the fully reamed wing still has the bi-stability problem but it is somewhat lessened compared to W1 alone.

F4: `1-- 4-- or -23 45- or -2- 456`

The early charts again give a simple fingering here, either -2- --- -, or --- --- - in the same two charts that gave that for F3.

The former is quite usable on the Denner, while on this instrument it is less easy and can be sharp. When tongued, -2- --- # does not speak at all, though it will play if slurred from E3 1-- ---#. But since it is necessary to open # to play E4 with the simple fingering, and that key can be held open for all notes down to C4, the necessity to close it for a tongued F4 makes scale-wise passages difficult, so it is better to use a 'harmonic' fingering.

Berlin again comes up with the first harmonic fingering; 1-- 45- - which is a variation of that for E4, with the opening of II sharpening the pitch. It remains a little flat on this instrument (and on the Denner) though is flexible and can easily be lipped up. 1-- 4-- makes a sharper alternative. Either of these two fingerings is a better solution for scale-wise passages. Both speak easily with good tone. A slightly sharper variation, using hole I as the vent, is given by Cugnier/Delaborde; -23 45-. Other alternatives that appear in various later charts also work, at slightly differing pitches: -2- 456 -, -2- 456 # and --- 456 -

F#3: `-23 456 F and 123 456 - E`

The first of these is given by nearly all of the charts and the second not at all.
The first utilises the low F2 fingering overblown, with the help of venting through open hole I, to produce not the octave above F2 but an octave plus a semitone.

This works because of the 'mode stretching' found in the fingerings below G2 (discussed under D2 above). So here the second peak of the F2 fingering (123 456 F) lies higher than F3 and closer to F#3. Opening hole I forces the note into the second register; since it is well placed to produce the octave of G, it must be too high up the bore for F#, so it helps to pull the pitch up a little too. In practice this note usually remains somewhat flat on early bassoons and needs lipping up in performance, especially if an equal-tempered leading note for G major is required, less so in a more 'mean-toned' temperament. Kopp has drawn attention to an embouchure technique prescribed in early instructional texts; that of the oblique embouchure, which helps to raise the pitch of this note particularly.[61]

On this instrument the cross-fingering for F#2; 123 456 -E can also be overblown to the next octave. On the Denner it is somewhat sharp but here it is better in tune and makes a useful alternative, particularly in arpeggiating passages requiring rapid movement to A3 when the right thumb can be kept on hole VIII.

Rapid passages with G# are also easier because it saves the need to switch the left little finger between the two keys # and F. A good example here is in the Bourée 2 bassoon solo from Bach's Orchestral Suite No 4, starting in B minor and modulating to F# major by the end of the first section (bar 12). It is generally played rather fast; minim = 100 or more.

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[61] James B. Kopp, 'The Oblique Embouchure for Bassoon 1780-1911', paper presented to the International Double Reed Society conference, Birmingham July 2009. In this technique, the reed is held at an angle between the lips rather than parallel to them. Kopp suggests that greater control is possible thereby, of the larger (than modern) reeds required for early bassoons, and several problematic notes are improved.

Fig 5.3.2. The opening, and bars 8 to 12 of the bassoon part of Bourée 2 from JS Bach's Ochestral Suite No. 4.

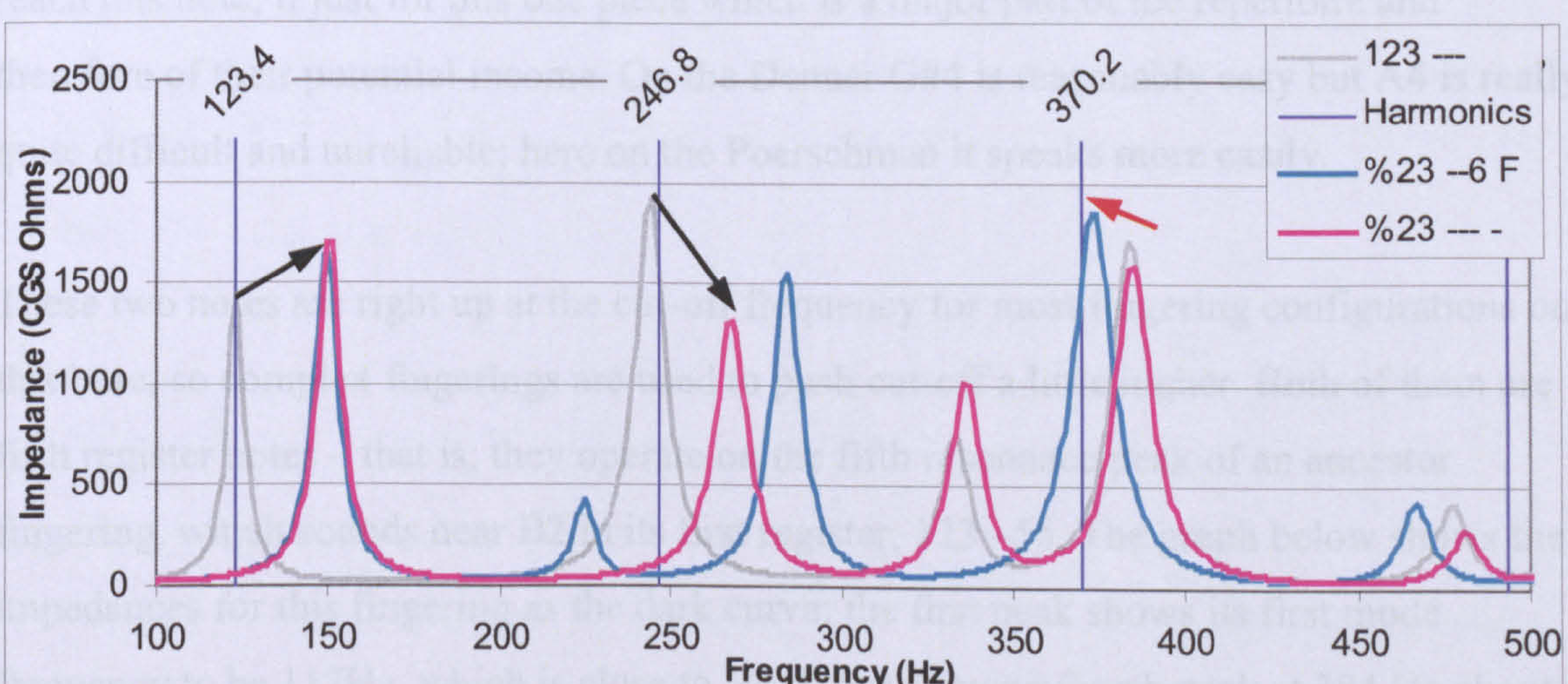
F#4: ~~1~~23 4-6 F

Some of the early charts, right up to 1800, give the same fingering as F#3; a fourth register note using the fourth resonance peak of the F2 fingering, with venting at hole I. Here F#4 will play with the full F2 fingering, but opening hole V helps it to speak more easily by venting the air column at a pressure node. That is, the pressure node can be established with V closed but opening it makes a small but useful difference, and half-holing I rather than leaving fully open adds a little more facility of speech. The result is the fingering given above. If this is too sharp, hole VI can be used as the vent instead of V, pulling that node a little further down the air column to increase the wavelength: ~~1~~23 45- F.

G4: ~~1~~23 --- F or ~~1~~23 --6 F

This is a third register note using the third resonance peak of C3 fingering; 123 ---.

Leaking hole 1 (shown as ~~1~~ in text but as % on the graph) facilitates overblowing to this third register. It does so by shifting the first two resonances as seen in the graph below, where the grey line shows the resonances for 123 ---. When 1 is leaked (pink curve) the first two peaks are made considerably sharper as shown by the black arrows. At 151Hz and 269 Hz they are no longer harmonically related and therefore cannot work together to support any regime of oscillation.



Graph 5.3.21. Finding G4: grey curve is the 'ancestor' fingering, black arrows show effect of leaking hole 1, red arrow shows effect of closing 6 and F

However the next tall peak at 370.2 Hz is not changed in pitch and is still far too sharp to be used for G4, so hole VI and the F key are closed to bring that peak down in pitch (cyan line and red arrow).

On the Denner the resonance is less sharp so only the F key needs to be closed. Many modern players expect ~~1~~23 4-- to work. This is given in the French charts of Baileux/Hotteterre 1765 and Ozi in 1787, and it is probably the prevalence of using (copies of) instruments by Prudent of Paris in the second half of the eighteenth century as 'baroque' instruments that leads to this expectation. It is too flat on German and English models, which need a sharper fingering.

This is the highest note given in all charts of the period of this study, apart from Diderot in 1751. It is actually relatively easy to obtain on most baroque bassoons of whatever design, and the fingering is again similar to one commonly used on the transverse flute and the oboe.

G#4: **`123 -56 D`**

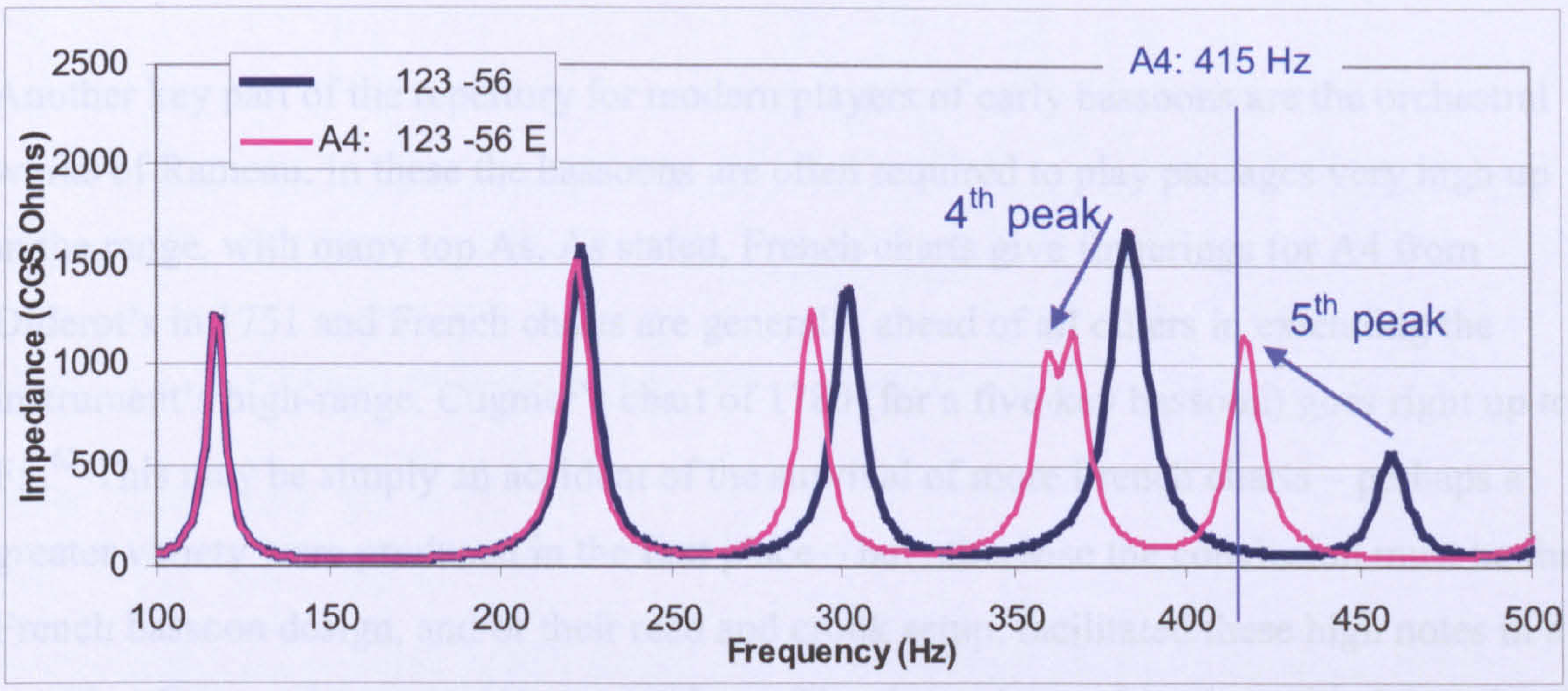
A4: **`123 -56 E`**

The earliest chart to give any notes above G4 is Diderot, and it is only in French charts that these higher notes are found until 1795 when Reynvaan published his chart in Amsterdam. However these high notes do occasionally appear in German compositions, notably in the Quoniam of J. S. Bach's B minor mass, where the first bassoon has A4 once. All modern players of baroque bassoons would like their instruments to be able to reach this note, if just for this one piece which is a major part of the repertoire and therefore of their potential income. On the Denner G#4 is reasonably easy but A4 is really quite difficult and unreliable; here on the Poerschman it speaks more easily.

These two notes are right up at the cut-off frequency for most fingering configurations on this bore, so complex fingerings are used to push cut-off a little higher. Both of them are fifth register notes – that is, they operate on the fifth resonance peak of an ancestor fingering, which sounds near B2 in its first register; 123 –56. The graph below shows the impedances for this fingering as the dark curve; the first peak shows its first mode frequency to be 117Hz, which is close to B2. It has a strong fourth peak at 384 Hz about half a semitone below G#4, and a weak peak 5 at 461Hz.

Closing E (hole VIII) (pink curve) affects the fourth peak, reducing it both in strength and frequency, in fact it begins to divide into two.

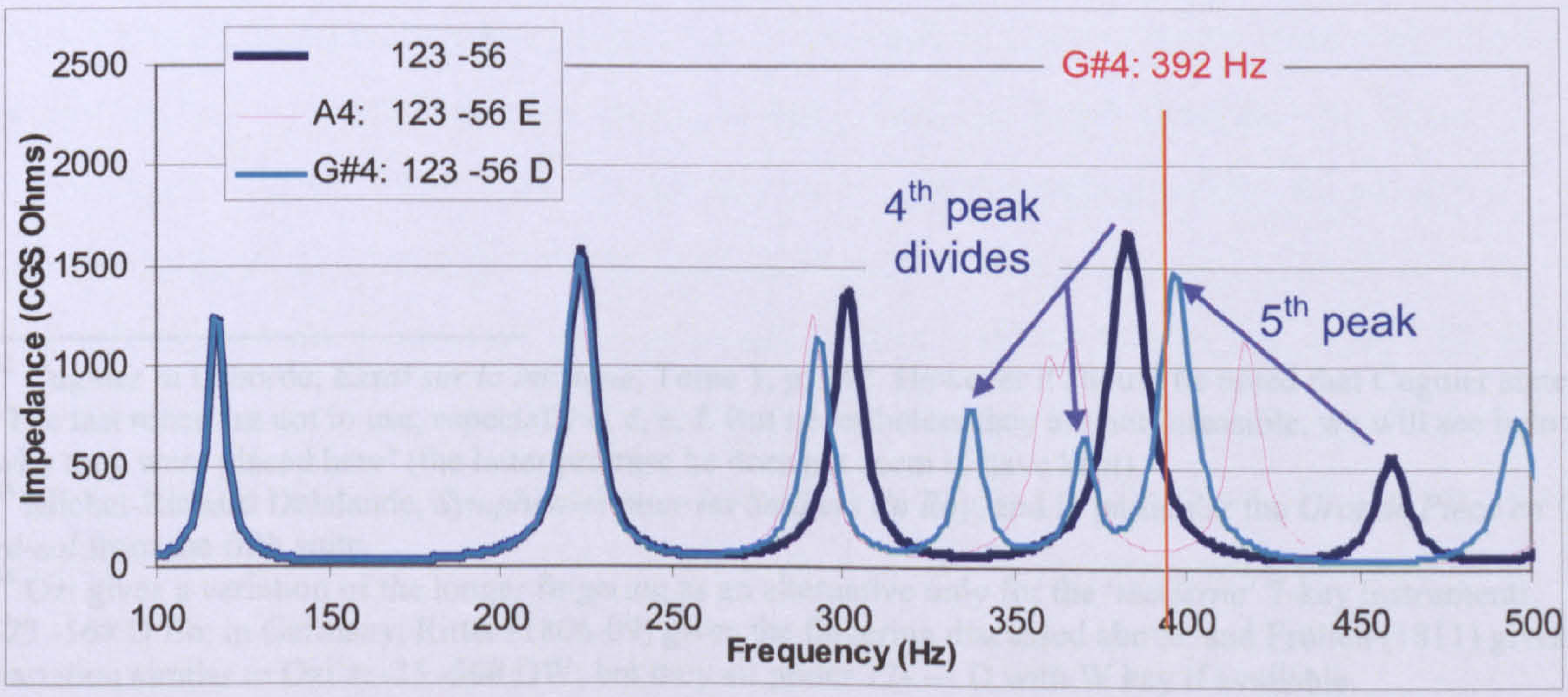
Peak five is also flattened but increased in strength, it now stands at the frequency of A4, although it remains weaker than the second and third peaks.



Graph 5.3.22. A4 with 'ancestor fingering'

This means that A4 can be made to speak but not particularly easily. It is more difficult to get the air column to vibrate at a less-strong resonance, and in practice the note played often lands on the frequency of peak 4 which is close to G4 at 368Hz, or the next lower peak which is near D#4 at 292Hz. The second peak at 223.5Hz is strongest of all but because the player uses his/her embouchure to set the reed resonance to co-operate with a higher note, it will not easily set up a co-operative regime with a note that low when there is a sufficiently strong higher resonance available.

The next graph shows what happens when the D key is closed instead of E (cyan curve).



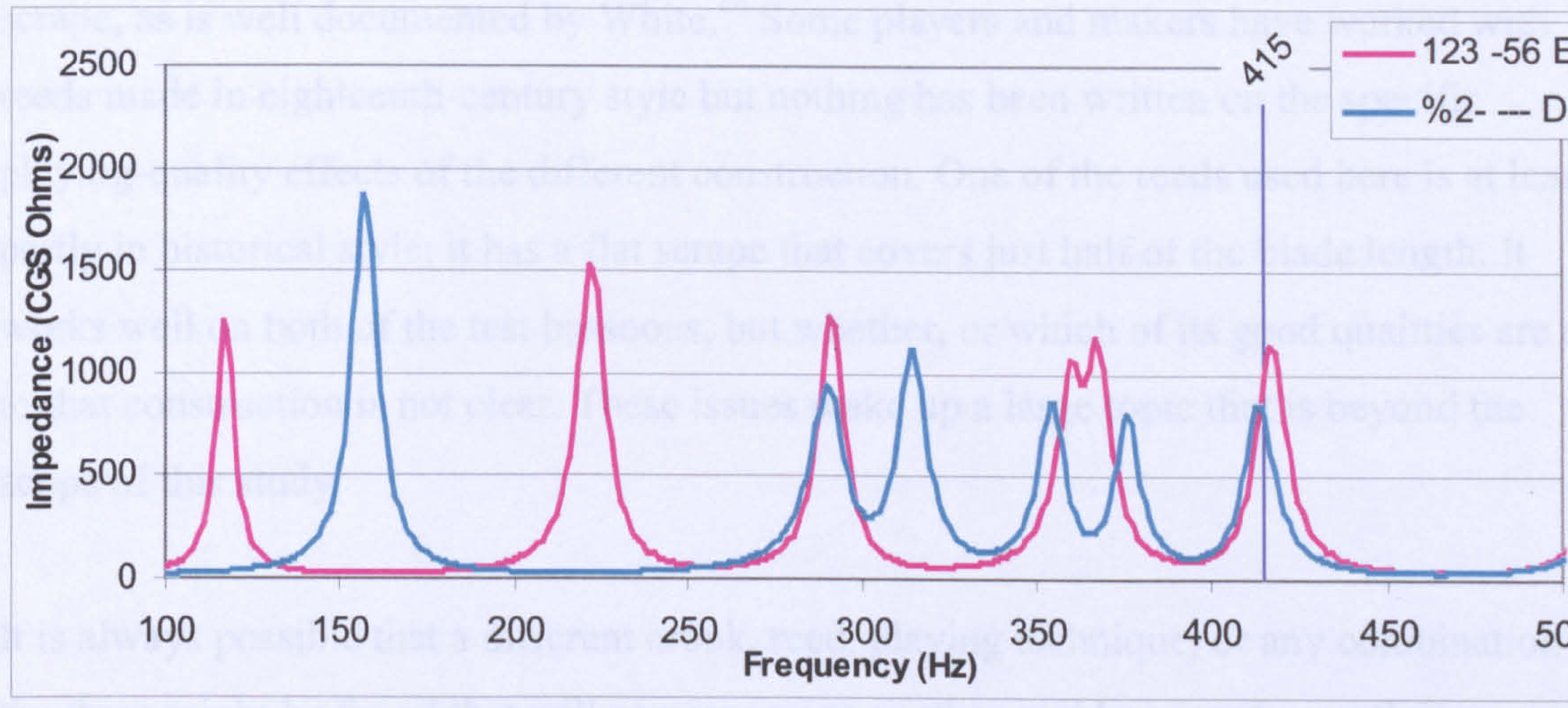
Graph 5.3.23. G#4 with A4 and their ancestor fingering

The fourth peak is broken into two even weaker peaks, one flatter and one remaining at the same frequency. The fifth peak is promoted further in strength while flattened further in pitch to provide a strong resonance at G#4 (392 Hz). This peak is now nearly the strongest (tallest) of all, so the note is relatively easy to produce.

Another key part of the repertory for modern players of early bassoons are the orchestral works of Rameau. In these the bassoons are often required to play passages very high up in the range, with many top As. As stated, French charts give fingerings for A4 from Diderot's in 1751 and French charts are generally ahead of all others in extending the instrument's high-range. Cugnier's chart of 1780 (for a five-key bassoon) goes right up to F5.[62] This may be simply an accident of the survival of more French charts – perhaps a greater variety were produced in the first place – but otherwise the conclusion must be that French bassoon design, and/or their reed and crook setup, facilitated these high notes in a way that German instruments/setups did not. The charts, in combination with demands of repertoire such as Rameau's, show a French appreciation of the lyrical qualities of the bassoon's tenor range that goes right back to the compositions of Delalande in the 1680s.[63]

The French charts do not use the above fingering for A4 but instead use the third register of the D3 fingering: 12- ---, usually with D closed (Bb in the case of Diderot), and in later charts a wing key is opened.[64] A4 can be produced with this fingering on the Poerschman, but it is less easy, and weaker sounding, than with the long fingering. The impedance graph shows a weaker peak at the A4 frequency. (If the Poerschman M3 crook is used on the Denner bassoon the note does play, though it is flat).

[62] Cugnier in Laborde, *Essai sur la musique*, Tome 1, p. 342. However it should be noted that Cugnier states: 'The last tones are not in use, especially c, d, e, f. But nevertheless they are not infeasible, we will see below why they were placed here' (the latter promise he does not seem to have kept).
[63] Michel-Richard Delalande, *Symphonies pour les Soupers du Roy*, and in particular the *Grande Pièce en G-ré-sol* from the fifth suite.
[64] Ozi gives a variation of the longer fingering as an alternative only for the '*moderne*' 7-key instrument: -23 -56# D Eb; in Germany, Ritter (1806-09) gives the fingering discussed above; and Frölich (1811) gives a variation similar to Ozi's: -23 -56# DW; but they all prefer 12- --- D with W key if available.



Graph 5.3.23. Alternative fingerings for A4; half covered hole I is indicated by '%'

Bb4: `123 456 #F D`

B4: `12- 45- #F D`

Both of these are possible with the right reed. Although not called for in music of this instrument's time, they certainly were in the next generation, with Bb4 being made something of a feature in Mozart's concerto KV191 written in 1774. The first charts to give fingerings for these notes were again French, starting with De Laborde in 1780. As with the harmonic fingerings, it seems likely that the better players, pushing the instrument to its limits, would have discovered these notes, and it was Poerschman's apprentices C. A. Grenser and J. F. Grundmann who produced the instruments in Germany on which these were a known, and expected, capability.

5.4 Concluding comments comparing Poerschman and Denner bassoons

The issue of the crook pinhole indicates that we today either have expectations that differ from those of eighteenth century players as to the ease of playing notes around middle C, or that we have not yet found the correct setups – reed and crook designs – for these instruments, or both. There may also be aspects of playing technique that we are not getting right; for example, the oblique embouchure is well documented in early sources, and yet little attention has been paid to its application until Kopp's recent work.[65] He finds it useful in ameliorating some of the tuning problems on early instruments and further exploration into its applications should be carried out. The modern form of bassoon reed is certainly different from those of the eighteenth century, particularly in the gouge and the

[65] See note 51 above.

scrape, as is well documented by White.[66] Some players and makers have worked with reeds made in eighteenth-century style but nothing has been written on the specific playing-quality effects of the different construction. One of the reeds used here is at least partly in historical style; it has a flat scrape that covers just half of the blade length. It works well on both of the test bassoons, but whether, or which of its good qualities are due to that construction is not clear. These issues make up a large topic that is beyond the scope of this study.

It is always possible that a different crook, reed, playing technique, or any combination of the three might be found that will correct one or another problem, or change the instrument's character in a more general way. Yet both of the test instruments have been made to operate satisfactorily with the setups described, and perhaps Cugnier's words previously quoted bear repetition:

> Some care is taken to make the bassoon in the most correct proportions, as well as for the selection of the reed and the crook, [yet] it is hardly possible to find an instrument that bears all the tones and semi-tones just and fixed as they are located on the monochord; there are always some notes that are a bit stronger or a little weak.[67]

The two instruments have distinguishing characteristics that are worthy of description and comparison, so with the above considerations in mind, the following evaluations are made.

There is a feeling of a general shift to higher tessitura in the Poerschman compared to Denner. Although notes from E4 upwards require the more complex, harmonic fingerings, the notes speak with greater facility, and playing in the high range is more comfortable (even if using harmonic fingerings on the Denner too). In contrast, the Denner is more facile and stable in the low range (below G2) than the Poerschman is.

On any bassoon the harmonic fingerings speak with greater facility than the simpler fingerings (the difficulty instead lying in the complexity of the fingering pattern) and can produce a remarkable beauty of tone; it seems unlikely that proficient players did not know of and utilise this extra dimension. With this Poerschman instrument, it seems that the harmonic fingerings become not an option but a necessity.

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66 White, 'The Early Bassoon Reed'.
67 Cugnier, p. 335.

While this is one indication of the overly simplistic nature of the earlier fingering charts, it might also indicate that Poerschman, as a skilled player, had decided that the advantages of the harmonic fingerings were such that there was no longer a need to retain the capability of simple fingerings. Perhaps he abandoned those to focus more on what became characterised as the 'tenor register' and which became a particularly attractive feature of the bassoon to composers from the next (classical) generation on. In this the French were seemingly ahead, but even in Poerschman's milieu these capabilities were, occasionally, fully exploited. A good example is Fasch's Quartetto in G minor for two oboes, bassoon and continuo where the bassoon part, although not going higher than G4, spends a good deal of time in the high range in both fast and slow movements. Without the facility of the harmonic fingerings this opening Largo would be exhausting playing, and with that facility the player has room for expressive playing in passages such as this.

Fig 5.3.3. Opening of bassoon part to Quartetto in G minor by J.F. Fasch, (note the tenor clef).[68]

The Poerschman gives an impression of strength and power of tone not found on the Denner. It has a direct, positive feel and forthrightness of character, though this can tend to inflexibility; each note has a certain way it plays and it is difficult to bend from that.

The Denner by contrast is a very malleable instrument; notes can be pushed and pulled in dynamic and tone quality, auxiliary fingerings used or omitted as desired, a smoothly graded *messa di voce* is possible on most notes and importantly, so are both *piano* entries and a continuous decrescendo to *ppp* fade-out. That is not to say that the Poerschman cannot be played quietly too, but maintaining the tone and accurately placing the pitch of some notes at low dynamic level can be more difficult. The Poerschman is more easily played strongly, the Denner more readily played with delicacy.

[68] J.F. Fasch, *Quartetto for two oboes, bassoon and continuo*, FaWV N:g1, Dresden, Sächsische Landesbibliothek, Staats- und Universitätsbibliothek (Sonatas - Mus.2423-Q-12).

The Denner tone quality is one that blends well with strings and other woodwind, to the extent that it can even provide a well-balanced continuo to flutes or recorders. In these qualities it could be said that the Denner better suits French music and the earlier baroque ideal of blended sonorities in the orchestra and, in more exposed context, the model of the voice (singing quality). Its flexibility certainly suits it to the flattements, battements, and other ornaments and affects of French playing style. Since we have no surviving early French bassoons, and considering Denner's stated desire to make '*französischen musicalischen Instrumenta*', perhaps we can find here a good indication of how those instruments played. Which is not to say that it does not also suit German-composed music: French musical style spread to German courts along with the instruments, and much German music of the time was composed in avowed imitation of the style of Lully or later French composers. This style of bassoon was clearly in widespread use across the German lands and further east given the number and spread of surviving instruments. It makes a gracious continuo to wind chamber music and an agile partner to oboes in chamber and orchestral playing.

The Poerschman has a more distinctive, instrumental voice that seems designed to stand out somewhat and be more clearly heard. It is well suited to the solos found in Bach's choral works (consider that in church music in many parts of Germany the transition was from *chorist fagott* to bassoon – the former, even in its *gedact* form has a voice that stands out in the choir), as well as to the virtuosic style of music from the Dresden court. It suits the masculine, bold and gallant statements of the Fasch Sonata in C major for example. Perhaps a pair of them might even make themselves heard in the Quoniam from Bach's B minor Mass, where the two bassoonists work hard at their beautiful duet, but are typically hardly distinguishable below the horn and bass singer.

This more distinctive voice is a trend that is further extended (in all the orchestral winds) in the classical period by the next generation of makers, of whom Poerschman's two apprentices were particularly important. Taking also the extended range of this instrument into consideration, Poerschman can perhaps be seen to be leading the way towards the German classical style. While it cannot be claimed that he was seeking to produce the sound and playing characteristics of the later Dresden classical bassoon (that his apprentices were to create), it could be argued that whatever it was that he was trying to achieve with his design, the characteristics of his instrument did trigger off, or at least allow, the further developments that led to the German classical designs.

Returning to the design of these instruments, it must be admitted that some of the qualities discussed are to some extent due to the crook design. If the standard Denner crook (M2) is used in the Poerschman the dynamic range becomes restricted but there is greater flexibility within that range. Several notes become less demanding of precise embouchure and fingering (for example, F3, C#3&4, D2). Putting the M3 crook on the Denner allows it to play up to A4 (with long or short fingering), and even Bb4. It has a greater dynamic range with a feeling of greater power but the whole instrument becomes generally more stiff and unyielding; D3, C4 and C#4 become difficult to produce at all.

So it may be said (with the proviso that it may be due to familiarity of use), that the M2 crook better suits the Denner; with M3 it becomes just too stiff and difficult, and at the same time, M2 on the Poerschman feels too restricting, not allowing its full voice capabilities to be available; if the difficulties of M3 can be mastered the rewards are worth the effort. So it might be argued that although the crooks can be changed around, M3 is right for the Poerschman, M2 for the Denner.

The Poerschman bore has a sophisticated looking profile, quite different from those of his immediate forebears and of some of his contemporaries. Poerschman made other woodwinds too, and was apparently a successful maker (hence his apprentices), so the sophisticated details can be presumed to be deliberate; put there for particular purposes. Yet there are difficulties with this instrument, and it is not entirely obvious what the purposes of those details are. In the following generations' bassoons the bore profiles, the wing joints at least return to a simpler form; there is an argument that later makers replaced sophisticated bore design with increasingly sophisticated keywork, but those earlier (and some contemporary) bassoons did not seem to need such complex bores either. The complex wing bore shapes, also found to some extent in the bassoons of the Wietfelts, Rottenburgh, Eichentopf and perhaps Scherer, are the products of only a short period of experimentation by these particular makers, perhaps trying out techniques found useful in the recorders, oboes and flutes they also made. The baroque bassoon, though, is a more flexible system than those smaller instruments; it has to be in order to deal with the clustered, non-optimally placed toneholes. It appears that in attempting to be more precise in tuning and response on his bassoon, Poerschman created a less-compliant system, and started a process that could only satisfactorily be resolved, several generations later, with the addition of more toneholes and complex keywork.

Chapter 6

Conclusions

This study has examined bassoons from, as far as is possible, the instrument's beginnings as a four-piece, three- or four-keyed instrument, throughout its development in the baroque period (up to the point where more keys began to be added). The sample examined includes about 80% of known surviving bassoons of this group.

A classification by external morphology, consisting of two types and five subtypes, is proposed to parallel one established for the eighteenth-century oboe, and provides a framework into which bassoons other than those studied here can be fitted.

The examination of internal designs has found that these are not consistently related to external characteristics. Examples of a common internal design occurring in two different external forms are Rottenburgh versus Wietfelt, and Meiningen MJ17 versus Deper. Examples of instruments of similar external form having quite different bore profiles are Rottenburgh versus Roth, and Haka versus Rykel, the latter being particularly surprising as the makers were master and apprentice.

A consistent match of bore profile to external form is found in England. The surviving English bassoons from the beginning of the eighteenth century, for the next seventy years, all fit into a single, well-defined subtype. It is a particularly plain style, in marked contrast to the finely turned, decoratively profiled recorders and oboes that the same makers produced. There is, nevertheless, a conformity of turned style in those instruments too, with only Stanesby Junior apparently making an effort to establish design concepts of his own (an effort he does not seem to have applied to the bassoon, though we only have one example of his to judge by). The English bassoon bore designs, too, all fall within a narrow envelope, and are of a relatively simple profile. This cannot, however, be taken to indicate that the bassoons are unsophisticated as tools for the musician – that by Stanesby Junior has been very much appreciated by players as a fine and expressive instrument. It seems that this modest-looking English design was capable of fulfilling all the roles required of it: church, military, theatre and concert hall; amateur and professional. The design was so stable that it changed only a little in the Classical period; the bassoon by Gedney dated 1768 has the additional keys expected of this period, but the same bore and external form of his master's design. The next generation, of which William Milhouse was a particularly skilled craftsman, modified the bell into a flaring form and changed the tonehole sizes, but otherwise left the bore shape, the key designs and much of the external form unchanged. In the baroque period, the case for a national school or style is strongest in England, but glimpses of the instruments that followed indicate that national characteristics, across Europe, became more clearly delineated in the next generation.

The internal design of a bassoon can provide clues to relationships when external forms do not. Though Bizey is of the second generation of French makers of baroque woodwinds, none of his predecessors' bassoons survive; Haka, of the first generation of makers of baroque instruments outside France, professed in 1685 to be making 'French bassoons'. The similarity in the bore designs of Haka and Bizey illuminates the shared origins of both; confirming the Frenchness of Haka's internal design; and suggesting that Bizey used his predecessors' design with little change. A question of outside form still remains; did the French make ornately turned bassoons; or did Haka (or another) invent that for himself?

The illustrations by Collier (1690 or earlier) and de Konink (1696) provide iconographic evidence for an early Dutch ornate style; and Randle Holme, who illustrated a bassoon with at least some ornately turned elements (key-mount beads, a flared finial and more turned beads on the wing), before 1688, allows the argument to be extended a little earlier. His illustration has similarities with that of de Konink, and Haka may well have had trade links in England, from where his family originated. It is possible that Holme was representing a Dutch instrument then present in England.

The morphological examinations assist investigations of makers and their relationships. For example, the recent suggestion that the instruments marked 'J.C.DENNER/D/I' are made by Johann Chrisoph's second son David, is supported by the similarity (external) of the two bassoons so marked; and by their differences from those marked 'J.C.DENNER/D', said, in the same argument, to be by Johann Christoph himself. Meanwhile David (if it was him), and his brother Jakob, may have shared their bassoon reamers, as their bore profiles are so similar.

Another relationship worthy of further investigation is suggested by evidence from bassoons alone. Although a bassoon by Haka, with a long Sondershausen provenance, might simply have been purchased from Amsterdam by the Sondershausen court, design features shared with other bassoons made, or found, in the area of Thuringia bordering on Saxon-Anhalt, suggest stronger cultural links with Amsterdam than the merely commercial.

There are few clues to methods of knowledge transmission between woodwind instrument makers, apart from the known master-apprentice relationships. Two mentions made in England of an instrument 'pattern' and, more particularly, 'pattern instruments' raise intriguing questions. If instrument design data, including bore design, was stored and transmitted in the form of master models, then the owner, or recipient, must have had the means of retrieving that data from the model. In that case, that craftsman also had the means to extract the corresponding data from any bassoon (or recorder or flute), acquired from whatever source. Gedney's bassoons perhaps indicate how this might have worked: his multi-stepped bores indicate the use of a range of augers or reamers in small increments of diameter. One of these at a time could be inserted into the model until it stuck in the bore; the distance relative to the end of the joint marked on the shank; and then the same tool bored into the workpiece to the same distance. Thus the set of augers could serve both to measure and form the bore. This is not to say that all craftsmen acquired their designs, or made their instrument bores in this way; Gedney's bassoons are unique in seeming to demonstrate such a process so clearly (there are less obvious clues that Stanesby Junior may have acted similarly, but with greater refinement of execution). It is also possible that each pattern instrument was associated with a set of reamers, which effectively encoded the internal design, and that both pattern and reamers were needed to reproduce the instrument.

Internal designs are not so readily categorised as the external forms. Perhaps this should not be surprising as their hidden nature and pragmatic purpose makes them less susceptible to artistic regard or vagaries of fashion. The internal design was perceived only in the effects it had on the playing characteristics.

Two contrasting forms are seen: a continuously expanding sort and a step-wise sort. Although the bassoon is conventionally called a conical bore instrument, in several of the measured bassoons, sections of the bore are cylindrical, and the bore as a whole expands in a series of steps. The cylindrical sections help to flatten the pitch so that this bass instrument can be made shorter for a given pitch standard, and they reduce the strength of the lowest air-column resonance, which facilitates overblowing. The sections can be more easily produced using several general-purpose augers, rather than specially made, tapered reamers. This form is frequently found in both boot bores and in parts of the long joint of German type 2c instruments, associated with a more complex wing bore, which together indicate a willingness to adjust the bore shape as part of the tuning process. Written historical evidence for the use of multiple, short reamers for this is provided by Almenraeder and Golde, and some of the bore shapes in the Poerschman example were found to correspond to their instructions. However, bore modifications on this small scale in the bassoon, were found to operate at a fairly subtle level; they were not needed for gross adjustments of tuning, but acted to refine response characteristics.

A continuously expanding bore, usually of a simpler profile though never an entirely straight cone, was also widely used, even by well-known and competent makers such as the Denners; so a complex bore form is not necessary to produce a well-tuned and fine-toned bassoon. The Poerschman and Denner bassoons reproduced for this project represent the two contrasting types; their differences in playing qualities must, at least in part, be due to the bore designs. Exactly which differences in design produce which playing characteristics, though, is a subject for further study.

The bell design is a third feature (after the four-part, three- or four-keys, definition) that defines the baroque bassoon and separates it from both the curtals and proto-bassoons that went before, and the classical bassoons that came after. It was an essential addition when an instrument was being sought to act as woodwind bass in the new musical milieu of the French baroque, allowing the low range to be tamed in brightness and power of tone. The low C2 is especially affected as it now speaks from a tonehole rather than an open bell. A reduction in taper angle of the bass bore, up to that C2 vent, also lowers the favoured frequency range(s) in the radiated sound spectrum (the formants); bassoonists would say the tone is 'darkened'. The added bell further reduced the taper angle, especially when makers used a reverse-tapered bore: reducing the diameter of the terminal opening and thus the radiation efficiency there. This had the additional benefit of allowing a significantly shorter bell joint. There are two classes of reverse taper apparent: the English, and Rottenburgh in Brussels, used the same reamers for both long joint and bell, resulting in a bell opening diameter equal to that of the bore at about halfway along the long joint. The German makers used a steeper taper, making the bell opening as narrow as the top of the boot bore. Either of these, or the longer cylindrical bell of the French and Dutch, helped to balance the dynamics available through the range of the instrument. The bell chamber remains something of a mystery; only, and nearly all of, the German makers used it (Rottenburgh being the only outsider and Poerschman eschewing it). Both it and the reverse taper were removed by the following generation of bassoon makers.

This study has made use of calculated input impedances as a way of examining the bassoons inner workings - the operation of the air column, created in the instrument's internal spaces. Graphs of impedances can be used to analyse and explain some of the aspects of the instrument's playing characteristics; and they can, in a limited way, be used to explore changes in design and to predict their effects. Their purpose here has been threefold: to learn how to interpret them; to test their usefulness in reflecting instrument characteristics; and to learn about individual bassoons by using them.

Two aspects of this form of investigation make it particularly useful to the study of historical instruments: 1) input impedance is a function of the instrument's design only; it is independent of any player and is thus an objective method. 2) After measuring, calculated impedance analysis does not require any further contact with the instrument, and even methods of direct measurement are non-destructive, requiring no blowing of humid air into the bore. The calculations are made here from numerical representations of the bore and toneholes that can be quite as detailed as measurements of an actual instrument, and the design of damaged instruments can readily be reconstructed in a numerical model. This opens up possibilities of testing and comparing at least some aspects of many more bassoon designs, including those that are too damaged to play. The design of replacement crooks is one particular task that might be approached this way.

Other methods of impedance assessment exist: methods of direct impedance testing (including the BIAS system designed and produced by the *Institut für Wiener Klangstil*) are being made more readily useable by the less scientifically trained. Such methods can, and should be used in future studies to verify the calculated results presented here. While the *Impedps* program includes consideration of viscous and thermal boundary layer effects, and the numerical model of the bore can be very detailed, there will always be aspects of a real instrument that are not modelled. Surface finish (internal); porosity of the wood, thread bindings and leather pads; the finish of tonehole edges; can all make differences to the way the instrument plays, and might also make differences between calculated and tested impedances.

There is probably not, though, any substitute for making instruments and playing them. Some of the considerations for designing a faithful reproduction have been outlined here, with methods of divining the maker's original tooling designs. The main intention behind making the reproduction for this study was to have a bassoon such as might have come new from Poerschman's workshop. Making, playing, and testing the instrument was an attempt to understand his intentions, his capabilities, and his methods. Further ventures of the sort are supported by the measurement data presented in Appendix 3; here are details from bassoons by famous makers, by the little known, and by some anonymous makers now known only by their few surviving works, presented in enough detail to enable the sort of design analysis described in Chapter 5. A rich variety of artistic endeavour remains to be explored; these methods and this collection of data can provide a starting point.

Appendix 1

Extract from Carl Almenraeder, *Die Kunst des Fagottblasens,* (Mainz: Schott, 1842/43).

Chapter XVIII: On various faults occasionally met with on a bassoon, which may often be overcome with little trouble.

Adapted from a translation by William Bailey[1] with the assistance of Kai Toenjes.

1) One often has an otherwise good bassoon, which has here and there some faults that render it quite useless. These faults being not, as a rule, irremediable, the following remarks may be of some utility.

2) When the octave C3-C4 is not true, and the C4 is too sharp as is often the case, this cannot be remedied by hole VI through which the note speaks; the wing joint must be reamed wider, which can be done without prejudice to the clarity of the instrument. If the octave D3-D4 is not correct, and D4 is too sharp, hole III is not drilled at enough of an angle or the wood in this area is not thick enough, thus preventing the hole reaching far enough down the bore. This defect is not so easy to remedy; the fingerhole must be plugged and a new one drilled to enter the bore lower down. If this cannot be done, it will be necessary to make a new wing joint in which the wood shall be left thicker around the hole.

3) When G3 is too high in the octave G2-G3, the reason is often that the wing joint end up to a bit beyond its tenon, is too narrow. In this case it has to be re-reamed a little in this area. Should this not be sufficient the boot needs to be reamed wider where the G hole [VII] enters the bore. Should the octave now be pure but, but too low against the rest of the instrument, one only needs to increase the diameter of the G hole. For this octave it is necessary to remark that the Bb, B, C, D, E and F, which lie below G2, must be exactly in tune because otherwise it is impossible to get the octave G2 to G3 pure.

[1] William Bailey, unpublished, hand-written translation of Carl Almenraeder, *Die Kunst des Fagottblasens,* (Mainz: Schott, 1842/43), located in the Waterhouse Archives, ex Parr Collection.

4) The note F3 is sometimes not sufficiently certain, and by a slightly stronger embouchure can be raised as easily as it can be lowered by a light embouchure. The cause is usually that [hole II] is not bored sufficiently diagonally downwards, or that the wood is not thick enough, thus causing too much communication with hole I. This fault cannot be corrected except in the manner indicated for D4 (§2), namely to bore the second hole [II] more obliquely, so that it may open into the bore lower down.
The holes through which only one note speaks (rather than two) have more independence than the others; they may be made sharper by being enlarged, or when too large, made flatter by having a liner inserted. This applies to the notes from Bb1 to F2.

5) On some bassoons one occasionally hears a buzzing/croaking (*Schnarren*) which gives a disagreeable sound in some notes, for example A3, Bb3 and C4; a strong attack seems to divide the note, and it generally does not remain smooth. The fault is that the relevant tonehole is not placed correctly in proportion to its size, so that it is too large in comparison with the bore or the bore is too small compared to the hole. In the latter case the defect can be remedied by slightly enlarging the small boot bore.

6) The wing joint may become enlarged at the crook socket [the bore throat] if the precautions indicated in Chapter XVII §2 are not observed or when it is not lined with hardwood.[2] Thus several notes such as G4, A4 and Bb4 are made difficult and lacking precision (*unrein*). This can be remedied by boring out the [top of] the joint to half an inch wide or more if the wood is rotten, and lining it with hardwood such as cocus or ebony, to make the bore a proportionate size [to the crook].
When the crook is not the correct inner diameter it may render the bassoon quite out of tune (*unrein*). If too wide, the notes D3, E3, F3 and G3 will be too flat and will speak with difficulty; if too narrow these notes will be too sharp. In the case that the crook is lost, which can easily happen, it is therefore necessary to exercise care in the selection of another and as far as possible to choose a crook which expands gradually and consistently from its narrow end to the width of the interior of the wing. The crook must be quite clean and smooth inside and no solder must remain on the bore. If the sound is unstable and wavers back and forth, it is certain that the Es should be a little wider from the middle to the end.

[2] Chapter XVII gives instructions on cleaning and drying out the bassoon after playing, particularly the crook socket, wing and boot small bores and the socket where they fit together.

7) When the small hole in the crook is too large, several notes in the upper and lower registers are bad, for example Bb3, C#4, D4, F4 and Eb2, D2, and C2. This hole should be made with a very small drill and if too wide, reduced with a burnisher. On a well-bored bassoon where the bores of all the pieces fit exactly to each other and the wing and boot small bore are particularly accurately reamed (*gut ausgeshliffen sind*), one can close the pinhole after a time when the instrument has been much used, if it is otherwise in good condition. The slurs for which this hole really exists are not impaired, and all the notes of the instrument gain in fullness/richness as well as in delicacy/softness (*gewinnen dabei an Fülle, wie an Zartheit*). On new bassoons I have not, at first, been able to dispense with this hole, but after several years I have found it no longer necessary on my instruments.

Appendix 2

Historical Fingering Charts for Bassoons with 3 or 4 keys

Collated from Paul White, 'Early Bassoon Fingering Charts', GSJ, 43 (1990), 112-124

NOTE	STANDARD FINGERING 4-key	Musica Bellicosa London 1730 4-key	Prelleur London 1731? 4-key	Majer Nurnberg 1732 3-key	Eisel Erfurt 1738 4-key
A1		NL	NL	NL	NL
Bb1	123 456F EDCBb	S	S	S	S
B1		123 456F EDCBb	NL	NL	NL
C2	123 456F EDC	S	S	S	S
C#2	123 456F ED[C]	123 456F EDC	123 456F EDBb	NL	NL
D2	123 456F ED	S	S	S	S
D#/Eb2	123 456F EDBb	123 456- E B	123 456F EC *	123 456F E[D]	NL
E2	123 456F E	S	S	S	S
F2	123 456F	S	S	S	S
F#2	123 456- E	123 456- E	S *	S	NL
G2	123 456-	S	S	S	S
G#/Ab2	123 456-#	S	S *	123 45[6]-	S
A2	123 45--	S	S	S	S
Bb2	123 4-6-	S	S *	S	S
B2	123 4---	S	S	S	S
C3	123 ----	S	S	S	S
C#3	12- 4----	S	12- 4--# *	S	S
D3	12- ----	S	S	S	S
D#/Eb3	1-3 ----	S	S *	S	S
E3	1-- ----		S	S	S
F3	--- ----	-2- ----	S	-2- ----	-2- ----
F#3	-23 456F	123 456F	-23 456F DCBb	-23 456-(sic)	--- ----
G3	123 456-	S	-23 456	S	S
G#/Ab3	123 456#	S	S *	123 45[6]-	S
A3	123 45--	S	S	S	S
Bb3	123 4-6-	S	S *	S	S
B3	123 4---	S	S	S	S
C4	123 ----	S	S	S	S
C#4	12- 4---	12- 4--#	12- 4--# *	S	S
D4	12- ----	S	S	S	S
D#/Eb4	1-3 ----	S	S *	S	S
E4	1-- ----	S	S	S	S
F4	--- ----	-2- ----	S	-2- ----	NL
F#4	no standards above	--- ----	-23 4--- *	1-3 ----(sic)	NL
G4		-23 ----	-23 ---F	NL	NL
G#4			* These derived from instructions or trills chart.		

Key:
[ ] - half cover the hole.
S - the standard fingering is given.
NL - no fingering listed for this note.

Historical Fingering Charts for Bassoons with 3 or 4 keys

Collated from Paul White, 'Early Bassoon Fingering Charts', GSJ, 43 (1990), 112-124

NOTE	J.D.Berlin Trondheim 1744 4-key	Diderot 1751 Paris 4-key	Apollo's Cabinet Liverpool 1756 4-key	Hotteterre/Baileux Paris c.1765 5-key (Eb)
A1	NL	slacken Bb'	NL	
Bb1	S	S	S	S
B1	NL	pinched Bb'	123 456F EDCBb	
C2	S	S	S	S
C#2	NL	S	123 456F EDC	S
D2	S	S	S	S
D#/Eb2	NL	123 456F ECB	123 456- E B	123 456 EDEb
E2	S	S	S	S
F2	S	S	S	S
F#2	S	S	123 456- E	S
G2	S	S	S	S
G#/Ab2	S	S	S	S
A2	S	S	S	S
Bb2	123 4-6#	S	S	S
B2	S	S	S	S
C3	S	S	S	S
C#3	S	S	S	S
D3	S	S	S	S
D#/Eb3	1-3 4-6-	S	S	S
E3	S	S		S
F3	-2- ----	S	-2- ----	S
F#3	S	S	123 456F	S
G3	-23 456-	-23 456-	S	S
G#/Ab3	S	S	S	S
A3	S	S	S	S
Bb3	S	S	S	S
B3	S	S	S	S
C4	S	S	S	S
C#4	S	12- 4---#	S	S
D4	S	S	S	S
D#/Eb4	12- 456- 1-3 ----	S	S	S
E4	12-45-- 1-- ----	S	S	S
F4	1-- 45-- -2- ----	S	-2- ----	-23 456#
F#4	-23 456F	-23 45-F	--- ----	-23 456F
G4	-23 456	123 ----	-23 ----	-23 4--
G#4		123 ---- Bb		123 ----
A4		12- ---- Bb		12- ---- D
Bb4				
B4				
C4				

Historical Fingering Charts for Bassoons with 3 or 4 keys

Collated from Paul White, 'Early Bassoon Fingering Charts', GSJ, 43 (1990), 112-124

NOTE	W. Tans'ur London 1767 4-key	Longman & Broderip London c.1770 4-key	Preston & Son London c.1790 4-key	Reynvaan 1795 Amsterdam 4-key
A1		NL	NL	
Bb1	S	S	S	
B1		NL	NL	pinched Bb
C2	S	S	S	
C#2		NL	NL	
D2	123 456#FED(sic)		S	
D#/Eb2		123 456F ECB	123 456F ECB	
E2	S	S	S	
F2	S	S	S	
F#2		S	S	
G2	S	S	S	
G#/Ab2	S	S	S	
A2	S	S	S	
Bb2	S	S	S	
B2	S	S	S	
C3	S	S	S	
C#3	S	12- 4--#	12- 4--#	
D3	S	S	S	
D#/Eb3	-2- 4-- -(sic)	S	S	
E3	S	S	S	
F3	S	--- ---#	--- ---#	-2- ----
F#3	S	-23 456F DCB --- 456F E	S --- 456F E	S --- --- -
G3	-23 456-	-23 456-(# E)	-23 456	
G#/Ab3	S	-23 456#	-23 456#	123 456#
A3	123 456 (sic)	S	S	
Bb3	S	S	S	123 4-6#
B3	S	S	S	
C4	S	S	S	
C#4	S	12- 4--#	12- 4--#	12- 4--- 12? 4-6-
D4	S	S	S	
D#/Eb4		12- 456-	12- 456-	12- 456-
E4	S	S	S	
F4	S	--- --6- --- 456- -23 456- E	--- --6- --- 456- 12- 456F	S -2- ----
F#4	-23 4--F	-23 4--#	-23 4--#	-23 456F -2- 456F
G4	-23 --- -	-23 ---#	-23 ---#	-23 4--# -23 4--#F
G#4				-23 -5-# D -23 -5-#F D
A4				12- ---# D
Bb4				123 456#F D
B4				-23 45-#F D
C4				--- ---#

Fingering Chart for Poerschman Bassoon

	Low Range
Bb	123 456 F EDCBb
C	123 456 F EDC
C#	123 456 F EDC
D	123 456 F ED
Eb	123 456 F ED
E	123 456 F E
F	123 456 F
F#	123 456 - E (Bb)

	First Octave	Second Octave	Third Octave
G	123 456	123 456 ~~1~~23 456	~~1~~23 --- F ~~1~~23 --6(F)
G#	123 456 # (DC)	123 456 # (DC)	123 --6 D 123 -56 D
A	123 45- (E)	123 45- E	123 -56 E ~~1~~2- --- D
Bb	123 4-6 (E) 123 45- # 123 4-6 #	123 4-6 123 45- #	123 456 #F D
B	123 4--(#) 123 4-- EB 123 -56 #	123 4--(#)	12- 45- #F D
C	123 ---	123 ---	
C#/Db	12- 4-- 12- 4-- #	12- 4--(#) 12- 4-- #E 123 -56 F	
D	12- --- (#/B/D)	12- --- (B)	
D#/Eb	1-3 --- 1-3 -56 E	12- 456 E 1-3 ---#	
E	1-- --- (#/E) 1-- -56 E	1-3 456 (E) 1-- ---(#) 12- 34-	
F	-2- --- --3 --- --- --- #	-2- 456 1-- 45- 1-- 4--	
F#	~~1~~23 456 E -23 456 F	~~1~~23 4-6 F ~~1~~2- 45- E -2- 45-	

Numbers and letters indicate holes closed or keys operated.

Thumb holes and keys are labeled 'E,D,C,Bb' as they appear to the player.

# indicates the Ab/G# key is to be opened.

- through a number/letter indicates that the hole should be partially opened.

Those keys/holes in parentheses are optional.

Fingering Chart for Denner Bassoon

	Low Range
Bb	123 456 F EDCBb
C	123 456 F EDC
C#	123 456 F EDC
D	123 456 F ED
Eb	123 456 F ED
E	123 456 F E
F	123 456 F
F#	123 456 - E (Bb)

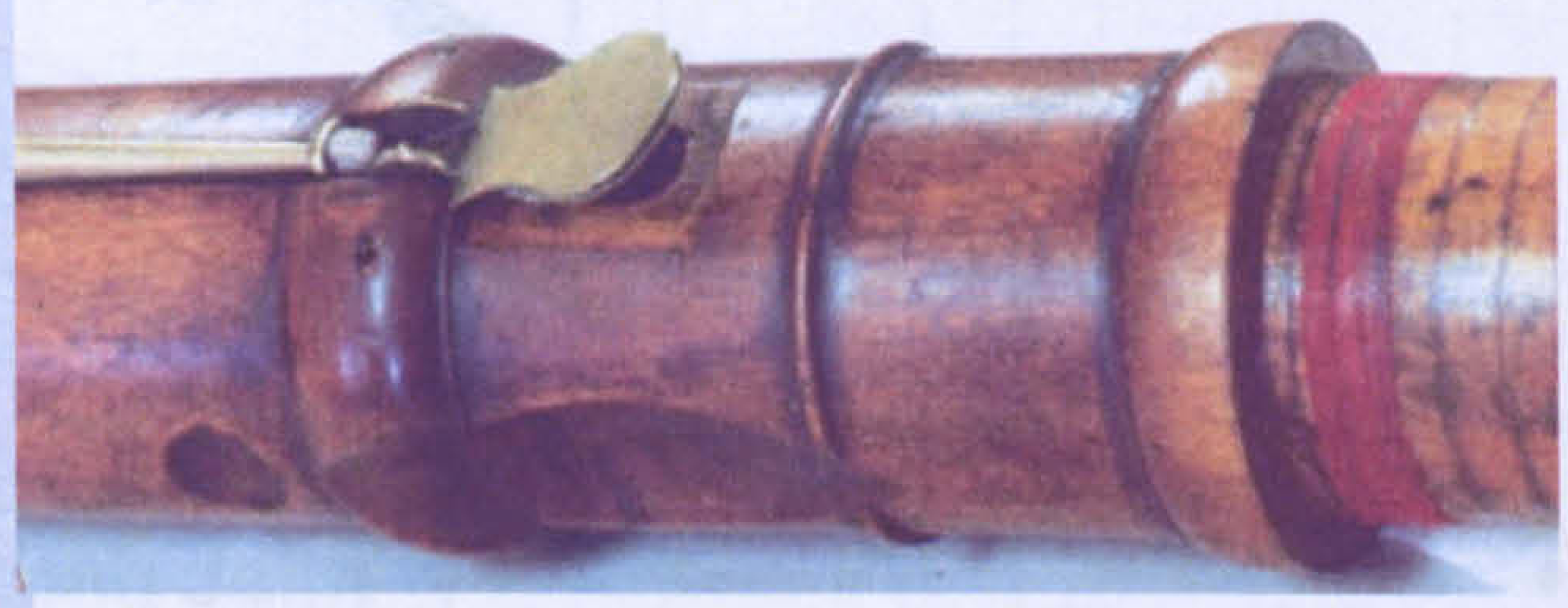
	First Octave	Second Octave	Third Octave
G	123 456	~~1~~23 456	~~1~~23 --- F ~~1~~23 --6(F)
G# Ab	123 456 # (DC)	123 456 # D 123 45- - D	~~1~~23 --- D
A	123 45- -	123 45- - (Bb)	~~1~~2- --- D 123 -56 #E
Bb	123 4-6 # 123 4-6 - EDC	123 4-6 # 123 4-6 - 123 45- #	
B	123 4-- - E 123 4-- - Bb	123 4-- - 123 -56 - 123 --- -	
C	123 ---	123 ---	
C#/Db	12- 4-- - D 12- 4-- - E or Bb	12- 4-- -(#)	
D	12- --- - (Bb)	12- --- -(# or Bb)	
D# Eb	1-3 --- - (Bb) 1-3 -56 (ForE)	1-3 --- -(#) 12- 456 -(D)	
E	1-- ---(#) 1-- -56 -	1-- --- - 1-3 456 -(E)or -56 or 4-6 12- 45- - D	
F	--- --- - -2- --- -	-2- --- - -2- 456 - --- --- - 1-- 45- - D	
F#	-23 456 F --- 456 F 123 456 - E	123 4-6 F (Bb)	

Numbers and letters indicate holes closed or keys operated.
Thumb holes and keys are labeled 'E,D,C,Bb' as they appear to the player.
# indicates the Ab/G# key is to be opened.
- through a number/letter indicates that the hole should be partially opened.
Those keys/holes in parentheses are optional.

Appendix 3
Photographs and measurements

Bassoons are presented in the same order that they are discussed in Chapter 3

Richard Haka, Schlossmuseum Sondershausen, Mu5



Measurements by
J. Bouterse and G. Wolfe
Richard Haka
Schlossmuseum Sondershausen Mu 5
Minimum
Maximum
Bell
Toneholes
Joint ends
Boot window
Bell
Long Joint
Boot Joint
Wing Joint
XI
X
IX
VIII
VII
Ab
IV
V
VI
III
II
I
Diameter
Distance

Measurements by J. Bouterse and G. Wolfe

Richard Haka: Schlossmuseum Sondershausen Mu 5

Joint Lengths
Tone Hole Positions and Sizes
Measurements by J. Bouterse and G. Wolfe

Richard Haka
Schlossmuseum
Sondershausen Mu 5

	Distance						**Diameter**			**Angle**
	Outside			**Inside**			**Surface**	**Inside**		
	centre	from end		centre	from end		E-W N-S	calliper min	rods etc	from perpindicular
Wing OAL:		**537.0**		**Tenon:**	**46.0**					°
I	302.0	S		308	S		6.0 7.1	4.7		28°N
II	258.0	S		252	S		6.1 6.7	4.6		28°S
III	218.5	S		207	S		6.4 7.4	5.1		28°S
Boot OAL:		**440.0**		Septum hole Nth edge:			**408.0**	Sth edge/Plug face:		**428.0**
IV	108.0	N		92.0	N		7.9 10.3	7.00	u/c north	31°N
V	150.0	N		150.0	N		7.6 8.5	6.8		9°S
VI	190.5	N		198.0	N		5.0 8.0	5.5		25°S
Ab	331.0	N					5.0	4.7		
VII	342.0	N					10.5	9.3		9°S
VIII	135.0	N		135.0	N		10.0 11.4	9.4		
Long OAL:		**617.2**		**Tenons N,S:**	**50.7**	**47.5**	E-W	N-S	U/C	Chimney
IX	537.7	N end					10.2	10.0	little	
X	340.7	N end					7.9	7.8	little	
XI	113.7	N end					10.9	10.3	little	
Bell OAL:		**375.0**								
Total Bore Length:			**2241.0**	= top of wing to plug face + plug face to top of bell.						
Standing Height:			**1334.0**	= bottom of boot to top of bell.						

NOTES: OAL = over all length (total length)

Angles are measured from perpindicular. They are in conventional directions unless otherwise stated.

"Calliper min" is the internal diameter measured with callipers as deep as possible.

"Rods" are plastic rods in 0.2mm increments of diameter used to test hole diameter.

The largest size to fit through is recorded.

Coenraad Rijkel, Stedelijk Museum
Zwolle

Bore profiles
Coenraad Rijkel
Stedelijk Museum, Zwolle
Transverse axis
Tonehole axis
Toneholes
Joint ends
Boot window
Long Joint
Boot Joint
Wing Joint
XI
X
IX
VIII
VII
VI
V
IV
III
II
I
Ab
Diameter
Distance

Coenraad Rykel, Stedelijk Museum Zwolle

	Distance						Diameter			Angle
	Outside			Inside			Surface	Inside		
	d1	from end	d2	d1	from end	d2	E-W N-S	calliper min	rods etc	from perpindicular
Wing OAL:	**552.5**		**Tenon:**	**49.0**						°
I	313.0	S end	321.0	327.0	S	338.5	5.25 7.45	5.2	5.0->6 4.8 loose	41°N
II	272.0	S end	278.0	267.5	S	275.0	5.7 6.7	5.3	5.0->9 4.8 loose	6°S
III	231.0	S end	238.5	203.0	S	220.5	5.45 8.05	5.0	4.8->4 4.6 tight	40.5°S
Boot OAL:	**430.0**	Septum hole North edge:					**403.0**	South edge/Plug face:		**418.5**
IV	99.5	N	108.5	82.0	N	100.0	6.90	6.60	6.4->1 6.2 loose	31°N
							7.40		undercut	
V	141.5	N	149.5	141.0	N	151.5	6.90	6.80	6.4->1 6.2 loose	10°S
							7.65		undercut	
VI	183.0	N	191.5	194.0	N	201.0	5.70	5.25	5.0->4 4.8 tight	46.5°S
							9.20		u/c, chimney 13	
Ab	271.0	N	276.0	275.0	N	281.5	5.20		4.6 tight	25°S
	159.0	S	165.0				6.70		On back! Looks like an F# key.	
VII	195.6	S	138.9	333.0	N	343.0	9.70		keys not	10°N
							9.70		removed	5°S
VIII	192.6	N	138.9	129.0	N	139.5	9.05	8.15	undercut	10°N
							9.75			3°S
Long OAL:	**605.5**		**Tenons N,S:**		**50.5**	**37.0**	E-W	N-S	U/C	Chimney
IX	546.2	N	535.1				11.0	11.2	27°S, 13°N E&W tangential	1.5
X	338.5	N	330.0				8.7	8.7	approx 5-10° now full of wax	2.7
XI	112.5	N	123.5				10.7	11.0	10°N&S E&W tangential	
Bell OAL:	**0.0**									
Total Bore Length:			**1858.5**	= top of wing to plug face + plug face to top of bell.						
Standing Height:			**948.0**	= bottom of boot to top of bell.						

NOTES: OAL = over all length (total length)

Angles are measured from perpindicular. They are in conventional directions unless otherwise stated.

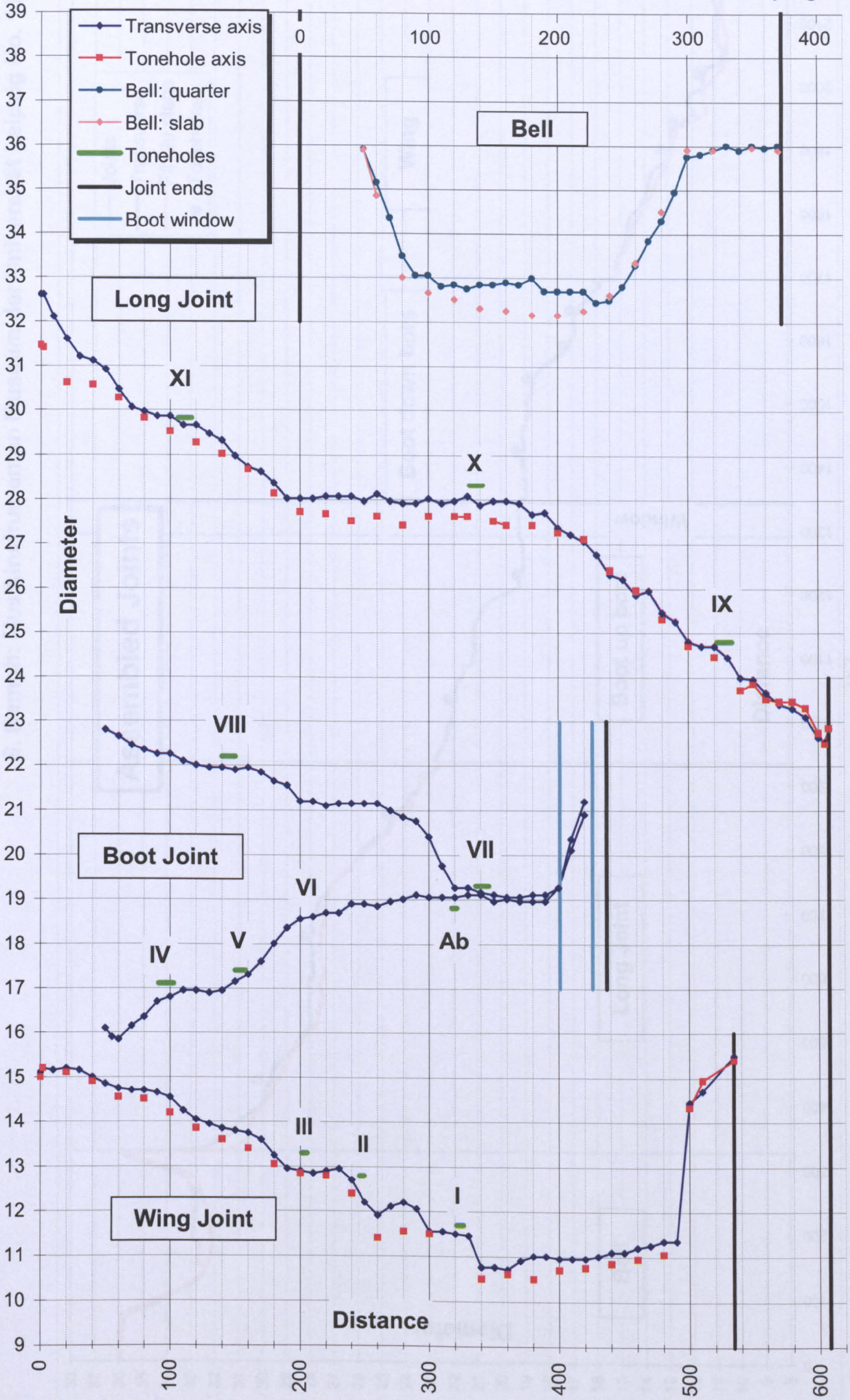
"Calliper min" is the internal diameter measured with callipers as deep as possible.

"Rods" are plastic rods in 0.2mm increments of diameter used to test hole diameter. The largest size to fit through is recorded.

S. Remph Musikinstrumenten Museum
No. 1371 der Universität Leipzig

Bore profiles **S. Remph No. 1371**

Musikinstrumenten Museum der Universität, Leipzig




S. Remph: Musikinstrumenten Museum der Universität Leipzig No. 1371
Assembled Joints
Joints
Transverse
F/hole plane
Toneholes
Diameter
Distance
Bell
Long Joint
Boot up bore
Window
Boot down bore
Wing

Joint Lengths
Tone Hole Positions and Sizes

S. Remph No. 1371
Musikinstrumenten Museum
der Universität, Leipzig

	Distance						**Diameter**			**Angle**
	Outside			**Inside**			**Surface**	**Inside**		
	d1	from end	d2	d1	from end	d2	E-W N-S	calliper min	rods etc	from perpindicular
Wing OAL:		**534.0**		**Tenon:**	**47.0**					°
I	294.0	S	303.5	321.0	S	326.0	6.5 9.2	5.7	5.4->6 4.6 tight	37°N
II	255.0	S	263.0	246.0	S	249.5	7.0 9.8	5.7	5.4->5 <4.6 >4.2	28.5°S
III	214.0	S	222.5	201.0	S	205.5	5.9 9.4	5.2	5.0->4 4.6 smooth	36.5°S
Boot OAL:		**437.0**		Septum hole Nth edge:			**401.0**		Sth edge/Plug face:	**426.5**
IV	101.5	N	111.5	91.0	N	102.5	7.70 10.30	7.25	6.6 smooth	28°N
V	145.5	N	154.5	150.0	N	158.0	7.80 8.70	6.90	6.2	13.5°S
VI	187.0	N	195.0	201.5	N	207.5	6.50 7.80	6.00	>5.0 <5.2	32°S
Ab	317.5	N	321.5	317.5	N	321.5	4.50 4.90			
VII	337.0	N	345.5	336.0	N	346.0	8.30 8.90	8.20		0°
VIII	136.5	N	148.0	140.0	N	150.0	10.10 11.30	9.70		13°S
Long OAL:		**608.0**	**Tenons N,S:**		**45.0**	**45.5**	E-W	N-S	U/C	Chimney
IX	533.2	N	522.2				10.0	11.0	a little all round	
X	342.0	N	332.0				9.1	9.4	none	
XI	106.0	N	116.5				10.5	10.3	a little all round	
Bell OAL:		**372.5**								
Total Bore Length:			**2230.0**		= top of wing to plug face + plug face to top of bell.					
Standing Height:			**1327.0**		= bottom of boot to top of bell.					

NOTES: OAL = over all length (total length)

Angles are measured from perpindicular. They are in conventional directions unless otherwise stated.

"Calliper min" is the internal diameter measured with callipers as deep as possible.

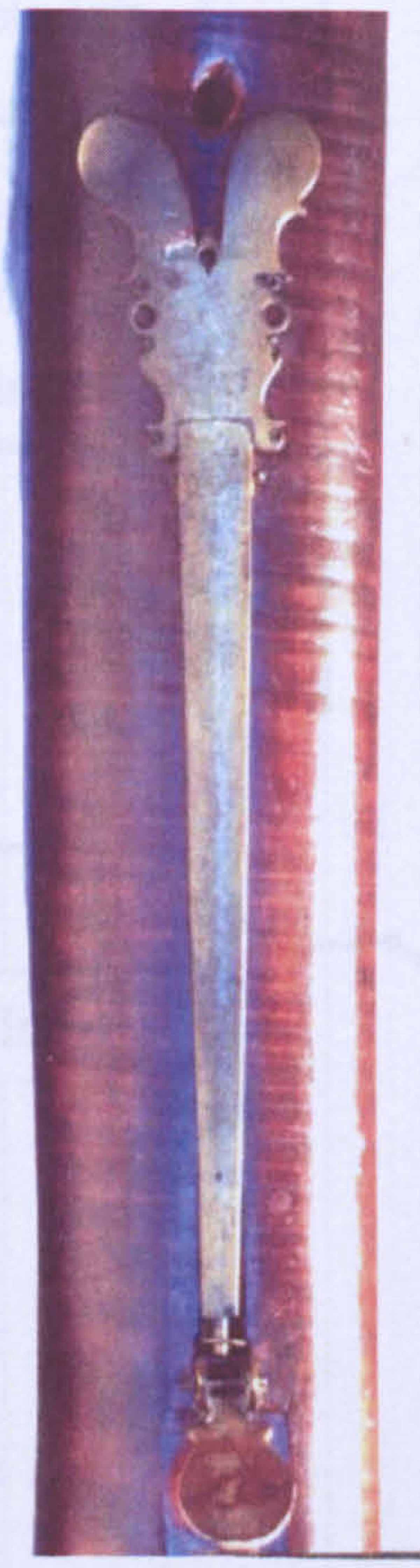
"Rods" are plastic rods in 0.2mm increments of diameter used to test hole diameter.

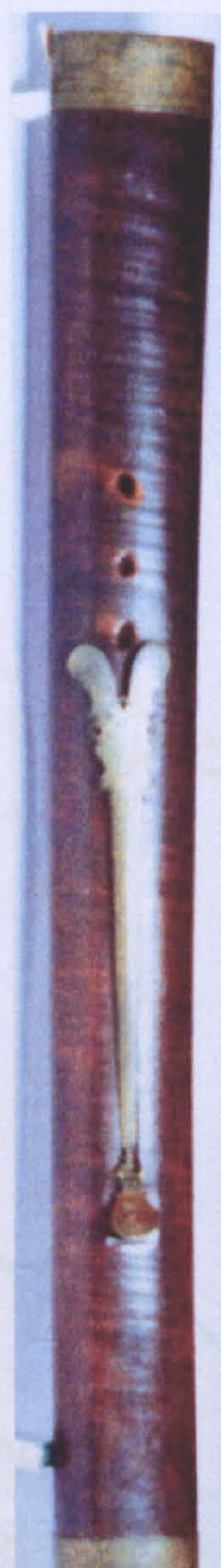
The largest size to fit through is recorded.

Contrabassoons

Anonymous
Schlossmuseum
Sondershausen
Mu 2

Andreas Eichentopf
Musikinstrumenten Museum der
Universität Leipzig, No. 3394





Bore Profiles
Andreas Eichentopf, No. 3394
Musikinstrumenten Museum der Universität, Leipzig
Transverse axis
Tonehole axis
Bell: slab
Toneholes
Joint ends
Boot window
Bell
Long Joint
Boot Joint
Wing Joint
Diameter
Distance
XI
X
IX
VIII
VII
VI
V
IV
III
II
I

Andreas Eichentopf Contrabassoon
Musikinstrumenten Museum der Universität Leipzig, No. 3394

Joint Lengths
Tone Hole Positions and Sizes

Andreas Eichentopf, No. 3394
Musikinstrumenten Museum
der Universität, Leipzig

	Distance						**Diameter**			**Angle**
	Outside			**Inside**			**Surface**	**Inside**		
	d1	from end	d2	d1	from end	d2	E-W N-S	calliper min	rods etc	from perpindicular
Wing OAL:		**1028.0**		**Tenon:**	**70.5**					°
							8.1			
I	448.0	S	459.5	521.5	S	539.5	12.3	7.6	>7.6 <7.8	34°N
							7.85			
II	403.5	S	415.0	443.0	S	451.5	12.6	7.2	>6.2 <6.4	41°S
							7.3			
III	367.0	S	378.0	399.5	S	411.5	11.3	6.3	>6.2 <6.4	45°S
Boot OAL:		**869.0**	Septum hole Nth edge:				**820.0**	Sth edge/Plug face:		**847.5**
IV	245.0	N	260.0	228.0	N	254.5	11.10	10.20		35°N
							15.20			
V	290.0	N	302.0	312.0	N	324.5	9.20	8.00	7.5 smooth fit	32°S
							12.50			
VI	326.5	N	342.0	354.0	N	364.5	9.90	8.20	>6.8 <7.0	39°S
							15.40			
Ab										
VII	667.0	N	652.5	653.5	N	668.0	15.10		u/c to E,	0°
							16.00		tangent to bore	
VIII	264.5	N	279.0	266.5	N	285.5	13.60	13.0		10°S
							14.30			
Long OAL:		**1220.0**	**Tenons N,S:**		**60.5**	**72.0**	E-W	N-S	U/C	Chimney
IX	1117.3	N	1105.0				12.1	12.3	none	
X	716.5	N	704.0				12.9	12.6	a little N	
XI	92.2	N	110.7				19.3	19.2	none (thin wall)	
Bell OAL:		**720.0**								
Total Bore Length:			**4460.0**	= top of wing to plug face + plug face to top of bell.						
Standing Height:			**2676.5**	= bottom of boot to top of bell.						

NOTES:

OAL = over all length (total length)

Angles are measured from perpindicular. They are in conventional directions unless otherwise stated.

"Calliper min" is the internal diameter measured with callipers as deep as possible.

"Rods" are plastic rods in 0.2mm increments of diameter used to test hole diameter.

The largest size to fit through is recorded.

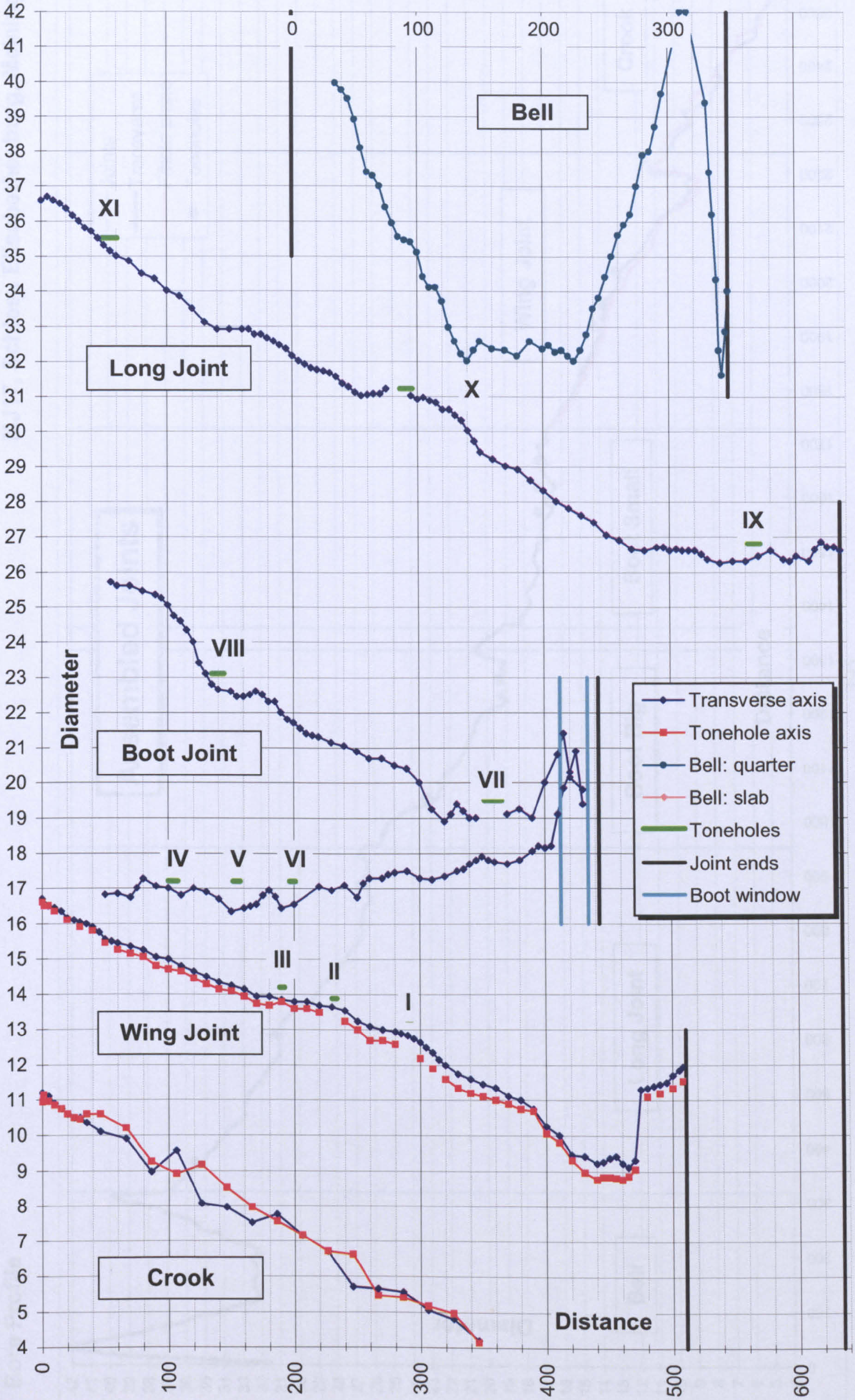
Anonymous

Schloss Elisabethenburg
Meiningen, MJ17








Bell
Long Joint
Boot Joint
Wing Joint
Crook
XI
X
IX
VIII
VII
IV
V
VI
III
II
I
Diameter
Distance
Transverse axis
Tonehole axis
Bell: quarter
Bell: slab
Toneholes
Joint ends
Boot window
0
100
200
300
400
500
600
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
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40
41
42


Bore Profile
MJ17, Schloss Elisabethenburg, Meiningen
Assembled Joints
Joints
Transverse
F/hole plane
Toneholes
Diameter
Distance
Bell
Long Joint
Boot Big
Boot Small
Wing Joint
Crook

	Distance						**Diameter**			**Angle**
	Outside			**Inside**			**Surface**	**Inside**		
	d1	from end	d2	d1	from end	d2	E-W N-S	calliper min	rods etc	from perpindicular
Wing OAL:	**510.5**		**Tenon:**	**44.5**						°
I	278.0	S	286.5	289.5	S	293.5	6.8 9.4	5.8	4.8 to 19 4.6 through	26°N
II	240.0	S	248.5	230.0	S	234.0	6.87 8.85	5.8	5.8 to 9, 4.8 to 21 4.6 just through	24°S
III	201.5	S	210.0	188.5	S	192.2	5.7 8.3		5.4 just in 4.6 to 20	28°S
Boot OAL:	**443.0**		Septum hole Nth edge:				**412.5**		Sth edge/Plug face:	**434.0**
IV	104.5	N	114.5	100.0	N	107.5	8.6 10.6	7.50		17°S
V	146.5	N	156.0	151.5	N	157.0	8.2 8.2		12.5 5.6 through	8°S
VI	185.5	N	195.0	196.5	N	201.0	7.0 9.8		6.4 just in 5.2 just through	29°S
Ab										
VII	451.0	N	461.0	352.0	N	366.0	9.0 11.5	8.7	U/C south from 5 in	S
VIII	129.0	N	141.5	135.0	N	145.0	11.7 12.0	9.8		16°S
Long OAL:	**635.0**	**Tenons N,S:**		**29.0**	**49.0**		E-W	N-S	U/C	Chimney
IX	571.7	N	562.1				9.7surface 9.4	9.9 9.6	overcut no u/c	
X	296.0	N	286.0				9.8surface 9.4	10.2 9.8	overcut v little u/c E-W	4.5
XI	48.3	N	60.5				12.9 12.4	12.2 12.1	ditto	2.9
Bell OAL:	**347.0**									
Total Bore Length:		**2238.0**		= top of wing to plug face + plug face to top of bell.						
Standing Height:		**1347.0**		= bottom of boot to top of bell.						
NOTES:		OAL = over all length (total length)								
		Angles are measured from perpindicular. They are in conventional directions unless otherwise stated.								
		"Calliper min" is the internal diameter measured with callipers as deep as possible.								
		"Rods" are plastic rods in 0.2mm increments of diameter used to test hole diameter.								
			The largest size to fit through is recorded.							


Bore profiles
HK·ICW·
Waterhouse Collection
Bell
Long Joint
Boot Joint
Wing Joint
(not original)
XI
X
IX
VIII
VII
VI
V
IV
III
II
I
Ab
Diameter
Distance
Transverse axis
Tonehole axis
Bell: quarter
Bell: slab
Toneholes
Joint ends
Boot window

HK·ICW· Waterhouse Collection

	Distance						**Diameter**			**Angle**
	Outside			**Inside**			**Surface**	**Inside**		
	d1	from end	d2	d1	from end	d2	E-W N-S	calliper min	rods etc	from perpindicular
Wing OAL:		**517.0**		**Tenon:**	**41.0**					°
I	282.5	S	288.5	295.0	S	299.5	4.8 6.3	4.8	4.8 smooth	30°N
II	240.5	S	247.0	230.0	S	234.5	5.1 6.8	4.8	ditto	27°S
III	203.0	S	209.0	192.0	S	196.5	5.15 6.5	4.7	4.8 tight	39°S
Boot OAL:		**446.0**	Septum hole Nth edge:				**405.0**	Sth edge/Plug face:		**433.0**
IV	108.0	N	116.5	102.0	N	109.5	7.20 10.00	6.90	7.0 just in 6.8 loose	20°N
V	150.0	N	158.0	153.0	N	157.0	6.80 8.30	6.05	6.0->7.5 5.8 loose	0°
VI	191.0	N	198.0	196.0	N	202.0	6.75 8.30	5.85	6.0->6.5 5.8 loose	13.5°S
Ab	328.0	N	334.0	329.0	N	337.0	6.10		hole now blocked	
VII	348.0	N	358.0	342.0	N	358.0	9.90 11.60	9.60	u/c 22°N	0°
VIII	134.0	N	145.0	135.0	N	144.0	10.20 12.90	9.65		0°
Long OAL:		**566.0**	**Tenons N,S:**		**36.0**	**40.0**	E-W	N-S	U/C	Chimney
IX	503.1	N end	493.3				9.7	9.6	tangential E&W some N&S	2.0
X	313.0	N end	303.0				10.0	9.7	5°all round	
XI	75.6	N end	88.0				12.3	12.0	tangential E&W thin walls N&S	2.0
Bell OAL:		**352.0**								
Total Bore Length:			**2184.0**		= top of wing to plug face + plug face to top of bell.					
Standing Height:			**1288.0**		= bottom of boot to top of bell.					

NOTES: OAL = over all length (total length)

Angles are measured from perpindicular. They are in conventional directions unless otherwise stated.

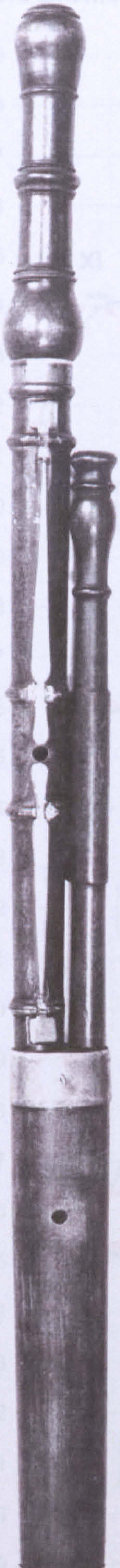
"Calliper min" is the internal diameter measured with callipers as deep as possible.

"Rods" are plastic rods in 0.2mm increments of diameter used to test hole diameter.

The largest size to fit through is recorded.

J.C. Denner/D Musikinstrumenten-Museum Berlin

No. 2970



Bore profiles
J.C. Denner/D
Musikinstrumenten-Museum, Berlin No. 2970
Transverse axis
Tonehole axis
Bell: quarter
Bell: slab
Toneholes
Joint ends
Boot window
Long Joint
Boot Joint
Wing Joint
Bell
Diameter
Distance
XI
X
IX
VIII
VII
VI
V
IV
III
II
I

J.C. Denner/D, Musikinstrumenten-Museum Berlin, No. 2970

	Distance						Diameter			Angle
	Outside			Inside			Surface	Inside		
	d1	from end	d2	d1	from end	d2	E-W N-S	calliper min	rods etc	from perpindicular
Wing OAL:		519.0		Tenon:	53.0					°
I	306.5	S	298.5	312.5	S	318.0	6.15 9.55	5.6	5.4 through tight 5.6 -> 9.5	29°N
II	265.0	S	257.5	252.5	S	256.5	6.15 8.35	5.6	5.2 loose 5.4->21.5, 5.6->1	14°S
III	227.5	S	219.0	205.5	S	212.0	6.0 9.2	5.8	5.6->10.5 5.4 through smooth	29°S
Boot OAL:		446.0		Septum hole Nth edge:			405.0	South edge/Plug face:		422.0
IV	95.0	N	104.0	86.5	N	94.5	7.7 10.8	7.4	7.0 tight through oval NS but not much u/c apparent	25°N
V	136.0	N	146.0	146.5	N	153.5	7.5	6.75	6.2 loose 6.4 -> 14	25°S
							10.5		no u/c apparent	
VI	178.0	N	186.0	190.0	N	196.0	6.3	5.5	5.4 just loose 5.6 to 1	33°S
							10.5		no u/c apparent	
Ab										
VII	323.0	N	344.5	321.0	N	334.5	12.2		key not removed	
							13.2			
VIII	123.5	N	134.5	124.0	N	133.0	10.8	9.6		0°
							12.2			
Long OAL:		587.5	Tenons N,S:		26.0	44.5	E-W	N-S	U/C	Chimney
IX	66.8	S end	54.6				12.5	12.2	28°E&W 40°S, 30°N	1mm S 0.5mm N
X	282.0	S end	270.5				11.9	10.9	30°N&S tangent to bore E&W	
XI	44.6	N end	57.6				13.65	12.9	22°E&W 40°N&S	1mm N&S
Bell OAL:		297.0								
Total Bore Length:			2124.0		= top of wing to plug face + plug face to top of bell.					
Standing Height:			1260.0		= bottom of boot to top of bell.					

NOTES:

OAL = over all length (total length)

Angles are measured from perpindicular. They are in conventional directions unless otherwise stated.

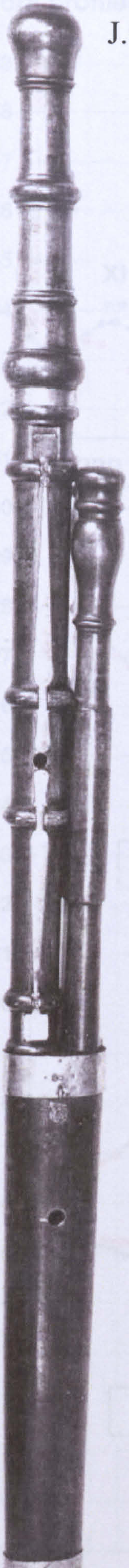
"Calliper min" is the internal diameter measured with callipers as deep as possible.

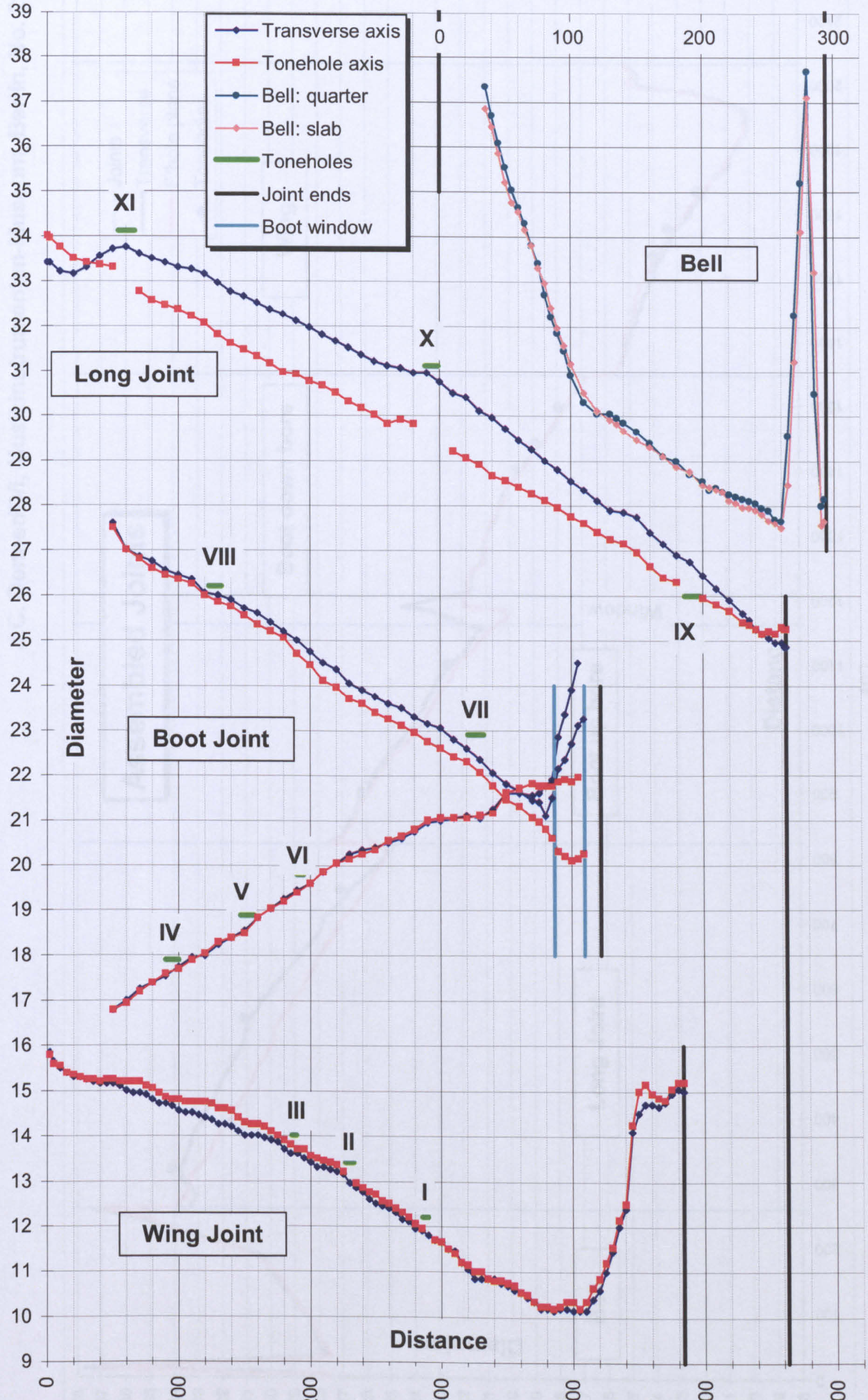
"Rods" are plastic rods in 0.2mm increments of diameter used to test hole diameter.

The largest size to fit through is recorded.

J.C. Denner/D/I Musikinstrumenten-Museum Berlin

No. 2969



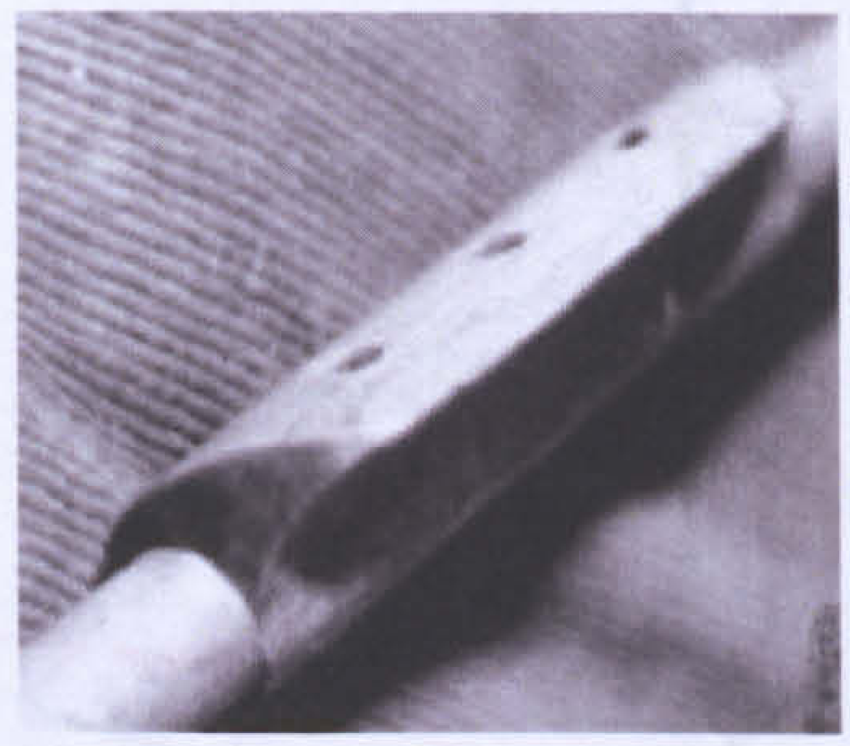

Transverse axis
Tonehole axis
Bell: quarter
Bell: slab
Toneholes
Joint ends
Boot window
Long Joint
Boot Joint
Wing Joint
Bell
Diameter
Distance
I
II
III
IV
V
VI
VII
VIII
IX
X
XI

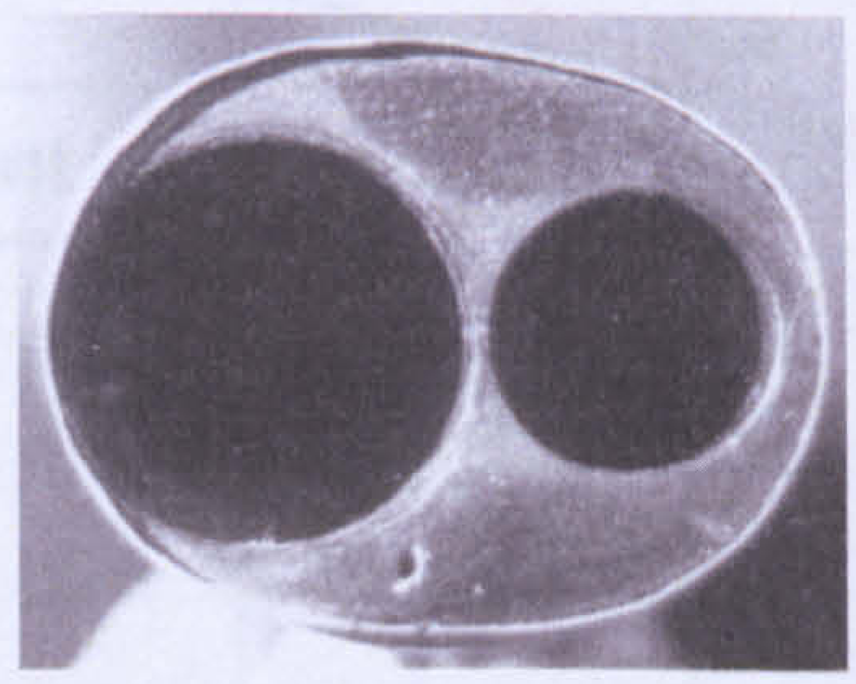
J.C. Denner/D/I, Musikinstrumenten-Museum, Berlin, No. 2969

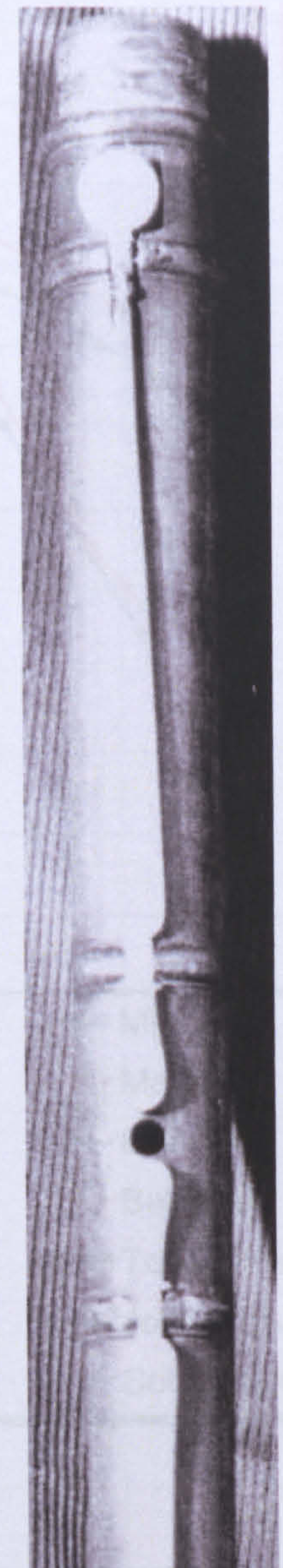
	Distance						**Diameter**			**Angle**
	Outside			**Inside**			**Surface**	**Inside**		
	d1	from end	d2	d1	from end	d2	E-W N-S	calliper min	rods etc	from perpindicular
Wing OAL:	**484.0**			**Tenon:**	**46.5**					°
I	273.0	S	281.0	285.5	S	290.0	5.8	5.0	4.6 loose 4.8 to 18	29°N
							8.1		5.0 to 3 no undercutting	
II	234.0	S	241.5	227.0	S	233.0	6.8	5.3	5.2 tight through 5.4 to 4	21°S
							7.9		5.6 just in a little u/c north	
III	193.5	S	202.0	186.0	S	189.5	5.8	5.0	4.6 to 26.5 4.8 to 10.5	38.5°S
							7.8		5.0 to 3 no u/c	
Boot OAL:	**422.0**		Septum hole North edge:				**387.0**		South edge/Plug face:	**410.0**
IV	100.5	N	109.5	90.0	N	100.0	7.8	7.30	7.0 loose	25°up
							10.5		u/c NW to surface plus a little all round	
V	142.0	N	151.0	147.0	N	157.0	7.8	7.2	7.0 through touching	11°down
							9.1		u/c NW to 3 from surface + a little SE	
VI	180.0	N	189.0	190.0	N	195.0	6.8	5.9	5.8 through touching 6.0 to 5	20°down
							7.7		u/c a little N&W innermost 10mm	
Ab										
VII	319.0	N	330.0	321.0	N	333.0	11.1		Key not removed	
							12.0			
VIII	118.0	N	129.0	123.0	N	132.5	10.6	9.6	u/c N&W for	16°down
							12.2		innermost 5mm	
Long OAL:	**563.0**		**Tenons N,S:**		**34.0**	**49.0**	E-W	N-S	U/C	Chimney
IX	76.5	S end	66.0				10.7	10.4	10°all round	2.0
X	266.0	S end	257.0				9.0	9.4	15-20°all round	4.5
XI	126.0	N end	137.0				11.0	11.1	15°E&W	4.5
Bell OAL:	**294.0**									
Total Bore Length:			**2031.5**		= top of wing to plug face + plug face to top of bell.					
Standing Height:			**1196.0**		= bottom of boot to top of bell.					

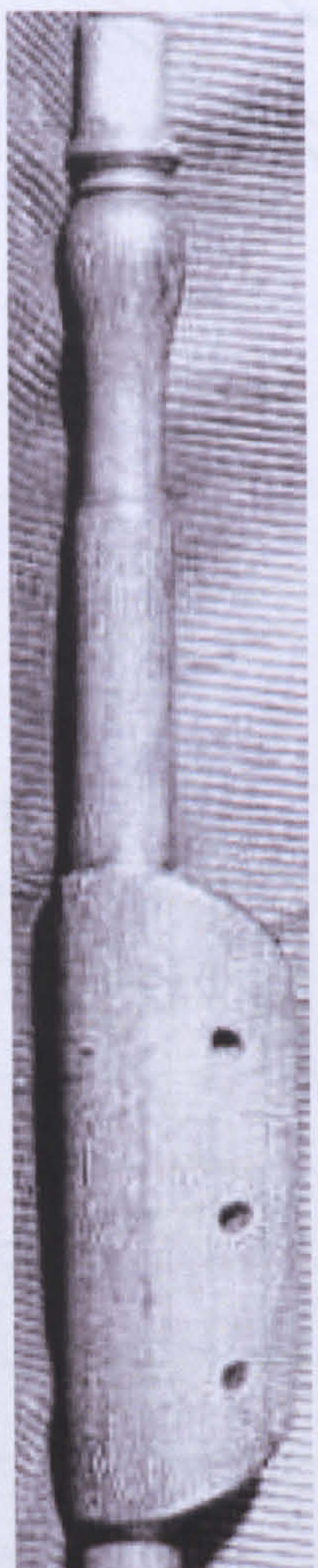
NOTES:
OAL = over all length (total length)
Angles are measured from perpindicular. They are in conventional directions unless otherwise stated.
"Calliper min" is the internal diameter measured with callipers as deep as possible.
"Rods" are plastic rods in 0.2mm increments of diameter used to test hole diameter.
The largest size to fit through is recorded.

J.C. Denner/D Musée Instrumental Brussels, M427









Measurements courtesy of
G. Lyndon-Jones
J.C. Denner, M427
Musée Instrumental, Brussels
Bell
Long Joint
Boot Joint
Wing Joint
XI
X
IX
VIII
VII
VI
V
IV
III
II
I
Diameter
Distance
Min
Max
Bell min
Bell max
Toneholes
Joint ends
Boot window

Measurements courtesy of G. Lyndon-Jones

J.C. Denner, M427
Musée Instrumental, Brussels

Joint Lengths
Tone Hole Positions and Sizes
Measurements courtesy of G. Lyndon-Jones

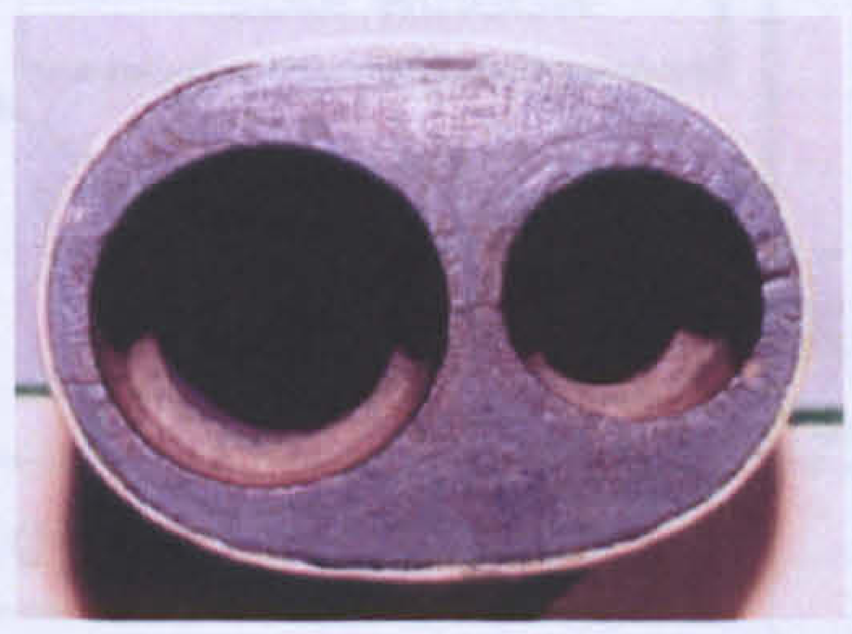
J.C. Denner/D
Musée Instrumental
Brussels, M 427

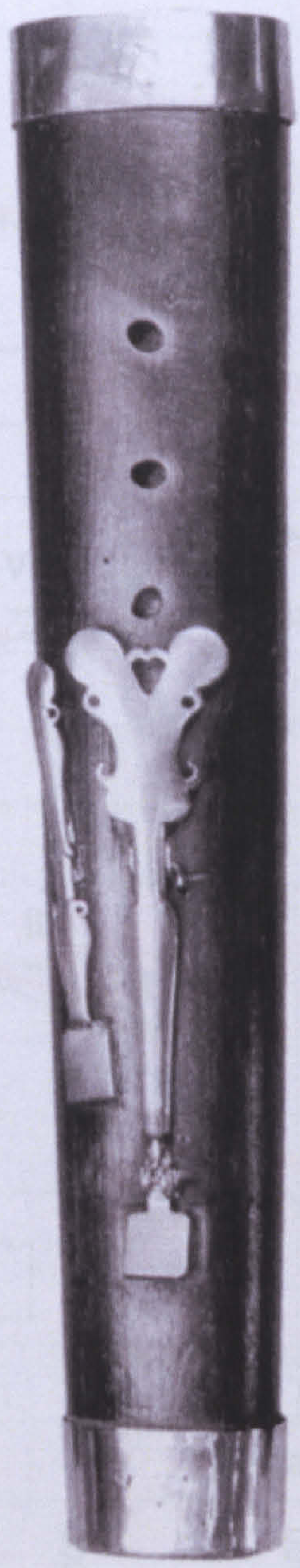
	Distance						**Diameter**			**Angle**
	Outside			**Inside**			**Surface**	**Inside**		
	centre	from end		d1	from end	d2	E-W N-S	calliper min	rods etc	from perpindicular
Wing OAL:		**514.5**		**Tenon:**	**38.0**					°
I	281.5	S	233.0	291.0	S	296.5	6.6 9.7	5.7		20.5°N
II	243.0	S	271.5	232.5	S	237.5	6.5 8.4	5.7		1°S
III	207.7	S	306.8	193.0	S	198.0	5.6 7.2	5.0		31°S
Boot OAL:		**446.0**	Septum hole North edge:				**391.0**	South edge/Plug face:		**427.0**
IV	106.0	N		89.5	N	98.5	7.7 9.7	7.5		23°N
V	149.5	N		153.0	N	160.0	7.1 8.6	6.7		19°S
VI	189.5	N		196.5	N	202.0	6.9 8.8	7.0		28°S
VII	333.0	N		332.5	N	343.5	11.5	11.2		20°S
VIII	138.5	N		144.0	N	153.0	11.1 11.5	10.3		20°S
Long OAL:		**580.0**	**Tenons N,S:**		**30.0**	**35.0**	E-W	N-S	U/C	Chimney
IX	537.0	S end	529.0				8.5		moderate all round	2.0
X	317.5	S end	308.5				9.2	9.0	moderate all round	
XI	49.0	N end	59.0				12.0		extreme all round	2.0
Bell OAL:		**297.5**								
Total Bore Length:			**2157.0**	= top of wing to plug face + plug face to top of bell.						
Standing Height:			**1258.5**	= bottom of boot to top of bell.						

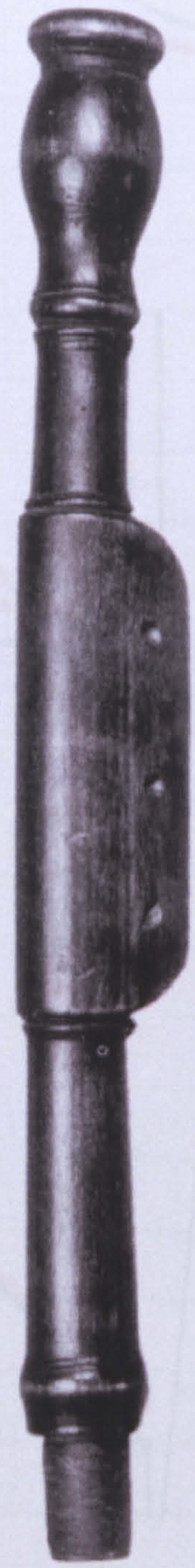
NOTES: OAL = over all length (total length)
Angles are measured from perpindicular. They are in conventional directions unless otherwise stated.
"Calliper min" is the internal diameter measured with callipers as deep as possible.
"Rods" are plastic rods in 0.2mm increments of diameter used to test hole diameter.
The largest size to fit through is recorded.

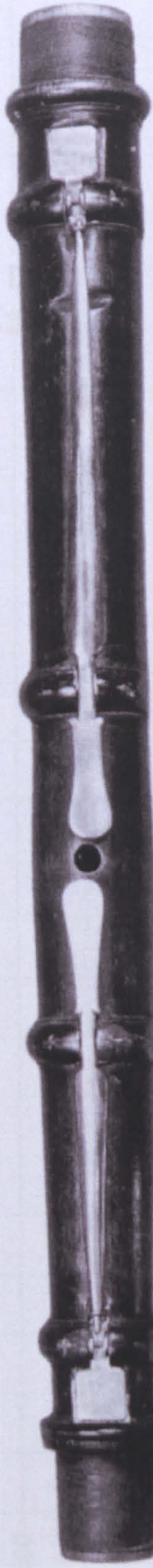
J. Denner, Oberösterreichisches Landesmuseum

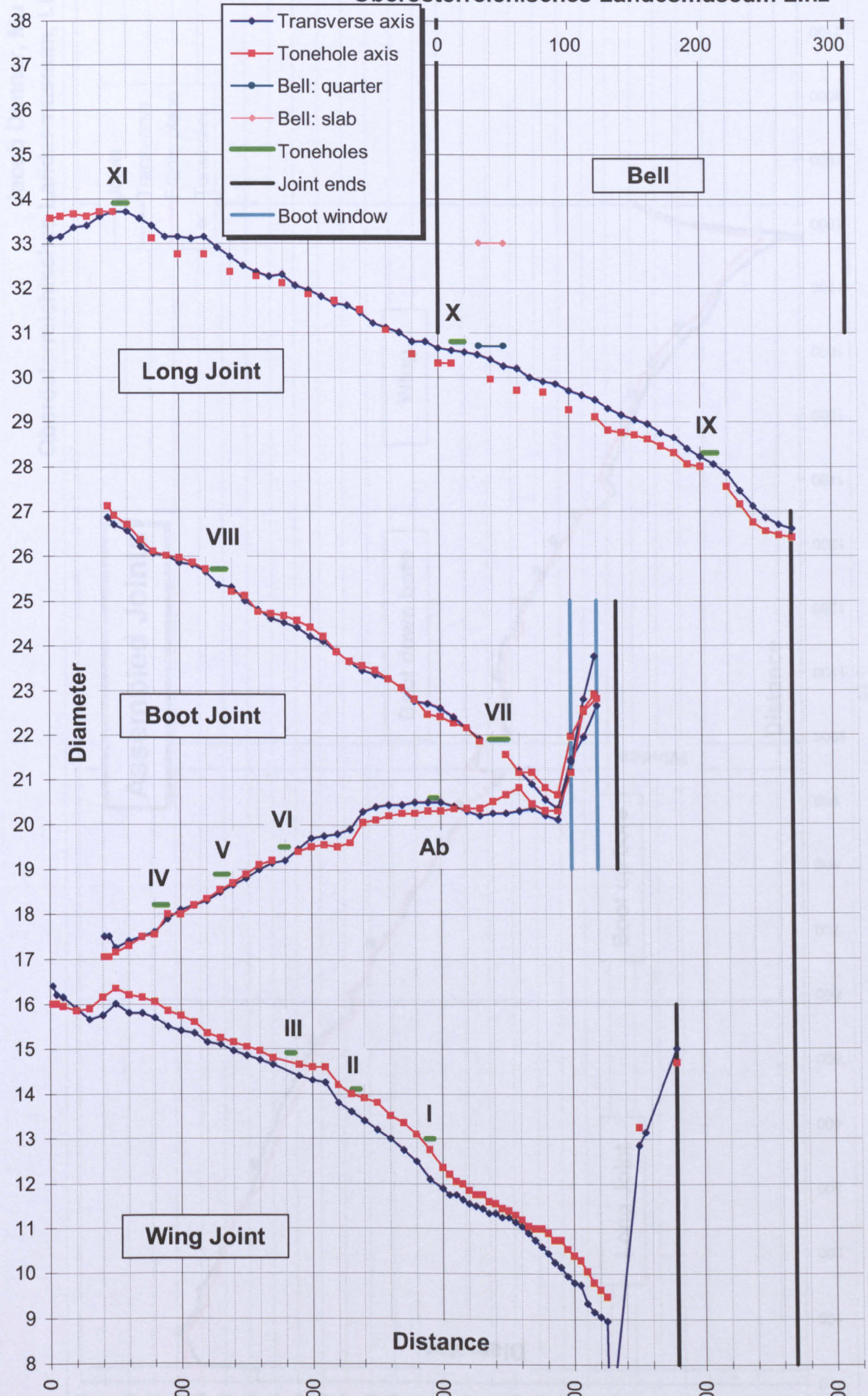
Linz Mu 33










Transverse axis
Tonehole axis
Bell: quarter
Bell: slab
Toneholes
Joint ends
Boot window
Bell
Long Joint
Boot Joint
Wing Joint
XI
X
IX
VIII
VII
VI
V
IV
III
II
I
Ab
Diameter
Distance
0
100
200
300
400
500
600
38
37
36
35
34
33
32
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8

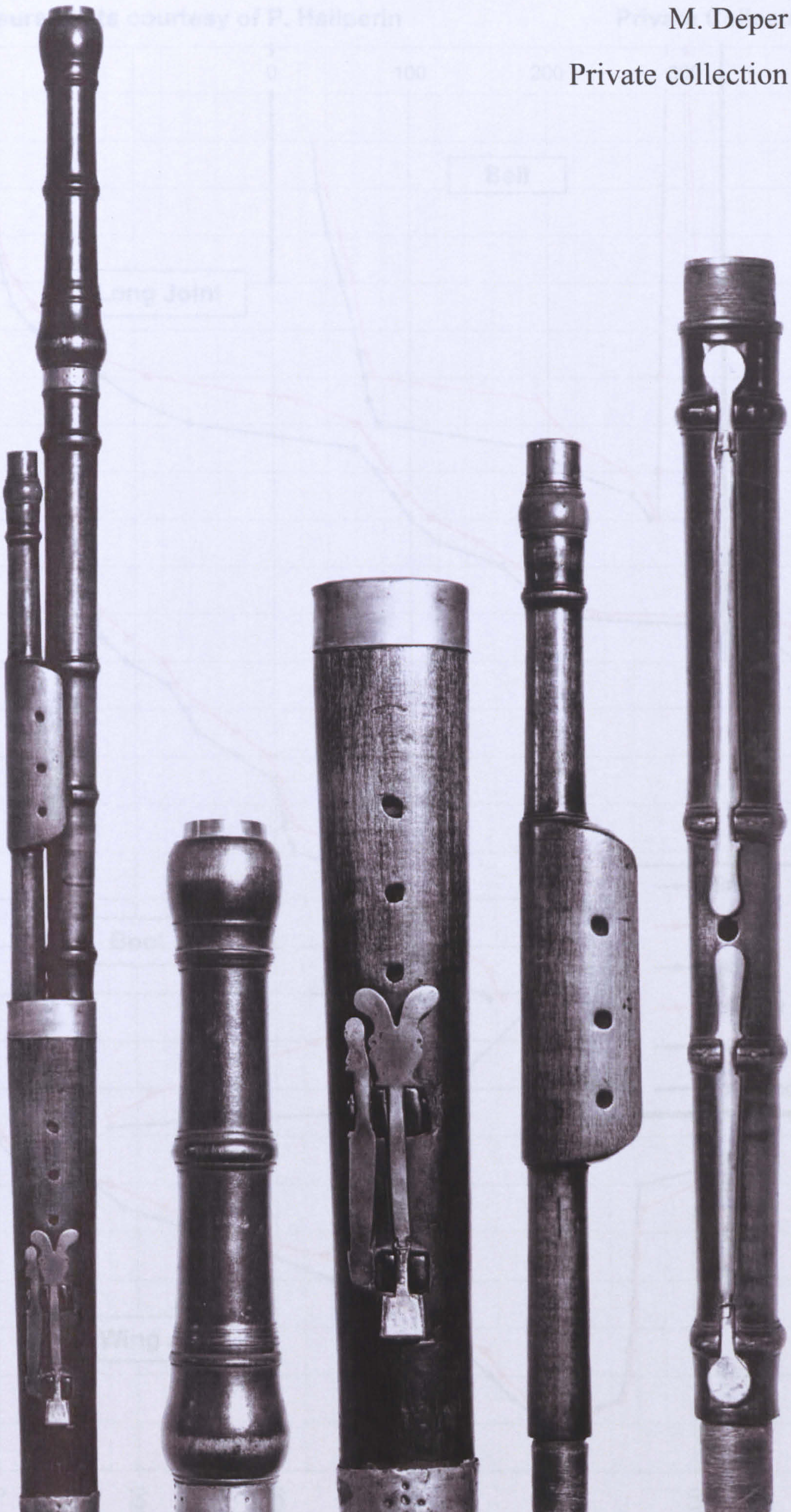
Jacob Denner, Mu 33
Oberösterreichisches Landesmuseum, Linz

	Distance						Diameter			Angle
	Outside			Inside			Surface	Inside		
	d1	from end	d2	d1	from end	d2	E-W N-S	calliper min	rods etc	from perpindicular
Wing OAL:		479.0		Tenon:	40.0					°
I	287.0	S	279.5	293.0	S	287.0	5.9 8.0		4.6 tight	21°N
II	240.0	S	232.5	230.5	S	236.5	6.45 7.8		5.2 tight	11°S
III	201.0	S	192.0	180.8	S	187.0	6.7 9.0		4.6->11	38°S
Boot OAL:		435.0	Septum hole North edge:				400.0	South edge/Plug face:		420.0
IV	86.5	N	95.5	79.7	N	90.0	8.10 10.20		7.4 just passes	18°N
V	126.0	N	134.0	126.5	N	136.5	7.75 9.50		7.4 just passes	3°S
VI	162.0	N	171.0	176.2	N	182.5	7.20 9.70		6.0 just passes	32°S
Ab	297.0	N	290.8	291.5	N	297.0			key not removed	
VII	339.5	N	350.0	337.5	N	352.0	11.00 13.50	10.35	u/c N&S 30°e	N 11° S 6°
VIII	120.0	N	131.0	125.0	N	135.5	9.90 11.90	8.70		16°
Long OAL:		569.0	Tenons N,S:		28.8	40.0	E-W	N-S	U/C	Chimney
IX	76.5	S end	66.0				10.7	10.4	10° all round	2.0
X	266.0	S end	257.0				9.0	9.4	15-20° all round	4.5
XI	126.0	N end	137.0				11.0	11.1	15°E&W	4.5
Bell OAL:		50.0								
Total Bore Length:			1829.2		= top of wing to plug face + plug face to top of bell.					
Standing Height:			985.2		= bottom of boot to top of bell.					

NOTES:
OAL = over all length (total length)
Angles are measured from perpindicular. They are in conventional directions unless otherwise stated.
"Calliper min" is the internal diameter measured with callipers as deep as possible.
"Rods" are plastic rods in 0.2mm increments of diameter used to test hole diameter.
The largest size to fit through is recorded.

M. Deper

Private collection



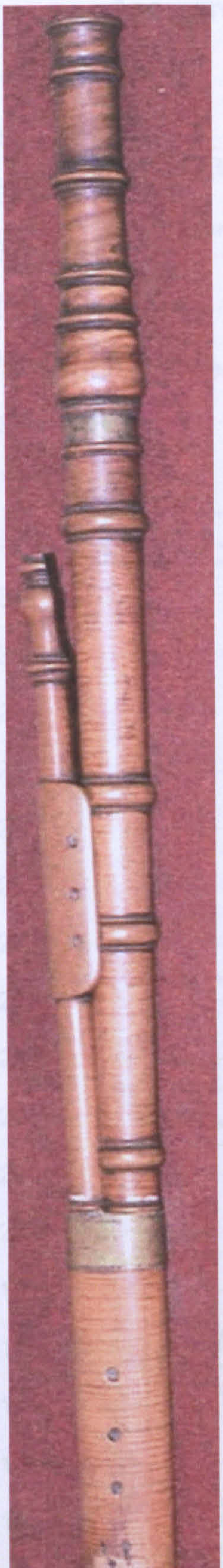

Bore profiles
Measurements courtesy of P. Hailperin
M. Deper
Private Collection
Bell
Long Joint
Boot Joint
Wing Joint
Diameter
Distance
Min
Max
Bell min
Bell max
Joint ends
Boot window

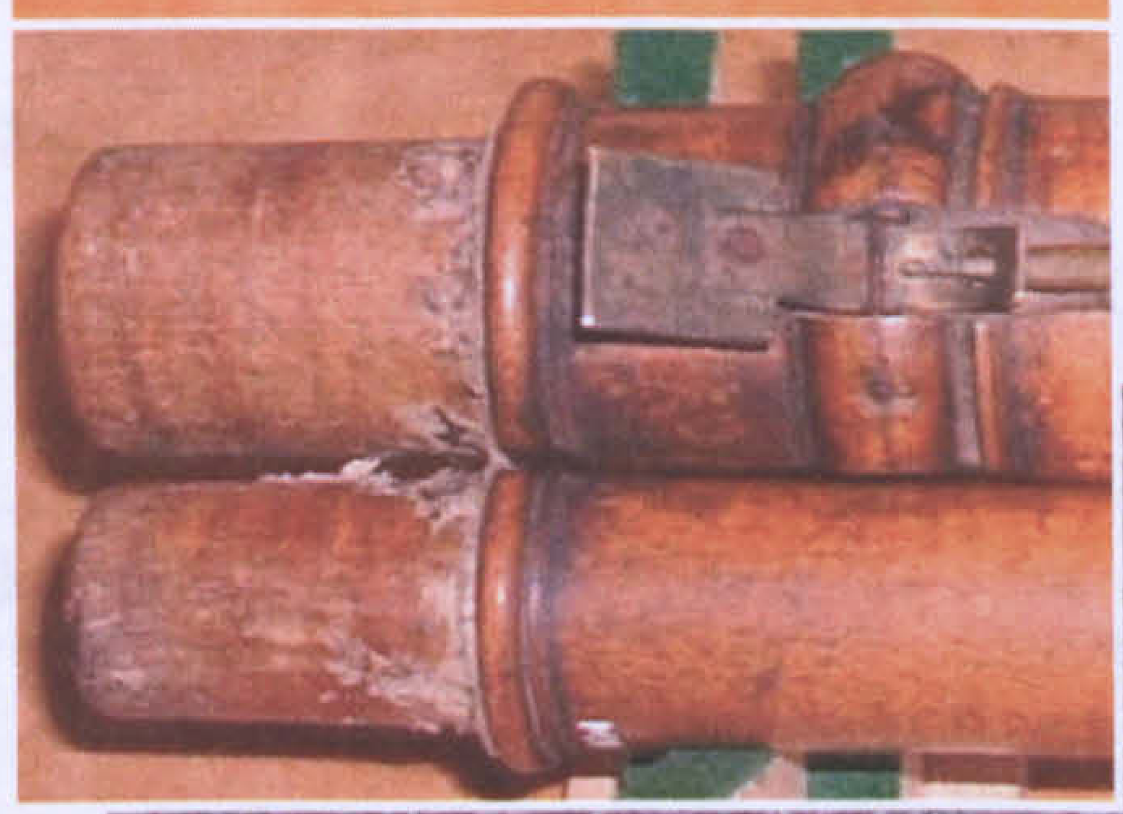
Measurements courtesy of P. Hailperin
M. Deper
Private Collection
Assembled Joints
Joints
Max
Min
Diameter
Distance
Bell
Long Joint
Boot up bore
Window
Boot down bore
Wing

Joint Lengths
Tone Hole Positions and Sizes
Measrements courtesy of P. Hailperin

M. Deper
Private Collection

	Distance						**Diameter**			**Angle**
	Outside			**Inside**			**Surface**	**Inside**		
	centre	from end		d1	from end	d2	E-W N-S	calliper min	rods etc	from perpindicular
Wing OAL:		**505.0**		**Tenon:**	**40.5**					°
I	281.0	S						6.4		30°N
II	236.0	S						6.0		10°S
III	199.0	S						5.5		20°S
Boot OAL:		**440.0**	Septum hole North edge:				**401.0**	South edge/Plug face:		**421.0**
IV	107.0	N						7.00		25°N
V	148.0	N						6.8		15°S
VI	186.0	N						5.7		25°S
Ab	322.0	N						4.7		
VII	344.0	N						10.5		18°N
VIII	136.0	N						9.5		18°S
Long OAL:		**591.0**	**Tenons N,S:**		**28.5**	**45.5**	E-W	N-S	U/C	Chimney
IX							12.0	10.8		
X	342.5	N					9.0			
XI							11.8	13.3		
Bell OAL:		**327.0**								
Total Bore Length:			**2150.5**		= top of wing to plug face + plug face to top of bell.					
Standing Height:			**1284.0**		= bottom of boot to top of bell.					
NOTES:		OAL = over all length (total length)								
		Angles are measured from perpindicular. They are in conventional directions unless otherwise stated.								
		"Calliper min" is the internal diameter measured with callipers as deep as possible.								
		"Rods" are plastic rods in 0.2mm increments of diameter used to test hole diameter.								
			The largest size to fit through is recorded.							





Anonymous, Muzeum Insrumenów Muzyczynch Poznan No. 1376

Anonymous, Muzeum Instrumenów Muzyczynch, Poznan No. 1376
Bell chamber maximum diameter 47.0mm
Bell
Long Joint
Boot Joint
Wing Joint
XI
X
IX
VIII
VII
Ab
VI
V
IV
III
II
I
Diameter
Distance
Transverse axis
Tonehole axis
Bell: quarter
Bell: slab
Toneholes
Joint ends
Boot window

Anonymous, Muzeum Instrumenów Muzyczynch, Poznan 1376
Assembled Joints
Joints
Transverse
F/hole plane
Toneholes
Diameter
Distance
Bell
Long joint
Boot big
Boot small
Wing
40
39
38
37
36
35
34
33
32
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200

	Distance						**Diameter**			**Angle**
	Outside			Inside			Surface	Inside		
	d1	from end	d2	d1	from end	d2	E-W N-S	calliper min	rods etc	from perpindicular
Wing OAL:		**501.0**		**Tenon:**	**41.5**					°
							6.0		5.6->2	
I	293.0	S	300.5	304.0	S	311.5	8.9	5.7	tight	24°N
							6.4			
II	257.5	S	264.8	244.5	S	251.0	7.3	5.95	5.4 smooth	28°S
							6.35		<5.6	
III	226.0	S	233.0	214.0	S	221.0	6.8	5.95	5.4 smooth	24.5°S
Boot OAL:		**450.0**		Septum hole Nth edge:			**418.0**	Sth edge/Plug face:		**440.5**
IV	103.5	N	112.5	96.0	N	103.5	8.40	7.40	7.0 tight at	23°N
							9.90		bottom of hole	
V	145.0	N	154.0	153.5	N	161.0	8.50	7.45	7.2 T passes EW not NS	22.5°S
							8.95		7.0 loose	
VI	182.0	N	191.0	191.0	N	198.5	8.05	6.40	6.4->6	26.5°S
							8.30		6.2 loose	
Ab	308.0	N	315.0	311.0	N	317.5	6.30		>5.8, <5.6	31°Nth side 23°sth side
							7.90		roughly cut	to S
VII	324.0	N	336.8	321.0	N	336.5	12.70	12.30	U/C all round	0°
							13.80		tangent to bore E&W	
VIII	131.0	N	141.0	131.0	N	142.5	9.85	9.30		0°
							10.50			
Long OAL:		**613.0**	**Tenons N,S:**		**38.0**	**43.5**	E-W	N-S	U/C	Chimney
							10.1	9.8	25-30°	3°nth
IX	554.4	N end	544.4				9.8	9.7	all round	1°sth
X	334.0	N end	323.0				12.3	10.7	5°E&W	none
							14.7	15.85		
XI	61.5	N end	77.2				14.4		10°S,E&W	none
Bell OAL:		**300.0**								
Total Bore Length:			**2172.0**	= top of wing to plug face + plug face to top of bell.						
Standing Height:			**1281.5**	= bottom of boot to top of bell.						

NOTES: OAL = over all length (total length)

Angles are measured from perpindicular. They are in conventional directions unless otherwise stated.

"Calliper min" is the internal diameter measured with callipers as deep as possible.

"Rods" are plastic rods in 0.2mm increments of diameter used to test hole diameter.

The largest size to fit through is recorded.

Anonymous Musikinstrumenten Museum
der Universität Leipzig, No 1366

Bore profiles
Anonymous, No. 1366
Musikinstrumenten Museum der Universität Leipzig
Bell
Long Joint
Boot Joint
Wing Joint
XI
X
IX
VIII
VII
VI
V
IV
III
II
I
Diameter
Distance
Transverse axis
Tonehole axis
Bell: quarter
Toneholes
Joint ends
Boot window

Anonymous, No. 1366
Musikinstrumenten Museum der Universität Leipzig

	Distance						Diameter			Angle
	Outside			Inside			Surface	Inside		
	d1	from end	d2	d1	from end	d2	E-W N-S	calliper min	rods etc	from perpindicular
Wing OAL:		**511.0**		**Tenon:**	**45.5**					°
I	229.0	N	239.0	214.0	N	223.0	8.2 11.6	6.6	7.0->7 6.4 through	31°N
II	273.5	N	283.0	280.5	N	288.0	8.3 9.5	6.8	<6.6 >6.4	14°S
III	316.0	N	326.0	335.0	N	343.0	7.9 10.7	6.9	7.0->4 6.4 tight	35°S
Boot OAL:		**434.0**	Septum hole North edge:				**400.6**	South edge/Plug face:		**421.0**
IV	97.0	N	106.0	86.5	N	95.0	8.20 12.30	7.10	<6.6 >6.8	29°N
V	139.5	N	148.5	146.5	N	154.5	8.60 14.00	7.45	<6.4	12°S
VI	179.5	N	189.0	195.5	N	203.0	7.65 11.00	6.70	6.4 smooth	35°S
Ab		n/a								
VII	346.5	N	356.0	349.0	N	363.5	10.20 11.00	9.40		S
VIII	127.0	N	138.0	129.5	N	139.0	11.10 12.65	9.70		0°
Long OAL:		**600.0**	**Tenons N,S:**		**34.5**	**46.5**	E-W	N-S	U/C	Chimney
IX	526.5	N	536.5				10.1		key not removed	
X	317.5	N	328.0				9.8	10.0	none	
XI	77.5	N	90.5				13.0		key not removed	
Bell OAL:		**333.0**								
Total Bore Length:			**2159.5**	= top of wing to plug face + plug face to top of bell.						
Standing Height:			**1286.0**	= bottom of boot to top of bell.						

NOTES: OAL = over all length (total length)

Angles are measured from perpindicular. They are in conventional directions unless otherwise stated.

"Calliper min" is the internal diameter measured with callipers as deep as possible.

"Rods" are plastic rods in 0.2mm increments of diameter used to test hole diameter.

The largest size to fit through is recorded.

J.W. Kenigsperger

Munich Stadtmuseum, 52-49

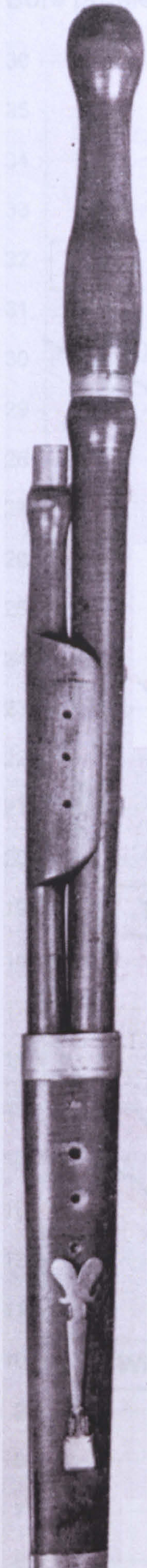
Bore profiles
J.W. Kenigsperger
Munich Stadtmuseum 52-49
Long Joint
Boot Joint
Wing Joint
Crook
Bell
XI
X
IX
VIII
VII
VI
V
IV
III
II
I
Diameter
Distance
Transverse axis
Tonehole axis
Bell: quarter
Toneholes
Joint ends
Boot window

J.W. Kenigsperger, Munich Stadtmuseum 52-49

	Distance						Diameter			Angle
	Outside			Inside			Surface	Inside		
	d1	from end	d2	d1	from end	d2	E-W N-S	calliper min	rods etc	from perpindicular
Wing OAL:		**464.0**		**Tenon:**	**41.4**					°
I	266.0	S	274.0	275.0	S	279.0	5.3 6		4.6->6 4.4 min	24°N
II	234.0	S	242.0	220.0	S	244.5	5.9 8.7		4.6->17	40°S
III	202.0	S	210.0	187.0	S	190.5	5.4 8.2		4.6->9 4.5 min	36°S
Boot OAL:		**398.0**	Septum hole North edge:				**368.0**	South edge/Plug face:		**388.0**
IV	83.0	N	92.0	98.0	N	104.5	6.60 7.60	5.50	4.6 through	originally 0°N now south
V	118.0	N	126.0	118.0	N	125.0	6.20 7.20	6.30	<5.8, >5.6	0°S
VI	154.0	N	160.5	159.0	N	163.0		5.50	<5.0, >4.8	11°S
Ab		N			N					
VII	308.5	N	299.0	298.0	N	311.5	11.10		key not removed	
	89.5	S	99.0				12.25			
VIII	110.0	N	121.0	111.0	N	123.5	10.40 12.00	10.00		25°
Long OAL:		**529.0**	**Tenons N,S:**		**26.2**	**43.0**	E-W	N-S	U/C	Chimney
IX	450.0	N end	440.0				9.8	9.9	very undercut tangent to bore	0
X	279.5	N end	271.5				8.3	8.0	20°E&W 10°N&S	
XI	72.8	N end	83.3				10.5	10.5	very undercut tangent to bore	0
Bell OAL:		**281.0**								
Total Bore Length:			**1939.4**	= top of wing to plug face + plug face to top of bell.						
Standing Height:			**1138.8**	= bottom of boot to top of bell.						

NOTES: OAL = over all length (total length)
Angles are measured from perpindicular. They are in conventional directions unless otherwise stated.
"Calliper min" is the internal diameter measured with callipers as deep as possible.
"Rods" are plastic rods in 0.2mm increments of diameter used to test hole diameter.
The largest size to fit through is recorded.

J.W. Kenigsperger   Händelhaus Halle, MS-435




Bore profiles
J.W. Kenigsperger
Händelhaus, Halle, MS-435
Long Joint
Bell
Boot Joint
Wing Joint
Diameter
Distance
XI
X
IX
VIII
VII
VI
V
IV
III
II
I
Transverse axis
Tonehole axis
Bell: quarter
Toneholes
Joint ends
Boot window
0
100
200
300
400
500
600
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
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32
33
34
35
36

J.W. Kenigsperger, MS-435
Händelhaus, Halle

	Distance						Diameter			Angle
	Outside			Inside			Surface	Inside		
	d1	from end	d2	d1	from end	d2	E-W N-S	calliper min	rods etc	from perpindicular
Wing OAL:		**462.0**		**Tenon:**	**39.0**					°
I	265.0	S	270.5	268.5	S	274.0	4.95 7.1	4.1	>3.7, <4.0	11°N
II	235.0	S	241.5	237.0	S	241.5	5.8 6.8	4.4	4.0 tight	4°S
III	201.0	S	207.0	198.0	S	203.5	5.3 6.3	4.1	>3.7, <4.0	8.5°S
Boot OAL:		**402.0**	Septum hole North edge:				**358.0**	South edge/Plug face:		**381.0**
IV	81.5	N	90.0	76.0	N	88.5	8.00 9.25	7.60		12°N
V	113.5	N	120.5	115.5	N	121.5	6.75 7.20	6.00	5.6 tight	3.5°S
VI	148.5	N	156.0	156.0	N	161.5	6.30 8.10	5.75	>5.0, <5.2	23°S
Ab										
VII	295.0	N	305.0	296.0	N	306.5	9.30 10.20			
VIII	111.5	N	121.5	115.5	N	126.5	8.90 10.25	8.15		17°S
Long OAL:		**523.0**	**Tenons N,S:**		**27.0**	**39.0**	E-W	N-S	U/C	Chimney
IX	387.5	N end	377.5				9.5	10.3	25° all round	4.5
X	215.5	N end	207.5				7.9	7.8	26° E&W 20° N&S	1.5
XI	70.5	N end	80.5				10.7	10.5	32° all round	4.0
Bell OAL:		**284.0**								
Total Bore Length:			**1926.0**		= top of wing to plug face + plug face to top of bell.					
Standing Height:			**1143.0**		= bottom of boot to top of bell.					
NOTES:		OAL = over all length (total length)								
		Angles are measured from perpindicular. They are in conventional directions unless otherwise stated.								
		"Calliper min" is the internal diameter measured with callipers as deep as possible.								
		"Rods" are plastic rods in 0.2mm increments of diameter used to test hole diameter.								
			The largest size to fit through is recorded.							

J.W. Kenigsperger, Grazzi Collection

Bore profiles
J.W. Kenigsperger, Grazzi Collection
Long Joint
Boot Joint
Wing Joint
Crook
Bell
Diameter
Distance
XI
X
IX
VIII
VII
Ab
VI
V
IV
III
II
I
Transverse axis
Tonehole axis
Bell: quarter
Bell: slab
Toneholes
Joint ends
Boot window

J.W. Kenigsperger, Grazzi Collection

	Distance						Diameter			Angle
	Outside			Inside			Surface	Inside		
	d1	from end	d2	d1	from end	d2	E-W N-S	calliper min	rods etc	from perpindicular
Wing OAL:	**463.2**		**Tenon:**	**41.3**						°
							5.8		5.2->7	
I	266.0	S	273.0	271.0	S	276.5	6.9	5.4	5.0 loose	
							6.35		5.0->4	
II	233.5	S	241.0	236.0	S	241.0	7.6	4.7	4.8 loose	
							6.05		5.2->10	
III	196.0	S	204.0	191.0	S	196.0	7.6	5.3	5.0 tight	
Boot OAL:	**404.0**	Septum hole North edge:					**360.0**	South edge/Plug face:		**380.0**
IV	79.0	N	88.0	72.5	N	85.5	8.25	8.10		
							9.90			
V	116.0	N	123.0	118.0	N	123.5	6.25	5.75	5.6->2	
							6.90		5.4 smooth	
VI	154.0	N	160.5	162.0	N	166.5	5.90	5.40	5.2->2.5	
							6.75		5.0 through	
Ab	274.0	N	280.0	273.0	N	279.0	4.90	4.75		
	124.0	S	130.0				4.90			
VII	304.0	N	313.5	301.0	N	315.0			key not removed	
VIII	107.0	N	120.0	119.0	N	125.0	10.50	10.35	very undercut to W	
							12.30		a little to N&S	
Long OAL:	**522.5**	**Tenons N,S:**		**27.6**	**39.2**		E-W	N-S	U/C	Chimney
IX	453.5	N	444.5				9.5			
X	280.5	N	271.5				8.4	8.3		
XI	72.5	N	82.3				10.9			
Bell OAL:	**280.0**	**Crook OAL:**				**345.0**				
Total Bore Length:		**1917.7**	= top of wing to plug face + plug face to top of bell.							
Standing Height:		**1139.7**	= bottom of boot to top of bell.							
NOTES:		OAL = over all length (total length)								
		Angles are measured from perpindicular. They are in conventional directions unless otherwise stated.								
		"Calliper min" is the internal diameter measured with callipers as deep as possible.								
		"Rods" are plastic rods in 0.2mm increments of diameter used to test hole diameter.								
			The largest size to fit through is recorded.							

C. Schramme Tschechisches Museum für Musik, Prague

Bore Profiles
C. Schramme
Tschechisches Museum für Musik, Prague
Transverse axis
Tonehole axis
Bell: slab
Toneholes
Joint ends
Boot window
Bell
Long Joint
Boot Joint
Wing Joint
XI
X
IX
VIII
VII
VI
V
IV
III
II
I
Diameter
Distance

C. Schramme

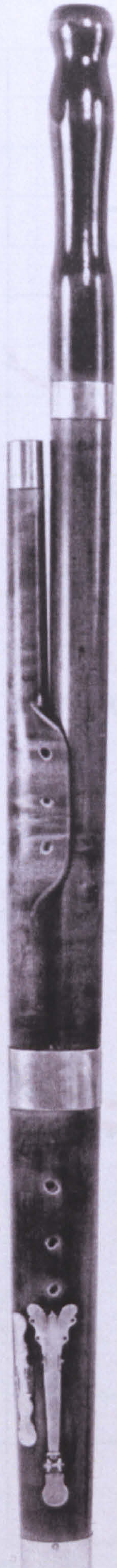
Tschechisches Museum für Musik, Prague

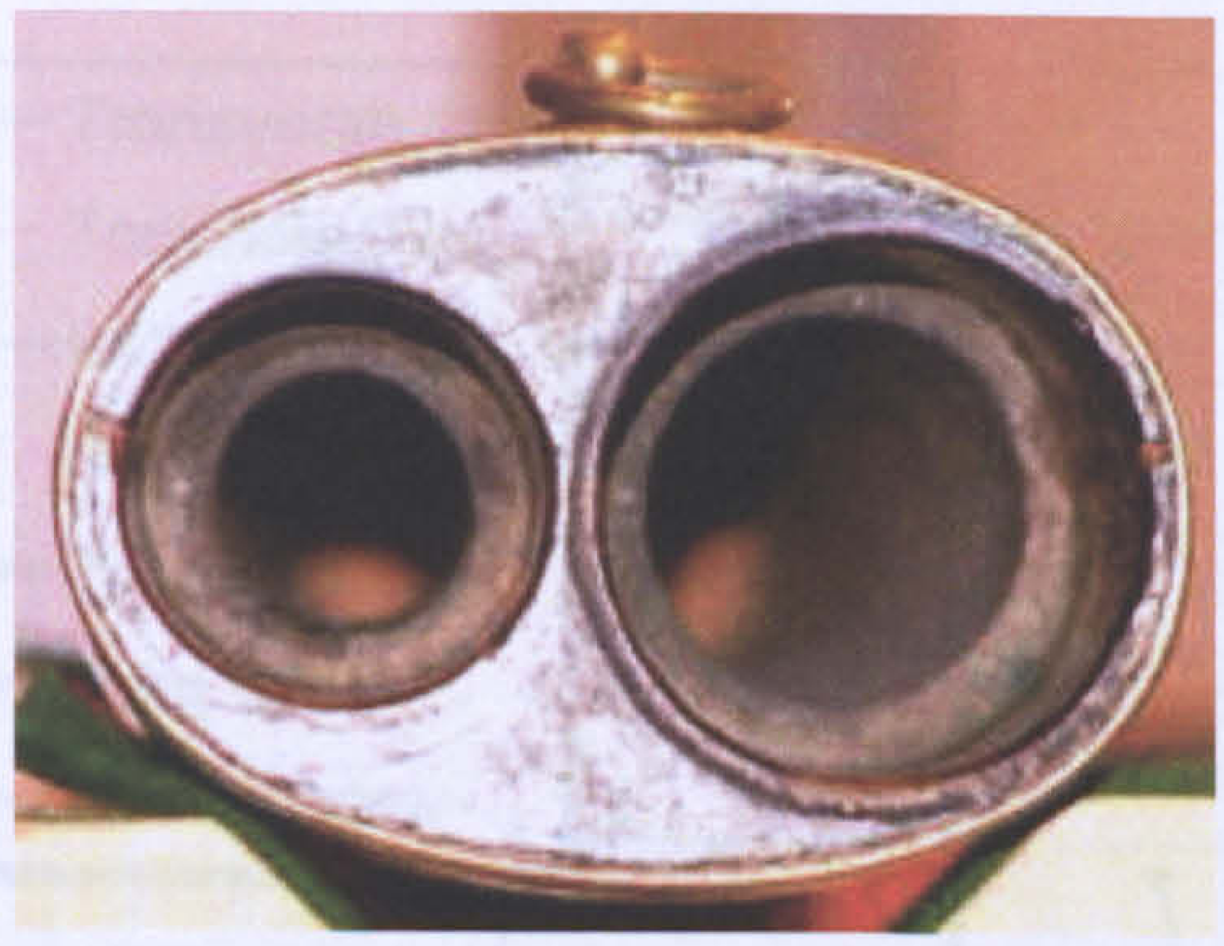
	Distance						Diameter			Angle
	Outside			Inside			Surface	Inside		
	d1	from end	d2	d1	from end	d2	E-W N-S	calliper min	rods etc	from perpindicular
Wing OAL:		460.0		Tenon:	38.0					°
I	196.0	N	204.0	264.5	S	269.5	6.95	6.0	5.0 tight	20°N
II	232.5	N	239.5	217.8	S	222.2	7.3	5.9	4.7 passes	10°S
III	268.0	N	275.0	181.2	S	184.8	6.3	5.8	4.0 tight	17°S
Boot OAL:		373.0	Septum hole North edge:				341.0	South edge/Plug face:		364.0
IV	77.5	N	84.5	74.0	N	80.0	6.8	6.3	5.4 tight	16°N
							8.8		undercut	
V	115.5	N	122.5	120.0	N	125.5	6.6	5.9	5.25 tight	14°S
							8.0		undercut	
VI	144.5	N	152.5	153.0	N	158.0	6.3	5.9	4.85 tight	26°S
							7.85		undercut	
Ab										
VII	293.7		302.0	295.5		302.0	8.0		9.5?	
							9.5		key not removed	
VIII	115.5		123.5	115.0		122.0	8.0		>7.0 <7.5	6°N (!)
							9.1			
Long OAL:		494.0	Tenons N,S:		22.8	37.0	E-W	N-S	U/C	Chimney
IX	54.6	S end	62.0				7.0		none	
X	224.0	S end	232.5				7.8-8.4	7.9-8.3	none	
XI	37.0	N end	46.3				9.1		none	
Bell OAL:		239.0								
Total Bore Length:			1823.2		= top of wing to plug face + plug face to top of bell.					
Standing Height:			1046.2		= bottom of boot to top of bell.					

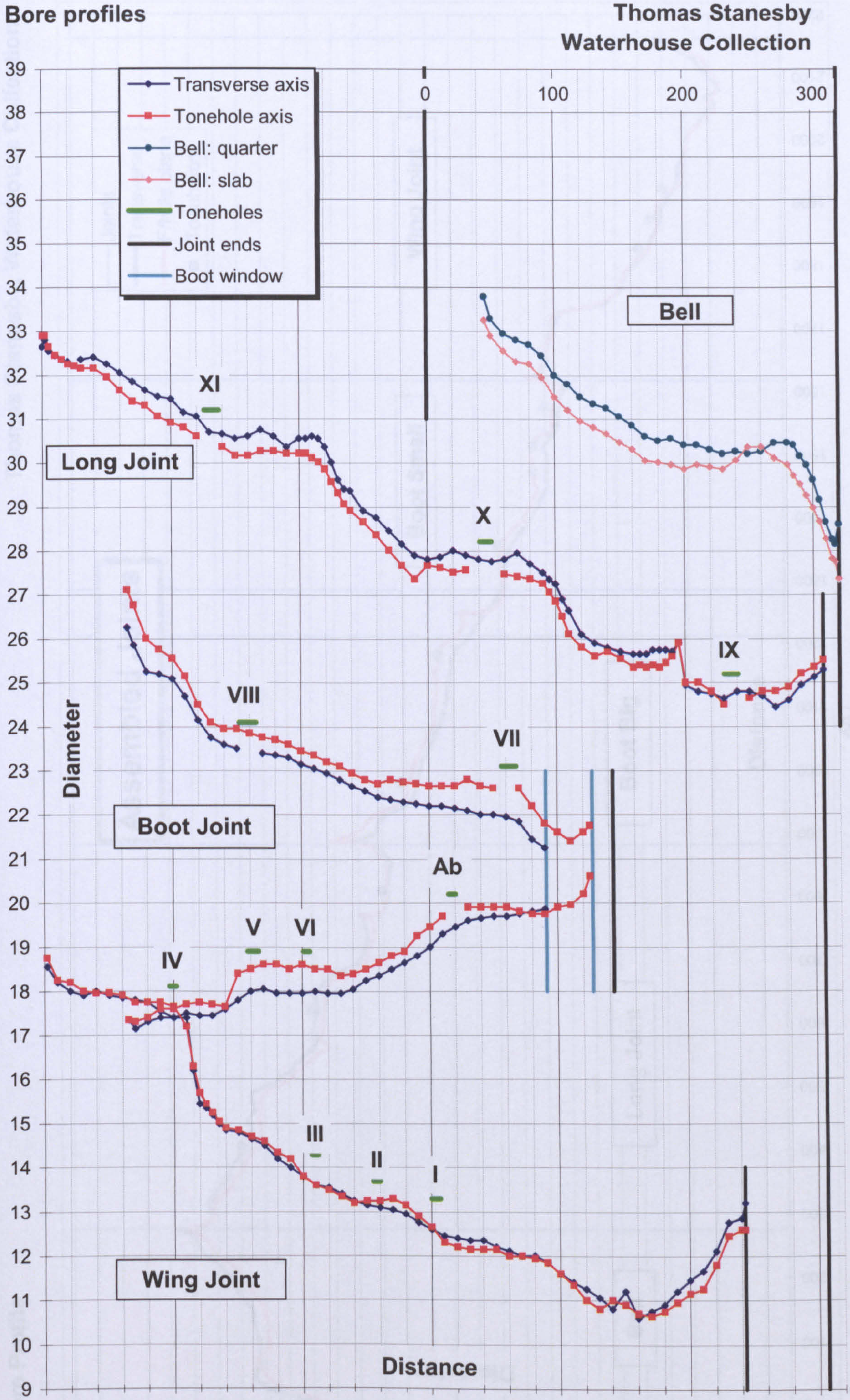
NOTES: OAL = over all length (total length)
Angles are measured from perpindicular. They are in conventional directions unless otherwise stated.
"Calliper min" is the internal diameter measured with callipers as deep as possible.
"Rods" are plastic rods in 0.2mm increments of diameter used to test hole diameter.
The largest size to fit through is recorded.

Thomas Stanesby

Waterhouse Collection






Bore profiles
Thomas Stanesby
Waterhouse Collection
Transverse axis
Tonehole axis
Bell: quarter
Bell: slab
Toneholes
Joint ends
Boot window
Bell
Long Joint
Boot Joint
Wing Joint
XI
X
IX
VIII
VII
VI
V
IV
III
II
I
Ab
Diameter
Distance
0
100
200
300
400
500
600
39
38
37
36
35
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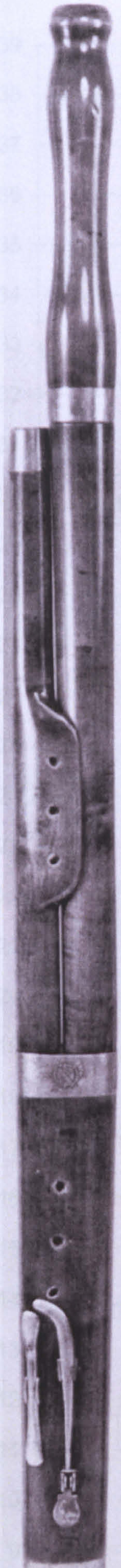
10
9

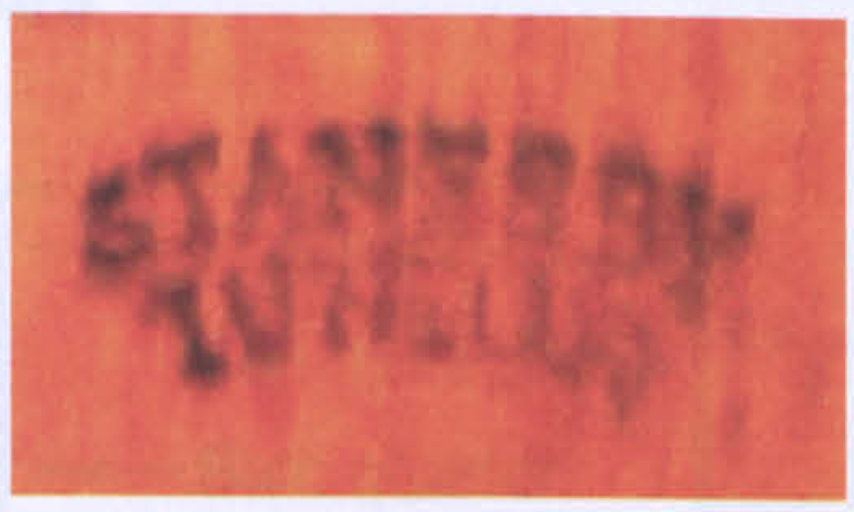
Bore Profile
Thomas Stanesby, Waterhouse Collection
Assembled Joints
Joints
Transverse
F/hole plane
Toneholes
Diameter
Distance
Bell
Long Joint
Boot Big
Boot Small
Wing Joint

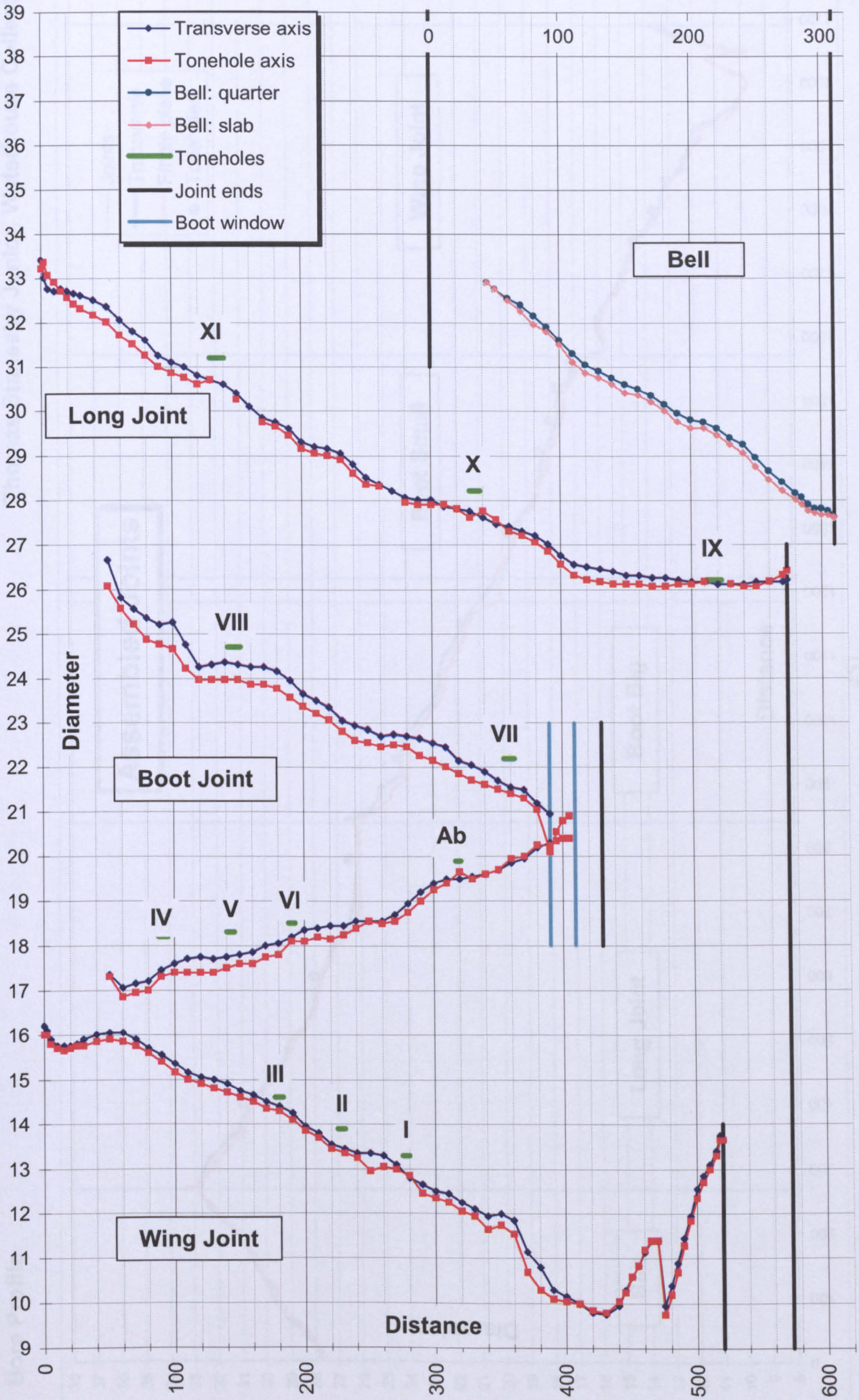
	Distance						**Diameter**			**Angle**
	Outside			**Inside**			**Surface**	**Inside**		
	d1	from end	d2	d1	from end	d2	E-W N-S	calliper min	rods etc	from perpindicular
Wing OAL:		**543.0**		**Tenon:**	**58.0**					°
I	293.5	S	301.0	300.5	S	307.0	5.75 7.8	5.7	5.4 tight	20.5°N
II	256.0	S	261.2	255.0	S	260.0	5.2 6.4	5.2	5.0 just through brass liner	1°S
III	218.0	S	226.0	207.0	S	212.0	5.8 7.95	5.4	5.0	31°S
Boot OAL:		**443.0**	Septum hole Nth edge:				**391.0**	Sth edge/Plug face:		**427.0**
IV	105.5	N	114.5	97.0	N	102.0	7.65 9.80	7.50		23°N
V	151.0	N	159.0	158.0	N	166.0	7.05 8.60	6.95	6.8 just through	19°S
VI	190.0	N	197.5	201.0	N	206.0	6.15 8.00	5.75	5.2 loose	28°S
Ab	316.5	N	321.0	315.0	N	320.0	4.05 4.35	3.90		0°
VII	359.0	N	368.0	357.0	N	368.0	8.45 9.65	8.30		0°
VIII	152.0	N	162.5	152.0	N	165.0	9.90 11.55	9.50	very undercut to W a little to N&S	0°
Long OAL:		**607.0**	**Tenons N,S:**		**45.0**	**60.0**	E-W	N-S	U/C	Chimney
IX	76.5	S end	66.0				10.7	10.4	10° all round	2.0
X	266.0	S end	257.0				9.0	9.4	15-20° all round	4.5
XI	126.0	N end	137.0				11.0	11.1	15°E&W	4.5
Bell OAL:		**320.0**								
Total Bore Length:			**2161.0**		= top of wing to plug face + plug face to top of bell.					
Standing Height:			**1265.0**		= bottom of boot to top of bell.					
NOTES:		OAL = over all length (total length)								
		Angles are measured from perpindicular. They are in conventional directions unless otherwise stated.								
		"Calliper min" is the internal diameter measured with callipers as deep as possible.								
		"Rods" are plastic rods in 0.2mm increments of diameter used to test hole diameter.								
			The largest size to fit through is recorded.							

Stanesby Junior

Waterhouse Collection






Transverse axis
Tonehole axis
Bell: quarter
Bell: slab
Toneholes
Joint ends
Boot window
Bell
Long Joint
Boot Joint
Wing Joint
XI
X
IX
VIII
VII
Ab
IV
V
VI
III
II
I
Diameter
Distance
0
100
200
300
400
500
600
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Bore Profile
Thomas Stanesby Junior, Waterhouse Collection
Assembled Joints
Joints
Transverse
F/hole plane
Toneholes
Bell
Long Joint
Boot Big
Boot Small
Wing Joint
Diameter
Distance
38
37
36
35
34
33
32
31
30
29
28
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22
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12
11
10
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8
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200

	Distance						**Diameter**			**Angle**
	Outside			**Inside**			**Surface**	**Inside**		
	d1	from end	d2	d1	from end	d2	E-W N-S	calliper min	rods etc	from perpindicular
Wing OAL:		**520.0**		**Tenon:**	**42.0**					°
							5.35		5.0 through tight	
I	263.0	S	270.0	275.0	S	280.0	8.85	4.90	5.2->1	27.5°N
							5.7		5.4->19	
II	226.0	S	232.5	225.0	S	230.5	7.7	5.65	5.2 through	3°S
							5.8		5.4->3.5	
III	186.5	S	193.5	177.0	S	183.0	7.9	5.30	5.2 through	28°S
Boot OAL:		**430.0**	Septum hole North edge:				**395.0**	South edge/Plug face:		**404.0**
IV	97.5	N	107.0	88.0	N	95.0	6.95	6.45	6.6 not in	31°N
							10.60		6.4 through loose	
V	141.0	N	148.0	140.5	N	146.0	6.45	6.30	6.2->4	6°N (!)
							9.35		6.0 through tight	
VI	182.0	N	188.0	188.0	N	193.0	5.35	5.05	5.0->3.5	20°S
							7.40		4.8 loose	
Ab	316.0	N	321.0	317.0	N	321.0	4.20	4.15		6°S
VII	354.0	N	363.0	355.0	N	363.0	8.55	8.35		0°
							10.80			
VIII	140.0	N	150.5	142.0	N	152.0	10.20	9.05		4°S
							16.60			
Long OAL:		**573.0**	**Tenons N,S:**		**43.0**	**46.0**	E-W	N-S	U/C	Chimney
IX	50.0	S end	61.0				9.5	9.4	over and under a little all round	4.0
X	235.0	S end	243.0				7.9	7.9	ditto	3.0
XI	129.5	N end	140.5				11.1	11.2	23° all round	3.0
Bell OAL:		**310.0**								
Total Bore Length:			**2090.0**		= top of wing to plug face + plug face to top of bell.					
Standing Height:			**1224.0**		= bottom of boot to top of bell.					

NOTES:
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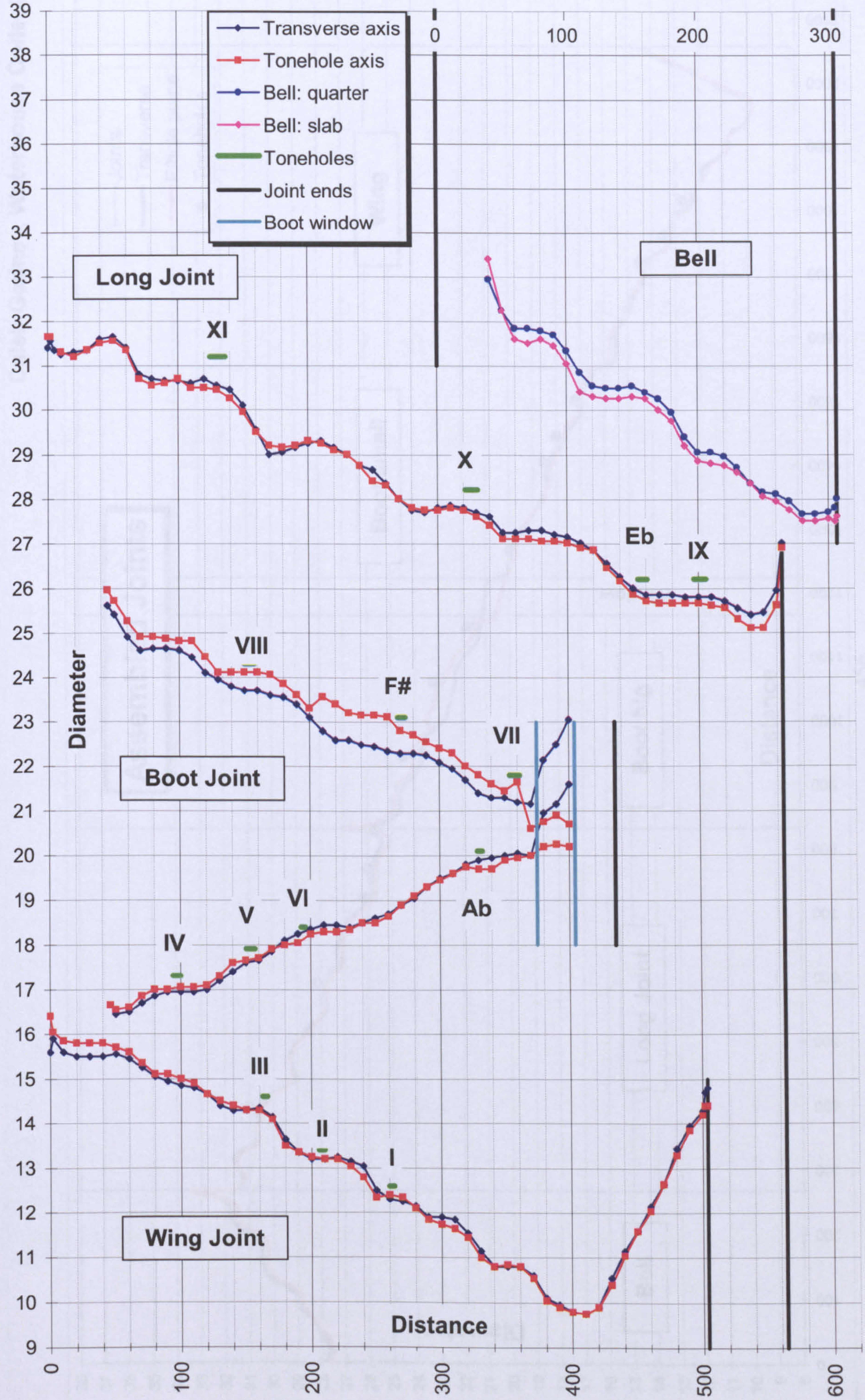
- "Calliper min" is the internal diameter measured with callipers as deep as possible.
- "Rods" are plastic rods in 0.2mm increments of diameter used to test hole diameter.
- The largest size to fit through is recorded.


Thomas Stanesby and Stanesby Junior
Waterhouse Collection
Stanesby Junior
Toneholes S. Jnr
Window S. Jnr
Joint ends S. Jnr
Th. Stanesby
Toneholes T.S.
Window T.S.
Joint ends T.S.
Bell
Long Joint
Boot Joint
Wing Joint
XI
X
IX
VIII
VII
Ab
IV
V
VI
III
II
I
Diameter
Distance
39
38
37
36
35
34
33
32
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
0
100
200
300
400
500
600
0
100
200
300

Caleb Gedney, Waterhouse Collection


Transverse axis
Tonehole axis
Bell: quarter
Bell: slab
Toneholes
Joint ends
Boot window
Long Joint
Bell
Boot Joint
Wing Joint
XI
X
Eb
IX
VIII
F#
VII
VI
V
IV
Ab
III
II
I
Diameter
Distance
0
100
200
300
400
500
600

Caleb Gedney, Waterhouse Collection

	Distance						Diameter			Angle
	Outside			Inside			Surface	Inside		
	d1	from end	d2	d1	from end	d2	E-W N-S	calliper min	rods etc	from perpindicular
Wing OAL:	**504.0**		**Tenon:**	**45.0**						°
I	253.0	S	258.5	260.0	S	263.5	4.5 6.1	4.3	4.3->6.0 3.9 tight	21°N
II	212.5	S	219.5	206.0	S	210.0	5.5 7.25	5.4	5.2->3, 5.0->18 4.8 loose	20°S
III	175.5	S	183.5	162.5	S	166.0	5.35 7.8	5.1	4.8->3, 4.4 loose 4.6 tight to 18	39°S
Boot OAL:	**435.0**	Septum hole North edge:					**375.0**	South edge/Plug face:		**404.0**
IV	99.5	N	103.0	94.0	N	100.0	6.50	6.10	6.0->11, 5.8->11	26°N
							9.00		5.6->13, 5.4 through	
V	140.5	N	149.0	150.5	N	157.0	6.60	6.40	62.->1, 6.0->6	29°S
							9.00		5.8 loose	
VI	180.0	N	188.0	192.5	N	196.0	5.85	5.30	5.4->1.5, 5.2->12.5	29.5°S
							8.15		5.0->15.5, 4.8 through	
Ab	322.5	N	328.5	329.0	N	333.0	4.90	4.60	4.6->3	33°S
							5.70		rough, sharp edges at bore	
VII	354.0	N	363.5	354.0	N	362.0	8.30	8.20	some glue or similar	19.5°S
							12.50		retuning?	
VIII	143.0	N	153.5	149.5	N	158.0	8.85	7.85		20°S
							11.50			
F#	266.0	N	273.0	268.0	N	274.0	6.20	6.00	6.0 just in 5.8 smooth through	7°S
Long OAL:	**564.0**	**Tenons N,S:**		**38.5**	**41.0**		E-W	N-S	U/C	Chimney
IX	506.0	N	497.0				8.9	8.9	27°S concave 0°N	0.0
Eb	454.0	N	461.0				6.3	6.1	no u/c, rough	
X	321.5	N	331.0				8.9	8.6	a very little all round	5.0
XI	124.5	N	136.5				11.4	11.4	not really; messy!	
Bell OAL:	**306.5**									
Total Bore Length:		**2058.0**		= top of wing to plug face + plug face to top of bell.						
Standing Height:		**1226.0**		= bottom of boot to top of bell.						

NOTES:

OAL = over all length (total length)

Angles are measured from perpindicular. They are in conventional directions unless otherwise stated.

"Calliper min" is the internal diameter measured with callipers as deep as possible.

"Rods" are plastic rods in 0.2mm increments of diameter used to test hole diameter.

The largest size to fit through is recorded.

Caleb Gedney, Horniman Museum

Bore profiles
Caleb Gedney
Horniman Museum
Transverse axis
Tonehole axis
Bell: quarter
Bell: slab
Toneholes
Joint ends
Boot window
Long Joint
Bell
Boot Joint
Wing Joint
Diameter
Distance
XI
X
IX
VIII
VII
VI
V
IV
III
II
I
Ab

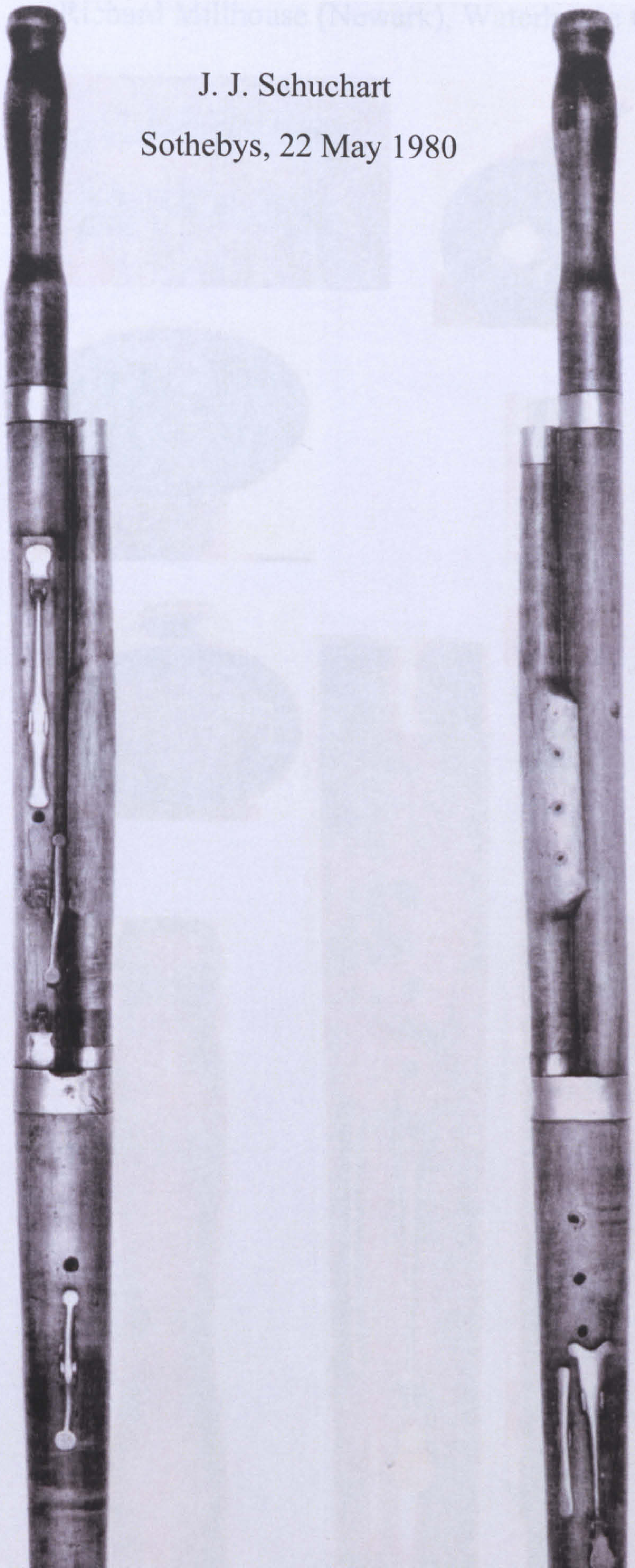
Caleb Gedney, Horniman Museum

	Distance						Diameter			Angle
	Outside			Inside			Surface	Inside		
	d1	from end	d2	d1	from end	d2	E-W N-S	calliper min	rods etc	from perpindicular
Wing OAL:		519.0		Tenon:	50.0					°
I	281.0	S	287.5	298.0	S	303.0	3.7 7.0	3.6	3.2->21	43°N
II	238.0	S	245.0	227.0	S	234.0	5.9 8.0	5.6	5.4->7.5 5.2 through	26°S
III	199.0	S	205.0	187.5	S	194.0	5.0 6.6	4.4	4.4->1 4.2 through	26°S
Boot OAL:		431.0		Septum hole Nth edge:			381.0		Sth edge/Plug face:	402.0
IV	100.0	N	107.5	91.0	N	97.5	7.00 9.50	5.90	6.2->6, 6.0->6 5.8 through	25°N
V	141.0	N	150.5	154.0	N	159.5	7.00 9.00	6.20	5.4->12, 5.2->20 5.0 through	33°S
VI	182.5	N	190.0	194.0	N	199.5	5.60 8.40	4.80	4.8->1 4.6 through	34°S
Ab	320.5	N	326.5	332.0	N	335.5	4.60 6.00	4.00		38°S
VII	58.5	N	77.5	355.0	N	361.0	10.40 7.90	7.30	6.8 through	5°S
VIII	141.0	N	153.0	151.0	N	157.0	8.50 12.40	7.70		29°S
Long OAL:		573.0		Tenons N,S:	41.0	52.0	E-W	N-S	U/C	Chimney
IX	506.0	N end	515.0				9.2	8.9		
X	322.0	N end	331.5				8.7	8.8	none	
XI	126.5	N end	136.5				8.8 9.1	8.5 9.7	none overcut	
Bell OAL:		311.0								
Total Bore Length:			2064.0	= top of wing to plug face + plug face to top of bell.						
Standing Height:			1222.0	= bottom of boot to top of bell.						

NOTES:
OAL = over all length (total length)
Angles are measured from perpindicular. They are in conventional directions unless otherwise stated.
"Calliper min" is the internal diameter measured with callipers as deep as possible.
"Rods" are plastic rods in 0.2mm increments of diameter used to test hole diameter.
The largest size to fit through is recorded.

J. J. Schuchart

Sothebys, 22 May 1980



Richard Millhouse (Newark), Waterhouse Collection

Bore profiles
Richard Millhouse (Newark)
Waterhouse Collection
Transverse axis
Tonehole axis
Bell: quarter
Bell: slab
Toneholes
Joint ends
Boot window
Bell
Long Joint
Boot Joint
Wing Joint
Diameter
Distance
XI
X
IX
VIII
VII
Ab
VI
V
IV
III
II
I

Richard Millhouse (Newark), Waterhouse collection

	Distance						Diameter			Angle
	Outside			Inside			Surface	Inside		
	d1	from end	d2	d1	from end	d2	E-W N-S	calliper min	rods etc	from perpindicular
Wing OAL:	**543.0**			**Tenon:**	**52.6**					°
I	282.0	S	289.5	295.0	S	300.0	6.6 8.6	6.2	5.8->6.5, 5.6->8 5.2 tight	30°N
II	242.0	S	250.0	232.0	S	238.0	6.1 8.85	6.0	5.4->2 35.2 tight	31°S
III	202.5	S	209.5	190.0	S	196.0	5.1 8.2	5.1	5.0->2 4.8 loose	35°S
Boot OAL:	**440.0**		Septum hole Nth edge:				**399.0**	South edge/Plug face:		**410.0**
IV	104.5	N	115.0	88.0	N	99.0	8.6	8.4		32°N
							13.1			
V	147.5	N	156.5	158.0	N	167.0	8.1	7.9		20°S
							10.3			
VI	184.0	N	192.0	195.5	N	201.5	6.6	6.15	5.8->8	25°S
							8.8		5.6 loose	
Ab	316.0	N	311.0	310.0	N	304.5	4.75	4.65		0°
							4.5			
VII	369.5	N	360.0	359.0	N	369.0	8.8	8.8		0°
							10.2			
VIII	151.0	N	163.0	166.0	N	178.5	10.2	10.0	very undercut to W	33.5°S
							13.2		a little to N&S	
Long OAL:	**598.0**		**Tenons N,S:**		**49.0**	**50.0**	E-W	N-S	U/C	Chimney
IX	542.5	N	532.2				9.2	9.7	key not removed	
X	349.5	N	340.5				9.2	9.2	moderate	
XI	133.5	N	144.0				10.9	11.1	key not removed	
Bell OAL:	**314.0**									
Total Bore Length:			**2123.4**	= top of wing to plug face + plug face to top of bell.						
Standing Height:			**1253.0**	= bottom of boot to top of bell.						

NOTES:
OAL = over all length (total length)
Angles are measured from perpindicular. They are in conventional directions unless otherwise stated.
"Calliper min" is the internal diameter measured with callipers as deep as possible.
"Rods" are plastic rods in 0.2mm increments of diameter used to test hole diameter.
The largest size to fit through is recorded.

Thomas Cahusac Senior

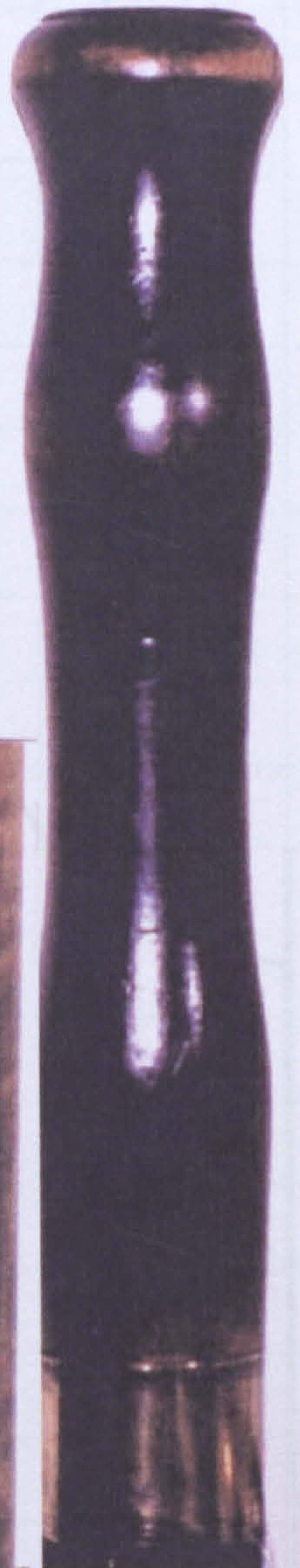
Bate Collection, Oxford


Bore profiles
Thomas Cahusac Senior
Bate Collection, Oxford
Min
Max
Bell min
Bell max
Toneholes
Joint ends
Boot window
Bell
Long Joint
Boot Joint
Wing Joint
XI
X
IX
III
II
I
Diameter
Distance


Thomas Cahusac Senior, Bate Collection, Oxford
Assembled Joints
Joints
Horizontal
Vertical
Toneholes
Diameter
Distance
Bell
Long Joint
Boot up bore
Window
Boot down bore
Wing

	Distance						Diameter			Angle
	Outside			Inside			Surface	Inside		
	d1	from end	d2	d1	from end	d2	E-W N-S	calliper min	rods etc	from perpindicular
Wing OAL:		524.5		Tenon:	53.7					°
I	236.7	S	240.8	309.5	S	313.6	4.1	4.1		33.5°N
II	197.3	S	201.4	246.3	S	252.4	4.1	6.1		12.5°S
III	155.5	S	159.5	201.0	S	206.0	4.0	5.0		18°S
Boot OAL:		439.0	Septum hole North edge:				391.0	South edge/Plug face:		412.0
IV	104.8	N	112.5				7.70	6.50		49°N
V	151.5	N	158.3				6.80	6.25		35°S
VI	190.5	N	196.0				5.50	4.80		57.5°S
Ab	319.3	N	323.6				4.25	3.25		17.5°S
VII	364.5	N	371.9				7.35	6.40		28°S
VIII	156.2	N	165.6				9.40	8.70	u/c	40°S
Long OAL:		594.4	Tenons N,S:		46.5	49.4	E-W	N-S	U/C	Chimney
IX	76.5	S end	66.0				8.5	8.3	to 13.5x12	
X	266.0	N end	257.0				8.8	8.6		
XI	126.0	N end	137.0				10.8	10.9	to10.3x11	
Bell OAL:		321.5								
Total Bore Length:			2114.8	= top of wing to plug face + plug face to top of bell.						
Standing Height:			1259.0	= bottom of boot to top of bell.						
NOTES:		OAL = over all length (total length)								
		Angles are measured from perpindicular. They are in conventional directions unless otherwise stated.								
		"Calliper min" is the internal diameter measured with callipers as deep as possible.								
		"Rods" are plastic rods in 0.2mm increments of diameter used to test hole diameter.								
			The largest size to fit through is recorded.							

Charles Bizey, Private Collection




Bore profiles
Measurements courtesy of O. Cottet
Charles Bizey
Private collection
Max
Bell
Joint ends
Boot window
Bell
Long Joint
Boot Joint
Wing Joint
Diameter
Distance

Measurements courtesy of O. Cottet

Charles Bizey, Private Collection

	Distance						Diameter			Angle
	Outside			Inside			Surface	Inside		
	d1	from end		d1	from end	d2	E-W N-S	calliper min	rods etc	from perpindicular
Wing OAL:		**521.7**		**Tenon:**	**45.7**					°
I	260.0	N						4.7		45°
II	305.0	N					5.6	5.5		
III	345.0	N					5.6	4.9		40°
Boot OAL:		**449.0**	Septum hole Nth edge:				**391.0**	Sth edge/Plug face:		**427.0**
IV	115.0	N								
V	153.0	N								
VI	193.0	N						5.2		
Ab	325.0	N						3.2		
VII	362.0	N						8.4		
VIII	158.0	N						8.4		
Long OAL:		**600.0**	**Tenons N,S:**		**50.0**	**52.0**	E-W	N-S	U/C	Chimney
IX	63.4	N					10.0	9.5		
X	336.0	N					8.2	8.0		
XI	479.3	N					11.2	11.5		
Bell OAL:		**327.5**								
Total Bore Length:			**2164.5**		= top of wing to plug face + plug face to top of bell.					
Standing Height:			**1274.5**		= bottom of boot to top of bell.					

NOTES: OAL = over all length (total length)

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The largest size to fit through is recorded.



DONDEINE








Bore profiles
Dondeine
Bate Collection, Oxford
Transverse axis
Tonehole axis
Bell: quarter
Bell: slab
Toneholes
Joint ends
Boot window
Bell
Long Joint
Boot Joint
Wing Joint
XI
X
IX
VIII
VII
IV
V
VI
Ab
III
II
I
Diameter
Distance

Dondeine, Bate Collection, Oxford
Assembled Joints
Joints
Transverse
F/hole plane
Toneholes
Diameter
Distance
Bell
Long Joint
Boot up bore
Window
Boot down bore
Wing

	Distance						Diameter			Angle
	Outside			Inside			Surface	Inside		
	d1	from end	d2	d1	from end	d2	E-W N-S	calliper min	rods etc	from perpindicular
Wing OAL:		**560.0**		**Tenon:**	**51.0**					°
I	307.5	S	316.0	322.0	S	327.0	6.5 9.5	5.9	5.8->13 5.6 tight	36°N
II	273.0	S	280.0	266.5	S	272.0	7.3 7.35	5.8	5.6->2 5.4 tight	19°S
III	232.5	S	240.2	220.0	S	224.5	6.45 7.9	5.95	5.4->12 5.2 loose	34.5°S
Boot OAL:		**444.0**	Septum hole Nth edge:				**388.0**	Sth edge/Plug face:		**428.0**
IV	110.0	N	121.0	98.0	N	113.0	7.65 9.80	8.30	u/c to N, S & E 43°N edge 29°S edge	37°N
V	150.5	N	159.0	157.0	N	165.0	7.05 8.60	6.90	a little u/c N&W	20°S
VI	191.0	N	198.0	202.0	N	206.0	6.15 8.00	5.25	5.0 smooth	32°S
Ab	325.0	N	330.0	325.0	N	329.0	4.05 4.35		key not removed	
VII	355.0	N	364.5	358.0	N	368.0	8.45 9.65	8.60	u/c a little N, S & E	24°S
VIII	145.0	N	154.5	149.0	N	159.0	9.90 11.55	8.15	a little N&W	22°S
Long OAL:		**607.5**	**Tenons N,S:**		**41.5**	**44.5**	E-W	N-S	U/C	Chimney
IX	536.5	N end	526.5				9.4	9.8		0
X	337.5	N end	327.5				9.5	9.4	16° all round	0
XI	85.0	N end	95.0				10.2	10.8	key not removed	
Bell OAL:		**344.0**								
Total Bore Length:			**2230.5**	= top of wing to plug face + plug face to top of bell.						
Standing Height:			**1309.5**	= bottom of boot to top of bell.						

NOTES:
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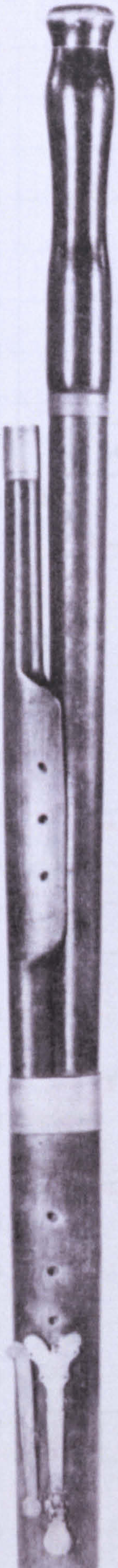
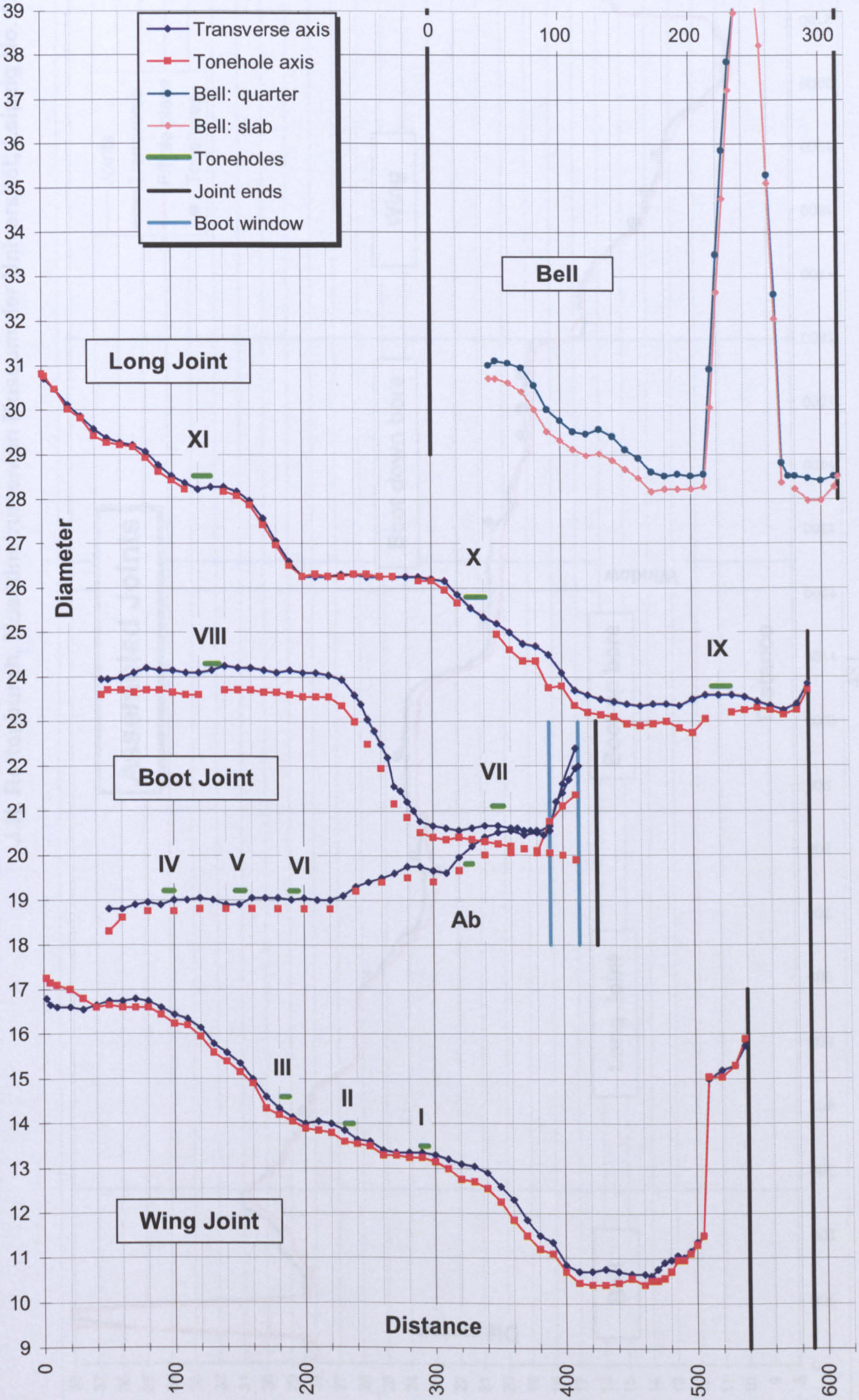
"Rods" are plastic rods in 0.2mm increments of diameter used to test hole diameter.
The largest size to fit through is recorded.

J.H. Rottenburgh, No. 1374

Musikinstrumenten Museum der Universität, Leipzig




Transverse axis
Tonehole axis
Bell: quarter
Bell: slab
Toneholes
Joint ends
Boot window
Bell
Long Joint
Boot Joint
Wing Joint
XI
X
IX
VIII
VII
IV
V
VI
Ab
III
II
I
Diameter
Distance
0
100
200
300
400
500
600


J.H. Rottenburgh, Musikinstrumenten Museum der Universität, Leipzig No. 1374
Assembled Joints
Joints
Transverse
F/hole plane
Toneholes
Diameter
Distance
Bell
Long Joint
Boot up bore
Window
Boot down bore
Wing
38
37
36
35
34
33
32
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200

	Distance						Diameter			Angle
	Outside			Inside			Surface	Inside		
	d1	from end	d2	d1	from end	d2	E-W N-S	calliper min	rods etc	from perpindicular
Wing OAL:		540.0		Tenon:	43.0					°
I	276.5	S	284.0	289.0	S	294.5	5.2 9.5	4.8	4.8 smooth fit	34°N
II	237.5	S	244.5	230.5	S	236.5	6.2 7.8	5.8	5.6 smooth	22°S
III	194.0	S	201.0	182.0	S	187.5	5.5 7.2	5.0	4.8 tight	34°S
Boot OAL:		426.0	Septum hole North edge:				390.0	South edge/Plug face:		412.0
IV	100.7	N	109.5	92.5	N	100.0	7.25 9.90	6.70	6.8 smooth	26°N
V	142.0	N	150.5	147.0	N	154.5	7.40 8.80	6.90	as IV	13°S
VI	180.5	N	188.0	189.0	N	195.5	6.70 8.50	5.90	5.6 loose	22°S
Ab	331.5	N	326.7	325.0	N	330.5	5.20 4.90		4.6 tight	0°
VII	346.0	N	347.2	346.0	N	354.5	10.40 8.90	8.70		0°
VIII	121.0	N	132.0	125.0	N	135.5	10.15 11.70	9.60		17°
Long OAL:		589.0	Tenons N,S:		42.5	43.5	E-W	N-S	U/C	Chimney
IX	515.0	N	529.0				11.9	12.2	10°N&S 15°E&W	4.0
X	327.0	N	341.5				11.0	11.0	u/c below brass tube	brass 3.2
XI	117.0	N	130.0	key not removed			12.1	12.1	very little	
Bell OAL:		313.0								
Total Bore Length:			2137.0		= top of wing to plug face + plug face to top of bell.					
Standing Height:			1242.0		= bottom of boot to top of bell.					

NOTES:
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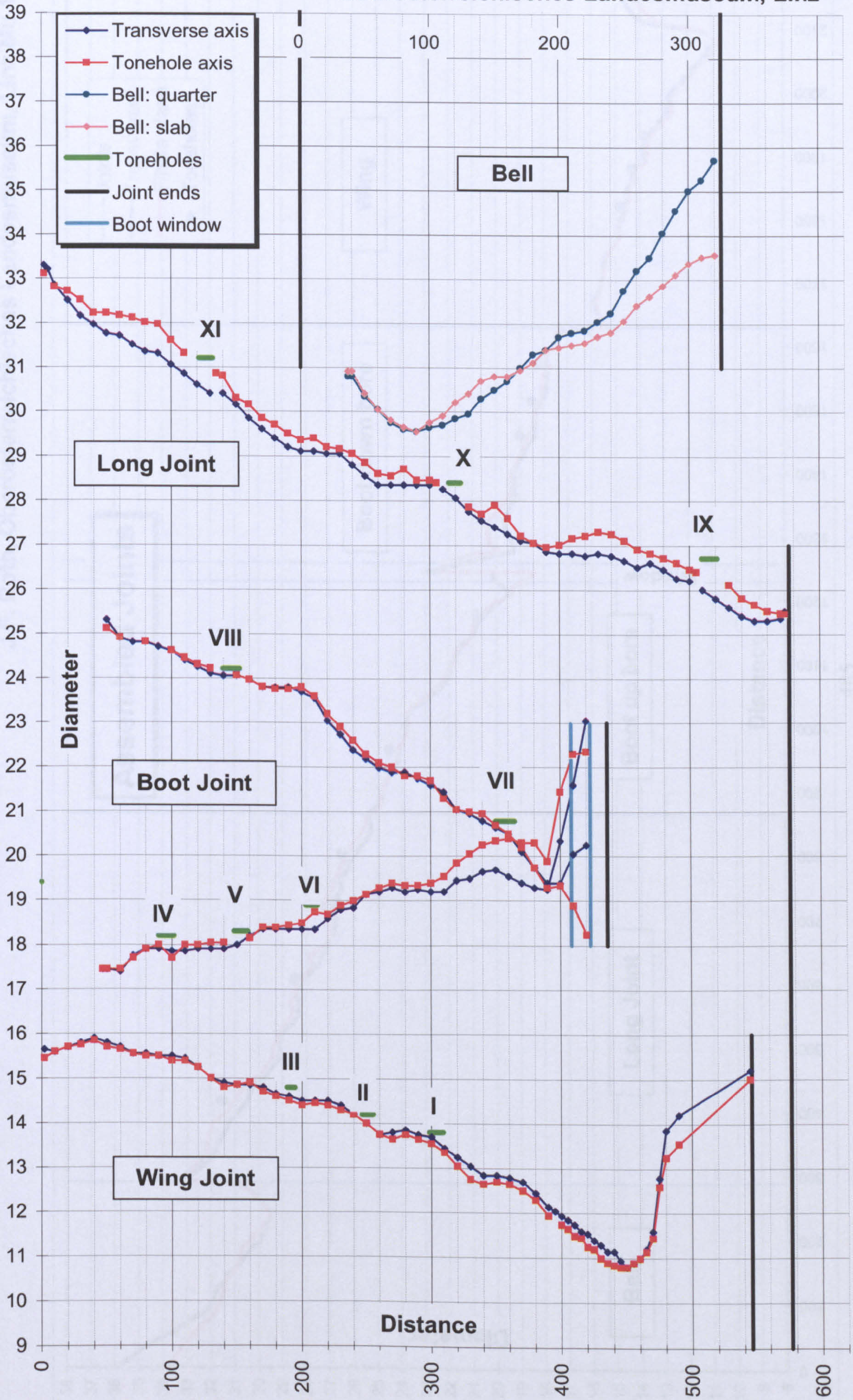
"Rods" are plastic rods in 0.2mm increments of diameter used to test hole diameter.
The largest size to fit through is recorded.

J.F. Roth, Mu 129

Oberösterreichisches Landesmuseum, Linz


Transverse axis
Tonehole axis
Bell: quarter
Bell: slab
Toneholes
Joint ends
Boot window
Bell
Long Joint
Boot Joint
Wing Joint
Diameter
Distance
XI
X
IX
VIII
VII
VI
V
IV
III
II
I


J.F. Roth, Oberösterreichisches Landesmuseum, Linz Mu 129
Assembled Joints
Joints
Transverse
F/hole plane
Toneholes
Diameter
Distance
Bell
Long Joint
Boot up bore
Window
Boot down bore
Wing

	Distance						Diameter			Angle
	Outside			Inside			Surface	Inside		
	d1	from end	d2	d1	from end	d2	E-W N-S	calliper min	rods etc	from perpindicular
Wing OAL:		**546.0**		**Tenon:**	**37.0**					°
I	286.5		295.0	298.5	S	309.0	6.45 9.9	5.7	5.6 U/C N,E&W	32°N
II	246.0		253.5	255.0	S	246.5	6.85 8.9	5.2	6.4 U/C N&E	3.5°N (!)
III	202.0		212.0	194.5	S	188.7	6.2 10.25	5.4	5.2 loose 5.4 ->6	38°S
Boot OAL:		**436.0**	Septum hole North edge:				**408.5**	South edge/Plug face:		**423.0**
IV	103.0	N	112.0	90.0	N	101.2	7.70 10.00	6.90	6.8	31°N
V	150.5	N	157.5	148.0	N	158.5	7.25 9.35	6.80	6.8 U/C all round	0°
VI	190.5	N	199.5	203.3	N	212.0	7.00 10.40	6.50	6.4 loose	32°S
Ab										
VII	85.5	N	76.0	350.0	N	364.7	9.60 9.70	9.70	8.5 min	10°S
VIII	138.0	N	148.0	139.7	N	152.0	9.80 10.60	10.60	8.75 min	17°S
Long OAL:		**576.5**	**Tenons N, S:**		**35.5**	**45.0**	E-W	N-S	U/C	Chimney
IX	76.5	S end	66.0				10.7	10.4	10° all round	2.0
X	266.0	S end	257.0				9.0	9.4	15-20° all round	4.5
XI	126.0	N end	137.0				11.0	11.1	15°E&W	4.5
Bell OAL:		**325.0**								
Total Bore Length:			**2176.0**		= top of wing to plug face + plug face to top of bell.					
Standing Height:			**1248.5**		= bottom of boot to top of bell.					

NOTES: OAL = over all length (total length)
Angles are measured from perpindicular. They are in conventional directions unless otherwise stated.
"Calliper min" is the internal diameter measured with callipers as deep as possible.
"Rods" are plastic rods in 0.2mm increments of diameter used to test hole diameter.
The largest size to fit through is recorded.

J.F. Roth, No. 1372

Musikinstrumenten Museum der Universität Leipzig

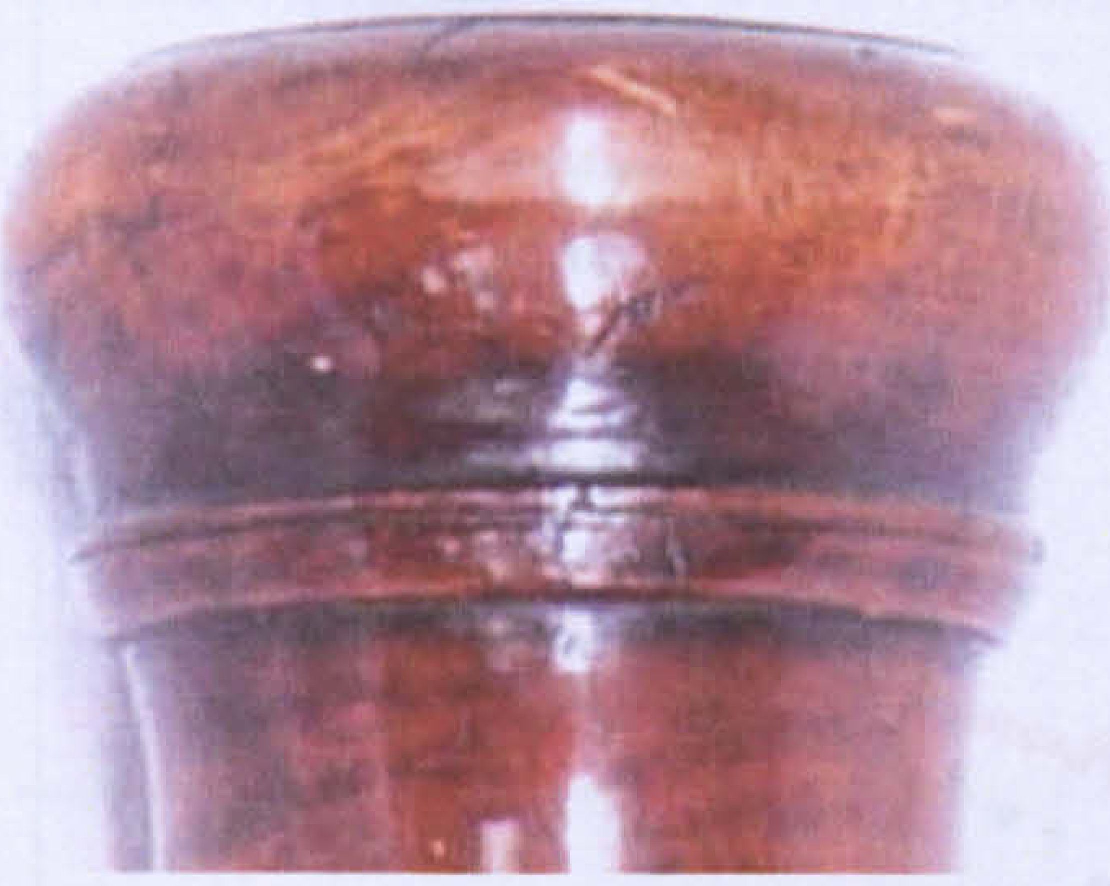

Bore profiles
J.F. Roth No.1372
Musikinstrumenten Museum der Universität Leipzig
Transverse axis
Tonehole axis
Bell: quarter
Toneholes
Joint ends
Boot window
Long Joint
Boot Joint
Wing Joint
Bell
Diameter
Distance
XI
X
IX
VIII
VII
VI
V
IV
III
II
I

J.F. Roth: Musikinstrumenten Museum der Universität Leipzig No. 1372

	Distance						Diameter			Angle
	Outside			Inside			Surface	Inside		
	d1	from end	d2	d1	from end	d2	E-W N-S	calliper min	rods etc	from perpindicular
Wing OAL:	**451.0**		**Tenon:**	**34.0**						
I	220.5	S	227.5	237.3	S	230.5	5.0 8.8	4.5		
II	260.5	S	267.0	191.5	S	186.5	5.3 8.0	4.5		
III	301.0	S	308.0	145.5	S	141.0	5.0 7.5	4.3		
Boot OAL:	**431.0**	Septum hole North edge:					**401.0**	South edge/Plug face:		**423.5**
IV	86.0	N	94.5	71.5	N	80.2		5.90		
V	121.0	N	133.0	127.5	N	134.5		5.95		
VI	163.5	N	172.5	180.7	N	187.5		5.20		
Ab										
VII	362.0	N	371.5	360.5	N	374.5			hole filled	
	original position								and altered	
VIII	203.0	N	212.5	203.7	N	214.0				
IX	91.5	n	99.7	90.7		101.5		7.50		
Long OAL:	**500.0**	**Tenons N,S:**		**20.0**	**36.0**	E-W	N-S	U/C	Chimney	
X	292.0	N end	306.5				10.1	10.3	very undercut	0.0
XI	54.0	N end	68.0							
Bell OAL:	**253.0**									
Total Bore Length:	**1961.0**	= top of wing to plug face + plug face to top of bell.								
Standing Height:	**1128.0**	= bottom of boot to top of bell.								

NOTES:
OAL = over all length (total length)
Angles are measured from perpindicular. They are in conventional directions unless otherwise stated.
"Calliper min" is the internal diameter measured with callipers as deep as possible.
"Rods" are plastic rods in 0.2mm increments of diameter used to test hole diameter.
The largest size to fit through is recorded.

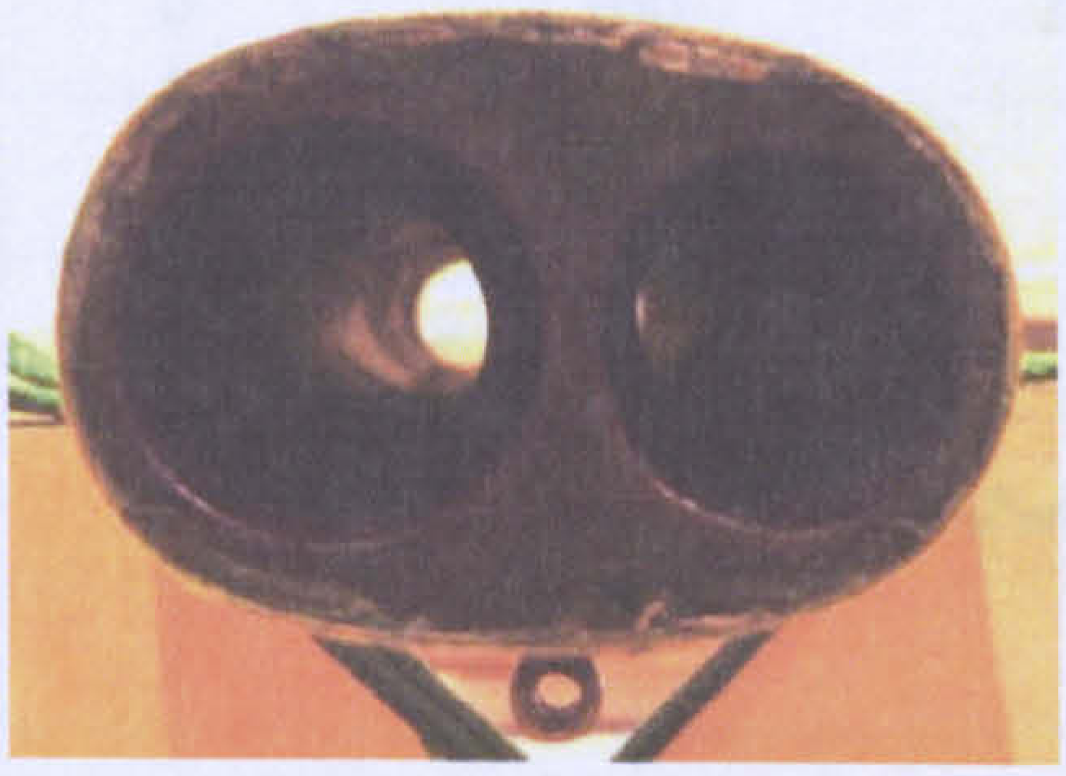
H. Wietfelt, Horniman Museum




Bore profiles
Harmen Wietfelt
Horniman Museum
Transverse axis
Tonehole axis
Bell: quarter
Bell: slab
Toneholes
Joint ends
Boot window
Bell
Long Joint
Boot Joint
Wing Joint
Diameter
Distance
XI
X
IX
VIII
VII
VI
V
IV
III
II
I
Ab

Harmen Wietfelt, Horniman Museum

	Distance						Diameter			Angle
	Outside			Inside			Surface	Inside		
	d1	from end	d2	d1	from end	d2	E-W N-S	calliper min	rods etc	from perpindicular
Wing OAL:		526.8		Tenon:	40.0					°
							6.0		5.4->3	
I	270.0	S	278.0	283.0	S	288.5	9.0	5.5	5.0 smooth fit	42°N
							6.55		5.8->3.5	
II	230.0	S	238.0	223.0	S	229.5	7.7	5.9	5.6->8, 5.4 loose	35°S
							6.2		5.2->4.5	
III	192.0	S	201.0	178.0	S	183.5	9.4	5.4	5->14, 4.8 loose	48°S
Boot OAL:		425.0		Septum hole Nth edge:			362.0	Sth edge/Plug face:		408.0
IV	101.0	N	111.0	91.0	N	98.5	7.6	7.4	7.0 smooth fit	29°N
							11.1			
V	141.5	N	150.0	145.0	N	152.5	8.1	7.7	7.0 tight	7°S
							10.3			
VI	180.0	N	188.0	189.0	N	192.5	6.7	6.4	6.2->4, 6.0->15 5.8 loose	15°S
							9.2			
Ab	94.6	N	102.0	326.5	N	333.5	5.7		key not removed	S
							6.9			
VII	70.5	N	79.0	347.0	N	355.5	9.5		key not removed	S
							9.5			
VIII	123.5	N	136.0	127.0	N	142.5	11.1	10.8	u/c: N, W&S	23°S
							12.8			
Long OAL:		589.0	Tenons N,S:		38.0	44.0	E-W	N-S	U/C	Chimney
IX	531.0	N	514.5				11.6	11.6	key not removed	
X	342.5	N	316.0				15.2	15.9	to tangent with bore	0.0
XI	123.0	N	135.0				16.3	16.6	key not removed	
Bell OAL:		303.0								
Total Bore Length:			2116.8		= top of wing to plug face + plug face to top of bell.					
Standing Height:			1235.0		= bottom of boot to top of bell.					
NOTES:		OAL = over all length (total length)								
		Angles are measured from perpindicular. They are in conventional directions unless otherwise stated.								
		"Calliper min" is the internal diameter measured with callipers as deep as possible.								
		"Rods" are plastic rods in 0.2mm increments of diameter used to test hole diameter.								
			The largest size to fit through is recorded.							

GOTTLIEB.
WIETFELT.






Bore profiles
Gottlieb Wietfelt
Waterhouse Collection
Bell
Long Joint
Boot Joint
Wing Joint
Crook
XI
X
IX
VIII
VII
IV
V
VI
Ab
III
II
I
Diameter
Distance
Transverse axis
Tonehole axis
Bell: quarter
Bell: slab
Toneholes
Joint ends
Boot window

Gottlieb Wietfelt, Waterhouse Collection

Gottlieb Wietfelt, Waterhouse Collection

	Distance						Diameter			Angle
	Outside			Inside			Surface	Inside		
	d1	from end	d2	d1	from end	d2	E-W N-S	calliper min	rods etc	from perpindicular
Wing OAL:		**550.0**		**Tenon:**	**37.5**					°
I	272.0	S	282.0	289.0	S	301.0	5.5 11.0	5.1	4.8->6, 4.6->9.5 4.2 tight	51°N
II	234.5	S	242.0	229.0	S	236.5	6.45 8.1	6.2	5.6->6, 5.4->15 5.2 smooth	14°S
III	197.0	S	208.0	175.0	S	182.5	6.0 11.0	5.5	5.2->5, 5->12 4.8 tight	52°S
Boot OAL:		**426.5**		Septum hole Nth edge:			**392.5**	Sth edge/Plug face:		**410.0**
IV	103.0	N	115.0	85.0	N	93.5	7.20 10.20	6.45	6.4->12 6.2->18 6.0 just touches	45°N
V	146.0	N	154.0	150.0	N	157.5	6.70 9.30	6.50	6.4->2 6.2 loose	12°S
VI	182.0	N	190.5	194.0	N	198.5	6.05 8.70	5.90	5.8->14, 5.6->19 5.4 v. loose	29°S
Ab	325.0	N	330.0	323.0	N	328.5	5.45 5.50	5.00	5.0->8 4.8 loose	6°N
VII	347.5	N	356.5	347.0	N	354.0	8.30 10.45	8.00		0°
VIII	122.0	N	132.5	126.0	N	136.5	9.00 10.60	8.65		12°S
Long OAL:		**611.0**	**Tenons N,S:**		**42.0**	**41.5**	E-W	N-S	U/C	Chimney
IX	553.0	N end	540.6				11.9	11.8	over and undercut, tangent to bore	6.4
X	363.0	N end	351.5				11.4	11.2	none	
XI	145.5	N end	156.5				10.6	10.5	over and undercut, tangent to bore	3.6
Bell OAL:		**324.0**		**Crook OAL:**		**335.0**				
Total Bore Length:			**2184.0**	= top of wing to plug face + plug face to top of bell.						
Standing Height:			**1278.0**	= bottom of boot to top of bell.						

NOTES: OAL = over all length (total length)
Angles are measured from perpindicular. They are in conventional directions unless otherwise stated.
"Calliper min" is the internal diameter measured with callipers as deep as possible.
"Rods" are plastic rods in 0.2mm increments of diameter used to test hole diameter.
The largest size to fit through is recorded.

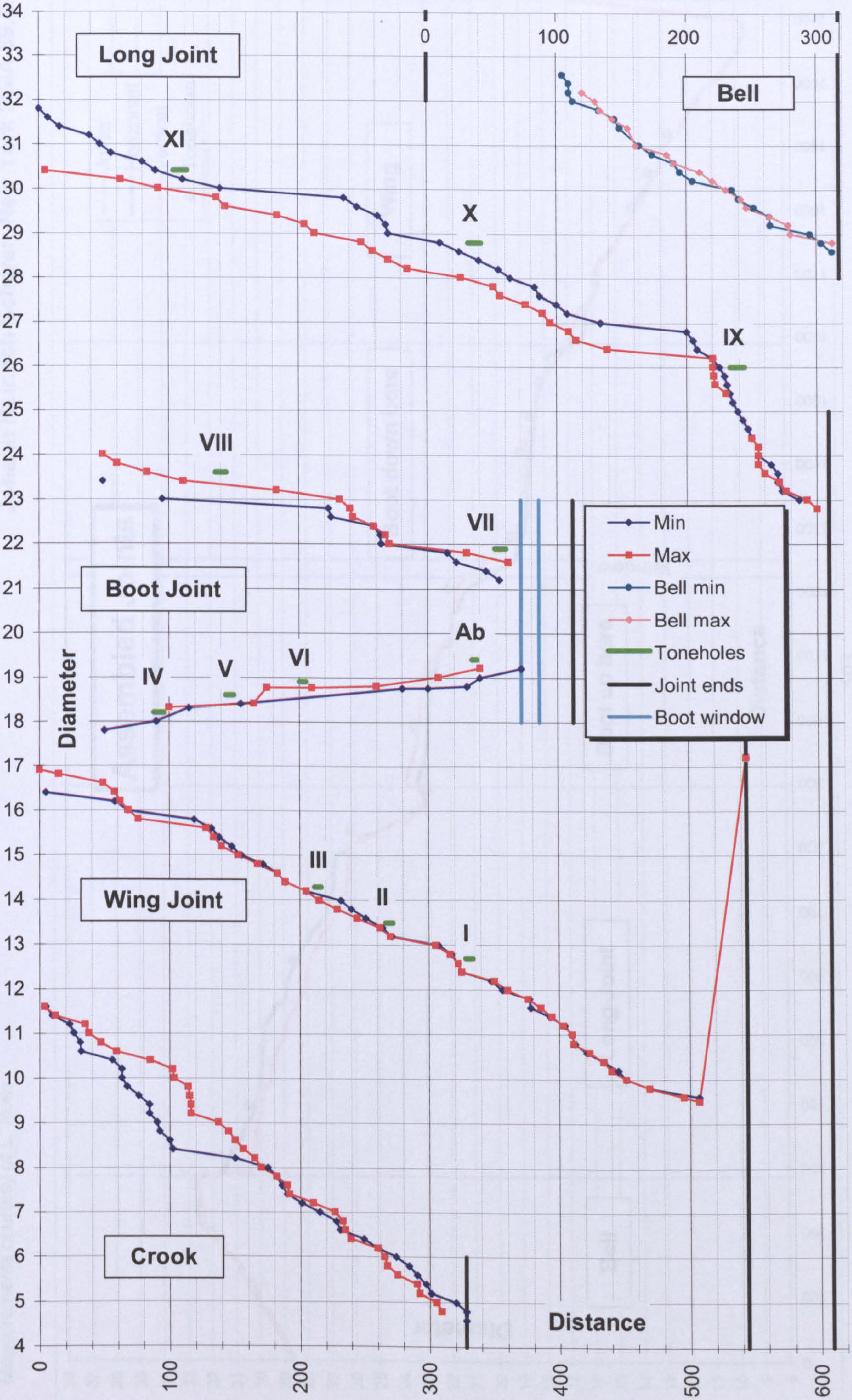

Bore profiles
Harmen and Gottlieb Wietfelt
Johann Scherer II, 89.4.886
Metropolitan Museum of Art New York
G. Wietfelt
Toneholes G.W.
Joint ends G.W.
Window G.W.
H. Wietfelt
Toneholes H.W.
Joint ends H.W.
Window H.W.
Bell
Long Joint
Boot Joint
Wing Joint
Diameter
Distance
XI
X
IX
VIII
VII
IV
V
VI
Ab
III
II
I

Johann Scherer II, 89.4.886

Metropolitan Museum of Art, New York

Bore profiles **Johann Heinrich Scherer**

Measurements courtesy of Leslie Ross **New York MMA 89.4.886**



Measurements courtesy of L. Ross

Johann Heinrich Scherer: New York MMA 89.4.886

Measurements courtesy of L. Ross
Johann Heinrich Scherer: New York MMA 89.4.886
Assembled Joints
Joints
Horizontal
Vertical
Toneholes
Diameter
Distance
Bell
Long joint
Boot big
Boot small
Wing
Crook
38
37
36
35
34
33
32
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
2500

Joint Lengths
Tone Hole Positions and Sizes
Measurements courtesy of L. Ross

Johann Heinrich Scherer
New York MMA 89.4.886

	Distance						Diameter			Angle
	Outside			Inside			Surface	Inside		
	centre	from end		centre	from end		E-W N-S	calliper min	rods etc	from perpindicular
Wing OAL:		**544.0**		**Tenon:**	**32.8**					°
I	311.0	S		331.0	S		5.3			38°N
II	272.0	S		269.0	S		5.5			10°S
III	233.0	S		214.0	S		5.3			35°S
Boot OAL:		**412.0**	Septum hole Nth edge:				**372.0**	Sth edge/Plug face:		**386.0**
IV	103.0	N		92.0	N			7.80		38°N
V	148.0	N		146.0	N			6.00		5°S
VI	185.0	N		203.0	N			5.10		45°S
Ab	336.0	N		336.0	N					
VII	356.0	N		356.0	N			8.20		
VIII	136.0	N		140.0	N			8.40		15°S
Long OAL:		**609.0**	**Tenons N,S:**		**30.0**	**46.0**	E-W	N-S	U/C	Chimney
IX	539.0	N					11.1	11.9	N&S	
X	337.0	N					9.0	10.0	S only	
XI	109.0	N					10.2	10.3		
Bell OAL:		**317.0**								
Total Bore Length:			**2133.2**		= top of wing to plug face + plug face to top of bell.					
Standing Height:			**1262.0**		= bottom of boot to top of bell.					

NOTES:
OAL = over all length (total length)
Angles are measured from perpindicular. They are in conventional directions unless otherwise stated.
"Calliper min" is the internal diameter measured with callipers as deep as possible.
"Rods" are plastic rods in 0.2mm increments of diameter used to test hole diameter.
The largest size to fit through is recorded.

Bore profiles
Measurements courtesy of Leslie Ross
Johann Heinrich Scherer
Zurich Museum Bellerive 106
Bell
Long Joint
Boot Joint
Wing Joint
Crook
Diameter
Distance
XI
X
IX
VIII
VII
VI
V
IV
Ab
III
II
I
Min
Max
Bell min
Bell max
Toneholes
Joint ends
Boot window

Measurements courtesy of L. Ross

Johann Heinrich Scherer: Zurich Museum Bellerive 106

Measurements courtesy of L. Ross

Johann Heinrich Scherer: Zurich Museum Bellerive 106

Joint Lengths
Tone Hole Positions and Sizes
Measurements courtesy of L. Ross

Johann Heinrich Scherer
Zurich Museum Bellerive 106

	Distance						Diameter			Angle
	Outside			Inside			Surface	Inside		
	d1	from end	d2	d1	from end	d2	E-W N-S	calliper min	rods etc	from perpindicular
Wing OAL:		**552.0**		**Tenon:**	**47.0**					°
I	320.0	S		330.0	S			4.8		28-33°N
II	279.0	S		280.0	S			4.8		0-5°S
III	239.0	S		231.0	S			4.3		24-27°S
Boot OAL:		**426.0**	Septum hole Nth edge:				**388.0**	Sth edge/Plug face:		**416.0**
IV	103.0	N		95.0	N			8.30		27°N
V	144.0	N		145.0	N			6.00	widens in bore	4°S
VI	184.0	N		192.0	N			5.40		33°S
Ab	327.0	N			N			5.00		0°
VII	350.0	N			N			8.70		0°
VIII	140.0	N		135.0	N			9.80	widens in bore	10-15°S
								10.70	towards south	
Long OAL:		**590.0**	**Tenons N,S:**		**42.0**	**46.0**	E-W	N-S	U/C	Chimney
IX	526.0	N					11.8	12.5	all round	
X	318.0	N					12.3	13.2	all round	
XI	101.0	N					11.2	11.9	all round	
Bell OAL:		**317.0**								
Total Bore Length:			**2156.0**		= top of wing to plug face + plug face to top of bell.					
Standing Height:			**1245.0**		= bottom of boot to top of bell.					

NOTES: OAL = over all length (total length)

Angles are measured from perpindicular. They are in conventional directions unless otherwise stated.

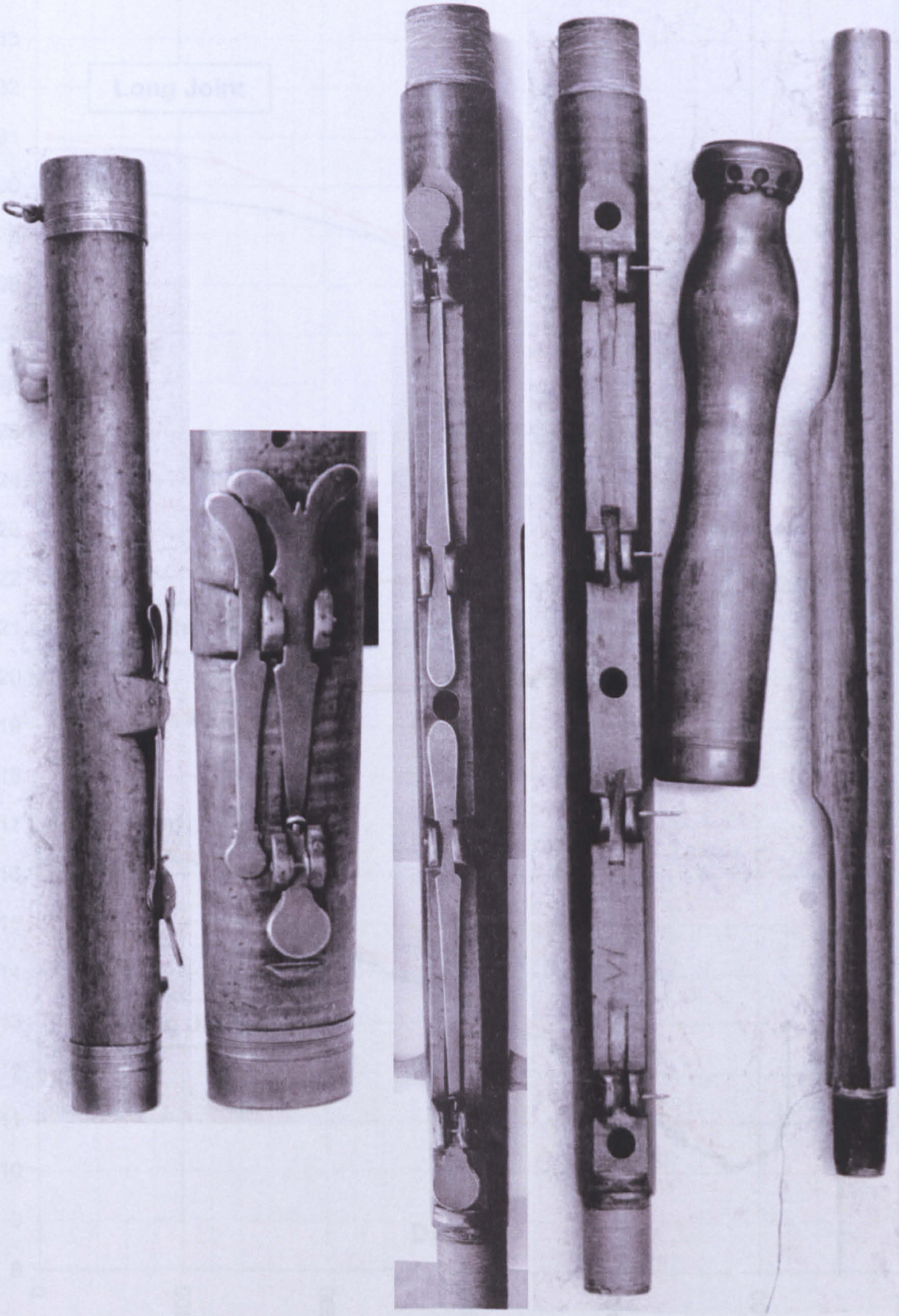
"Calliper min" is the internal diameter measured with callipers as deep as possible.

"Rods" are plastic rods in 0.2mm increments of diameter used to test hole diameter.

The largest size to fit through is recorded.

Johann Scherer II, Ea 62-X-1952

Gemeentemuseum, Den Haague



Bore profiles
Measurements courtesy of John Hanchet
Johann Scherer
Gemeentemuseum Ea 62-X-1952
Minimum
Maximum
Bell
Joint ends
Boot window
Bell
Long Joint
Boot Joint
Wing Joint
Diameter
Distance

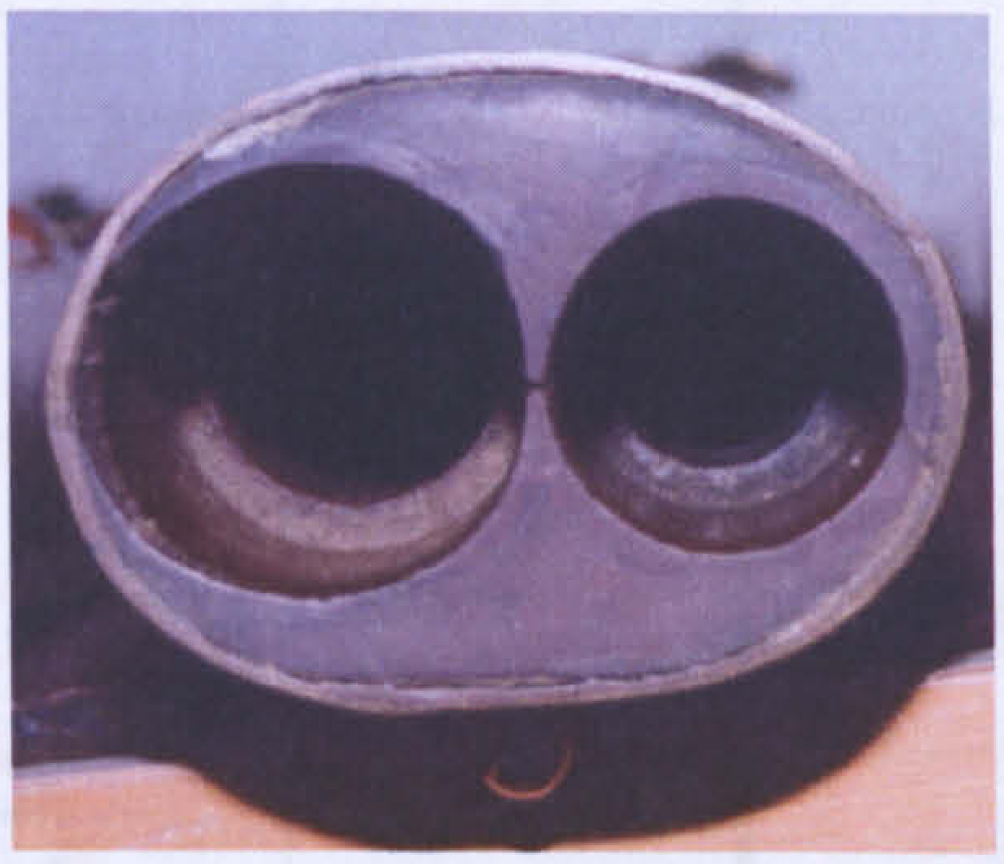
Measurements courtesy of John Hanchet

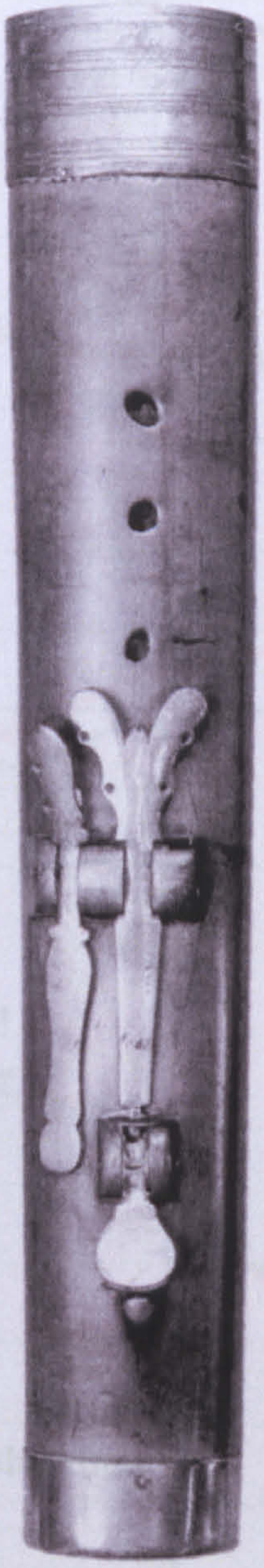
Johann Scherer, Gemeentemuseum Ea 62-X-1952

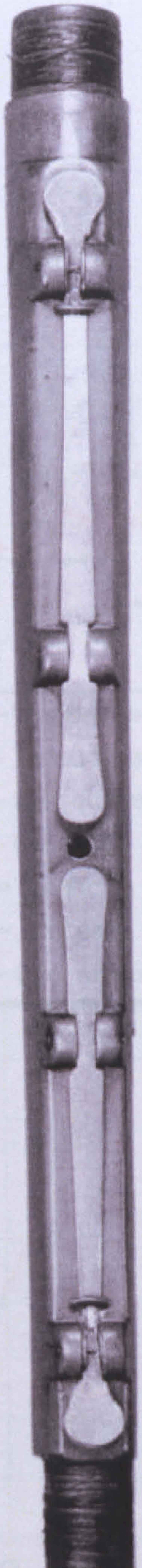
	Distance						Diameter			Angle
	Outside			Inside			Surface	Inside		
	from end	Centre		d1	from end	d2	E-W N-S	calliper min	rods etc	from perpindicular
Wing OAL:		**556.0**		**Tenon:**	**43.0**					°
I	S	321.0						5.0		
II	S	282.0						4.8		
III	S	243.0						4.8		
Boot OAL:		**427.0**	Septum hole North edge:				**389.0**	Sth edge/Plug face:		**409.0**
IV	N	103.5						7.5+		
V	N	142.0						6+		
VI	N	182.0						5.7		
Ab	N	331.5								
VII	N	356.0						8.5		
VIII								12.3		
Long OAL:		**598.0**	**Tenons N,S:**		**37.0**	**45.0**	E-W	N-S	U/C	Chimney
IX	96.5	N								
X	315.0	N								
XI	528.0	N								
Bell OAL:		**304.0**								
Total Bore Length:			**2151.0**		= top of wing to plug face + plug face to top of bell.					
Standing Height:			**1247.0**		= bottom of boot to top of bell.					
NOTES:		OAL = over all length (total length)								
		Angles are measured from perpindicular. They are in conventional directions unless otherwise stated.								
		"Calliper min" is the internal diameter measured with callipers as deep as possible.								
		"Rods" are plastic rods in 0.2mm increments of diameter used to test hole diameter.								
			The largest size to fit through is recorded.							

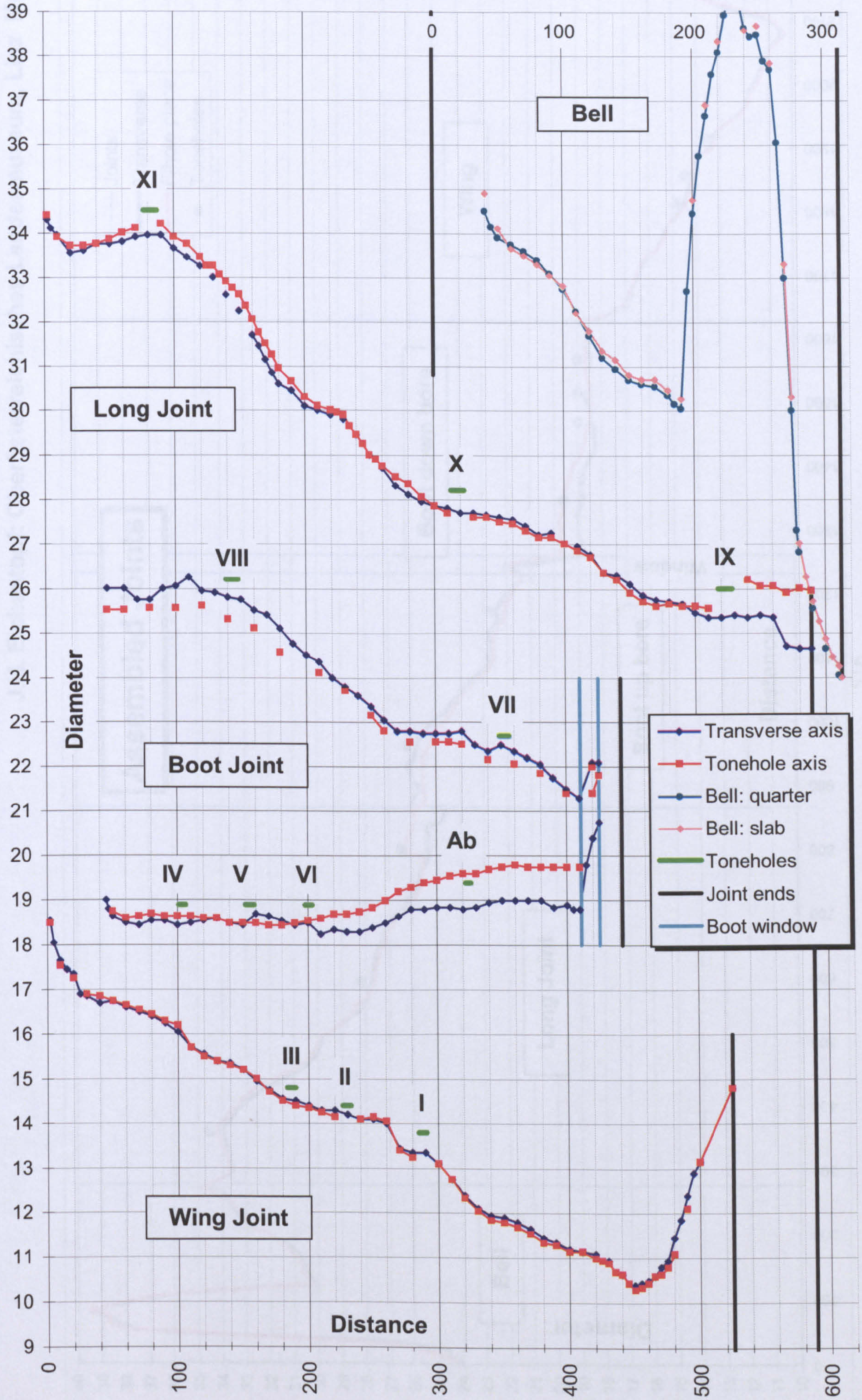
J.H. Eichentopf, Mu 35

Oberösterreichisches Landesmuseum, Linz








Bell
Long Joint
Boot Joint
Wing Joint
XI
X
IX
VIII
VII
IV
V
VI
Ab
III
II
I
Diameter
Distance
Transverse axis
Tonehole axis
Bell: quarter
Bell: slab
Toneholes
Joint ends
Boot window


J.H. Eichentopf: Oberösterreichisches Landesmuseum, Linz Mu35
Assembled Joints
Joints
Transverse
F/hole plane
Toneholes
Bell
Long Joint
Boot up bore
Window
Boot down bore
Wing
Diameter
Distance
40
39
38
37
36
35
34
33
32
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200

	Distance						Diameter			Angle
	Outside			Inside			Surface	Inside		
	d1	from end	d2	d1	from end	d2	E-W N-S	calliper min	rods etc	from perpindicular
Wing OAL:		**525.5**		**Tenon:**	**43.0**					°
I	270.5	S	279.5	285.0	S	291.0	6.25 8.8		5.6 tight	32.5°N
II	236.5	S	245.0	232.5	S	226.5	6.5 8.0		5.6 through	29°S
III	195.0	S	204.0	184.0	S	190.0	6.65 8.55		5.8->5.5, 5.6 loose	30°S
Boot OAL:		**442.0**	Septum hole North edge:				**411.0**	South edge/Plug face:		**425.0**
IV	110.5	N	120.0	100.8	N	106.0	7.70 10.80		6.8->8.5, 6.6->14 6.4 just rhough	31°N
V	141.5	N	150.5	152.0	N	158.5	7.60 8.70		6.8->7, 6.6->16 6.4 just through	23°S
VI	179.0	N	188.0	198.0	N	203.5	6.40 8.90		5.6 smooth	40°S
Ab	327.0	N	321.7	322.0	N	326.2	5.10 5.00		key not removed	0°
VII	350.0	N	359.0	349.0	N	356.0	9.20 9.90	8.80	8.8 tight	0°
VIII	130.0	N	141.5	138.5	N	148.0	9.20	9.00		21°S
Long OAL:		**589.0**	**Tenons N,S:**		**34.0**	**46.0**	E-W	N-S	U/C	Chimney
IX	60.5	S end	71.0				8.7	8.9	21°E&W, 24°N, 18°S	
X	266.2	S end	276.3				8.0	8.2	17°E&W 24°N, 20°S	
XI	76.3	N end	86.7						key not removed	
Bell OAL:		**312.0**								
Total Bore Length:			**2153.5**		= top of wing to plug face + plug face to top of bell.					
Standing Height:			**1263.0**		= bottom of boot to top of bell.					

NOTES:
OAL = over all length (total length)
Angles are measured from perpindicular. They are in conventional directions unless otherwise stated.
"Calliper min" is the internal diameter measured with callipers as deep as possible.
"Rods" are plastic rods in 0.2mm increments of diameter used to test hole diameter.
The largest size to fit through is recorded.

J.H. Eichentopf

St Annen-Museum Lübeck

Bore profiles
J.H. Eichentopf
St Annen Museum, Lübeck
Diameter
Distance
Transverse axis
Tonehole axis
Bell: slab axis
Toneholes
Joint ends
Boot window
Long Joint
Bell
Boot Joint
Wing Joint
Crook
XI
X
IX
VIII
VII
VI
V
IV
III
II
I
Ab

J.H. Eichentopf: St Annen Museum, Lübeck

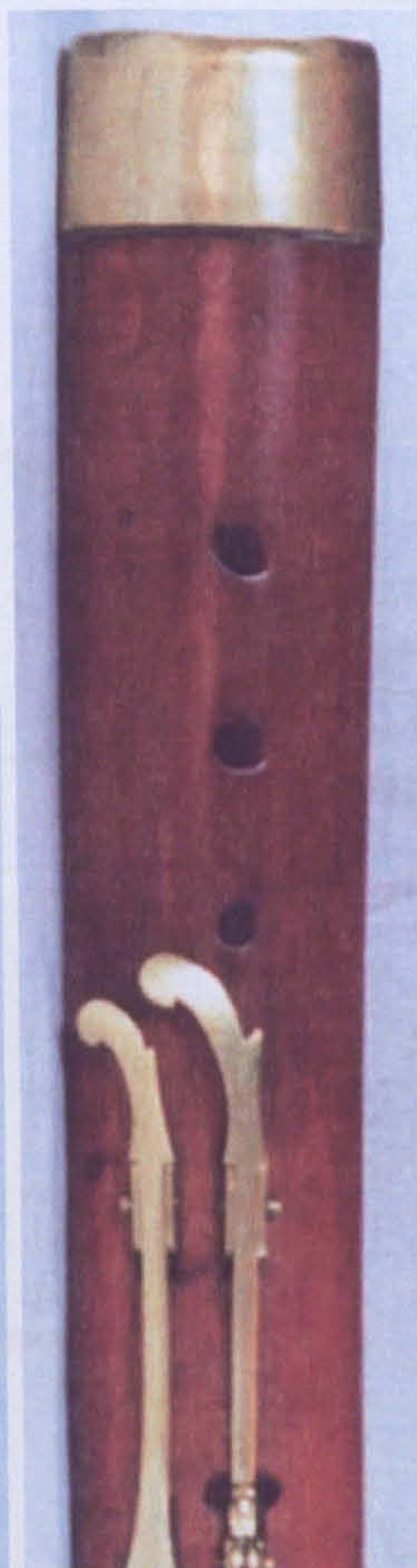
	Distance						Diameter			Angle
	Outside			Inside			Surface	Inside		
	d1	from end	d2	d1	from end	d2	E-W N-S	calliper min	rods etc	from perpindicular
Wing OAL:		**654.0**		**Tenon:**	**41.5**					°
I	308.5	S	318.5	329.0	S	336.5	6.25 10.5	6.1	5.8 just passes	43°N
II	266.5	S	274.5	257.0	S	264.0	6.5 9.0	6.1	5.6 to 17 5.4 loose	24°S
III	226.0	S	235.5	210.0	S	215.5	6.8 10.65	6.5	5.8 just through	37.5°S
Boot OAL:		**543.0**	Septum hole North edge:				**501.0**	South edge/Plug face:		**522.0**
IV	105.0	N	115.0	92.0	N	100.5	8.3 12.0	7.60	7.0 just passes	30°N
V	149.5	N	158.5	151.0	N	162.5	7.8 10.0	7.2	>6.4 <6.6	15°S
VI	189.5	N	200.0	204.0	N	210.0	7.30 12.4	6.7	7.0 to 5 6.4 to 15 6.2 loose	33°? S
Ab	424.0	S	431.5	426.0	N	434.0	6.75 6.9		key not removed	
VII	460.0	S	471.0	466.0	N	475.5	8.8 10.3		key not removed	S
VIII	144.5	N	157.0	146.0	N	157.0	13.1 11.75			~ 0°
Long OAL:		**706.0**	**Tenons N,S:**		**35.0**	**44.5**	E-W	N-S	U/C	Chimney
IX	646.5	N	636.0				10.0?		none or v. little	
X	413.0	N	402.0				10.5	10.6	10°E&W 15°S, 10°N	2.5
XI	101.0	N	88.0				13.4	13.4	very steep all round	1.0
Bell OAL:		**420.0**		**Crook OAL:**		**413.0**				
Total Bore Length:			**2703.0**	= top of wing to plug face + plug face to top of bell.						
Standing Height:			**1589.5**	= bottom of boot to top of bell.						

NOTES: OAL = over all length (total length)
Angles are measured from perpindicular. They are in conventional directions unless otherwise stated.
"Calliper min" is the internal diameter measured with callipers as deep as possible.
"Rods" are plastic rods in 0.2mm increments of diameter used to test hole diameter.
The largest size to fit through is recorded.

Johann Poerschman, No. 1384

Musikinstrumenten Museum der Universität

Leipzig



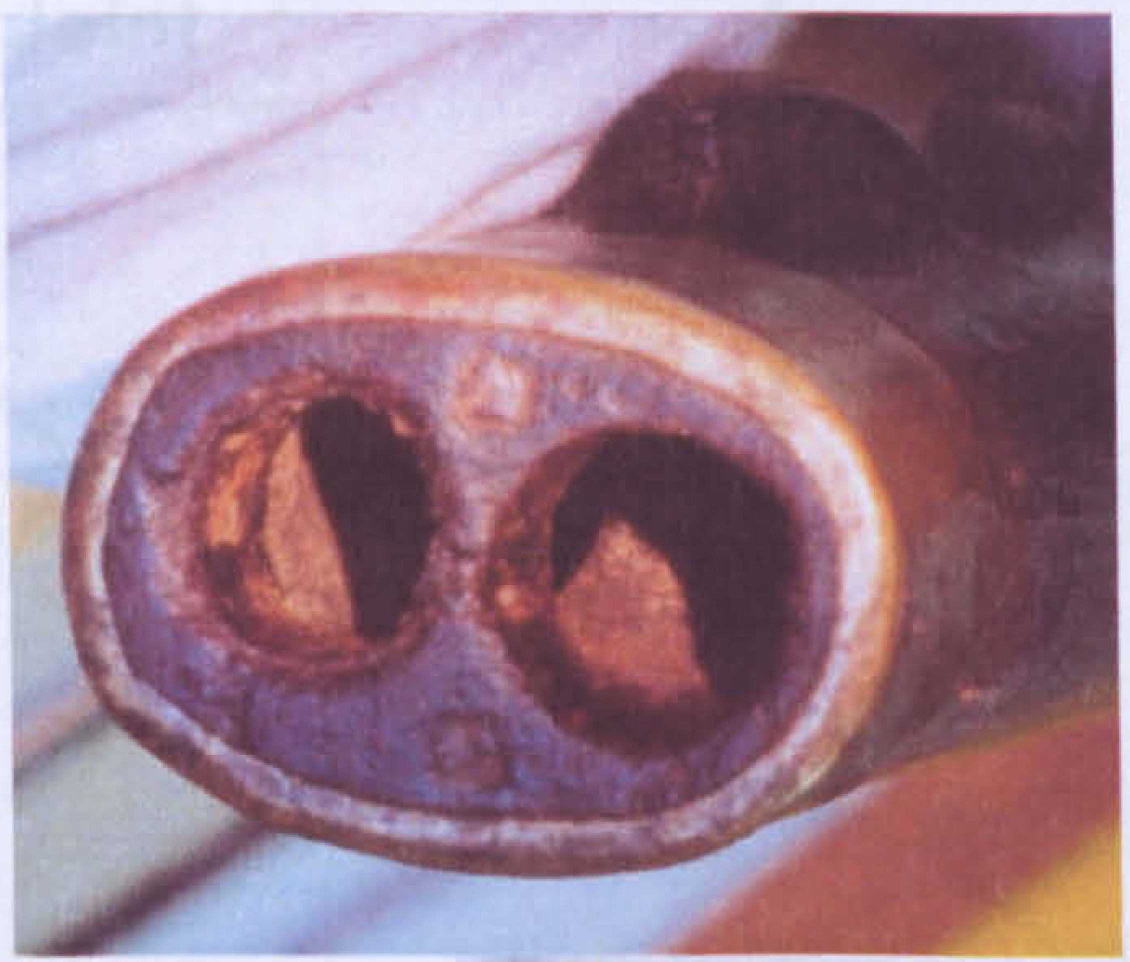
Bore profiles
Johann Poerschman No. 1384
Musikinstrumenten Museum der Universität, Leipzig
Min
Max
Bell min
Bell max
Toneholes
Joint ends
Boot window
Long Joint
Bell
Boot Joint
Wing Joint
XI
X
IX
VIII
VII
IV
V
VI
Ab
III
II
I
Diameter
Distance

Johann Poerschman: Musikinstrumenten Museum der Universität, Leipzig No. 1384

	Distance						Diameter			Angle
	Outside			Inside			Surface	Inside		
	d1	from end	d2	d1	from end	d2	E-W N-S	calliper min	rods etc	from perpindicular
Wing OAL:		527.5		Tenon:	44.8					°
I	270.0	S	279.0	282.0	S	288.5	7.3 9.3	6.6	6.4 smooth	30°N
II	232.0	S	241.0	227.5	S	234.0	7.4 9.3	6.9	6.6 through	18°S
III	191.5	S	200.0	184.0	S	190.5	7.5 9.45	6.4	6.2 through	25°S
Boot OAL:		422.0	Septum hole North edge:				380.0	South edge/Plug face:		401.5
IV	101.0	N	111.0	94.0	N	103.5	9.55 12.00	8.40		23°N
V	142.0	N	151.5	148.5	N	157.5	9.80 11.00	8.70		14°S
VI	179.0	N	188.5	191.0	N	198.5	7.80 10.15	6.90	6.8 almost passes	27°S
Ab	321.0	N	328.0	323.0	N	330.5	6.00 7.10		5.6 smooth	18°S
VII	335.5	N	345.5	337.0	N	344.5	10.04 10.00	9.30		0°
VIII	131.0	N	142.0	131.5	N	141.5	10.30 10.30	9.70		0°
Long OAL:		590.0	Tenons N,S:		39.2	50.0	E-W	N-S	U/C	Chimney
IX	517.2	N	532.2						no access under cover	
X	328.2	N	340.2				10.6	11.0	20° all round	4.0
XI	123.7	N	134.2				10.1	10.7	27°N&S 18°E&W	3.2N 2.2S
Bell OAL:		279.0								
Total Bore Length:			2065.5	= top of wing to plug face + plug face to top of bell.						
Standing Height:			1201.8	= bottom of boot to top of bell.						
NOTES:		OAL = over all length (total length)								
		Angles are measured from perpindicular. They are in conventional directions unless otherwise stated.								
		"Calliper min" is the internal diameter measured with callipers as deep as possible.								
		"Rods" are plastic rods in 0.2mm increments of diameter used to test hole diameter.								
			The largest size to fit through is recorded.							

Johann Poerschman

Tschechisches Museum für Musik, Prague




Bore profiles
Johann Poerschman No. 1375E
Tschechisches Museum für Musik, Prague
Transverse axis
Tonehole axis
Bell: quarter
Bell: slab
Toneholes
Joint ends
Boot window
Long Joint
Bell
Boot Joint
Wing Joint
Diameter
Distance
XI
X
IX
VIII
VII
IV
V
VI
Ab
III
II
I

Johann Poerschman, Tschechisches Museum für Musik, Prague No. 1375E
Assembled Joints
Joints
Transverse
F/hole plane
Toneholes
Bell
Long Joint
Boot up bore
Window
Boot down bore
Wing
Diameter
Distance

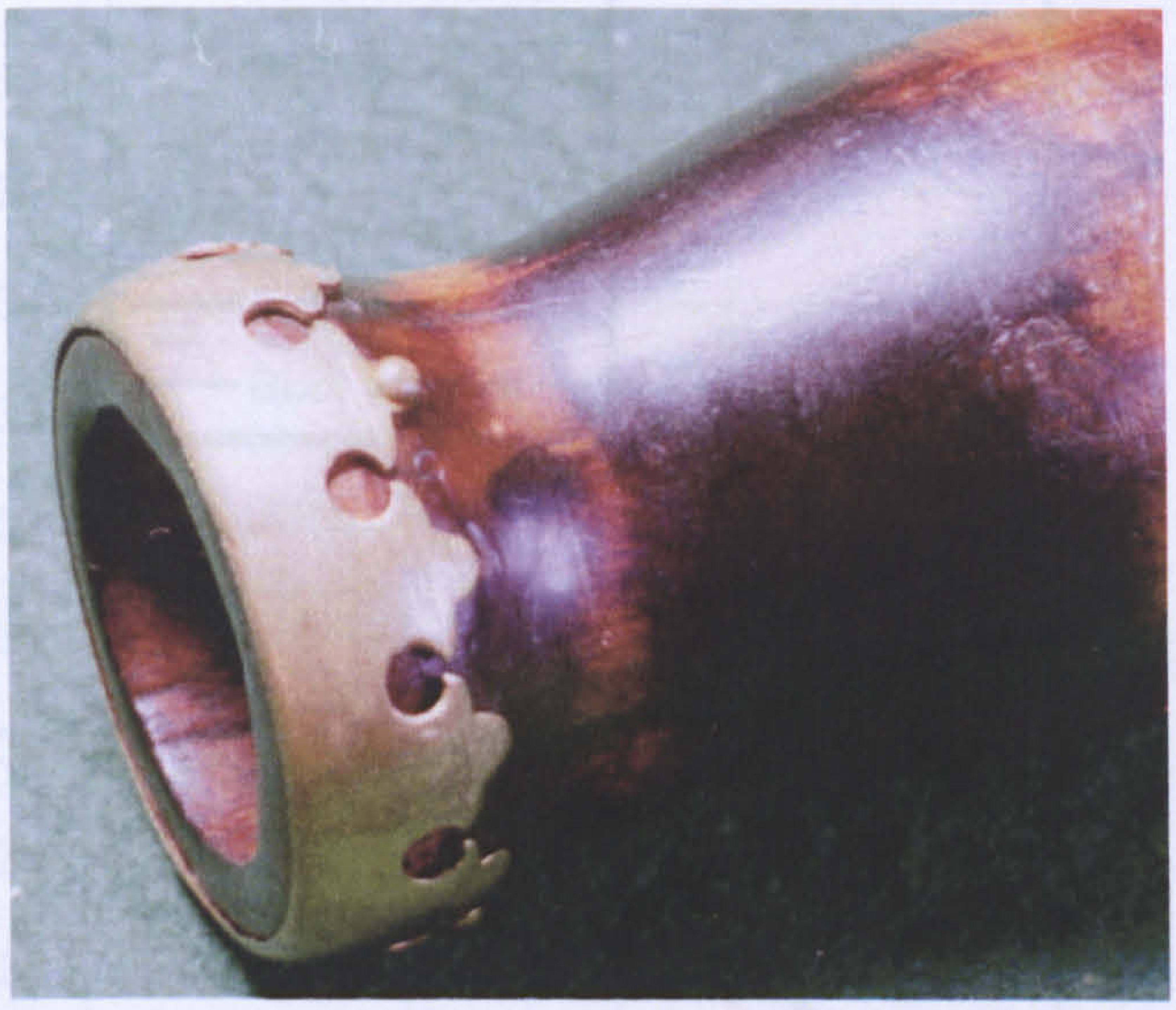
	Distance						**Diameter**			**Angle**
	Outside			**Inside**			**Surface**	**Inside**		
	d1	from end	d2	d1	from end	d2	E-W N-S	calliper min	rods etc	from perpindicular
Wing OAL:		**513.5**		**Tenon:**	**44.5**					°
I	261.5	S	268.5	269.0	S	274.0			4.5	
II	219.5	S	226.8	216.0	S	220.5			5.2	
III	180.0	S	187.2	174.5	S	180.5			4.8	
Boot OAL:		**425.5**		Septum hole Nth edge:			**384.5**	Sth edge/Plug face:		**410.5**
IV	102.5	N	112.5	94.0	N	102.5	8.2	7.45	>7.0	25° N
							12.0			
V	142.0	N	151.0	149.0	N	156.0	7.7	7.0	<7 >6.8	16.5° S
							10.2			
VI	180.0	N	190.0	191.0	N	199.0	7.35	6.6	<6.0 >5.8	28° S
							10.4			
Ab	318.0	N	325.0	318.0	N	325.5	5.5	5.3	<5.4 >5.2	5° S
							6.4	6.1		
VII	348.0	N	336.0	348.0	N	336.0	9.1	8.5		6° S
							11.2			
VIII	130.0	N	141.5	131.0	N	141.5	10.6	9.5		0°
							11.1			
Long OAL:		**592.4**	**Tenons N,S:**		**40.7**	**46.2**	E-W	N-S	U/C	Chimney
IX	519.4	N	533.4				13.9	14.2	none	0.0
X	331.7	N	341.7				9.0	9.5	none	
XI	125.7	N	138.0				11.7	12.3	little	
Bell OAL:		**282.5**								
Total Bore Length:			**2076.5**	= top of wing to plug face + plug face to top of bell.						
Standing Height:			**1213.5**	= bottom of boot to top of bell.						

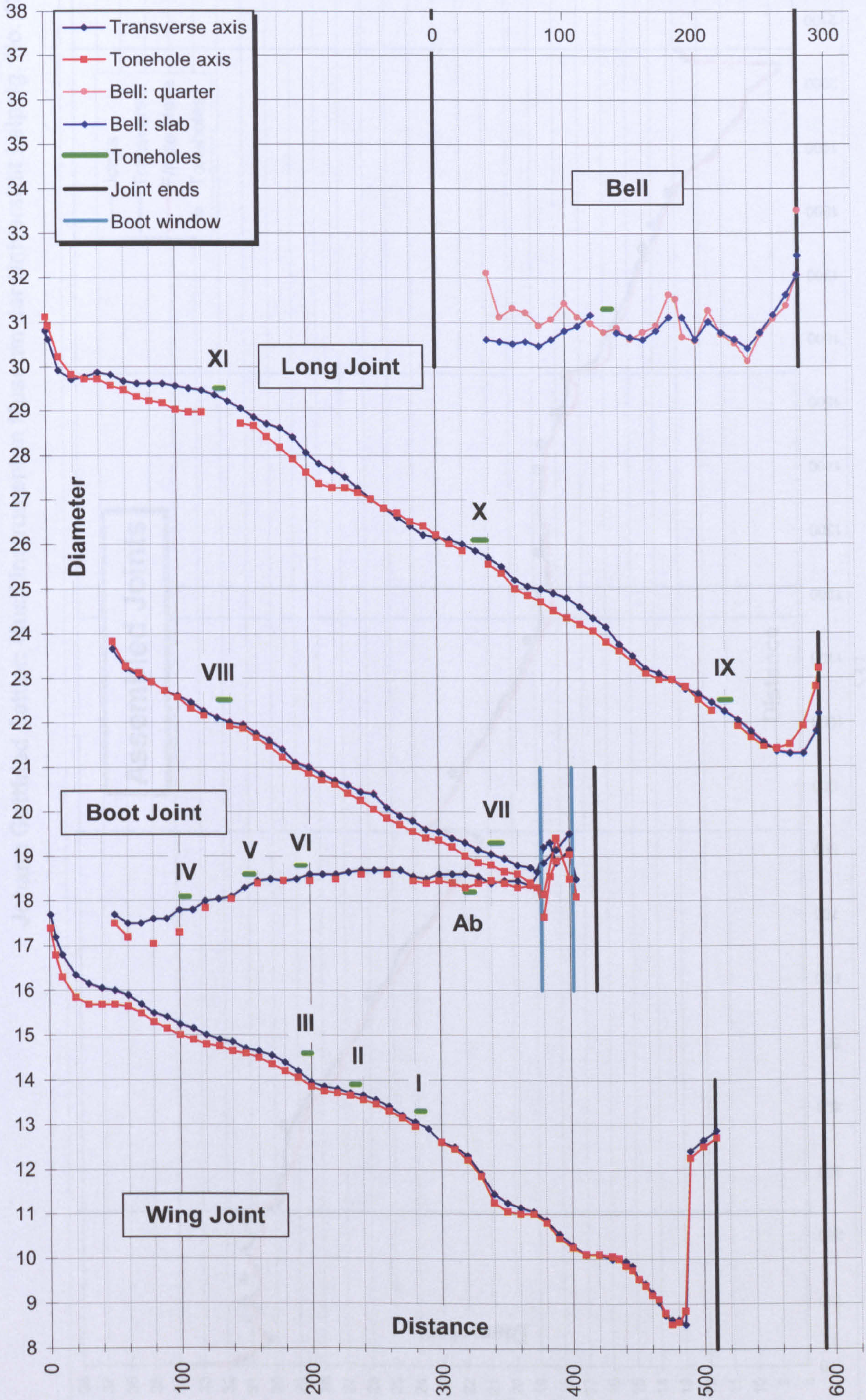
NOTES:
OAL = over all length (total length)
Angles are measured from perpindicular. They are in conventional directions unless otherwise stated.
"Calliper min" is the internal diameter measured with callipers as deep as possible.
"Rods" are plastic rods in 0.2mm increments of diameter used to test hole diameter.
The largest size to fit through is recorded.

Johann Gottfried Sattler, No. 1369

Musikinstrumenten Museum

der Universität, Leipzig




Transverse axis
Tonehole axis
Bell: quarter
Bell: slab
Toneholes
Joint ends
Boot window
Bell
Long Joint
Boot Joint
Wing Joint
XI
X
IX
VIII
VII
VI
V
IV
Ab
III
II
I
Diameter
Distance
0
100
200
300
400
500
600

Johann Gottfried Sattler: Musikinstrumenten Museum der Universität Leipzig, No. 1369
Assembled Joints
Joints
Transverse
F/hole plane
Toneholes
Diameter
Distance
38
37
36
35
34
33
32
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200

Joint Lengths
Tone Hole Positions and Sizes

Johann Gottfried Sattler, No. 1369
Musikinstrumenten Museum
der Universität, Leipzig

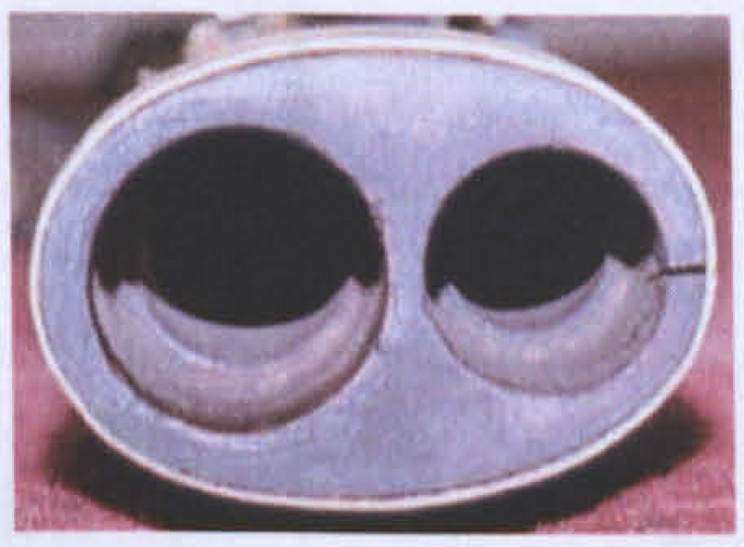
	Distance						Diameter			Angle
	Outside			Inside			Surface	Inside		
	d1	from end	d2	d1	from end	d2	E-W N-S	calliper min	rods etc	from perpindicular
Wing OAL:		**509.5**		**Tenon:**	**43.5**					°
I	271.5	S	279.0	281.0	S	287.0	5.8 7.9	5.5	5.2 smooth	32°N
II	237.0	S	244.5	231.0	S	237.0	6.2 7.3	5.8	ditto	23°S
III	201.5	S	209.5	194.0	S	200.0	6.2 7.6	5.7	5.2 loose <5.4	32°S
Boot OAL:		**420.0**		Septum hole Nth edge:			**378.0**	Sth edge/Plug face:		**402.0**
IV	105.0	N	112.0	101.0	N	107.5	6.50 8.80	6.00	>5.6 <5.8	14°N
V	143.0	N	151.0	150.0	N	157.0	6.85 9.50	6.20	>5.8 <6.0	20°S
VI	180.0	N	188.0	190.0	N	196.5	6.50 9.00	6.00	>5.4 <5.6	31°S
Ab	321.0	N	326.0	320.0	N	327.0	4.90			
VII	340.0	N	348.0	339.5	N	348.5	8.20 11.30	7.80		0°
VIII	130.0	N	140.0	131.0	N	140.5	9.10 9.10	7.70		?
Long OAL:		**592.0**	**Tenons N,S:**		**39.3**	**46.3**	E-W	N-S	U/C	Chimney
IX	525.2	N	516.4				8.85	8.6		
X	338.7	N	328.7				9.0	9.0		
XI	130.3	N	136.8				9.2	8.9		
Bell OAL:		**279.0**								
Bell hole:				129.5	S end	136.2	5.5	5.7		
Total Bore Length:			**2055.4**	= top of wing to plug face + plug face to top of bell.						
Standing Height:			**1205.4**	= bottom of boot to top of bell.						
NOTES:		OAL = over all length (total length)								
		Angles are measured from perpindicular. They are in conventional directions unless otherwise stated.								
		"Calliper min" is the internal diameter measured with callipers as deep as possible.								
		"Rods" are plastic rods in 0.2mm increments of diameter used to test hole diameter.								
			The largest size to fit through is recorded.							

Anonymous, No. 178

Muzeum Insrumenów

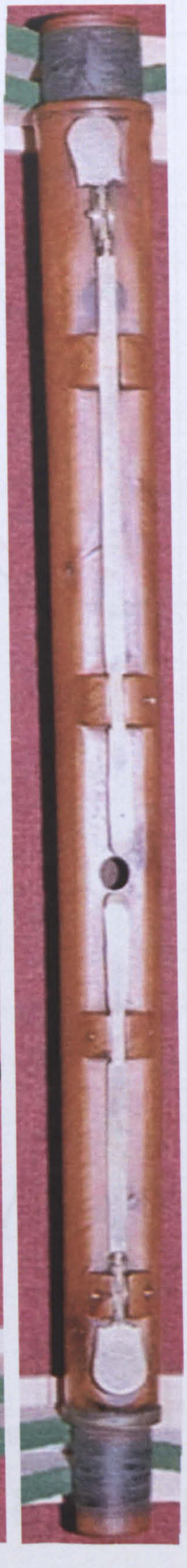
Muzyczynch, Poznan










Transverse axis
Tonehole axis
Bell: quarter
Bell: slab
Toneholes
Joint ends
Boot window
Diameter
Distance
Long Joint
Bell
Boot Joint
Wing Joint
XI
X
IX
VIII
VII
VI
V
IV
III
II
I
Ab
Brass lining

Anonymous, Muzeum Insrumenów Muzyczynch, Poznan No. 178

	Distance						Diameter			Angle
	Outside			Inside			Surface	Inside		
	d1	from end	d2	d1	from end	d2	E-W N-S	calliper min	rods etc	from perpindicular
Wing OAL:		**509.0**		**Tenon:**	**36.5**					°
I	266.5	S	275.0	280.0	S	289.5	6.5 9.0	6.0	6.0 through undercut	38°N
II	231.0	S	237.2	228.0	S	236.5	6.0 6.7	5.5	5.6 touches undercut	1°S
III	192.0	S	198.5	181.0	S	189.5	5.5 7.0	5.0	>5.0, <5.2	34°S
Boot OAL:		**428.0**	Septum hole Nth edge:				**386.0**	Sth edge/Plug face:		**405.0**
IV	98.5	N	108.0	94.0	N	100.0	8.25 11.00	7.70	<8.0, >7.8 undercut N & NW	26°N
V	141.7	N	149.0	139.0	N	149.5	6.90 8.80	6.50	<6.6, >6.4	1°S
VI	181.0	N	188.6	186.5	N	196.0	6.50 8.70	5.90	5.8-> 2 6.5 loose underecut	23.5°S
Ab	318.5 375.0	original now	325.0 382.5	318.5	N	325.0	7.00 7.20			
VII	338.0	N	350.0	336.0	N	349.0	11.50 13.20	10.90	u/c south	0°?
VIII	127.2	N	138.2	124.5	N	138.5	10.40 12.40	9.55	u/c 5°S, 12°N	0°
Long OAL:		**585.0**	**Tenons N,S:**		**33.3**	**42.5**	E-W	N-S	U/C	Chimney
IX	521.0	N	505.0				12.4	12.6	tangent to bore E&W	
X	324.8	N	336.3				11.4	12.5	ditto 30°N&S	
XI	46.8	N now	61.3						key not removed	
XI	103.0	N original	118.0							
Bell OAL:		**279.0**								

Total Bore Length:	**2067.7**	= top of wing to plug face + plug face to top of bell.
Standing Height:	**1216.2**	= bottom of boot to top of bell.

NOTES: OAL = over all length (total length)

Angles are measured from perpindicular. They are in conventional directions unless otherwise stated.

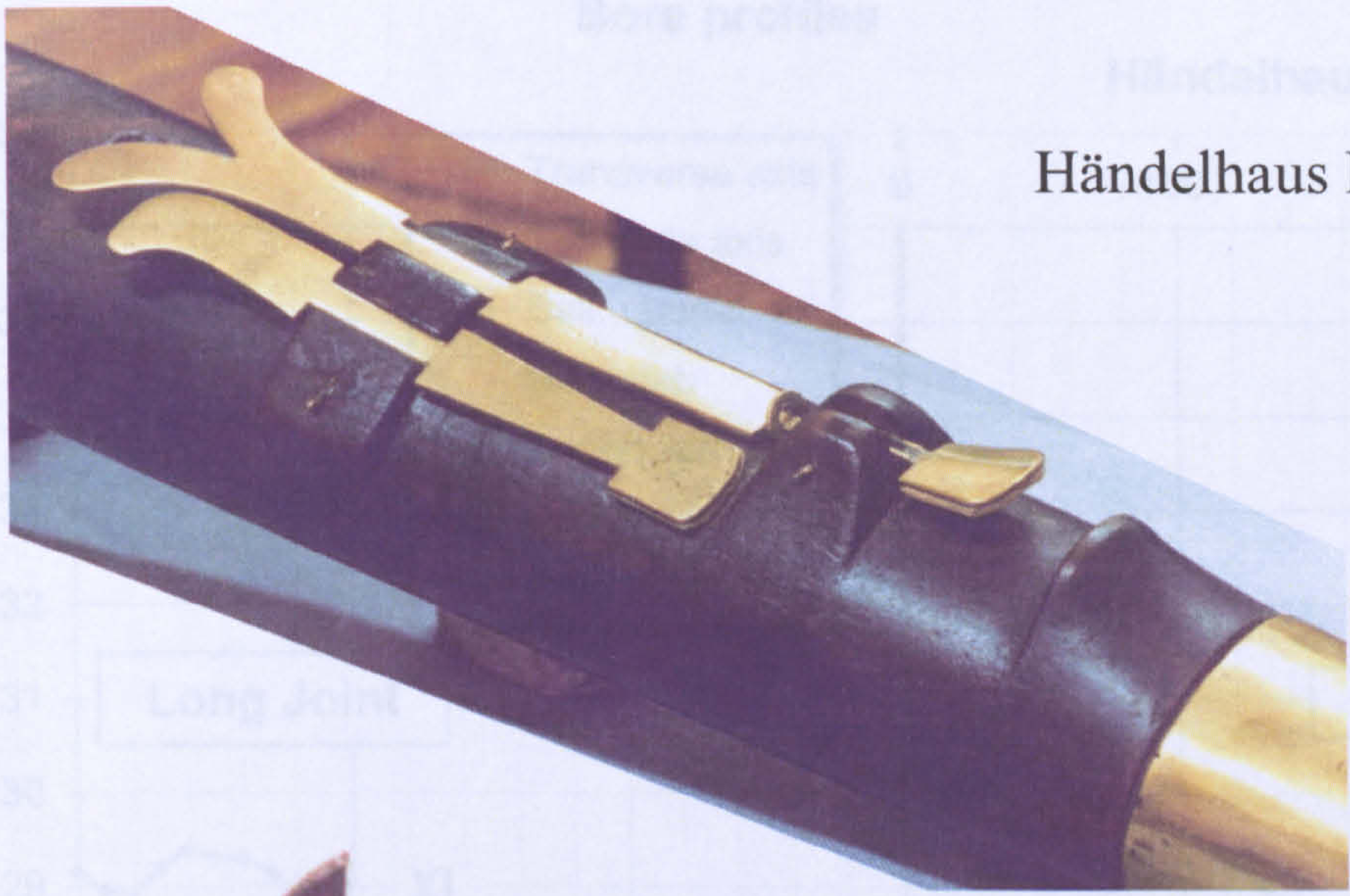
"Calliper min" is the internal diameter measured with callipers as deep as possible.

"Rods" are plastic rods in 0.2mm increments of diameter used to test hole diameter.

The largest size to fit through is recorded.

Anonymous,

Händelhaus Halle MS-684




Bore profiles
Anonymous
Händelhause Halle MS-684
Transverse axis
Tonehole axis
Bell: quarter
Bell: slab
Toneholes
Joint ends
Boot window
Long Joint
Bell
Boot Joint
Wing Joint
Diameter
Distance
XI
X
VIII
IX
VII
IV
V
VI
Ab
III
II
I

Anonymous, Händelhause Halle MS-684

	Distance						Diameter			Angle
	Outside			Inside			Surface	Inside		
	d1	from end	d2	d1	from end	d2	E-W N-S	calliper min	rods etc	from perpindicular
Wing OAL:		**498.5**		**Tenon:**	**38.0**					°
I	189.0		196.5	273.5	S	283.0	6.0 7.2	5.8	5.4 loose	20°N
II	228.0		234.5	224.0	S	231.0	6.2 7.7	5.4	5.4 smooth	15°S
III	269.5		275.5	185.0	S	193.5	5.9 7.1	6.3	5.8 smooth	16°S
Boot OAL:		**418.5**	Septum hole North edge:				**390.0**	South edge/Plug face:		**409.0**
IV	100.0	N	108.0	93.0	N	102.5	7.10 8.40	6.75		20°N
V	142.0	N	150.0	146.0	N	154.5	7.30 9.00	6.80	6.4 tight	7°S
VI	181.0	N	189.5	186.0	N	193.5	7.00 10.30	6.30		9°S
Ab	307.5	N	302.7	302.0	N	308.5	4.90	4.85		0°
VII	347.0	N	339.5	338.5	N	349.5	8.00 8.10	7.70	u/c to N & S	0°
VIII	129.5	N	140.5	130.0	N	141.0				0°
Long OAL:		**581.0**	**Tenons N,S:**		**34.2**	**41.8**	E-W	N-S	U/C	Chimney
IX	500.2	N	509.2				8.7	9.3	20°all round	1.0
X	322.7	N	331.2				8.4	8.5	20°all round	
XI	123.7	N	131.2				8.5	9.5	15°E&W	
Bell OAL:		**288.0**								
Total Bore Length:			**2071.0**	= top of wing to plug face + plug face to top of bell.						
Standing Height:			**1211.5**	= bottom of boot to top of bell.						

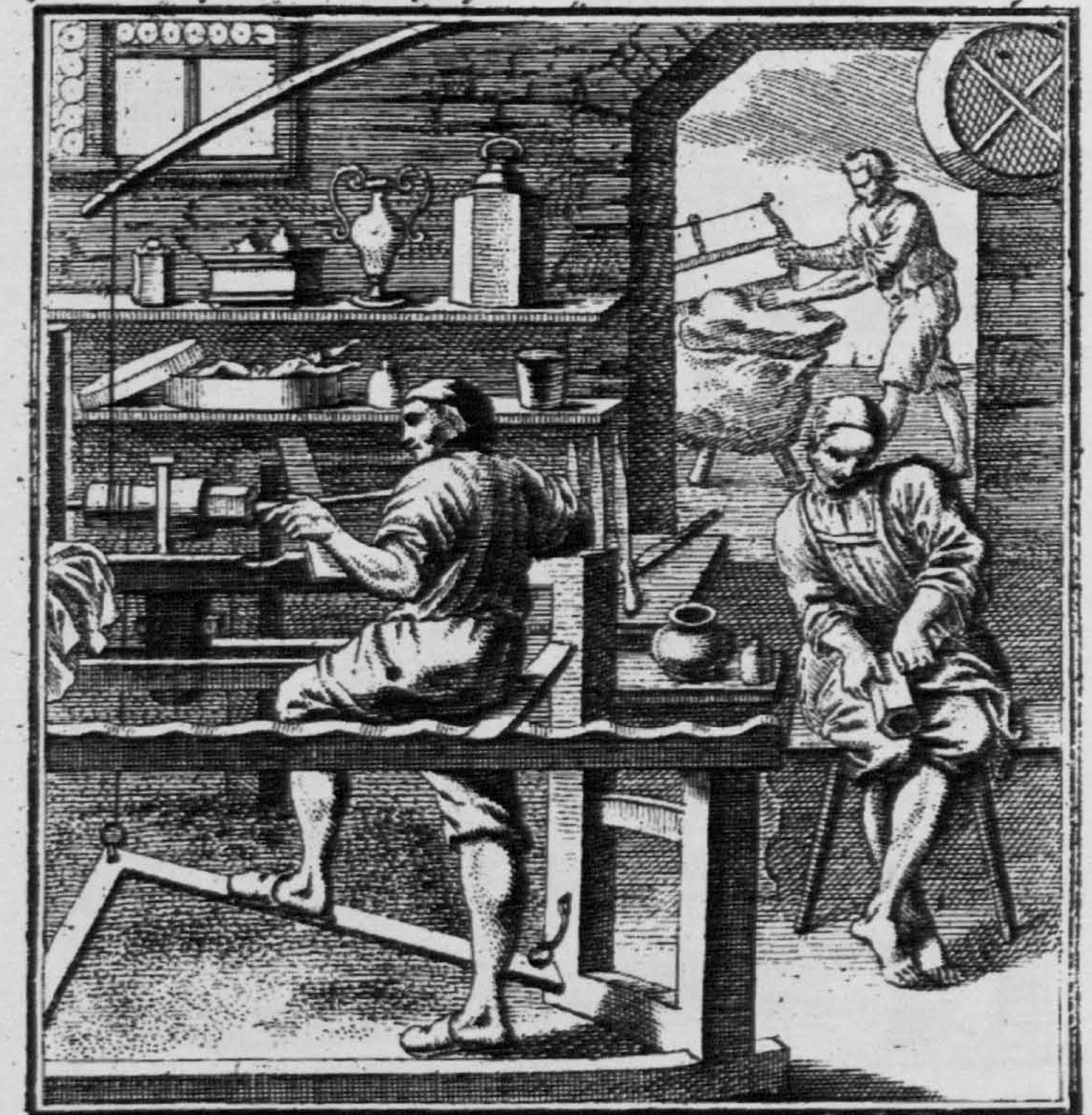
NOTES: OAL = over all length (total length)
Angles are measured from perpindicular. They are in conventional directions unless otherwise stated.
"Calliper min" is the internal diameter measured with callipers as deep as possible.
"Rods" are plastic rods in 0.2mm increments of diameter used to test hole diameter.
The largest size to fit through is recorded.

Appendix 4
Iconography

The full compositions, from which details have previously been shown, are reproduced in the order that they appear in the text.

Der Alabasterer.

Die Warheit läst sich sehen, wan man sie will verdrehen.



1. Die Lügen ist ein schwartzes Laster,
beflecket euch nicht mit ihrem Mist.
Seyd wie der weisse Alabaster,
der aussen wie von innen ist.
Legt nie den Schmuck der Warheit ab,
So ligt ihr Lob auff eurem Grab.

Two pages from Johann Christoff Weigel, *Abbildung der Gemein-Nützlichen Haupt-Stände*, (Regensburg, 1698).
Left: *Der Alabasterer*
Right: *Wildruff und Horn-dreher*,

see pp. 31-33.

Wildruff und Horn-dreher. 73

Vertrauet nicht, auff das, was bricht.

Das Trotz-Gewehr ergrimmter Macht,
das Horn, wird in dem Mund verlacht,
Es fiel das fallende zur Erden.
So geht es pochender Gewalt,
sie muss, gestürtzt und selten alt,
ein Spiel in vielen Mäulern werden.
K

Above: Georges Simoneau, frontispiece to Marin Marais, *Pieces en Trio Pour les Flutes, Violon, & Dessus de Viole* (Paris: 1692), see pp. 46-47.

Left: *Der Schiff Pompenmacher*
from Johann Christoff Weigel,
Abbildung der Gemein-
Nützlichen Haupt-Stände,
(Regensburg, 1698),
see p. 33.

André Bouys
Cæcilia de Lisorez, *Vide, & audi*, dated 1704,
mezzotint,
collection of Tony Bingham,
see pp. 54-56

Nicolas Lancret, *Mademoiselle de Camargo Dancing*,
oil on canvas,
Wallace collection, London,
see p. 57.

Evart Collier, *Vanitas,* 1680-1690

Evart Collier, *Vanitas / A Miscellany of Musical Instruments,* post 1702
see pp. 92-94

Balthasar van den Bossche Left: *Musical Reunion on a Terrace,* dated 1713.
Right: untitled, undated, see p. 100.

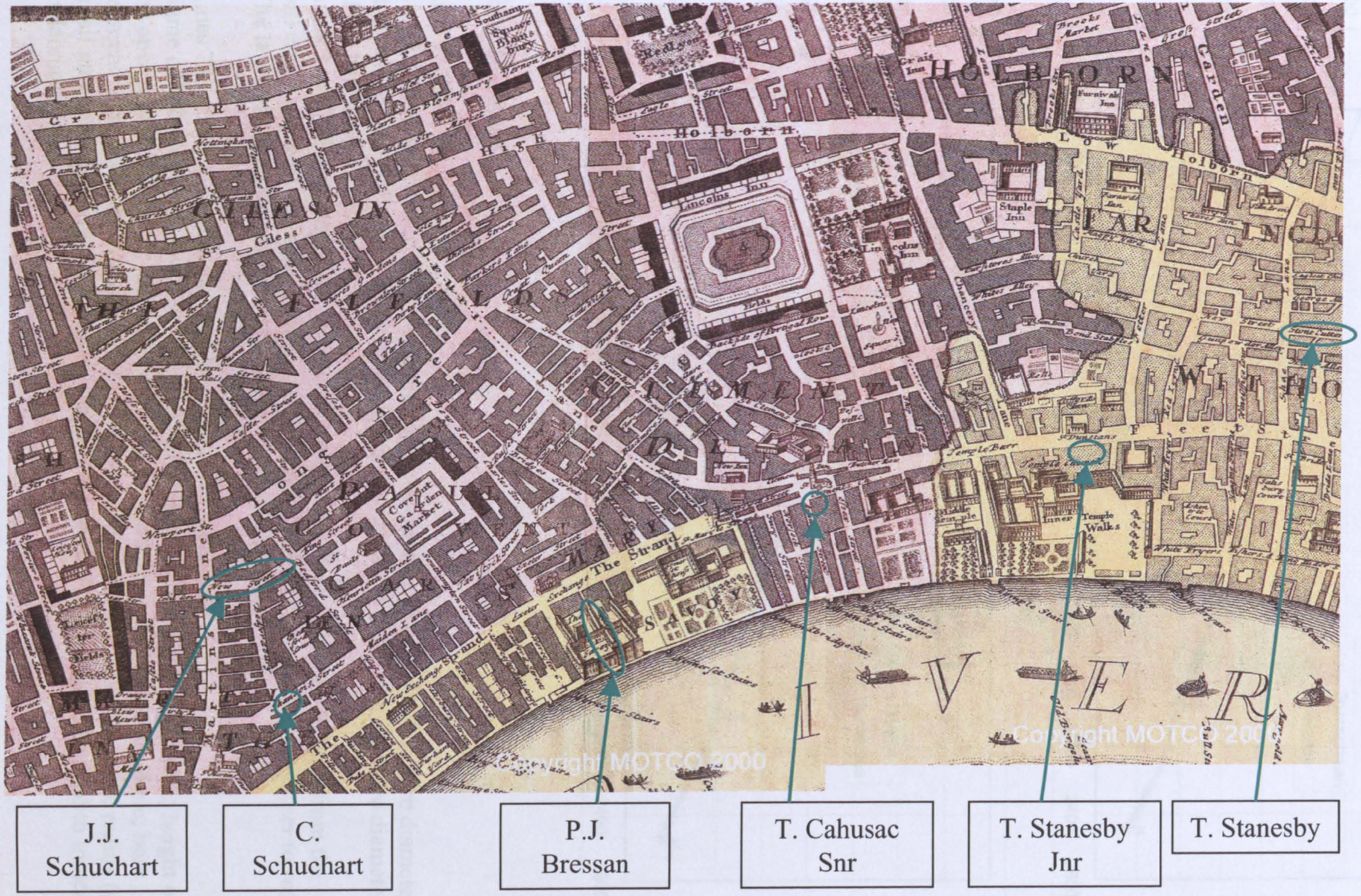
François Xaver Verbeeck,
A Musical Gathering
see p. 101

Nicolas Henri Tardieu
Le Festin Royal, 1722,
Collection of Tony
Bingham,
see pp. 207-209.

Left: *Der Peiffenmacher* from Johann Christoff Weigel, *Abbildung der Gemein-Nützlichen Haupt-Stände*, (Regensburg, 1698).

Right: 5th century BC Athenian red-figure cup, Ashmolean Museum, Ex Bourgignon Collection AN1896-1908 G.267.

See pp. 143-147.

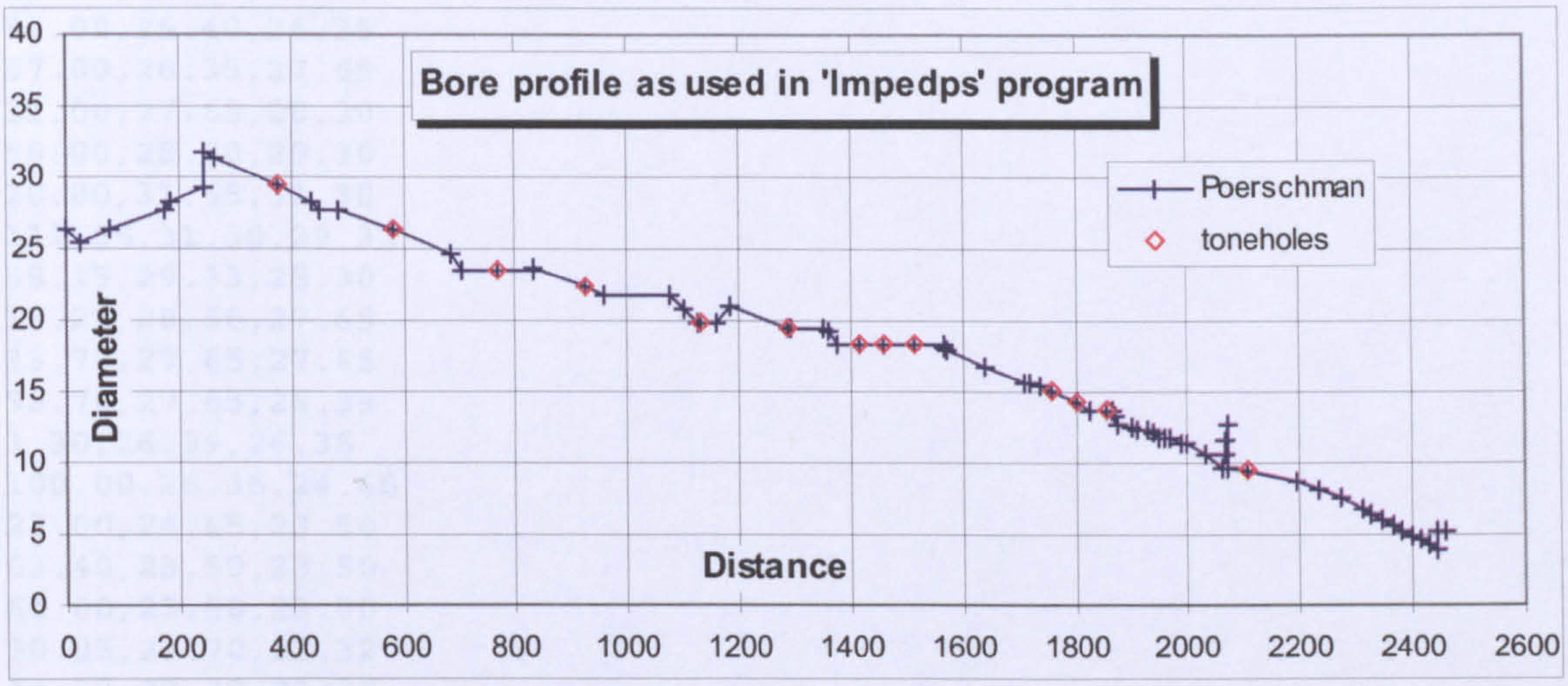


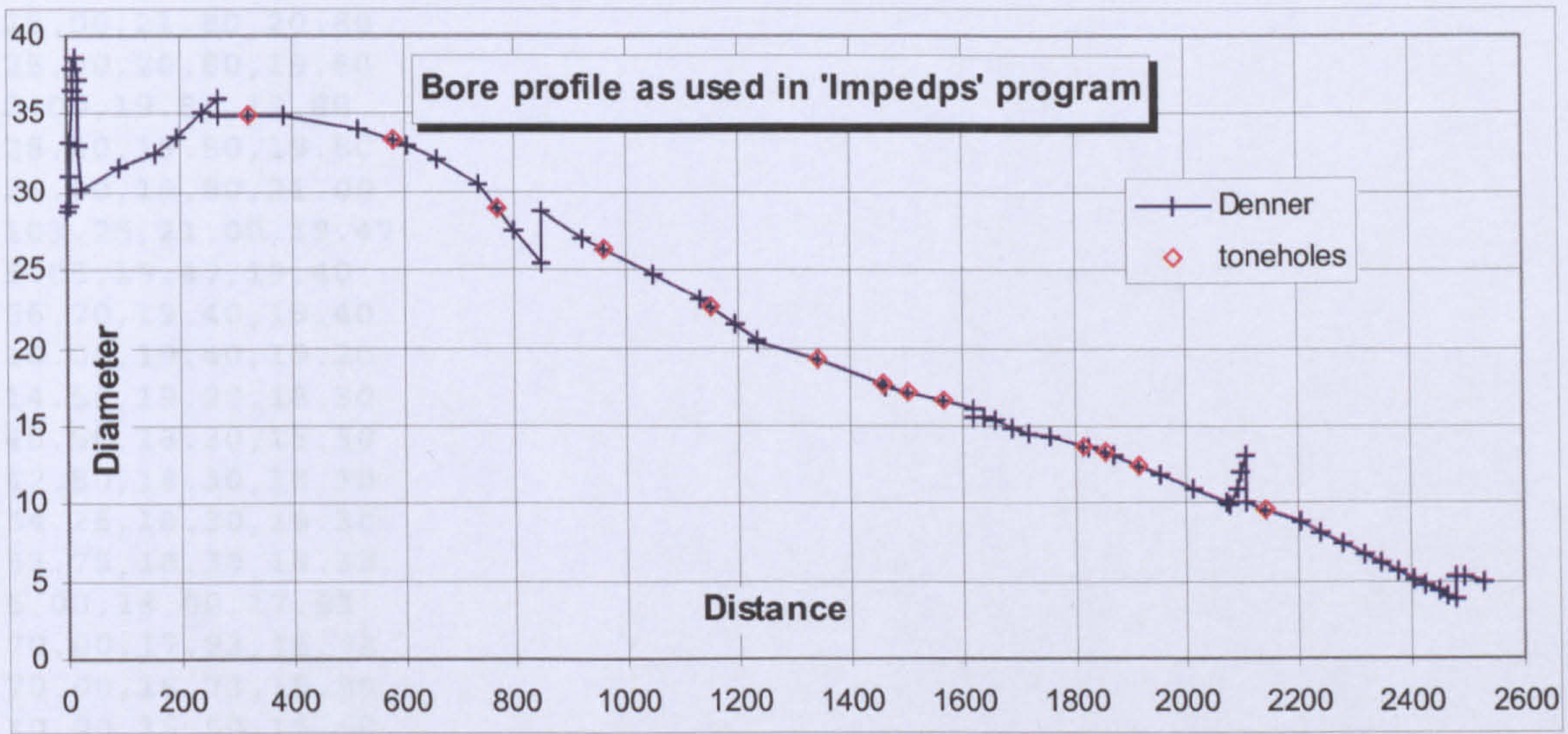
From:
Horman Hiers
Neuester Grundris der Stædte London und West-Münster,
Nuremberg 1736.

Workplaces of some 18th century woodwind instrument makers shown.

Appendix 5

Bore profiles and data files used for impedance calculations





<u>Data file format</u>

Line 1: Title.
Line 2: Units: IN, MM or CM; number of bore segments; number of holes; bore diameter at the end of the bell joint; outside diameter at the end of the bell joint; effective diameter of the half-hole.
Lines 3 to 77 (Poerschman file), 3 to 72 (Denner file): Bore segments starting from the bell end: Length of segment; bore diameter farther from reed; bore diameter closer to reed. The last two segments represent the actual volume of the reed.

Lines 78 to 90 (Poerschman), 73 to 85 (Denner): Toneholes.
Name of hole or key; O or C for Open or Closed standing; diameter of the hole; height of the open key (0 if no key); diameter of the key pad (ditto); length of the tonehole; bore segment on which hole located; outside diameter at the hole location; hole edge radius (a small number indicating if the edge of the hole is rounded off; it cannot be used to indicate undercutting).

Poerschman data

```
Poerschman as made, W12345, M3
MM 74,13,26.4,52.0,1.5
24.00,26.40,25.40
54.00,25.40,26.35
97.00,26.35,27.65
11.00,27.65,28.30
58.00,28.30,29.30
20.00,31.65,31.30
111.85,31.30,29.33
58.15,29.33,28.30
16.25,28.30,27.65
33.75,27.65,27.65
96.70,27.65,26.39
3.30,26.39,26.35
100.00,26.35,24.65
23.00,24.65,23.50
63.40,23.50,23.50
64.00,23.50,23.50
90.05,23.70,22.32
34.37,22.32,21.80
119.38,21.80,21.80
25.00,21.80,20.80
25.00,20.80,19.80
2.00,19.80,19.80
28.00,19.80,19.80
26.00,19.80,21.00
103.25,21.00,19.47
5.05,19.47,19.40
56.70,19.40,19.40
10.00,19.40,19.20
14.50,19.20,18.30
40.50,18.30,18.30
42.50,18.30,18.30
54.25,18.30,18.30
53.75,18.30,18.30
5.00,18.00,17.93
70.00,17.93,16.73
70.00,16.73,15.50
10.00,15.50,15.50
20.00,15.50,15.40
17.25,15.40,15.05
43.50,15.05,14.16
27.25,14.16,13.60
27.25,13.60,13.60
9.75,13.60,13.60
5.00,13.60,13.30
5.00,13.30,12.60
25.00,12.60,12.50
10.00,12.50,12.30
20.00,12.30,12.30
10.00,12.30,12.20
10.00,12.20,11.80
10.00,11.80,11.80
10.00,11.80,11.75
20.00,11.75,11.40
10.00,11.40,11.35
30.00,11.35,10.60
31.80,10.60,9.65
3.00,9.65,10.60
3.00,10.60,11.60
4.00,11.60,12.60
35.00,9.68,9.40
```

```
89.00,9.40,8.65
38.00,8.65,8.03
38.00,8.03,7.42
38.00,7.42,6.80
18.00,6.80,6.42
18.00,6.42,6.04
18.00,6.04,5.66
18.00,5.66,5.28
18.00,5.28,4.90
14.00,4.90,4.57
14.00,4.57,4.23
14.00,4.23,3.90
17.50,5.20,5.20
33.00,5.20,4.95
XI        O 10.00,6.50,25.00,3.00,7,44.00,0.25
X         O 9.80,0.00,0.00,3.00,11,40.50,0.25
IX        O 11.00,6.50,25.00,3.00,15,40.00,0.25
VIII      O 9.00,0.00,0.00,17.00,17,70.00,0.25
VII       O 9.20,6.00,25.00,15.50,22,68.00,0.25
Ab        C 5.20,6.00,16.60,11.00,25,68.00,0.25
VI        O 5.50,0.00,0.00,23.00,30,68.00,0.25
V         O 6.50,0.00,0.00,21.00,31,69.00,0.25
IV        O 6.90,0.00,0.00,23.00,32,70.00,0.25
III       O 5.00,0.00,0.00,26.00,39,56.00,0.25
II        O 5.50,0.00,0.00,24.00,40,56.20,0.25
I         O 5.00,0.00,0.00,25.50,42,57.20,0.25
P         C 0.25,0.00,0.00,0.70,60,10.70,0.05
```

Denner data

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MD DENNER with bell chamber, p/hole closed.
MM 69,13,28.8,32.0,1.2
3.50,28.80,29.00
1.40,29.00,31.00
1.40,31.00,33.15
2.30,33.15,36.40
2.20,36.40,37.95
3.30,37.95,38.60
3.50,38.60,37.25
1.50,37.25,35.90
2.90,35.90,33.00
2.10,33.00,30.10
69.50,30.10,31.50
64.00,31.50,32.50
40.00,32.50,33.50
42.00,33.50,35.00
28.00,35.00,35.90
54.00,34.90,34.90
66.00,34.90,34.90
130.00,34.90,34.00
63.20,34.00,33.28
24.80,33.28,33.00
55.50,33.00,32.00
73.00,32.00,30.50
33.50,30.50,28.98
32.00,28.98,27.53
48.00,27.53,25.35
73.00,28.70,27.00
40.00,27.00,26.25
87.00,26.25,24.60
85.00,24.60,23.00
18.00,23.00,22.55
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42.00,22.55,21.50
43.50,21.50,20.41
107.50,20.20,19.25
116.40,19.25,17.55
3.60,17.55,17.50
39.40,17.50,17.12
63.30,17.12,16.52
55.30,16.52,16.00
19.50,15.50,15.50
20.50,15.50,15.25
30.00,15.25,14.75
25.00,14.75,14.50
40.00,14.50,14.25
60.00,14.25,13.60
9.00,13.60,13.50
30.70,13.50,13.17
15.30,13.17,13.00
44.00,13.00,12.34
36.00,12.34,11.80
60.00,11.80,10.90
60.00,10.90,10.00
6.00,10.00,9.90
15.50,9.90,11.00
3.50,11.00,12.00
9.50,12.00,13.00
34.00,10.00,9.58
62.00,9.58,8.80
36.00,8.80,8.14
40.00,8.14,7.41
36.00,7.41,6.76
33.00,6.76,6.15
30.00,6.15,5.61
25.00,5.61,5.15
22.00,5.15,4.75
22.00,4.75,4.35
19.00,4.35,4.00
11.00,4.00,3.80
17.50,5.20,5.20
33.00,5.20,4.95
XI        O 11.45,5.00,21.00,5.00,16,46.50,0.25
X         O 8.65,0.00,0.00,4.11,19,41.50,0.25
IX        O 8.90,5.00,21.00,4.74,23,37.00,0.25
VIII      O 8.20,0.00,0.00,18.80,27,66.50,0.25
VII       O 11.50,5.00,21.00,16.50,30,62.30,0.25
Ab        C 4.00,3.00,14.00,10.75,33,62.30,0.15
VI        O 5.20,0.00,0.00,24.00,34,65.20,0.15
V         O 6.00,0.00,0.00,24.00,36,66.00,0.15
IV        O 7.00,0.00,0.00,26.00,37,67.00,0.15
III       O 4.60,0.00,0.00,27.60,44,40.00,0.15
II        O 5.20,0.00,0.00,25.0,46,40.00,0.15
I         O 5.20,0.00,0.00,25.6,48,40.00,0.15
P         C 0.25,5.00,5.00,0.70,56,11.00,0.1
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