This Document is an English version of my 2006 article:

Einblick in die Blockflöten des Kunsthistorischen Museums Wien aus der Perspektive des Blockflötenbauers. In *Die Renaissanceblockflöten der Sammlung Alter Musikinstrumente des Kunsthistorischen Museums*, Ed. Beatrix Darmstädter, Vienna: Edititon Skira. 97–121.

It is meant to compliment the published catalogue which is available from the Kunsthistorisches Museum shop and therefore all the illustrations have been removed.

An Insight inside the Recorders of the Vienna Kunsthistorisches Museum: The recorder maker's perspective

The collection of recorders in the Vienna Kunsthistorisches museum, containing as it does the largest single number of surviving renaissance recorders presents a unique resource for both makers and players.
Shortly after the start of this measuring project, it became evident that the profiles of some of the recorder bores were not as had been expected. Several bores showed the long cylindrical upper sections and sharply tapered foot sections that up to that point had only been associated with the Rafi recorders in Bologna. Other outwardly similar instruments had wildly differing bore profiles and tone hole positions, where common wisdom would have suggested a closer match. There was an immediate temptation to try to place the instruments speculatively in their original configuration, or consort sets, as certain constructional details can often indicate like craftsmen or workshops and thus whether similar instruments share a common origin. Factors such as the shape of the window, the carving of the labium, the drilling of the tone holes and the form of the keys and other metal parts, all help to identify and place renaissance recorders. In trying to find the original specification of a consort, it is perhaps possible to understand much more about the performing practice associated with these instruments, but even with 43 instruments and 4 original cases to hand, the possibilities are limited and the results must necessarily remain speculative.

The bore profile

The shape of the bore of renaissance recorders has been misrepresented in the past. The term 'wide bored renaissance recorders' has been used along with the term 'choked' to describe a variety of different bores, often without further explanation.[1]
The bore shape and the relative position of the tone holes are probably the most important features deciding the qualities of the resulting recorder. The fingering, the sound quality and the tuning will all depend to some extent on the design of the bore and the accuracy to which it was finely adjusted during the making process.[2]
The simplest form of bore, one with a cylindrical or near-cylindrical profile, works well enough for small instruments, but any recorder made in this fashion that is larger than an alto size, will tend to have narrow octave relationships and a difficulty in tuning the basic scale. This is because in a cylindrically bored recorder, any tuning adjustments have to be done using the tone holes alone, and there is a physical limit to both the position of these holes and their size. Although some compensation can be made by placing all the tone holes further down the instrument, the possibilities of adjusting their positions relative to one another are limited. The player, after all, will have to be able to cover these with his fingers, and this physical limit of both stretch

[1] Whilst it is clear to the author that the term 'choke' is purely a descriptive term attached to the kind of contractions found in recorder bores, the term 'choked bore' can be misleading if used without further qualification.
[2] For an understanding of the acoustical results obtained from different bore types see Lerch 1996, ...pages 58-70.....

and diameter will always be reached before they can be placed in their acoustically correct positions.
Any bore that is a deviation from a perfect cylinder would have been made with certain objectives in mind, and foremost here would be the construction of larger recorders. A bore that tapers over the section where the tone holes are placed will allow for more control in tuning adjustments and enable the tone holes to be positioned in groups, and thus within the reach of an average player. A tapered bore will also produce a greater acoustical end-correction and thus allow an instrument to be made correspondingly shorter, for a given pitch.[3]
Some bores were evidently designed to enable the instrument to play with a wider range, or to favour certain fingerings in the high register. Ganassi, as early as 1535 found that certain recorders could be coaxed into playing an extra octave in the high register and gave several alternative fingerings for these notes.[4] It seems clear from his text that these fingerings were his own discovery on his part, rather than any design on the part of instrument makers. With some instruments, however, there does seem to have been a decision made to favour an extended range in the high register, often at the expense of the strength of the lower notes.

Construction and Terminology

The inner bore of a renaissance recorder is more varied than one would think. The plain exterior and minimal decoration afforded to most instruments of this time belie the complexities involved in the acoustically important bore profile, and some simple descriptions are necessary as a basic requirement to any study. It must be remembered that it is not only the shape of the bore that is important to the acoustical properties of an instrument, but also the actual bore diameters in relation to the overall sounding length of the instrument.
To map the basic layout of the bore, two numerical values can be considered important in the first analysis:
Firstly, the change in diameter between the maximum bore diameter and the minimum can be expressed as a fraction and indicates the degree of contraction present in the bore. To simplify here: a small figure indicates a large difference between the maximum and minimum bore. In the following sections this fraction has been given the abbreviation d_{min}/d_{max}, and its value varies between about 0.6 and 0.96. Variations in this figure are seen not only between different sizes of recorder, but also between different bore types.
Secondly, the value between the speaking length of the recorder divided by the maximum diameter can give an idea of the basic layout of the instrument. A narrower bore, which would be indicated by a smaller fraction, will produce an instrument richer in harmonics and more willing to over-blow. Again, this ratio has been abbreviated to SL/d_{max} (This is the speaking length of the instrument, divided by the maximum bore diameter) and its value varies between 1/30 for a very narrow-bored 1/16 for a rather wide-bored instrument.

[3] Whilst a discussion of basic acoustical theory is necessarily outside the scope of this article, the reader is advised to refer to publications such as Benade 1976, chapters 21-22 (pages 430-504 of the Oxford University Press edition, New York, 1976)..
[4] Ganassi 1535, ... chapter?..”modo che isegna far » and « le settevoce de pui ».these are Pages 32 and 33 of the modern Hortus Musicus edition, (Rome 1991)

Bore Profiles

Concerning the shape, or profile, of the bore, it is necessary to start by suggesting some terms and descriptions that help to classify the wide variety of bore profiles found on these instruments.

For practical purposes, the bore of a renaissance recorder can be represented by the following figure. On this and all subsequent graphs, the vertical axis represents the diameter of the bore, expressed in millimetres. The horizontal axis represents the length of the instrument again in millimetres. The scale of the vertical axis has been exaggerated by a factor of one to ten, to give a clearer indication of small changes in the bore diameter. The small triangles represent the positions of the tone holes along the bore and the two traces indicate different longitudinal sections of the bore. Two traces are made to indicate the degree of ellipticity in the bore. Put simply, when the two traces show little difference between them, this would indicate a bore that is concentric, and thus little changed with the passage of time. A larger difference between the two traces would indicate a bore that has gone elliptical, since being made, a process mostly caused by wood shrinkage.

It is possible to divide a bore longitudinally into the following three sections as shown in the figure below, which represents the bore and tone hole positions of the soprano-sized recorder, inventory number SAM 131

Figure 1: Graph representing the bore of SAM 131, showing the bore divided into sections.

1. Head, the part between the blockline and around the first tone hole.
2. Middle, between the thumb tone hole **(x)** and the 7th tone hole.
3. Bell, between the 7th tone hole and the end of the recorder.

In practice these sections are not always of the same proportions, and the points at which they meet will vary in position, even between like instruments sharing a similar bore profile. To clarify matters further, it is necessary to explain the typical shapes found in the individual bore sections described above, so that an attempt can subsequently be made to describe the different types of bore profiles.

Figure 2: Chart showing various shapes found in the sections of renaissance recorder bores.

- *Cylindrical*
- *Concavous*, or having a once-cylindrical portion that has been hollowed out, or 'chambered' to a barrel-shaped larger diameter
- *Conical,* or tapered, (contracting from the blowing end)
- *Obconic*, or inversely conical, (expanding from the blowing end)
- *Contra-Campanulous*, or consisting of a parabolic cone, in which the straight conical shape takes on a concave form increasing in steepness
- *Campanulous*, bell shaped, or concavely obconic; opposite of Contra-Campanulous
- *Buccinatory*, or trumpet shaped

In addition the adjectives 'flat' and 'steep' will be used to approximately indicate the degree of taper, or contraction in a given shape.

By matching the previously indicated sections of a given recorder bore with the descriptions of their shapes, the following table of possibilities can be produced:

1. Head	a. Cylindrical b. Concavous c. Conical
2. Middle	a. Cylindrical b. Conical c. Contra-Campanulous
3. Foot	a. Cylindrical b. Obconic (inversely conical - expanding) c. Buccinatory (trumpet shaped) d. Campanulous (bell shaped)

Most renaissance recorder bores, even those with an almost cylindrical profile, have their minimum bore diameter at the point where the middle and bell sections meet, at a position near to, or around the 7th tone hole.

The shapes presented above can be found in many different proportions, with differing rates of taper. Often shapes are combined, particularly on the long middle section, which encompasses the tone holes. Here several differing shapes can often be found, each having different rates of taper. Whilst no studies have been made to test the acoustical differences between, for example, a recorder having a conical middle section and an otherwise identical instrument having a contra-campanulous middle section, it is nonetheless important to record such details. These could indicate perhaps the type of tool used, or that a certain section of bore was modified to tune certain intervals. The importance is in the combination of these shapes at different parts of the bore, and the way they interact to create an interdependent system.[5]

Rather than to explain the individual complexity of specific instruments, an attempt will be made to classify the bores into certain 'types'. As with all classification, there is always a danger of types overlapping and forming subtypes, which add to rather than diminish the complexity. For this reason, and to simplify the explanation about the workings of the bore, the present study has limited the number of bore types to three.

Before moving on to some description of these bore types, some explanation is necessary of the function of tone holes, which work as an independent, yet closely linked system from that of the bore.

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[5] Very little is known about the types of tool used to form the bore of woodwind instruments. An examination of the bore surface will often reveal steps in the profile, made by the use of consecutive tools. These tools, probably used on the majority of surviving instruments, would have been variations on the single cutting edge reamer, or spoon auger and probably represented as such, the most valuable pieces of equipment in the contemporary makers workshop. There is evidence that the same reamers were sometimes used on instruments of different pitches, and that the bore was in these cases 'stretched' to a lower pitch, presumably to save the effort and expense of having a separate set of reamers (see figure 29 in the appendix). Tools like these are pictured in Diderot/d'Alembert 1751, *Outils propres à la Facture des Instruments à vent,* table X. and may well represent the sort of technology already available in the 16th century. Mention must also be made to the technique of turning-, or scraping-out the bore of the instrument, using special tools. This technique has particular advantages over the reamer technique, in that it is able to produce concavous, or 'barrel' shapes. See the section on chambering below, and Lerch 2002, 104- 113 **too?]** See also: Lerch/Weber 1995, 14-24

Tone hole placement and sizes

The bore does not work in isolation from the system of tone holes, which in itself is responsible for certain characteristics of the instrument's performance. As stated earlier, the tone holes must lie within the reach of the player, and this implies that on larger instruments, the provision of a key is necessary to cover the lowest hole, which would otherwise be positioned too far away from the player's hand. As keys were, and still are, an expensive part to produce for any woodwind instrument, they were always kept to the barest minimum in number. Whilst double-bored columnar and extended bass recorders typically had four keys to cover the lowest tone holes, there is no evidence to suggest that even the largest un-extended great-bass sizes ever used more than one key to cover their tone holes.[6]

It is easiest to express the position of tone holes on the recorder as a percentage of the instrument's speaking length, measured from the block line.

On a small recorder, the tone holes are evenly spaced along its length, between the thumbhole, which is typically positioned at a spot around 30%, and the lowest hole, (or holes), placed at around 80% of the speaking length.[7] For the physical ease of the player, the tone holes of larger recorders are placed into an upper and lower group. The upper group comprises the thumbhole and holes 1, 2 and 3, and the lower group, holes 4, 5, 6 and 7. Usually holes **x,** 1, 4 and 7 are drilled in proportionally similar places on all sizes of recorders, and the lower two holes of each group consequently have to be smaller in diameter and placed higher on the instrument to compensate for their acoustically incorrect position. One exception concerns instruments of a tenor size, without key.[8] With these recorders, the 7th tone hole often has to be higher on the instrument, at a position of around 75% of the speaking length, in order to fall within comfortable reach of the little finger.

Overall position of the tone hole system

Whilst the percentages given in the previous paragraph are true for the majority of renaissance recorders, a number of exceptions can be found where the general position of the whole tone hole schema can be found further down the instrument. This is largely due to the type of bore, and the degree of cylindricality involved. The more cylindrical a bore is, the lower the general position of the tone holes will tend to be, often accompanied by larger diameter holes as a result. In those instances in which one group or the other is placed lower or higher than expected, an examination of the bore will often reveal signs suggesting why this is so.

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[6] Examples of double-bored columnar recorders are found in the Musée de la Musique, Paris. Inventory numbers E.127 and E.691. Examples of extended bass recorders are in the Vleeshuis Antwerp, inventory number 134(VH2111), the Bayerisches Nationalmuseum, Munich, inventory number 180/43, the Accademia Filarmonica, Verona, inventory number 13.249 and Museo degli strumenti musicali, Rome, inventory number 719. Modern reproductions of the larger sizes of renaissance recorders are often equipped with keys to cover tone holes 3 and 4. Whilst this might well be seen as an admirable principal, allowing players with small hands to tackle these large instruments, as stated here, there is no historical precedent for this practice. Likewise, the modern practise of using a joint to split the upper section of the instrument in two, so that these large instruments are more convenient to transport, could be seen in the same context.

[7] The lowest hole, or holes are normally referred to as tone hole 7. On a small un-keyed instrument, this hole is typically duplicated (in order to serve both right and left handed players), the unused hole of the pair having been sealed with wax. On a larger instrument, tone hole 7 is the hole covered by the key.

[8] Recorders having a speaking length greater than approximately 600 mm will normally need to have a key for tone hole 7.

Figure 3: Chart showing the relative tone hole positions of the recorders in the collection.

The above chart shows the position of the tone holes of all the instruments in the collection, relative to their speaking length. The number 1 in the left hand axis represents the end of the recorder, whilst 0 shows the block line, or the point just below the block. They are arranged in order of their lengths, with the smallest instrument to the left and the largest to the right. The chart shows clearly the transition between the more evenly spaced tone holes found on the small sizes, to the two groups of four holes in the middle sizes, before leading finally to the two distinctly separated groups and lone key-hole as found on the largest instruments. Note the rather low position of the tone hole system on instruments SAM 133, 140 and 148.

Different bore types

It is possible to define three different types of bore amongst the recorders in the collection, which are representative of the bore types found in all of the surviving examples. Whilst it might well be possible to divide these three basic types into further sub types, this has been resisted in an attempt to clarify the subject. The criteria for classification is largely based upon the features defined in the previous sections, but also by taking into account the musical properties that these physical differences imply.

1. Typical 'Conical' Bores

Figure 4: Graph representing the bore of SAM 131.

Using the terminology previously outlined, it is possible to describe a bore such as that of SAM 131 shown above, as follows:

1. Head a. Cylindrical
2. Middle b. Conical, with two clear conical shapes separated by a short, cylindrical portion
3. Bell d. Companulous

d_{min}/d_{max}, (Minimum/Maximum bore diameter): 0.76
SL/d_{max} (Speaking length/Maximum bore diameter): 1/18
Tone holes from block line in relation to SL: 32%, 35%, 42.5%, 49.5%, 58%, 65%, 73% and 81%

This first bore profile type accounts for the great majority of surviving instruments and produces an instrument having a sound strong in 1st and 3rd partials[9], that is ideally suited to the vocal character of renaissance polyphony. In addition, the possibility of making large sizes of recorder with this type of bore gave a potential range of around four octaves over the surviving sizes of instrument, each of which would have had an individual range of around an octave and a minor seventh. This first bore type can be best represented by comparing this first example with the following two instruments. With larger recorders the bore has a tendency to be slenderer, shown by the SL/**d** ratio often having a smaller value. The relationship between the maximum and minimum

[9] Harmonic series: The term 1st partial means the fundamental frequency of a given note, the 2nd partial indicates its harmonic, or octave, the 3rd partial, its second harmonic, or twelfth and so on.

bore diameters does not seem to change much in function to the size of the instrument, and this type of bore can have a d_{min}/d_{max} value anywhere in the range of 60 to 85%.

Using the graph of SAM 159 shown below, it is possible to draw up the following schema:

Figure 5: Graph representing the bore of SAM 159.

1. Head	a. Cylindrical, or perhaps very slightly b. Concavous
2. Middle	b. Conical, with three separate conical shapes
3. Bell	b. Obconic

d_{min}/d_{max}: 0.77
SL/d_{max} (Speaking length/Maximum bore diameter): 1/25
Tone holes from block line in relation to SL: 31%, 33%, 38%, 43%, 55%, 61%, 66% & 79%

This bore graph shows a recorder in good condition, having a bore that is highly circular, indicated by the closeness of the two traces of the bore profile. It can be seen that they never deviate by more than 0.3 mm, except in the head section, which shows a slight widening between 140 and 220 mm from the top of the bore. This section, slightly concavous in the longitudinal sense, with an elliptical cross-section, in a bore that is otherwise circular, could well indicate some sort of last-minute adjustment on the part of the maker.[10] The middle section of this bore has a conical region running between 260 and 325 mm from the top, a second, longer conical region between 365 and 480 mm and a third flatter region between 480 and 605 mm. These three conical regions have been adjusted as necessary by the maker to tune the octave relationships of the recorder. The foot section has an obconic profile, again with a slightly oval tendency in the cross-section.

Note that, whilst the value for d_{min}/d_{max} is almost the same as that of SAM 131, the value of SL/d_{max} is smaller, showing that the bore overall is proportionally narrower. Despite the fact that this instrument has a key, and that tone holes 2, 3, 5 and 6 are therefore much further up the instrument than was the case for SAM 131, the overall shape of the bore and its basic function with regard to the instrument's character remains very similar.

As stated earlier, one advantage of using a conical rather than a cylindrical bore on recorders is that the instrument can be made shorter for any given pitch. The value of d_{min}/d_{max} and the degree of taper of the conical middle section will determine both the pitch of the lowest note and the ability of the instrument to play above the standard renaissance range of an octave and a sixth. A cylindrically bored recorder in the same pitch as SAM 159 would have to be considerably longer and have much larger and wider spaced tone holes.

Turning now to a tenor sized instrument inventory number SAM 150, having a similar bore profile, the following description can be produced:

Figure 6: Graph representing the bore of SAM 150.

1. Head	a. Concavous
2. Middle	b. Contra-Campanulous, with two clear sections
3. Bell	b. Flat obconic

d_{min}/d_{max}: 84%

[10] See the section 'chambering' below.

SL/d_{max}: 1/22
Tone holes from block line in relation to SL: 33%, 36.5%, 43%, 49%, 59%, 65%, 71% & 77%

Again an example of a well-preserved recorder, this time made from boxwood, a material not known for its dimensional stability.[11] Despite this, the bore is highly circular, with the difference between traces less than 0.3 mm over the major part of the bore.
This instrument represents almost a sub-type of conically bored recorders, in that this size of instrument is probably the largest that can be made without resorting to a key. Consequently tone hole 7 is quite high up the instrument at 77%, a compromise position to position it well within the range of the small finger of the lower hand. The point at which the foot and the middle sections meet is also quite high on this instrument, and is found between tone holes 6 and 7. Two contra-campanulous profiles are clearly visible in the middle section, showing how short shapes within a bore section can be manipulated independently to achieve a certain desired effect on the tuning. The foot section has quite a flat obconic profile, probably to compensate for the high position both of tone hole 7 and the minimum bore diameter.

Step bores

This is a type of bore that with some variations is found on about 18% of all surviving renaissance recorders is represented by several of the Vienna collection's instruments, namely, SAM 128, 130, 133, 140 148, and 691. Outside of the collection, this bore type is to be found in all the surviving recorders made by the Rafi family, in some by H. F. Kynseker and in other anonymous examples.[12] The term 'step' indicates the large, abrupt diameter change between the middle and foot sections, presenting as such a marked difference from the previously described bore type.

Figure 7: Graph representing the bore of SAM 148.

Head a. Cylindrical
Middle a. Cylindrical / b. steeply conic
Bell a. Narrowly Cylindrical
d_{min}/d_{max}: 0.77

[11] Although boxwood is a much loved wood by both makers and players of woodwind instruments, it does have a distinct drawback being highly sensitive to both humidity and temperature changes, leading one commentator to state: *The tone of a boxwood flute is not surpassed in its sweetness, but no reliance whatever can be placed on this material as it absorbs moisture so readily that the bore of any wind instrument made of it is liable to continual change in its dimensions.Cornelius Ward (1844), formerly an eminent London flute-maker and a good authority on the subject, said that it was more fitted for the construction of a hygrometer than of a wind instrument.* Rockstro 1890, Chapter XI section 312..(or.page 141 of the Musica Rara edition, London, 1967.)... The preference historically for this material is probably due to its properties of denseness, its surface quality when drilled and turned and its tendency to bend rather than crack under the effect of the climatic changes mentioned above. See also: Weber 2002, 95-103
[12] Recorders by Rafi, Accademia Filarmonica of Bologna, inventory numbers: 599 and 602. Eisenach, Bachhaus inventory number: 1-100. Recorders by P. Grece, (presumably later copies of those by Rafi) Accademia Filarmonica of Bologna, inventory numbers: 595, 596, 597, 598, 600, 601, 603, 604 and 605. Recorders by Hieronimus Franciscus Kynseker in the Germanisches Nationalmuseum, Nuremberg, inventory numbers: MI 100, MI 101, MI 102 and MI 103. Other examples of recorders with this type of bore include an anonymous instrument, Paris, Musée de la Musique, inventory number: E.980.2.85 and an instrument stamped 'Valiani', Leipzig, Musikinstrumenten-Museum inventory number 1134.

SL/d_{max}: 1/23
Tone holes from block line: 37%, 39%, 46%, 54%, 64%, 70%, 77% & 83%

The graph above represents the bore of SAM 148, a tenor-sized recorder. This instrument has a head and middle section that are largely cylindrical, with a steep conical portion linking the lower middle and the foot section. The general position of the tone hole system is very low. Consequently, the diameter of the holes, is larger than those found on similar instruments having the conical-type bores described in the previous section. A result of this arrangement is that generally instruments with stepped bores will play with a larger range than the renaissance recorders having the more typical ‘conical’ bores described in the preceding section. This larger range concerns principally the notes XIV and XV, which closely follow those given in the 1556 treatise of Jambe de Fer. These fingerings could almost be described as the earliest reference to ‘baroque’ fingerings, for producing these notes, being given as: x/12-456- for note XIV and x/1--456- for note XV. These differ from the fingerings given in the earlier treatises, in that they use the 3rd partial, or twelfth of note II, which is then sharpened by half opening hole 2 in the case of note XIV and by completely opening hole 2 in the case of note XV.
Ganassi and Agricola give note XIV as x/1-----7, which is the second partial, or octave of note VII. Ganassi gives note XV as x/1234567, which is the forth partial, or double octave of note I, and seems to prefer this to the fingering x/1---5--, which he gives as alternative, and which uses the sharpened 3rd partial of note III.[13] The tag ‘pre-baroque’ is often applied today to any recorder showing an extended range, baroque turnery, or other distinguishing feature. It should be understood from the above, however, that there is evidence as early as 1529, in the case of Agricola, and 1535 in the case of Ganassi, of fingerings giving an extended range. Taking into account that the Kynseker recorders, which share both this bore type and the extended range, are instruments plainly from the latter half of the 17th century, there is consequently no evidence to suggest that recorders can be dated purely on their ability to play into the recorder’s high range, or on their bore profiles.

Figure 8: Extract from the fingering table given by Jambe de Fer showing the highest notes of a recorder.

3. Cylindrical, or Shallow Tapered Bores

Few instruments could be described as wholly cylindrical; even the most cylindrical of the recorders in the Kunsthistorisches Museum still has a d_{min}/d_{max} value of 97%. This term therefore, has been given to recorders whose bores follow a cylindrical form, but lack the step between the middle and foot sections, common to the bores covered in the previous section, or to bores having a very flat taper between largely cylindrical sections. They are in general, for the reasons outlined previously, necessarily small instruments, although some larger instruments (for instance, SAM 624), do provide exceptions. In nearly every case, however, there will be a slight deviation from the perfect cylinder, but their playing characteristics will remain largely the same as that of a cylindrically bored instrument. Often a cylindrical bore will terminate at the bell

[13] The fingering x/1---5--, found in the table of recorder fingerings having the instrument marked with a B, has often been overlooked by modern commentators. While it is true that this fingering only appears once in the tables, as opposed the fingering x/1234567, which appears three times, it does nonetheless show the variant behaviour of the instruments Ganassi had to hand.

section with a buccinatory, or trumpet-shaped, shape, a feature, which as many authors have noted, gives the extra range of Ganassi described above.[14] This is indeed the case of the recorder SAM 363 in the Vienna collection.

Figure 9: Graph representing the bore of SAM 363.

Head a. Cylindrical
Middle b. Conic / a. narrow cylindrical
Bell a. Cylindrical / c. Buccinatory
d_{min}/d_{max}: 0.89
SL/d_{max}: 1/22
Tone holes from block line: 31%, 35%, 42%, 48%, 57%, 63%, 69% & 81%

Despite having been heavily modified at some point in its history, with a replacement key having been fitted and its bell modified into a clarinet-form, this instrument still plays remarkably well and is well in tune. This leads to the suspicion that the basic qualities of the instrument have not been changed radically, despite the cosmetic modifications.

As can be seen from the graph above, the head section is cylindrical, and the middle section starts with a slender conical portion running to around the 4th tone hole. The middle section then continues with a narrower, cylindrical portion pretty well through the foot to almost the end of the instrument, where the buccinatory form takes over. The large d_{min}/d_{max} value (not taking into account the extremity of the bell) at almost 90% accounts for placing this bore under this classification. This instrument is still able to play an extended upper range using fingerings given by Ganassi in his *Fontegara* (1535).

Other instruments in the Kunsthistorisches Museum collection that share this type of bore include SAM 135 and 138; with SAM 146, 147 and 624 also being possible contenders. The latter two, being largely unplayable are, however, difficult to evaluate in the high register.

Effects of the bore on tuning and note stability

Only a brief description of the action on the tuning by local changes to the bore is possible within these pages. Although a lot can be learned from acoustical theory, the effect upon the musical intervals by changes to the bore profile is best learned in practice, by mapping out the bore using pieces of plasticine and flexible wire. Differences in the pitch of each note are traced and noted on a chart of the bore profile, and thus show the effects of a local bore reduction at each point along the bore of the instrument. It can be learnt from basic acoustical theory that an expansion at a given point will have an exact opposite effect on the notes concerned, as a contraction at that same point. For each note, places will be found that influence one partial more than the other and often these places will correlate, so that for example the **1st** partial, or fundamental, will become flatter and its **2nd** partial, or octave, sharper.

The basic musical intervals of a recorder that can be changed by bore modification are as follows:

- The octave between notes III/X
- The octave between notes V/XII

[14] see Morgan 1982, ...page..14-21.. and Marvin 1978, 40-46.

- The octave between notes VI/XIII
- The octave between notes VII/XIV, where note XIV is fingered as x/1-----7 or variant, or:
- The twelfth between notes III/XIV, where note XIV is fingered as x/12-45-- or variant

Note: The octave between notes IV/XI and other fork-fingered notes can also be changed by modification to the bore, but in reality are tuned more effectively by the shade fingerings used.

The bore can be mapped out using the method described above and the information noted longitudinally on a bore graph of the instrument. In this way an overview of the effects of local bore expansions and contractions become apparent.
A typical example is shown in the following figure, obtained using a copy of SAM 166, a recorder falling under the conical category of bore profiles described above. The red bar lines show that the pitch of a given note, indicated to the left side of the chart, will rise when a contraction is effected at this point. The blue bar lines indicate the opposite, that the pitch will fall if there is a contraction at this point. The upper six bar series show the main octave relationships of the instrument and the lower four, the 2nd and 3rd partials of notes I and II. These are obtained by blowing these notes with increased pressure while leaking several of the tone holes and thus forcing the instrument to overblow to the next partial. While these particular partials have no musical use, these notes being found generally with other, more stable fingerings, they do have some influence on the stability and sound of the lowest notes, as remarked upon by Marvin.[15]

Figure 10: Graph of the bore of a bass recorder, showing areas of the bore affecting the tuning of the instrument.

As can be seen from the diagram, a reduction of the size of the bore at a point around the thumb-hole would have the effect of narrowing the main octave relationships described above, whilst altering the stability of notes I and II by flattening their 2nd and 3rd partials.
It also follows that an expansion at this point would have the exact opposite effect, widening the octaves and sharpening the second and third partials of notes I and II.

Similarly, a contraction around hole 6 of the instrument would have the effect of narrowing the octave between notes III and X and, interestingly, changing the harmonic patterns of notes I and II in opposing directions. Here a contraction would sharpen the second and third partials of note I, whilst flattening the same partials of note II. In this way, the above method can be used to find areas in the bore that affect the stability of certain notes, most often in the form of wolf notes, or burbles found on the low notes. The areas of the bore that will correct these problems usually lie in positions that also affect the musical intervals indicated above, and so the solution often becomes a large puzzle involving not only the bore, but also the tone hole sizes, undercutting and voicing. Some literature exists on this subject, and the reader is advised to consult these for a more thorough explanation.[16]

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[15] See Marvin,   Bob Marvin. "Recorders and English Flutes in European Collections." Galpin Society Journal XXV (1972): 30-57...

[16] See Marvin, GSJ, ...pages. 55-57 (whole article is pages 30-57).. above and Brown 1989, ...pages 19-38....

Tone hole diameters and their effects on tuning

Tone holes 3, 4, 5 and 6 also play a certain role in setting the octave relationships between notes III/X, IV/XI, V/XII and VI/XIII. On instruments with an extended range in the high register, and depending on the fingerings used, hole 6 will also affect the twelfth relationship III/XIV or hole 2 the octave VII/XIV. As a general acoustical principle, it could be stated that the diameter of a tone hole affects the octave, or 2nd partial of a note, more than the fundamental, or 1st partial. The position of a given hole, conversely affects the fundamental of a note, more than the octave. Any change in position or diameter of a tone hole necessarily has to take account of these factors. As stated previously, that portions of the bore also affect these harmonic relationships, it can be seen that any well-tuned instrument is a fine balance between these two interdependent systems. As a rule, it can be observed that :

- The larger the bore is in proportion to the speaking length, the larger the tone holes will be.
- The general position of the tone hole system as described earlier will also have an influence on tone hole size. The lower this system is on an instrument, the larger the tone holes have to be to bring the octave relationships into tune.
- The larger the instrument, the larger the tone holes will be, but the proportions here can be deceiving. The larger instruments do indeed have larger diameter tone holes, but their size difference is not in proportion to their increase in bore size. Again, there are physical constraints at work here, as the tone holes have to be covered and sealed by the fingers.[17]

Undercutting

The undercutting of tone holes was a common technique used on most renaissance woodwind instruments. Its function can be considered from two positions; firstly as an increase in the size of the tone hole itself, but perhaps more importantly, as a local expansion of the bore diameter. There is a huge difference between otherwise similar instruments, one whose tone holes are straight drilled and another having undercut holes. The latter will usually have a far richer and fuller sound than the former, the acoustical reasons for which have been outlined in various studies of musical acoustics. These reasons primarily concern the removal by undercutting of sharp edges from the air column, which would otherwise produce unwanted turbulence.[18]

A related feature is what has become to be known as 'overcutting'. This indicates the rounding off of the top edge of a given tone hole, a detail which is also found on practically all the recorders in the collection, but which varies greatly in size between instruments. The acoustical reasons for doing this remain largely the same as for undercutting the tone holes: it increases the richness and definition of the sound and also makes the instrument more pleasing to the touch.

The undercutting can also be performed in such a way as to angle the tone hole up or down the instrument. The reason for doing so is to allow the exterior of the hole to lie in a more comfortable position for the player. However, the large recorders in this collection do not show signs of the obliquely drilled tone holes often found on other surviving large-sized recorders, particularly tone holes 3 and 6. It seems rather that

[17] A maximum tone hole diameter of about 13 mm would appear to be the limit for most players.

18 See Benade 1976, above. ...pages 500-501...

these holes were made of a smaller diameter and drilled at an angle of 90° to the body, rather than being made a larger diameter and angled down the instrument as in the following picture:

figure 11: Verona, 13.243: detail of tone hole 6.

Where there is a bias to the undercutting, it is usually a question of one side of the tone hole being undercut and the opposite side being ‘overcut’.

Figure 12: Brussels, 1031: detail of tone hole 6.

The general shape of the undercutting can be said to follow a smooth profile similar to that shown by tone hole A in the figure below, that runs from the exterior, in a fairly perpendicular progression towards the inside of the instrument, obliquely flattening out towards the bore. In this way the action of the undercutting seems to have a bigger influence on the bore, than would be the case were the undercutting to be more conical as show by tone hole B, below. The surface quality of the inside of the tone holes is mostly very smooth and it is rare to find any tool marks, which could indicate the manner in which this work was achieved.

Figure 13: Section through the bore of an imaginary recorder, showing the profile of the tone hole undercutting.

Chambering

Often a bore will show signs that it has been chambered, or widened at a certain point to modify and adjust some aspect of the recorder’s behaviour. This is often done even by modern recorder makers who fine-tune their instruments by making some small adjustments to correct certain problems with the tuning or the stability of certain notes. Chambering refers to the scraping, or carving out, of part of the inside surface of the bore to a diameter that is larger than that at either end, giving a sort of barrel shape to a section of the bore profile. Most commonly this feature is found in the head section of the bore, at a point above the tone holes, and the manner in which this was accomplished is often reflected in the quality of the bore’s surface at this point. The form of these modifications can often be seen as a regular enlargement over the entire circumference of the modified portion of the bore. This would probably have been carried out by the introduction into the bore of a specially made, long handled reamer or auger, having a very keen edge and used to cleanly remove the material necessary for the requisite adjustment. In other cases, it seems to have been removed by turning out the bore surface using a kind of cutting head, running on a pilot hole, and adjusted to each diameter change by hand.[19] In the more modest cases, the material seems to have been removed using whichever tool was to hand, often with varying success and producing a very rough bore surface. Sometimes the chambering was given a definite bias towards one side of the instrument or the other, resulting in some very strange bore geometry. At least one instrument in the collection shows signs of chambering in more than one portion of the bore, the material perhaps having been removed in alternation - first to cure one problem and then to correct another, that perhaps itself was a result of the first modification. More often, however, the chambering can be

[19] See Lerch/Weber 1995 above.....page 20 (the whole article is pages 14-24)

seen to follow a logical pattern, with the goal of correcting typical problems concerning the tuning of octaves.

Figure 14: Comparison between the head section of the bores of three tenor recorders from the HIERS group: SAM 142, 143 and 144.

Many surviving recorders that play at the same pitch and share the same makers mark would seem to have been made to a pre-determined design or template.[20] This is however, not the case concerning the three tenor sized instruments from the HIERS group, SAM 142-144.
In the above figure, it can be seen that the two green traces, representing SAM 144, show a definite and deliberate chambering over the longitudinal region between 90 and 250 mm from the top of the bore. This modification of just over 0.5 mm on the bore diameter would be enough to drastically change the octave relationships of notes III/X, IV/XI, V/XII and VI/XIII and must be seen in the light of the different hole positions and sizes found on this instrument, compared to those of SAM 142 and 143.

SAM 138

Figure 15: Graph showing a section of the bore of SAM 138.

Perhaps the most irregular recorder bore in the collection, SAM 138, shows signs of chambering which are highly unusual. In this extract we can see an example of concentric chambering around tone hole 4 and an elliptical example below hole 7. Note how at this point the blue trace shows a much larger diameter than the red trace. The reasons for these modifications will perhaps never be known, unless an attempt were made to reproduce this instrument faithfully and then compare what happens when the bore is modified in this fashion. It has to be said that this instrument falls into a class of its own in terms of bore profile, and as such represents an atypical method of construction.

Some Bore Comparisons

SAM 164 and Verona Accademia Filarmonica 13250-4

These instruments are highly interesting to compare due to their similar makers' mark, which is a variation of the commonly found **!!** stamp, and their pitch, which is around modern f#.[21] A comparison of their full-length bores can be found in figure 26, but this extract compares the area around the tone holes of the instruments:

Figure 16: An extract of a graph comparing SAM 164 with similar recorders in Verona, 13250-4.

The blue colours in this graph represent the bore traces and tone hole positions of SAM 164. The bore traces are clearly well within the average made by the Verona

[20] The most spectacular example of this tendency concerns 5 tenor-sized recorders in the museums of Berlin, Brussels and Frankfurt that bear the makers mark HD. Their tone hole positions, when expressed as a percentage of their speaking length, never deviate from one other by more than 0.5%.
[21] The author has taken a conservative view and only referred to the mark commonly know as 'rabbit's foot' as !!. He acknowledges that there are strong connections between the mark, which is found in more than 57 varieties on a vast number of different types of Renaissance woodwinds, and the Bassano family in Venice and London. See especially Lasocki/Prior 1995, chapter 12; and Lyndon-Jones [now Kilbey] 1999, 243–280.

instruments, and its tone hole positions, although slightly higher in comparison, are never more than about 5mm from those of the nearest Verona examples.
The yellow traces represent Verona 13254, which is a slightly smaller instrument pitched around a quartertone higher than the other instruments on this graph and bearing a different variation of the **!!** stamp from that found on Verona 13250-3.[22] The tone holes of this instrument are accordingly placed higher up the bore, and the bore diameter itself, although sharing the same rate of taper, is of a slightly smaller diameter.
The purple and pink traces, which show a consistently larger bore diameter, are those from Verona 13253 and represent a good example of an instrument that was re-worked in the latter stages of its manufacture, presumably to improve its tuning or get rid of certain instabilities. Unfortunately, during recent tests, its tuning was found to be the worst of the group of recorders 13250-3, and so in this case the subsequent modification would seem to have been to no avail.[23]
The point to be drawn from this comparison is that despite their different origins and the variations in their makers marks, all these recorders were probably made using the same reamers. The rates of taper in all traces are extremely close and there are clear comparisons in the shapes, showing the same, or similar, curves. Take for example the blue traces representing SAM 164 between the length axis values of 390 and 490 mm: These can be seen to match the purple and pink traces of 13253 between 550 and 650 mm. Similarly, the brown traces representing 13252 between the lengths of 530 and 590 mm mimic the purple and pink traces of 13253 between 690 and 750 mm.

SAM 363 and SAM 150

The following graph shows two recorders that have been previously used in figures 6 and 9, as examples of different bore types and which also are marked with different versions of the !! stamp. The blue traces represent SAM 150 and the red traces, SAM 363. As was seen earlier, the lower sections of these two instruments have completely different bore profiles, but in the section here they show a remarkably similar tool usage, possibly even indicating that the same reamer was used.

Figure 17: An extract of a graph comparing the bores of SAM 363 and SAM 150.

SAM 136 and 145

These are the intriguing recorders, stamped with the motif of a crown. Due to modifications carried out in the past and in view of its current length, SAM 136 was described until quite recently as an alto recorder. However, upon closer view, it can be seen that this instrument met with disaster at some time in the past, the whole mouthpiece section was removed and a new windway and window carved on the opposite, thumbhole side. Indeed, traces of the original scored blockline, normally found just above the window, can be seen on an extreme part of the beak as well as a portion of the original ramp on the opposing side of the instrument. The scored line enables us to make an accurate measurement of the original speaking length and to compare this instrument with SAM 145, which shares a similar stamp.

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22 See: Van der Meer/Weber 1982, ...page 39-42..... There are unfortunately several typographical mistakes in this book, one of which exchanges the lowest notes of the pair of bass sizes, inventory numbers 13245 and 13246, (marked !!), with the shorter pair 13247 and 13248 (marked with a double trefoil).
23 Tests carried out by the author during a measuring visit to the Accademia Filarmonica in July 2003.

Figure 18: An extract of a graph comparing the bores of SAM 136 and SAM 145.

Red traces: SAM 136
Original SL: 500.5mm
Head a. Cylindrical
Middle c. Contra-Campanulous
Bell d. Campanulous
d_{min}/d_{max}: 0.91
SL/d_{max}: 1/22
Tone holes from original block line: 32.3%, 35.1%, 42.2%, 49.2%, 57.4%, 64.8%, 71.7% & 78.2%.

Blue Traces: SAM 145
SL: 498mm
Head a. Cylindrical
Middle c. Contra-Campanulous
Bell d. CampanulousNarrowly Cylindrical
d_{min}/d_{max}: 0.86
SL/d_{max}: 1/21
Tone holes from block line: 32.3%, 35.9%, 42.9%, 49.9%, 58.3%, 65.2%, 72.3% & 79.3%.

SAM 145 is very bent and the bore has become very oval in places. This can be seen on the bore profile represented by the blue traces on the above graph, which show a considerable discrepancy between tone holes 4 and 6, and also in the head section of the instrument. Despite this discrepancy, by comparing the bore profiles of both instruments on the same graph we can see that in the stable and circular foot sections a very similar shape is to be found, possibly even produced by the same reamer. The same applies for the position of the tone holes, which in proportion to the original speaking length, are within 1% of each other. The slightly different values of d_{min}/d_{max} and SL/d_{max} can be explained by the ovality of SAM 145 and its slightly larger maximum bore diameter, but the similarity in shape of both bores in the middle section, particularly between 340 and 440 mm from the top, again suggests the same tool was used. However, the similarity of the physical dimensions, the pitch and the use of the similar symbol as a brand mark may point to these instruments having come from the same workshop, if not the same maker.

SAM 169 and other great-bass recorders

Figure 19: A graph comparing the bore of SAM 169 with two great-bass recorders from Verona, 13242-3.

Red Traces: SAM 169
SL: 1692mm
Head a. Cylindrical
Middle a. Cylindrical / b. Conical
Bell b. obconic / a. cylindrical /c. Buccinatory
d_{min}/d_{max}: 0.75
SL/d_{max}: 1/29
Tone holes from block line: 32.3%, 34.6%, 37.4%, 39.5%, 56.2%, 59.0%, 61.3% & 78.5%

Blue Traces: Verona 13243
SL: 1794mm
Head b. Concavous
Middle b. Conical / a. Cylindrical
Bell c. Buccinatory
d_{min}/d_{max}: 0.77
SL/d_{max}: 1/35

Tone holes from block line: 33.3%, 35.7%, 38.2%, 40.3%, 56.1%, 58.5%, 60.7% & 79.0%

Green Traces: Verona 13242
SL: 1740.5mm
Head a. Cylindrical
Middle b. Conical
Bell d. Campanulous
d_{min}/d_{max}: 0.74
SL/d_{max}: 1/30
Tone holes from block line: 30.9%, 33.6%, 36.0%, 38.0%, 54.6%, 57.2%, 59.6% & 79.6%

Of the almost two hundred original renaissance recorders, only four great-bass and one extended great-bass recorder survive, and two of the former are in the collection of the Verona Accademia Filarmonica. It is interesting to compare this group of instruments, of which three are illustrated in the above table. Note how the minimum bore position of SAM 169 is almost exactly between holes 6 and 7, at the point where the foot and body joints meet. Note, too, on this instrument the steep conical section between hole 4 and the minimum bore point and the use of the same angle in reverse over the portion of the bore between 1250 and 1450 mm. The two Verona instruments are marked again with variations of the **!!** stamp and once again show signs of a similar tool having been used on part of the middle section. 13243 has also had some chambering effected on the head section, bringing the maximum bore diameter up to that found on SAM 169. Again, this post-constructional work has been largely ineffectual, as 13243 suffers from very wide octave relationships.
Verona 13242 is one of the finest surviving renaissance recorders with a beautiful sound and perfect tuning, and as such is a fine example of just how good these instruments can be.

SAM 166-8 and Merano 6854

Figure 20: A graph comparing the bores of SAM 166-8 with another bass recorder from Merano.

Red Traces: SAM 166
SL: 1139.5mm
Head a. Cylindrical
Middle b. Conical
Bell b. Obconic
d_{min}/d_{max}: 0.74
SL/d_{max}: 1/27
Tone holes from block line: 31.2%, 34.1%, 37.8%, 41.7%, 55.6%, 59.2%, 63.1% & 78.4%

Blue Traces: SAM 167
SL: 1123.5mm
Head a. Cylindrical
Middle b. Conical
Bell d. Campanulous
d_{min}/d_{max}: 0.67
SL/d_{max}: 1/25
Tone holes from block line: 30.7%, 33.4%, 37.2%, 40.9%, 55.0%, 58.7%, 62.3% & 78.5%

Green Traces: SAM 168
SL: 1118.5mm
Head a. Cylindrical
Middle c. Contra-Campanulous
Bell d. Campanulous
d_{min}/d_{max}: 0.80
SL/d_{max}: 1/25

Tone holes from block line: 31.7%, 34.9%, 38.7%, 42.6%, 56.5%, 60.5%, 64.0% & 80.0%

Yellow Traces: Merano 6854
SL: 1169mm
Head a. Cylindrical
Middle a. Cylindrical / b. Conical / a. Cylindrical
Bell a. Cylindrical
d_{min}/d_{max}: 0.84
SL/d_{max}: 1/29
Tone holes from block line: 33.7%, 36.5%, 40.9%, 44.6%, 56.3%, 60.3%, 64.4% & 79.6%

As found with the three tenor sized recorders from the HIERS group mentioned above, considering the similarities of their workmanship and makers mark, the three bass recorders SAM 166-8, from the HIES group are, surprisingly different from one another. They show quite a lot of variation in the position of their tone holes, and consequently their bore profiles reflect this. They can also be compared with another, bass size recorder in modern c#, with the makers mark AA which is to be found in the Landesfürstliches Burgmuseum in Merano. This latter instrument has yellow traces on the graph and a much more cylindrical bore profile than the other recorders seen here. It is more similar to the bore profile of SAM 363 seen in figure 9, and thus falls into the cylindrical-bore category.

SAM 135, 138, 146, 363 and Hamburg 1926.206

Figure 21: A graph comparing the bore of five recorders falling into the cylindrical bore category.

Red Trace (top): Hamburg 1926.206, basset sized recorder in modern f#, with the makers mark: !!
SL: 849 mm
Head a. Cylindrical / b. Flat conical
Middle b. Flat conical / a. Cylindrical
Bell d. Campanulous
d_{min}/d_{max}: 0.85
SL/d_{max}: 1/28
Tone holes from block line: 31.1%, 34.2%, 39.7%, 44.6%, 55.7%, 61.0%, 66.0% & 80.1%

Blue Trace: SAM 363
SL: 559mm
Head a. Cylindrical
Middle b. Conical / a. narrow cylindrical
Bell a. Cylindrical / c. Buccinatory
d_{min}/d_{max}: 0.89
SL/d_{max}: 1/22
Tone holes from block line: 31%, 35%, 42%, 48%, 57%, 63%, 69% & 81%

Orange Trace: SAM 146
SL: 480.3mm
Head b. Concavous, perhaps even obconic
Middle a. Cylindrical / c. Flat contra-campanulous
Bell b. obconic
d_{min}/d_{max}: 0.87
SL/d_{max}: 1/22
Tone holes from block line: 35.8%, 37.1%, 43.4%, 50.0%, 58.8%, 65.7%, 72.8% & 79.2%

Green Trace: SAM 138
SL: 428.5mm
Head b. Concavous,
Middle b. Flat conical / a. cylindrical with chambering
Bell a. cylindrical with chambering

d_{min}/d_{max}: 0.88
SL/d_{max}: 1/19
Tone holes from block line: 35.2%, 37.6%, 44.8%, 51.8%, 59.6%, 66.6%, 73.7% & 81.0%

Brown Trace: SAM 135
SL: 381mm
Head b. Concavous,
Middle a. Cylindrical / c. Flat contra-campanulous
Bell d. Campanulous
d_{min}/d_{max}: 0.97
SL/d_{max}: 1/20
Tone holes from block line: 33.5%, 36.7%, 43.7%, 50.7%, 59.3%, 66.3%, 73.0% & 81.1%

These four instruments all share a similar bore profile and all would fit into the third category of bore types designated above, all having a near cylindrical profile. Interestingly, again all four instruments have a variant of the !! stamp. All four profiles show a tendency towards a wide, opening shape at the foot section, although this is slightly less marked on SAM 146 than on the other instruments. Unfortunately, it is not possible to evaluate the high notes on all of these four instruments but the probability is that each would play over a two-octave range, using fingerings similar to those given by Ganassi.

Voicing

Quite early on in the measuring process it was decided to record only minimal detail about the voicing areas of the instruments. The risk of damage and the unlikelihood of getting practical, useful information meant that the blocks of the instruments were kept *in situ* and only the most visible and accessible measurements taken. The voicing of most of the instruments in the collection has suffered the ravages of time. Most of the blocks are distorted, worn, infested by woodworm or completely missing, and so, even with the most advanced scanning technology, it would be difficult to envisage what kind of information they could render. The windways, too, are often so cracked or damaged that any through examination would be likely to conclude that their present state is far from their original.
Despite these reservations, the basic measurements of the voicing fall into remarkably similar templates, and the tolerance of each size with respect to window width and original cutup, where this has been possible to ascertain, are remarkably consistent. The following chart compares the size of the windway of each of the instrument in the collection. The green trace shows the windway width divided by the size of the cut up, in many cases this gives an uneven result, due to the bad current state of their labia and their probable consequent enlargement. Nevertheless, it can be seen that this value falls mostly in the range 2.5 to 3.5, the size of instrument notwithstanding. The blue trace on this chart compares the ratios between the maximum bore diameter and the width of the windway at the blockline. As can be seen, this gives a more reliable figure, falling in almost every case between the values of 1.5 to 2 windway widths to one maximum bore diameter.

Figure 22: Chart representing the windway widths and the cutups of the recorders in the collection.

Windway chamfers

Chamfers are normally found on both the block and the body of the instrument at both ends of the windway. On most of the instruments in the collection, the windway entrance has the most pronounced chamfers, presumably with the intention of easing the air into the windway. Chamfers to the windway exit are usually made as fine adjustments to the passage of air over the labium. They are, as such, extremely sensitive and have to be executed with a great deal of care. A surprising feature of many of the instruments in the collection is just how small or apparently non-existent these chamfers are. It is quite possible that chamfers here were only used sparingly and perhaps only as a last resort by makers in an attempt to find a little extra character, or quality, that would otherwise be missing.

Brass labia

Hitherto, all instruments with brass labia have been judged as having been restored. Admittedly, the edge of the labium is a fragile part of a recorder's construction and often one of the most frequently disturbed features of original instruments. Repairs here vary from the obvious method of increasing the cutup, which, if the labium is not thinned accordingly, will normally result in a breathy and edgy sound, to the exotic fitting of a completely new ramp section. The latter has often been achieved by the laying on of a thin piece of brass sheet, which is let into the corners of the ramp and held in place by a nail, or - in the case of SAM 146, - a screw. The brass edge is carefully lined up with the windway exit and thinned to the appropriate thickness by scraping.
This feature is to be found on many original recorders in geographically diverse collections and ranges in quality from the very crude, such as found on SAM 146, to the beautiful chevron-shaped edges on two of the recorders in Verona:

Figure 23, left: Verona 13.243, great-bass.

Consideration of the quality of workmanship of some of these inlays has recently led to the argument that some of the brass edges might indeed be original fittings.[24] It is after all quite imaginable that attempts would have been made by contemporary makers to develop a more durable method of making this most delicate part of the instrument.
The results of experiments with new instruments fitted with brass labia have shown that the sound qualities of the instrument are not adversely affected by the presence of a labium made from a harder material.[25]

Caps and Crooks

The bass and basset sizes of recorder have a cap to lead the air from the player's mouth to the entrance of the windway. The bass sizes additionally have a crook, to enable the player to be positioned behind the instrument rather than on top of it. Taking into account the extreme length of these sizes of instrument, this arrangement gives considerable ergonomic benefit to the player. The basset sizes normally have a blowhole cut directly in the edge of the cap, through which the player blows, although some small basset sizes remain direct blown in the manner of tenor-sized instruments.

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[24] The author is grateful to Friedrich von Huene for his endorsement of this idea.
[25] Experiments carried out in the authors workshop on alto sized recorders. At the time of writing, this technique is still in its infancy, but the results thus far are very encouraging.

This arrangement is not quite as simple as might be first thought, as the space inside the cap and the dimensions of the crook, or blowhole, can have a critical function in the production of the note and in the sensitivity and responsiveness the player feels whilst playing.
It is quite evident that the discrepancies between the dimensions of windway length, and cap depth, measured on instruments SAM 159 and SAM 160 are not examples of imprecision on the part of their maker. Rather they should be seen as examples of final adjustments, made in order to improve the response or feel of an instrument.
The space inside the cap, which is not filled by the tenon at the top of the instrument, forms a reservoir of air that acts like a cushion to the player's breath. A small space here gives the sound of the instrument a thinner quality. The advantage, however, is that the attack of the note is easier to execute, allowing the player greater ease in articulation and giving a tighter, more positive feel to the sound control. Having a larger cap space generally gives the sound of the instrument a bigger, booming quality, which is easier to combine with other recorders and generally seems to be preferred by players.[26] The drawback is that the player's control over the attack and precision of the note is reduced. Thus can be seen that, as with so many other facets of musical instrument making, a compromise has to be reached and the space for each size of instrument adjusted accordingly. Similarly, with the size of the blowholes in the basset caps and the dimensions of the basses' crooks, a balance has to be reached. The problem is that each individual instrument will have its own particular sound and consequently, will require a different setup. This is probably the reason for the discrepancies found between otherwise like instruments in the collection.
Burbles, or wolf-notes, are either due to an imprecision in the bore or voicing aspects of the instrument and can sometimes be cured by changing the spaces inside the caps. Modern makers often fit simple, slotted inserts to these spaces that channel the air directly from the crook, or blowhole to the windway entrance and give a very direct feel and response to the instrument. There is no evidence however that these simple devices, quite within the abilities and techniques of 16th century craftsman, were ever fitted to original recorders.

Crooks

The crooks of the bass sizes of recorder would have been proportionally the most expensive parts of a recorder consort. Like the other metal parts of the instruments, they were almost certainly bought in from a separate metalworking workshop. The work involved in manufacturing sheets of brass, rolling it into tubes, and bending it into shape is a difficult enough process for today's makers, and must therefore have been a great challenge for 16th century technology: little wonder that their existence and even quantity was often remarked upon in historical inventories and contracts.[27]
The crooks of instruments SAM 166-169 are original – some of the very few surviving. They are of a fairly large diameter and rather short in length, which, in the case of SAM 169, means the player has to be of quite a tall stature to be able to play

[26] The authors own subjective observations, based on comments made by modern players.
[27] For example: the Notary contract between the two wind instrument makers from Venetian branch of the Bassano Family and three of the *pifferi del doge* to supply various wind instruments at advantageous prices. There are two cases or *casse* of recorders mentioned, a large set comprising sixteen recorders, which would include four crooks (*suj torti*), which is priced in proportion to a smaller case of eight recorders for 37 lira and 4 soldi. See: Ongaro 1985, pp. 391-397. Unfortunately in this article, Ongaro has translated *suj torti* as 'crumhorns' - in the opinion of this author an illogical translation.

the instrument comfortably. Here, once again, a compromise has to be reached between the liveliness and precision of response that a short tube gives and the stability given by a longer and more restricted crook.

Some comparisons

To illustrate the points made in these sections, it is worth comparing the respective crooks and caps found on SAM 166-169 with their surviving cousins in the Accademia Filarmonica of Verona. The seven Verona instruments, inventory numbers 13242, 13245-6, and 13250-3 are the surviving members of a once proud 22 recorder consort and again bear a variant of the **!!** stamp also found on some of the recorders from the Sammlung Alter Musikinstrumente.[28] The Verona instruments form the F, B-flat, f combination (as opposed to the - perhaps earlier - F, c, g combination of the HIES group) and in many respects show signs of an evolution in their basic design.[29]
The following tables compare the relevant measurements of these recorders, together with additional instruments from separate sets, which are useful for comparison. These are another great-bass size, in Verona, inventory number 13243, together with basset sizes SAM 159 and 160, from the HIERS set.

	Great bass size			**Bass size**				
	SAM 169	**Verona 13242**	**Verona 13243**	**SAM 168**	**SAM 167**	**SAM 166**	**Verona 13245**	**Verona 13246**
Cap overall length	118,0	126,7	110,5	101,0	99,0	99,0	102,0	103,0
Cap internal diameter	76,0	76,2	74,0	57,0	57,6	57,0	64,5	63,7
Cap internal depth	85,0	80,0	65,0	74,5	73,0	69,0	65,0	66,0
Body: tenon end	44	66,5	44,5	41,2	37,5	36,0	60,3	60,7
Cap space	**41,0**	**13,5**	**20,5**	**33,3**	**35,5**	**33,0**	**4,7**	**5,3**
Hole diameter	13,9	12,5	12,7	11,8	11,8	11,9	13,3	13,2
Hole diameter inside		10,0	12,0				7,5	8,5
Crook inside diameter	11,9		11,0	11,0	10,7	10,0		
Crook approximate length	635		823	400	400	400		

Table 1: Table showing measurements relative to cap volume of representative great-bass and bass recorders

Taking first the great-bass and bass sizes in table 1, it can be seen that the cap space in the Verona instruments is consistently smaller. Although the original crooks for the bass sizes in Verona are missing, an original crook does survive for the great-bass 13243. This has a smaller diameter that that of SAM 169 and is additionally of a much greater length. The holes for the crooks in the caps of the Verona basses, although appearing to be of a larger diameter at the exterior, are in fact sharply tapered towards the interior, giving a compression to the air channel, entirely consistent with the small space inside the cap.

[28] See: Van der Meer/Weber 1982, ...pages.39-42.....above, and Di Pasquale 1987/1988, 8 and 11–12
[29] This is the exact combination of large recorders described by Praetorius and the 22 instruments of the original Verona set, are just one recorder more than Praetorius' *'Accort ob Stimwerck von Instrumente'*.

	Basset size							
	SAM 161	SAM 162	Verona 13250	Verona 13251	Verona 13252	Verona 13253	SAM 159	SAM 160
Cap overall length	65,8	68,3	75,1	76,2	76,0	76,2	66,3	66,7
Cap internal diameter	44,0	42,8	48,0	47,5	47,5	48,0	40,0	41,0
Cap internal depth	47,0	51,0	60,0	61,0	62,0	65,0	49,5	44,5
Body: tenon end	35,5	31,0	53,2	52,5	52,5	51,0	15,0	14,5
Cap space	**11,5**	**20,0**	**6,8**	**8,5**	**9,5**	**14,0**	**34,5**	**30,0**
Blowhole width	12,4	9,5	13,7	12,2	12,4	12,5	9,0	9,5
Blowhole height	4,0	4,2	3,4	3,7	4,9	3,6	4,3	4,5
Blowhole area (mm?)	**49,6**	**39,9**	**46,4**	**45,1**	**60,5**	**45,0**	**38,7**	**42,8**

Table 2: Table showing measurements relative to cap volume of representative basset recorders

Moving on to the basset sizes: again the cap spaces in the Verona examples, although not as consistent as in the former chart, are nevertheless smaller than the majority found on SAM 159-62. The blowholes seem to have been sized to fit each instrument individually, with no noticeable relation between cap space and blowhole cross-sectional area.[30]

Conclusions

A comparison of all surviving renaissance recorders shows a wonderful mixture of innovative craftsmanship and thorough acoustical knowledge learnt through generations of practical experience, rather than from mathematical modelling. Whilst it is quite clear that different styles of making were employed, it does not follow that these necessarily indicate a certain school of making, or a likely date. These various styles overlapped each other and often seem to have been employed in the same workshops.

Nevertheless, there is some evidence that amongst instruments having a similar stamp or makers mark, that the same design and even the same tools were used when forming the bore profile. This may well indicate that these tools were extremely valuable and were thus employed by the same makers over a great length of time to make stylistically different instruments, or by different craftsman from the same workshop.

It is also clear that while some makers used a high degree of accuracy to make their instruments to a predetermined design, there are also instruments from the same set, ostensibly in the same pitch, that have different tone hole positions, bore profiles and tuning. Whilst this may well be explained by the continual process of invention and discovery that is common to all makers of musical instruments, it is however surprising that many like instruments were made with so much variation.

Whilst it is clear that experimentation with bore profiles was a continuous part of the development of these instruments, it is possible today to categorise three distinct types of bore, on the basis of their profile and playing characteristics.

[30] Experiments carried out in the workshop would seem to indicate that there is a minimum and maximum barrier here. As the size of the blowhole is increased, the instrument can be heard to come alive once a certain size is reached. Subsequent enlargement increases and then quickly decreases the quality of the sound and feel of the instrument. Again, the adjustment process involves a combination of voicing factors working together to produce the desired result.