

An Investigation of a Baroque Musette Bourdon Using Micro-Computed Tomography

The technique of computed tomography or CT is known to many of us who, as patients, have experienced a CT scan in a hospital. Though originally developed for medical purposes, it is now in use in other scientific fields and has become one of the techniques available for the inspection of historical musical instruments. On the present occasion it was used to investigate the intricate and hidden interior of part of an eighteenth-century French bagpipe made in ivory, a Baroque musette. The part to be scanned was its highly complex drone system or *bourdon*. This extraordinary invention is entirely fashioned within a small cylinder of ivory enclosing intricate acoustic pathways and concealed interior connections. Though CT has been successfully used with a variety of other instruments resulting in excellent research,¹ this is the first instance of its use for the investigation of a musette as far as we are aware. Since there are few comparable early organological examples of such extreme miniaturisation and invisible detail in manufacture, the technique would seem to offer huge advantages in the investigation of such an instrument. Its name, computed tomography, derives from the Greek τόμος *tomos*, meaning a slice or section and during this investigation, it was used to obtain data which could be rendered as 2D cross sectional images of the *bourdon* at any depth and axis in minute increments, and also as 3D volumes (see Figure 1). The particular technique used here was micro-CT, using equipment intended for scanning smaller objects in very high definition. This was an exciting opportunity to explore detail at any point in the instrument's interior and to discover some of the events encountered during its creation.

Figure 1. Screenshot of a 3D volume revealing a near-tangential cross bore on the reed tenon, otherwise invisible. The perfect hole entry suggests that the operation was done before the tenon was turned to final diameter. (Author's photo).

The sophistication of the component under examination is characteristic of the musette as a whole and some further explanation of the instrument may be welcome here. The Baroque musette, also known as the *musette de cour* and originally, simply as musette, is a small bellows-blown bagpipe intended for chamber use. In its classic form it has two chanters, the *grand chalumeau* and the *petit chalumeau*, both with exceedingly narrow parallel bores, the diameters of those in the musette under discussion being 3.4mm and 2.9mm. Its smaller *petit chalumeau* provides an upper extension to the scale of the instrument as well as some limited opportunities for harmony playing. At a time when other wind instruments commonly had a single key and rarely more than three, a musette typically had 12 keys with the present example having been constructed with 14, now all absent. Unlike other bagpipes with drones extending as long,

¹ Geerten Verberkmoes, Anne-Emmanuelle Ceulemans, Danielle Balériaux and Berend Stoel, 'An Inside Look at Four Historical Violins by Brussels Makers', *The Galpin Society Journal* LXIX (2016), pp.109–136. Karen Loomis, David Caldwell, Jim Tate, Ticca Ogilvie and Edwin J. R. van Beek, 'The Lamont and Queen Mary Harps', *The Galpin Society Journal* LXV (2012), pp.113–129.

individual and extendable pipes, the musette *bourdon* functions with a number of parallel bores grouped and connected in series, (the longest – *Basse de Sol* – requiring six lengths) all contained within a single cylinder, usually of ivory or ebony. Diderot & D’Alembert’s labelled engraving of this component provides a clear depiction of its exterior elements (see Figure 2).

Figure 2. *Bourdon*, a detail from Diderot & D’Alembert, *Encyclopédie, Lutherie*, plate VI. Four reeds are shown (E) as well as the sliding tuning components or *layettes* (a–b) with their handles (A–B). Also visible are the dovetailed slots or *coulisses* in which these slide, as well as the narrow vents (e–e) progressively covered by the *layettes* to effect tuning.

The Baroque musette with its two *chalumeaux* had a relatively brief currency, enduring very approximately throughout the century between 1670 and 1770 and already in early decline by the time of its appearance in the *Encyclopédie*.² It was in use only in France and only within restricted social environments; royal, aristocratic and socially highly aspirational. Nevertheless it had an extensive repertoire in sonata, duet and small ensemble formats, and its use was indicated by Lully and Rameau among others, in operas intended for royal performance at Versailles. In paintings it is often to be found, though appearing discreetly, in the aristocratic *Fêtes Galantes* of Watteau, Lancret and Pater. In portraiture, the musette sometimes features more prominently as a proud accessory to high social status, representing an extremely codified and ceremonial pastoral aesthetic. Costumed performers often appear dressed *en berger/en bergère*, representing an extravagantly imaginary ideal of a shepherd or shepherdess existence, the evident richness being extraordinarily remote from the harsh realities of such a life. A particularly splendid example is that by the royal portraitist Hyacinthe Rigaud depicting Gaspard de Gueidan in the garb of the fictional shepherd, Céladon.³ The association of bagpipes with shepherds is an ancient one, and iconography from mediaeval times through successive centuries depicts shepherds attending the ‘adoration’ scenes at the Nativity, carrying with them simple and evidently loud bagpipes which in reality would be most unwelcome on such an occasion. In contrast the musette and its costumed performers, whilst emphasising the pastoral context, could hardly be more remote from the simple shepherd instrument with its powerful conical chanter and commonly a single drone. The musette, a relatively quiet bagpipe, was intended for display as much as for performance; its bag customarily has an elaborately embroidered silk or silk velvet cover, its components are made of very costly materials, typically ivory, ebony and silver, and its function is made possible by manufacturing techniques that are at the same time highly complex and extremely discreet. It is this aesthetic of extreme and ingenious miniaturization – the creation of multiple functioning drone systems within a single small cylinder, with its internal complexity invisible to the observer – that makes the musette *bourdon* an unusually suitable subject for micro-CT investigation. The example presented in this study appears in Figure 3.

² Denis Diderot and Jean le Rond d’Alembert, *Encyclopédie ou Dictionnaire des Sciences, des Arts et des Métiers, Recueil de Planches sur les Sciences, Les Arts Libéraux, et les Arts Mécaniques avec leur Explication* (Paris : publisher ?, 1767). The plates illustrating *Lutherie* are to be found in Volume 4.

³ Hyacinthe Rigaud, *Gaspard de Gueidan en Céladon, joueur de musette*, 146.5 x 113.7cm, 1735, Musée Granet, Aix en Provence.

Figure 3. *The bourdon with its decorative end cap or dôme detached.*

The *bourdon* under examination is part of a musette in a private collection. It is anonymous, as are most musettes, and impossible to date precisely. However it is fairly typical of the musette in its mature later form suggesting probable manufacture in the 1730s. It is also in remarkably good condition, unrestored and unusually complete, though with the sad exception of the usual silver keys, now lost, as are its bellows. Original leather bags are relatively rare, but here, it has survived, displaying the sophisticated and complex stitching which is typically evident in such early bagpipes. In short, the instrument is an ideal example for investigation and study. This musette *bourdon* was constructed for use with five reeds and has five separate drone systems formed by groups of bores connected end to end in series, all ingeniously contained within a cylinder of 152mm in length and 30mm in diameter. Each drone bore, whether multiple or single (as in the highest-pitched drone), has its final section adjacent to the exterior of the cylinder and emits sound through a slot which can be progressively covered by a slider contained within a dovetail slot. This provides a facility for convenient tuning adjustment. The positions of the multiple bores are normally clearly visible on both ends of musette *bourdons* and that is so on this example. It is frequently the case that most of the lateral links joining the bores can be traced externally, depending on the method used to create them. With a single exception, none are visible on this *bourdon*. However their positions became clearly apparent as a result of the micro-CT scan and all are shown in Figure 4.

Figure 4. *Micro-CT images showing cross sections throughout the bourdon. The ends are shown as well as all intermediate positions showing cross bores. These are not notably precise, though they are adequately functional. The vents emitting sound to the exterior may also be seen. The very bright circular detail is the metal tube.*

There are three principal methods of joining bores at the ends to form long sounding series. This can be done on the ends of the cylinder by removing the common wall between two adjacent bores to a sufficient depth and subsequently inserting a plug of softer material, usually a sufficiently compressible wood, to close the aperture at the end. Junctions formed thus at the ends are easy to observe and trace. A second method consists of drilling laterally through the cylinder. This is done on the tenons, usually close to the ends. The exterior holes are then plugged with small round wooden plugs that are easier to make than the oblong or kidney-shaped pieces required for the first method. Both methods are compared in Figure 5. In addition, the requirements of appropriate sounding lengths demand additional junctions between the bores that are remote from the ends of the *bourdon*. Other than on musettes in a state of considerable disrepair, these are normally invisible, concealed by the thin leather strips which line the floor of the tuning channels, providing a good pneumatic seal with the slider used for tuning.

Figure 5. *Two methods of bore-joining compared. Left, a single wooden plug appearing from beneath the leather strip, the present bourdon's sole visible evidence of cross bore positions. Right, adjacent bores with common walls removed to a moderate depth and with the plugs*

sealing the common aperture now absent. This is the important Lissieu musette in the Morpeth Chantry Bagpipe Museum, whose courtesy is acknowledged here. (Author's photo.)

Finally, where junctions are formed very close to the end of the *bourdon*, they can be cut with the oblique use of tools through the face of the tenon without disturbing the cylindrical surface. This and the second method described are the ones used on the present example. Although the dimensions and positions of the internal cross connections might have been reasonably guessed through comparison with other more accessible musette examples, all but one are invisible on this particular *bourdon*. Such evidence was unavailable because of the method of its construction and the fact that it remains in its original condition with the leather sealing strips extending along the lengths of both tenons.

Figure 6. *Images of the end of the bourdon remote from the reed end (left). Micro-CT image of the cross connections present beneath the position of the photo, at a depth of 7.45mm (right). No evidence of these is visible on the exterior.*

It was therefore extremely fortunate that an opportunity arose to examine the *bourdon* with close attention to its interior, through the generosity of the Cranfield Forensic Institute at Cranfield University. The Institute possesses a micro-CT scanner that is capable of high resolution imaging of small objects, generally less than 12cm tall or 20cm in diameter. Since the *bourdon* was too long for a single scan with this equipment, the operation was carried out in two phases to capture detail from the top and bottom halves, each scan requiring about 45 minutes. Unlike a medical scanner, the micro-CT scanner's X-ray source and detector remain fixed while the stage on which the scanned object is mounted slowly rotates through 360°. A precise statement of the procedure and equipment used on this occasion is provided in the Technical Appendix at the conclusion of this article.

Figure 7. *Bourdon mounted in Nikon XT H 225 micro-CT scanner at the Cranfield Forensic Institute.*

The methods of manufacture of these complex items with late seventeenth- and early eighteenth-century equipment are not entirely clear although there is often evidence of the precision with which the bore positions were marked out. Marks left by the use of compasses frequently remain to confirm this degree of care. Most simple drilling errors in the construction of single-bore wind instruments are largely insignificant, since in turning the exterior, the workpiece is re-centred on the bore. This is evidently not so when the bores are multiple, as with the present case which has 14 parallel bores contained within a circle of 27.5mm (the tenon dimension), with their diameters ranging from 2.9 to 4.3mm, all in extremely close proximity and requiring the passing of drills of varying sizes through an ivory workpiece 152mm in length. With current technology it is a relatively challenging task to ensure that all bores through material of irregular density are

accurately parallel, but with the use of contemporary equipment, the achievement is far more remarkable.

Figure 8. *Lathe, a detail also from the Encyclopédie, (Lutherie, Plate X bis, engraver's Fig. 1) Tour en l'air et à pointes à l'usage des faiseurs d'instruments à vent, Flutes, Hautbois, Musettes etc.*

Evidence of some of the equipment used to make musettes can be found in the plates illustrating Diderot & d'Alembert's account of contemporary lutherie in their *Encyclopédie* where items for the manufacture of wind instruments are depicted and labelled. Plate X. bis (engraver's Fig. 1) shows machinery and hand tools for the manufacture of wind instruments. The lathe (*tour à l'usage des faiseurs d'instruments à vent, comme flûte, hautbois, musette, etc*) is illustrated in useful detail (see Figure 8). It is suitable for manufacturing common, moderately sized woodwind but displays additional facilities used in turning ivory musettes. Equipment for use in the creation of screw threads on the workpieces is visible at the headstock (B). This permits the precise and secure fitting of the musette *chaluzeaux* into their stocks (or *boîtes*) allowing these precious and delicate items to be securely held without risk of falling. The decoratively turned ivory cap (or *dôme*) at the end of the *bourdon* is also given an internal screw thread to provide a secure fit for this vulnerable item. Hand tools for the finishing of exterior and interior screw threads are shown above the lathe (engraver's Figs. 15 and 16).

Figure 9. *Hand tools including drills (engraver's Figs 1–5 and 8) and coulissoire (Fig. 8), also from the Encyclopédie, (Lutherie, Plate X).*

A number of drills are also depicted in the preceding plate, Plate X, a detail of which is shown here (see Figure 9). Drills of varying sizes are shown (engraver's Figs. 1–5), these being 'spoon bits', capable of cutting efficiently though without the accuracy required for boring a *bourdon*. Another shown here (engraver's Fig. 8) is of an entirely different shape, named specifically as a *perce-bourdon* and this, perhaps was the type used for creating the bores in a musette *bourdon*, possibly followed by reamers to adjust bore diameters. Unlike the other drills shown, this has a fine conical point suggesting a tool that (if it possessed a cutting edge invisible from the angle shown) could initiate and continue a precisely positioned bore although its action would be relatively slow. Also of interest is the engraver's Fig. 10, showing a *coulissoire*, a tool for creating the left and right corners of the dovetail tuning slots or *coulisses*. However nothing further is revealed about the process of boring the *bourdon*, neither here nor in the text accompanying the plates, nor in the alphabetical *MUSETTE* entry in the *Encyclopédie*. With present day equipment, revolving the workpiece at high speed with a non-revolving or contra-revolving drill offers the best opportunity for accurate drilling. To achieve this, the workpiece is drilled at positions remote from its centre, and it requires careful balancing as it revolves, being quite heavy. This would seem impossible with the relatively light lathe shown here which could

not withstand the stresses occurring with this method and furthermore was capable only of very modest foot-driven speeds. Nevertheless, all types of drill here are depicted with handles, confirming that if one of these is the type used for this difficult job, it is indeed the workpiece that revolves although necessarily rather slowly. Sufficient accuracy would be achieved through meticulous marking out of hole positions (evidence of this frequently remains on the ends), skilful use of drills in optimal condition and a considerable quantity of optimism. The skills required to accomplish the successful production of multiple and very narrow bores in extreme proximity are unusual in the wind instrument making of the period and perhaps it is not unreasonable to wonder whether this work was the specialism of an even smaller number of individuals than the total number of musette makers. This might explain the notable absence of any illustration of equipment for this unusual process on a plate that is otherwise rich in detail. A remarkable similarity of basic dimensions and internal layout among some examples may also lend credibility to this thought although it can be no more than speculation.

It was evident from previous visual comparison of bore positions at both ends of this *bourdon* that accuracy, whilst being very far from perfect, was sufficient to create a well-functioning drone system. However, other measures necessary to ensure this were invisible and they and their exact positioning came to light through the facility of the micro-CT scanning. Possibly the most remarkable and unexpected of these was the presence of a metal tube introduced into one of the series of bass bores (see Figure 10). This appears to have an unsoldered joint resembling that of early reed staples (though far less neat) and was, perhaps, made from thin brass sheet intended for that purpose. Its function here is to restore the integrity of one of the larger bores that, while being formed, broke through into an adjacent one.

Figure 10. *(Left) A metal tube, unsoldered and probably of brass, inserted during manufacture to correct a failed bore. (Right) A cross section of the metal tube appears brightly here. This has apparently been introduced to replace a failed bore which appears adjacent and above, apparently filled with some compound.*

There is also evidence of a failed bore being filled with some grainy compound, perhaps ivory dust and glue. The scan revealed the presence of minute particles of metal, seen as brighter regions within the scan area. These were possibly from a file previously used for shaping keys or reed staples and subsequently for preparing the compound. It is apparent that the drilling had progressed successfully on the subsequent attempt.

Unsurprisingly, evidence of inaccuracy in the boring of musette *bourdons* is not at all rare and it is often easy to observe through visual comparison between the entry and exit drilling positions at either end. The operation is a very demanding task with a substantial risk of failure, sometimes necessitating the filling in of a misdirected bore followed by another operation to correct this. This is understandable given the very high cost of the material, in this case ivory and in many others, ebony. When extremely dark woods are used, mistakes and repairs are more difficult to detect. Whatever the material, interior mistakes and remedial measures would almost certainly be imperceptible to any customer. This discrepancy between an immaculate exterior and a poorly-finished but efficient interior is not at all unusual among historical musical instruments.

Aesthetic deficiencies invisible to the instrument's purchaser or audience were commonly disregarded, provided that the workmanship was satisfactorily functional.

Figure 11. *2D X-radiographs of the petit chalumeau, revealing the oblique boring of tone holes.*

Though the advantages of using micro-CT imaging for examining a musette are extraordinary, there are parallel benefits of using more conventional 2D X-radiographs of such an instrument, especially when details of particular interest are more or less in the same plane. Informative 2D images of another part of this musette, the small and relatively flat *petit chalumeau*, were also obtained during this session. These show the upper part of the *petit chalumeau* enclosing the extremely short and narrow bore with the oblique boring of the tone holes appearing very clearly (see Figure 11). The bore has no exit other than through the tone holes and in playing, this part of the instrument remains silent until one of its keys is operated. This oblique boring of tone holes is comparable with the principle involved in those on bassoons and it is done for similar reasons. Because of the miniature nature of this item, the natural hole positions would be too close for the use of keys and they are therefore spaced sufficiently to make this possible. In extreme contrast, natural positions on the bassoon are impossibly widely spaced to be controlled by the hands and the holes require oblique boring to bring their external positions within comfortable reach. Also of note on this image is the screw thread on the tenon similar to that on the accompanying *grand chalumeau*. Both *chalumeaux* are of ivory and originally furnished with keys probably of silver, and though small, they are relatively heavy as well as being extremely expensive. The advantages of this method of securing the *chalumeaux* will therefore, no doubt, be evident. The image also reveals the exact shape of the reed socket as well as the insertion of a small piece of ivory halfway along the bore, allowing an adjustment to the tuning of a note that was found to be deficient.

Much of this information provided by the 2D X-radiographs might also have been obtained through the use of gentle physical examination but it is clearly valuable to use these two methods in a complementary way, employing verifiable dimensional information from careful physical measurements to interpret the image correctly. However, the technique is especially useful when conservation requirements inhibit physical investigation. This is especially relevant in the case of rich and delicate original textile coverings that occasionally survive on musettes. An instance of such attention is described in an article describing the examination and conservation of an eighteenth-century bag cover with the musette in the Horniman Museum.⁴

Surprises are sometimes revealed. On two known occasions, X-radiography resulted in the discovery of extremely rare original reeds that had become displaced, falling into the bag where they were subsequently preserved. Both instruments are in the care of the Horniman Museum, London.⁵ The first, in the possession of the Museum, revealed a lost reed during X-radiography

⁴ S. François, 'The use of X-radiography in the conservation treatment and reinterpretation of an incomplete musette', in M.M. Brooks and S.A. O'Connor eds., *X-radiography of Textiles, Dress and Related Objects* (Oxford: Elsevier Butterworth-Heinemann, 2007), pp.314–318.

⁵ Horniman Museum, No. 851-1907, V&A Musette Museum No. 394-1871.

with the ornate textile cover as the principal interest. Another musette belonging to the Victoria and Albert Museum, London and currently on long term loan to the Horniman, revealed two concealed reeds similarly preserved in the bag, during X-radiography in the presence of one of the authors.

Although it is generally true of the examination of historical musical instruments using very advanced technology together with gentle physical investigation, the advantages of combining these in a complementary manner are especially clear with the present example. Internal positional and dimensional observation through micro-CT scanning, the examination of shapes and positions using 2D imaging together with physical measurement previously undertaken, have all contributed usefully to the survey of the instrument. This has provided not only a statement of the musette in its present condition, but also some account of the successes, mishaps and corrections occurring during its manufacture.

In conclusion, here perhaps is a partial answer to the puzzling question concerning how these items were made with such apparent precision using the equipment in use during that period. It is evident that these makers did the best they could and that total success was probably more accidental than usual. Mistakes were almost certainly frequent, though also easily corrected and concealed. Close comparison of the bore positions at either end on the exterior of other musettes confirms this assertion. It would indeed be interesting to know what other remedial measures have lain undetected beneath immaculate and delicate exteriors throughout three centuries or so, becoming visible only now with these advanced inspection techniques. This is, we believe a good demonstration of the value of using CT in the examination of historical musical instruments. It was adopted here not only because it was both interesting and informative but more importantly, because it was able to bring to light precise positional and dimensional information concerning this instrument together with some internal history of its manufacture, which could not otherwise have been obtained from this undisturbed and rare example without compromising conservation necessities.

TECHNICAL APPENDIX

The bourdon was imaged using a Nikon XT H 225 micro-CT scanner at the Cranfield Forensic Institute. It was mounted vertically with its longer reed tenon securely embedded in dense plastic foam (Plastazote®) attached to the sample stage. This proved to be a very stable method of securing the item without causing mechanical stress. Due to the height of the object, two scans were run, one of the upper part of the bourdon, and one of the lower part, with the middle portion therefore scanned twice to ensure no loss of information. Scanning was undertaken with a tungsten reflection target, at an accelerating voltage of 85 kV and a current of 50µA, and an exposure time per projection of 708ms. A total of 1571 projections were taken at two frames per projection over a 360° rotation. The voxel size of the resulting dataset was 83µm (i.e. the minimum discernible measurement volume was a cube with sides measuring 83µm). Three-dimensional volumes were reconstructed using CT Pro 3D software (Nikon), and images processed with VG Studio Max software v.2.1.

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