► From left, the ‘Betts’ scroll, a CT scan of the scroll, and a CNC-machined replica

‘BETTS’ SCROLL PHOTO MICHAEL ZIRKLE, REPLICA SCROLL PHOTO ANNA BOTZ

THE PROGRESS OF PROGRESS

A century after *The Strad* published its first article on the Stradivari ‘Betts’ violin, maker JOHN WADDLE asks what the magazine’s descriptions of the instrument reveal about lutherie expertise, and explains his latest high-tech analyses of the instrument

In May 1709 the 'Betts' violin was five years old and Antonio Stradivari would have been 65. Had the instrument been sold? Was it still in the Stradivari shop waiting for a buyer? We don't know.

Two centuries later, in May 1909, *The Strad* published its first article on the 'Betts'. Written by a Mr B. Henderson, the article includes some history, starting with the purchase of the violin by Arthur Betts in around 1820–30 from an unknown seller for a notoriously low sum. At that time, it would still have had its original neck and bass-bar. Nothing is known of the violin's history before Betts bought it.

Betts was a violinist and a pupil of Giovanni Battista Viotti. Viotti's name is associated with several of Stradivari's violins, including one, also of 1704, that is pictured on the page opposite the 'Betts' in the book *Iconography of Stradivarius* by Herbert Goodkind. The two violins have some distinct similarities. Betts must have been excited to have a violin similar to his teacher's, and finding one in such good condition would have been rare even then.

In his article in *The Strad*, Henderson goes on to describe the 'Betts', 'which bears the date 1704, and thus belongs to the so-called grand pattern period' as 'noticeably perfect in form, even amongst so many masterpieces'. His description of the violin catches the main qualities that set it apart – the full archings, the beautiful f-holes, the bold scroll, the excellent choice of wood, and the long corners with their extended purfling mitres. Whoever B. Henderson was, he had apparently acquired some expertise, and had a keen eye.

However, beyond the history of the violin, three black-and-white photos of the instrument and measurements not of the violin itself but of violins 'of this period', there is little information in the 1909 article that could be used by anyone interested in trying to use the 'Betts' as a model.

IN 1923 TOWRY PIPER WROTE an article on the 'Betts' for the September issue of *The Strad*. In it, he quotes Charles Reade's 1878 article on the 'Betts' in *The Pall Mall Gazette*, which said: 'Here is a violin, a picture, and a miracle all in one; and big diamonds increase in number; but these spoils of time are limited forever now, and indeed, can only decrease by shipwreck, accident, and the tooth of time.'

Twice in his article, Piper compares the 'Betts' with the 'Messiah' Stradivari: once when he describes the 'Messiah' as 'a much less attractive instrument in the matter of design'; and again towards the end of the article, where, referring to the outline, he says, 'It is much more graceful than that of the Messie with its sharp edges and slanting – not to say sprawling – soundholes.'

Piper, like Henderson before him, provides very little information on the 'Betts' that could be used by anyone wanting to make a copy. In fact, the only measurement given at all is: 'The body length is just fourteen inches.'

It seems that both Piper and Henderson were somewhat experienced in looking at violins, and knew that the 'Betts' was a special instrument, but that they had trouble coming up with anything new to say about it. It is obvious that neither author was a violin maker.

By contrast, Roger Hargrave's May 1989 article on the 'Betts', and the accompanying poster, was a milestone for *The Strad*. At last, here was something that would enable people to make some progress towards understanding this famous instrument and possibly even make a reasonable copy of it. There are finally useful photographs and a description of the features of the violin written by a violin maker with a well-trained eye. The article highlights details of the work done on the violin, and shows detailed measurements. High-quality colour photographs of the instrument are included, along with the now-expected outlines and arching shapes.

These kind of details and measurements have come to make the difference. It's not enough any more to generalise. Now, using current technology, better photography, imaging techniques and acoustic testing methods, we are starting to make advances in understanding wood structure, form and function. ▹

Figure 1 Axial slices with measurements

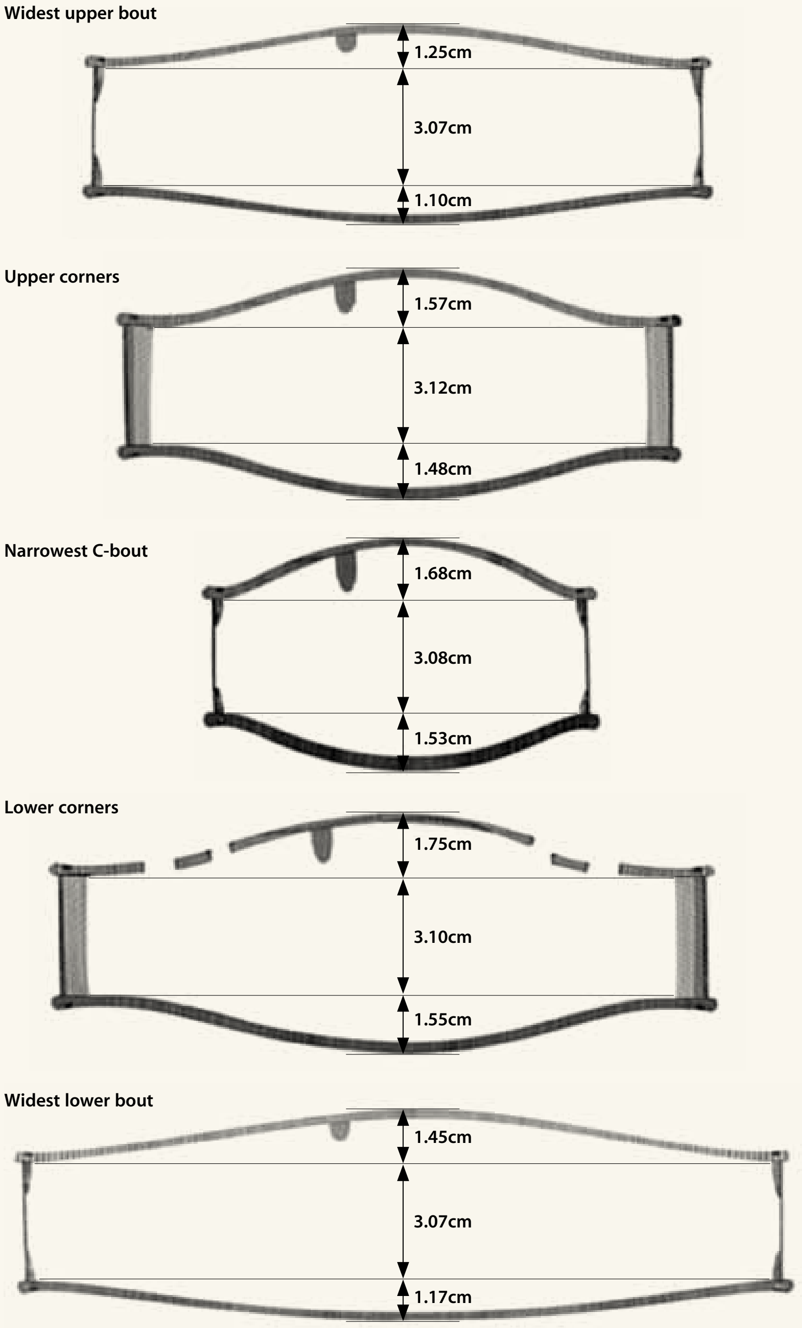


Figure 2 CT image of the front

Figure 3 CT scan of the back

CT SCANNING AND THE 'BETTS'

Radiologist and amateur violinist Steven Sirr and I have been using computed tomography (CT) scanning to study stringed instruments since 1989 and have scanned hundreds of stringed instruments. CT is a powerful technology that doctors use for looking into the human body to assess normal and abnormal anatomy. It uses many X-rays of predetermined plane sections of any solid object – in our case, the violin. We obtained the raw data from CT scans performed on the 'Betts' by Gary Sturm and Bruno Frohlich of the Smithsonian Institution in Washington, DC, where the 'Betts' is housed as part of the collection of the Library of Congress.

The most basic images that can be made from CT data are axial slices (**figure 1**) that show the shape of the archings, the thicknesses of the components and, to some degree, the grain structure. Using imaging software, the individual scans can be put together to make full-size images of all or parts of the instrument (**figure 2**). CT can also, in conjunction with computer software, be used for studying wood density; volumes of both the plates and the air chamber; mass; distribution of mass; and normal and abnormal features such as cracks, patches, repairs and woodworm holes.

The two-piece back of the 'Betts' is made of handsome, perfectly matched maple, cut on the quarter, with the curl slanting upwards from the centre seam. A CT scan of the wood of the back shows denser bands towards the centre on both sides of the centre and running from the upper to the lower blocks (**figure 3**).

The average CT-measured density of the back is 0.545g/cc, which is lower than other violins we have measured (**figure 4**). The CT-calculated weight of the back is 94.3g. The arching height is 15.3mm at the highest point, 4.0mm thick at the thickest point, and 2.2mm thick at the thinnest point.

Figure 4 Comparison of front- and back-plate densities and violin corpus volumes

Instrument	**Front Density** (g/cc)	**Back Density** (g/cc)	**Corpus Volume** (cc)
Stradivari 'Betts' (1704)	0.429	0.545	1,991
Stradivari 'Harrison' (1693)	0.394	0.504	1,922
Stradivari 'Titian' (1715)	0.363	0.560	1,891
Guarneri 'del Gesù' 'Plowden' (1735)	0.354	0.543	1,831
Stradivari 'Willemotte' (1734)	0.364	0.558	2,060

Figure 5 CT mass distribution curve for the major back plate

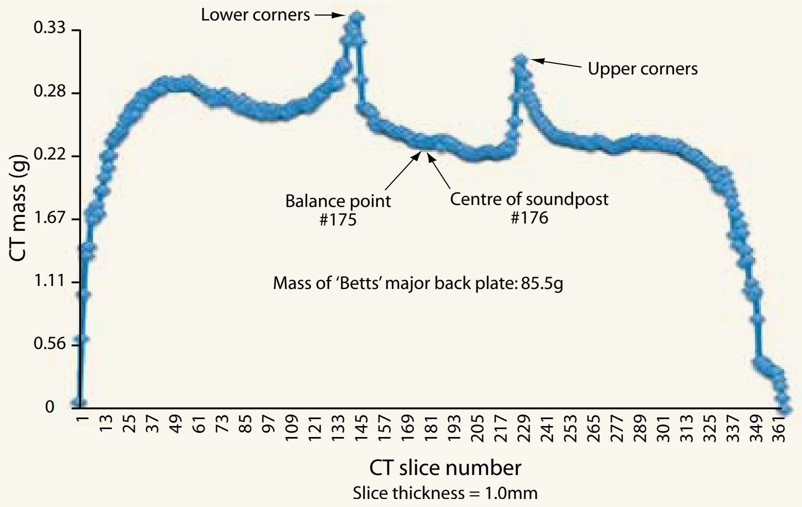


Figure 6 Densities of 'Betts' areas, in g/cc

Front plate	0.429
Back plate	0.545
Scroll	0.555
Neck	0.592
Fingerboard	0.911
Bass-bar	0.421

Upper block	0.366
Lower block	0.399
Upper treble corner	0.291
Lower treble corner	0.271
Upper bass corner	0.282
Lower bass corner	0.302

Figure 7 Scan of rib structure at centre

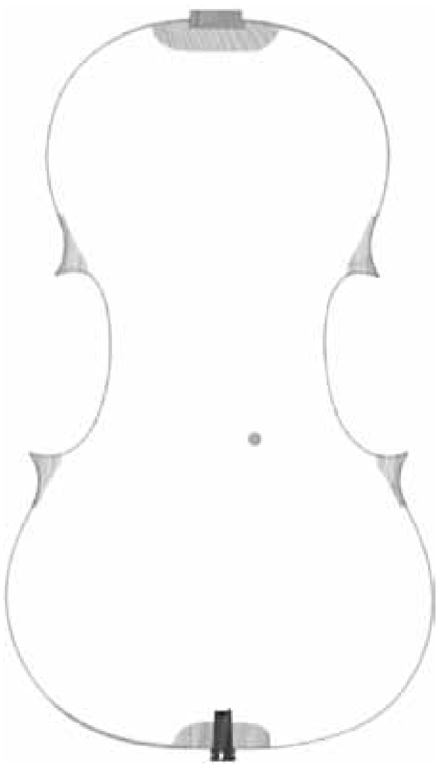


Figure 8 Scroll cross-section

Using CT to measure the distribution of mass shows that the total mass of the back can be divided into two parts, an upper part and a lower part, with the dividing line at the soundpost position (**figure 5**). Most audio speakers are designed as a round diaphragm with a central energy source mounted in a more or less rigid cabinet. A violin back is not round, but does have a somewhat central source of energy input (the soundpost), and is mounted in a semi-rigid form (the ribs). Because the violin back is left thicker in the middle and thinner in the upper and lower bouts, the result is like a speaker.

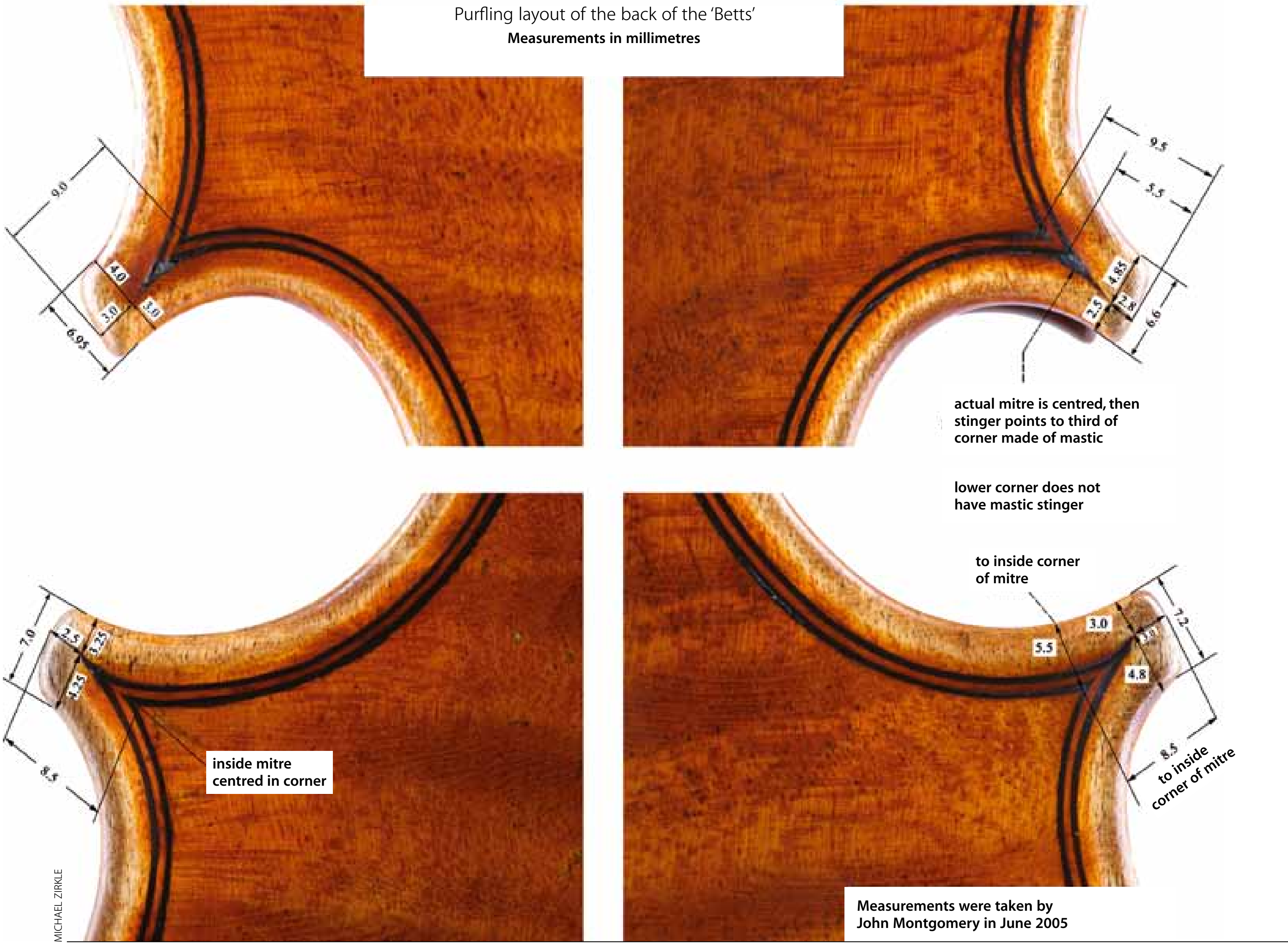
THE TOP IS EXCELLENT-QUALITY spruce of the type so often used by the Stradivari workshop, the Guarneris, the Amatis and others. Overall, the wood of the top seems heavy compared with other Guarneris and Stradivaris we have measured (figure 4). Why would Stradivari choose a light back and a heavy top? Did the Cremonese masters of the time measure density in their wood? We don't know.

CT images of the top show some hazel, as Hargrave noted in his article. The arching is 16.7mm high at the highest point, 3.4mm thick at the thickest point, and 2.1mm thick at the thinnest point.

Stradivari's typically shaped corner blocks are most likely willow, and their densities are listed in **figure 6**. The upper block would have been replaced when the neck was reset, and probably the lower block is also not original. The rib structure shown in **figure 7** is taken at the centre. The scroll is similar maple to the back with a density of 0.555g/cc and is perfectly quarter cut (**figure 8**).

With the 'Betts', as Hargrave stated, Stradivari seems to have been trying one last time to make the long, elegant corners ▹

Figure 9 Corners in close-up with measurements



MICHAEL ZIRKLE

reminiscent of the Amatis, but with his own personal style. His outline is beautiful, and the corners are long, but not as narrow. This results in difficult purfling corners. In fact, the purfling mitres are so long that, in order to achieve the look he was after, Stradivari used filler where the purfling didn't fill the channel. The amazing proportions of the corners are beautifully shown in **figure 9**.

Hargrave wondered if Stradivari may have placed filler material in the entire purfling channel before inserting the purfling. This would make sense, but our imaging shows that if he did, he missed quite a bit of the channel. In fact, there are air gaps under the purfling in some areas (**figure 10**).

The air volume of the interior of the 'Betts', without the area of the f-holes, is 1,991cc. A CT profile of the air volume shows that, as with the mass of the back, the air volume is divided vertically into two parts, an upper part and a lower part, with the dividing line again exactly at the soundpost (**figure 11**).

FROM SCANS TO MACHINED COPIES

CT scans can be used to make three-dimensional stereolithography (STL) files. From these, solid models can be created using a variety of materials. Companies use STL to make prototypes of new products to test them before production. STL is used in the medical field to make models of bone structures in planning complex surgery.

In collaboration with Steven Sirr and myself, Steve Rossow, a luthier from St Paul, Minnesota, has used CT-derived STL files to recreate violin tops, backs and scrolls. The CT scans are made into a 3D STL file (**figure 12**), which is programmed into a computer attached to a computer numerical controlled (CNC) machine, which accurately cuts away all but the exact shape of the object (**figure 13**). Purfling channels can be cut, and the mould in which the rib structure is made can also be created from the CT data. To make copies of instruments using this process requires an advanced understanding of CT technology, computer-aided design (CAD), computer-aided manufacturing (CAM), and violin making. Rossow, together with his friend Chris Ramirez, had to design and build a CNC machine specifically for making violins, violas and cellos.

For centuries, violin makers have made copies of violins by makers such as Stradivari, the Amatis, the Guarneris and Stainer. The copies are often made by taking measurements and making templates from the actual violin or from images and measurements taken from books or posters, resulting in

Figure 10 Scan of purfling channel showing air gaps

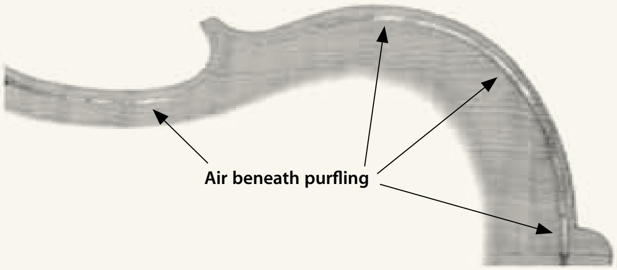


Figure 11 Profile of air volume

Internal corpus volume = 1,991cc
Soundpost volume ratio = 1.018

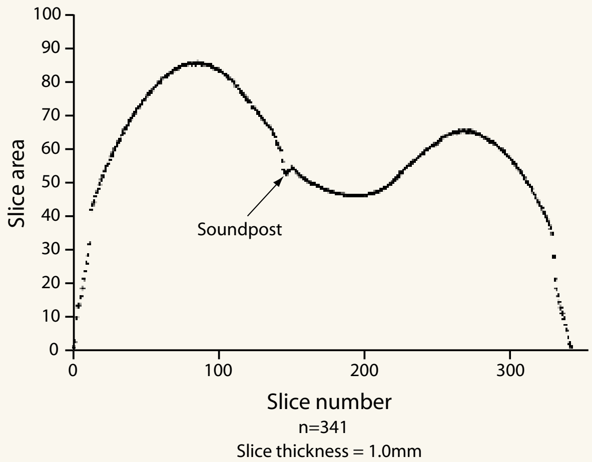


Figure 12 STL file of scroll

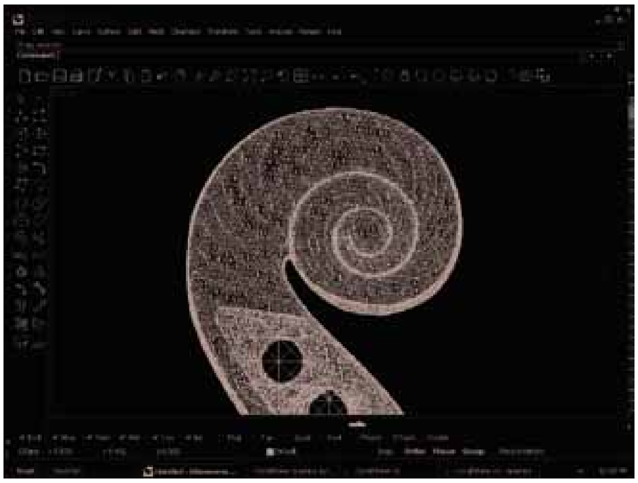


Figure 13 CNC machine cutting replica violin shape

ANNA BOTZ

violins that have outlines, archings, f-holes and other features that are all similar to the original violin. However, the violin parts that we carved on the CNC machine from the CT data have exactly the same detail as the original violin: the same beautiful archings, the same graceful outlines – even the texture of the flame has been recreated in the copy of the back. Our process is less one of making a new creation using our own ideas, and more one of helping a new violin emerge from wood and the digital data from an existing violin. We have copied exactly what the original maker did, not what we think the violin should be like.

KNOWING THE DENSITY of the woods used in the original instruments, and being able to carve the tops and backs using digital files created from the original instruments, we can make copies more accurately than ever before. Not only that, but we can do it accurately over and over again, something that has not been possible before.

The three of us are excited about the opportunities this new technology presents. Being able to make the same parts again and again will allow research that has not been possible before. For instance, if the top and back can be carved accurately, experiments can be made with the wood. What if a lower density top is used? What if a higher density back is used? What effect will wood treatments have if the archings are kept the same?

Having the three-dimensional form of the instrument digitised, it is also possible to reduce it or enlarge it. This will allow us to experiment with making the same instrument a bit larger or smaller, which will be a great help in making violas, for example. The possibilities are endless.

As revealed in *The Strad* of 1909, the art of expertise was highly developed, and there were skilled people with great understanding of the violin, but so much of today's technology was not available to them. If those same people could see CT scans of the 'Betts', or modal animations of how the 'Betts' moves when it is played, they would probably say that these new technologies just confirm what they knew instinctively.

And looking 200 years further back, I am still astounded by the sheer number and quality of instruments that the Stradivaris were able to produce using only hand tools – instruments that we are still studying and admiring. If Stradivari was working today, I wonder what he would do with an Apple Mac computer, a CT scanner and a CNC machine. ■