

Violin maker **SAM ZYGMUNTOWICZ** explores how high-tech ways of analysing violins and their sound could help makers and even influence the future forms of instruments

In recent years there has been an explosion of information available on fine violins, with high-quality photographs, measurements and detailed descriptions now commonplace.

This wealth of material has played a large role in the blossoming of contemporary violin making. Like my colleagues, I learnt that the easiest way to make a good new violin is to copy a great old violin. And, like them, I've often bumped my head on the 'Stradivari ceiling' – it seems not to be all that hard to make quite a good violin, but it is much harder to make a truly excellent violin, or to modify an existing violin in just the right way. This is

function of the violin, but their findings have not been easily funnelled into 'helpful shop tips'. As Erik Jansson, a physicist and music acoustics specialist at Stockholm's Royal Institute of Technology, once wryly commented, 'Your questions are not the same as our questions.' As a maker, when I sit down at the bench, I need more than theory – I need to decide what to do next, what arch shapes and thickness, what varnish and ground. Stradivari and Guarneri 'del Gesù' didn't use computers, and generations of violin makers and restorers have collected a very potent body of empirical knowledge, even if it is sprinkled with questionable folklore. What more could we want?

A SCANNER IN THE WORKS

especially evident when working with top players who demand higher performance and have their pick of fine violins – including Stradivaris. The current success of modern violin making has raised the stakes, however, as more players seek to use new violins and become more receptive to whatever works best for them. The last threshold of quality is frustrating and elusive, but if we want more control, we need to know more, and to reach in new directions.

Of course, the violin world has always had new concepts that can shift and fade with time, and caution is justified. Finding usable acoustic solutions can be a bit like eating spaghetti with a spoon – it's right in front of you, but hard to get a real grip.

The most important elements in the violin are those that we cannot easily see – the actual vibrations that create the sounds we hear, and the intimate interaction between player and instrument. These elements may seem intangible, but most musicians intuitively experience the violin almost as a living entity that

receives and transforms their intent and energy into music. The technological resources now available offer the chance to tease out some of these hidden functions. But these investigations may also have a more subversive effect – to enable an entirely new way of perceiving the violin.

Top academic researchers including George Bissinger and Jim Woodhouse have greatly expanded our understanding of the basic

Norman Pickering and the late Oliver Rodgers, engineers from outside the academic world, have been effective emissaries to the violin making community, explaining basic scientific principles and demonstrating workable testing methods. They also displayed the mindset needed for discovery – resourceful, open-minded, but gently sceptical. The same can be said about the best violin sound experts, such as Carl Becker and René Morel. At heart they all use the scientific method: observe, hypothesise, experiment and re-test. Computers and acoustic technologies are just extra tools in a general analytical approach.

My own trip through the looking glass began when Norman Pickering lent me his sound-testing apparatus. Only when I had this equipment in my hands could I really try to use the technology to answer my own questions. Peer-reviewed research might not be for everyone, but it is more realistic for a maker to document sound and reliably track changes made to their own instruments.

I made early use of a combined approach when I was reworking a 'problem' violin that I had made. The instrument was strong and clear, but lacked warmth. In addition to playing the violin, I was now able to record and analyse its sound-response spectra, before any changes were made. René Morel suggested that the top was too stiff, and recommended localised re-thickening and a bass-bar set at a straighter angle. With the top off, I could use tap-tone frequencies to measure the increase in stiffness from its pre-varnished state. Once reassembled, the violin sounded much warmer and more responsive – satisfying, if unsurprising. Yet in fact the spectra tests showed relatively minor change in the lower response, but a notable increase in the high-frequency range, and a drop in the mid-range 'nasal' frequency region. I liked the resulting sound, and because of the sound-response spectra tests I began to understand the changes in a different way.



JOSEPH REGH



The Strad3D study violins undergo computed tomography



The precious Cremonese violins about to enter the CT scanner

PHOTOS: GEORGE BISSINGER

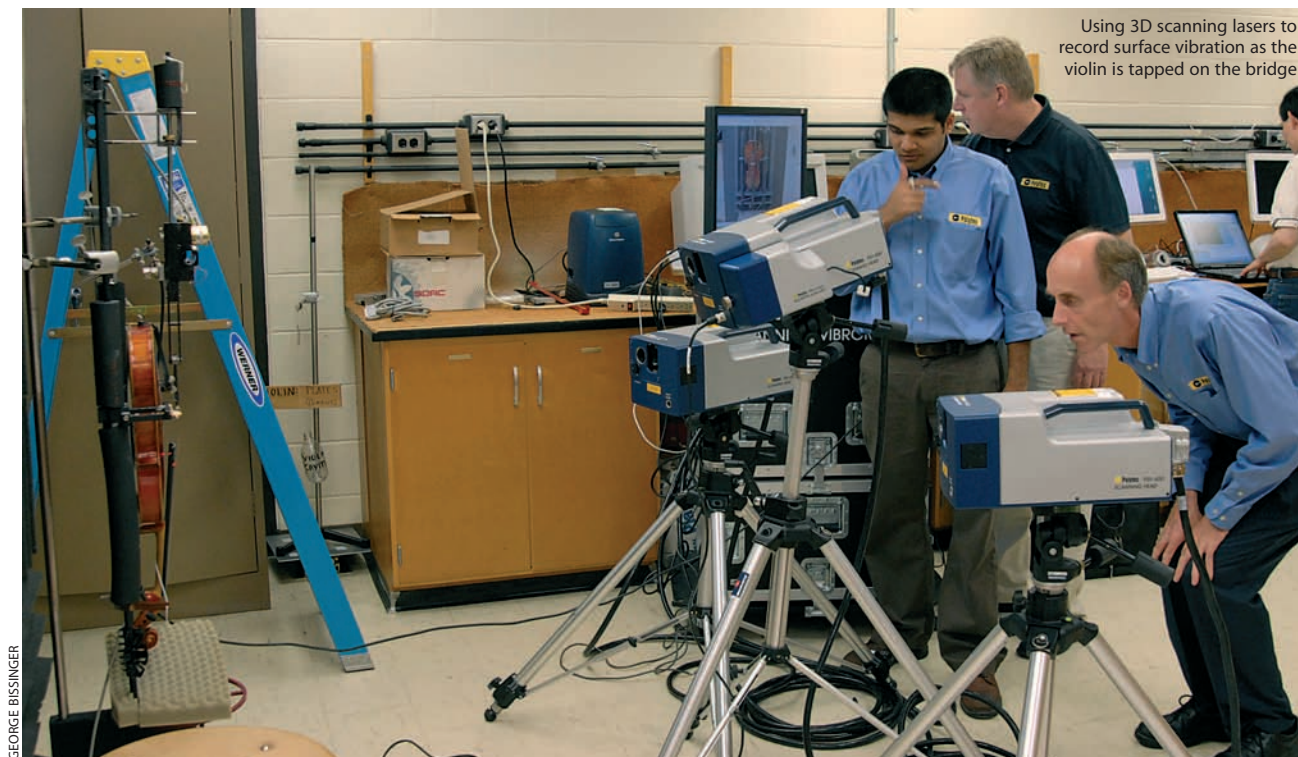
STRAD3D

In an attempt to bring together the disparate approaches of technology and traditional documentation in a unified inquiry, I joined George Bissinger in developing the Strad3D DVD project. For our study violins, we chose three acclaimed Cremonese instruments with obvious merit and appeal. Our investigation does not lay out many clear answers, but it does make available previously unseen images and information.

The technological resources now available offer the chance to tease out some of the violin's hidden functions

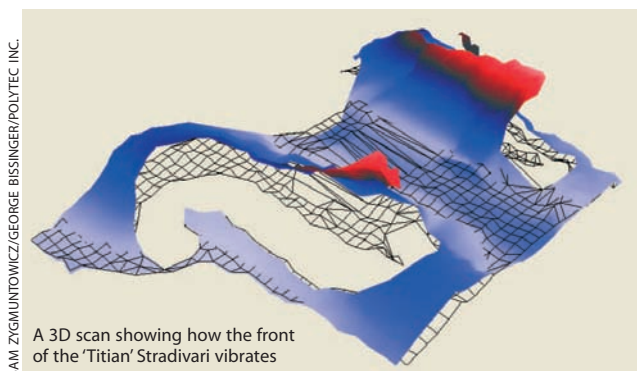
The project began at the Violin Society of America's Oberlin Acoustics Workshop when I joined the staff and met Bissinger. He had one of the world's best violin acoustics laboratories, but little access to truly great violins. The leading maker of vibrometry lasers, Polytec, had agreed to bring in their most advanced 3D scanning laser — as long as Bissinger could obtain a suitable Stradivari to scan. The stage was set.

Due to the great trust and generosity of Mark Ptashne, Cho-Liang Lin and the Miller family, we were able to borrow the 1715 'Titian' Stradivari, the 1735 'Plowden' Guarneri 'del Gesù' >



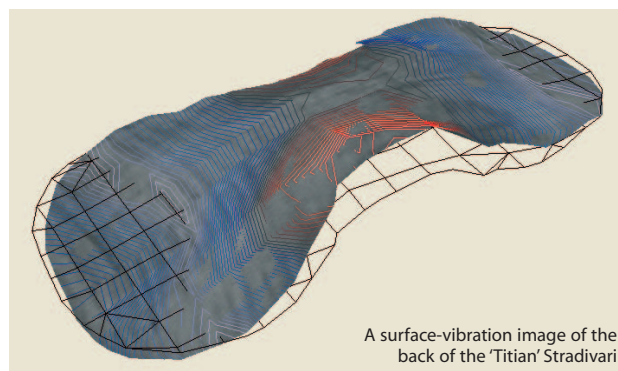
Using 3D scanning lasers to record surface vibration as the violin is tapped on the bridge

GEORGE BISSINGER



A 3D scan showing how the front of the 'Titian' Stradivari vibrates

SAM ZYGUNTOWICZ/GEORGE BISSINGER/POLYTEC INC.



A surface-vibration image of the back of the 'Titian' Stradivari

SAM ZYGUNTOWICZ/GEORGE BISSINGER/POLYTEC INC.

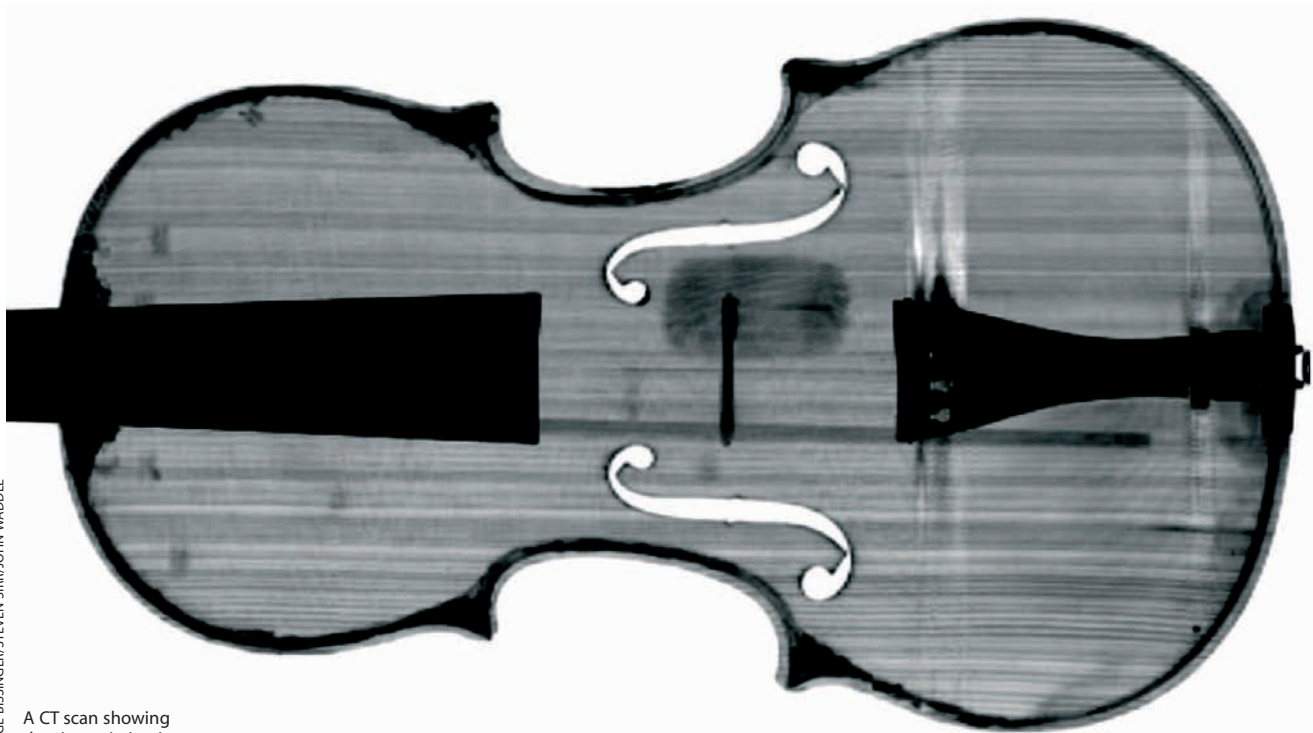
and the 1734 'Wilmotte' Stradivari. Our team of Fan-Chia Tao, Joseph Curtin, Joseph Regh and myself then made our way to Bissinger's acoustics laboratory at East Carolina University, with the trio of Cremonese violins in tow.

The instruments were carefully suspended on a testing apparatus and gently tapped on the bridge with a calibrated impulse system, while three laser 'cameras' scanned from point to point to record surface vibration. The sound radiation was later recorded in an anechoic chamber. In addition, the violins underwent computed tomography (CT scans) to determine their density and shape properties.

To study a violin's acoustics, we basically follow the energy trail into and through the instrument. When a player bows a string, impulses are sent through the bridge and into the violin, stressing and bending it. As the violin tries to return to rest, its surface vibrates as it dissipates the impulses into sound or heat. The violin bends in a variety of patterns, or modes, depending on its shape, and where it is stiff or flexible. Some of the vibration efficiently produces the sound radiation that we hear, but other modes of

vibration are relatively ineffective in producing sound. Much of the energy is silently absorbed as internal friction damping, especially at lower frequencies – even more so when the violin is held by the player's shoulder and hand. Damping and sound radiation are influenced by wood choice, varnishes and age, and it is in these material properties that the 'old Cremonese sound' may reside.

Using a calibrated input and acoustic scans to measure sound output, Bissinger has now calculated radiation efficiencies and damping characteristics for the 'Titian' and 'Wilmotte' Stradivaris and the 'Plowden' Guarneri 'del Gesu', as well as for other violins of varying quality. The 3D vibration scans allowed Bissinger to compare for the first time efficient 'out-of-plane' pumping vibrations with relatively ineffective 'in-plane' side-to-side vibration. With the acoustic radiation tests, he measured how much sound radiated from the front of the violins compared with the back – perhaps an important factor in directionality and projection. Bissinger presented his most recent findings in the paper *Structural Acoustics of Good and Bad Violins* (*The Journal of the Acoustical Society of America*, September 2008).



GEORGE BISSINGER/STEVEN SIRR/JOHN WADDLE

A CT scan showing density variation in the 'Wilmotte' Stradivari

Computed tomography uses the same hospital equipment that is safely used on people. As with a patient, the violin passes through a special X-ray machine that creates a series of cross-sectional slices. These can be analysed to calculate density, even comparing the hard and soft spruce grain lines, a process recently carried out by Terry Borman and Berend Stoel. The Strad3D study violins were scanned as 600 'slices', which can be viewed as frames in a video journey through the violins, or assembled into a 3D geometrical model of the entire violin, which can be rotated and studied from any angle, as can be seen in the stunning images prepared by Steven Sirr and John Waddle.

Bissinger hopes to take the 3D model from the CT scans and add the vibration and damping data from the laser scans to create a complex 'finite element' model, a computer-generated 'virtual Stradivari' in which individual variables such as arch height or wood properties can be changed at will, and the resulting vibration changes simulated and studied. Even a simplified finite-element model can dramatically show the effects of structural changes, as demonstrated by University of Birmingham physicist Colin Gough. This is a new frontier in acoustic research.

The new approaches are tantalising, but they do not replace or fully rival traditional documentation. For our project we included high-resolution photography, physical measurements and contour-thickness mapping. François Denis recreated the violin designs using his geometric design methods, which help show how the violin evolved and retained its current form. Most basically, we recorded a series of musical excerpts so that we could hear and compare the instruments in use. Film-maker Eugene Schenkman has assembled the music and images into several short videos, and the undulating CT curves and modal animations are strangely sensuous and mesmerising. We also included a dendrochronological wood study in the project, as well as additional articles and analysis.

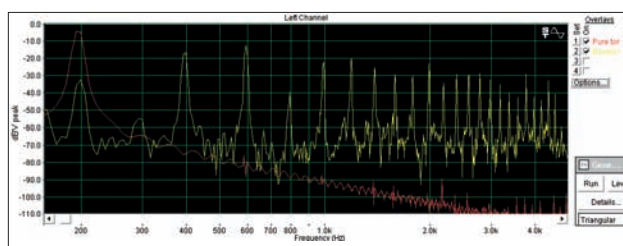
THE VIOLIN MAKER'S PERSPECTIVE

As violin makers become comfortable with basic acoustic concepts, and computer analysis gets ever cheaper and easier, the collaboration between scientists and violin makers is becoming more equal and more productive. As this community evolves, both camps can try out new roles. The makers know what works, but not always why; the scientists offer analysis and experimental rigour, and help us guard against assumptions that are fuzzy or simply wrong.

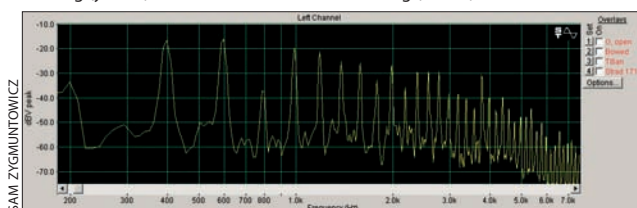
The methods and goals of pure research, which values repeatable and verifiable results, are beyond the practical interests of most violin makers. On the other hand, scientists don't need to actually make any violins. As makers, we can draw an immediate value from an enhanced understanding of the behaviour of the violin – a more informed intuition – and the tools of technology are helping us to form a dynamic acoustical vision of the instrument.

A first step in an acoustical view is to become aware of the complex harmonic content of every note on the violin, and of how that changing balance of frequencies defines the timbre of the sound. Spectral analysis can easily process any sound into its component frequencies, displayed as a simple graph with frequencies and relative loudness. For example, a spectrum of a tuning fork tuned to G would show a single clear peak (G being approximately 200Hz). The same G played on a violin would show the same 200Hz fundamental frequency, but also the second harmonic at 400Hz, then additional partials at 600Hz, 800Hz, 1,000Hz and so on, as far as the ear could hear.

One of the first acoustical tidbits to grab my attention was that when playing the open G string on any violin, the resulting rich, deep sound possessed very little of the fundamental G frequency, and that most of our perception depended on the high harmonics of this 'low' note. If this were true (and actually it is) then you ▶



Frequency graphs comparing (above) a tuning fork G (red) with a bowed G-string (yellow) and the 'Titian' Stradivari G-string (below)



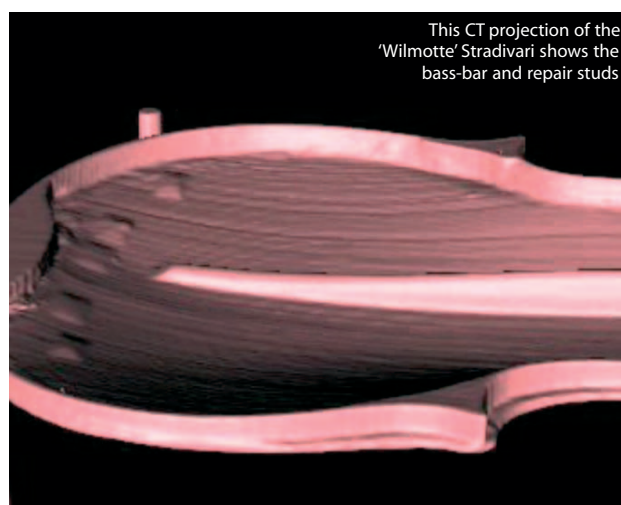
The most important aspects of the violin are those that we cannot easily see

could never make the violin much more bass-heavy — you would instead need more high partials to make the G string sound strong. It seemed unlikely, but it did explain why a strong bar and a tight soundpost could make the low G string sound more powerful, or why a small viola can still have strong C-string projection

Another acoustical fact that took getting used to is that uniform, even tone on the violin is a myth — some notes will always be hotter than others, and every violin has a jagged response potential with loud frequency peaks mixed among a variety of relatively dull valleys. That is what makes the violin sound so interesting, especially when it is played with vibrato. The spectral response of a violin will reveal its varied peaks and valleys.

Any instrument has a different type of motion, or mode, for each frequency peak, but in real use an instrument vibrates in many different ways simultaneously, to create the mix of frequencies that comprise any note. Modal analysis breaks down this complex mix of motions frequency by frequency to create maps of mode behaviour. The smallest modifications to these modes may be audible in the sound. Oliver Rodgers developed some simple techniques to find areas of modal activity with minimal equipment, and was even able to find 'hot spots' on a violin with his fingertips while someone played a strident note.

Looking at modal animations yields continual insights and speculations about the basic designs of the violin: 'Oh, that's what the corner-blocks are for; that's what the soundpost does; that's why the f-holes are shaped like that; that's why the arch has those shapes; that's what the bass-bar is doing; that's why the ribs are thin; that's why the back is thick in the centre' — and on and on. Some scans can even track air motion and sound radiation specifically from the f-holes, showing the workings of AO,



This CT projection of the 'Willemotte' Stradivari shows the bass-bar and repair studs

GEORGE BISSINGER/STEVEN SIRRO/JOHN WADDLE

the lowest violin mode, which is crucial to good violin sound. The new imaging tools are so vivid that a violin maker or musician can begin to absorb this vision in an intuitive way. The hidden motions of the violin that we see are also extraordinarily beautiful.

There is still a long leap to being able to understand the variables fully and to control them, but the clear implication is that all these design aspects of the violin could be used with real purpose and intention. If you can change the structure, it will change the vibration patterns, which will then change the frequency mix, resulting in a change to the tone. This chain of cause and effect indicates how malleable the sound and structure of a violin can truly be, and suggests possible strategies for shaping sound.

Martin Schleske's tonal copy approach showed the potential uses of modal analysis and modification. George Stoppani, a violin maker who is also an accomplished self-taught computer programmer and acoustician, has created his own modal software — an impressive example of the flexible use of technology by a non-scientist. He is adapting his modal maps to show not only maximum modal movement, but also areas of maximum bending where a violin maker might attempt effective interventions. My own experimental 'Gluey' project uses small, removable patches to change and rearrange the sound of a violin, working directly with a player and without the need for high-tech toys. Some makers, including Schleske and Curtin, are experimenting with composite materials to reconfigure the violin. The violin may take many forms in the future, depending on the intended use.

And what about Stradivari's purported 'secret'? For us, that turns out to be an unhelpful question. The real mystery is not why the old violins are so great (some are, some aren't), but how such a seemingly simple design functions so effectively, and how we can enhance our own new violins, working today with the resources at hand. ■

Scans and other images of the 1715 'Titian' Stradivari will be featured on a poster with next month's issue

>> ONLINE EXTRAS

Download additional images and video clips of the Strad3D project at www.thestrads.com