Spruce Surface Modifications for Improving the Tone of Musical Instruments

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Helen Hayes: In addition to a successful scientific career in solid-state physics, Dr. Joseph Regh has made a number of important contributions to the violin world. A prominent example is the biannual VSA Instrument Competition, now regarded as the most effective competition in the world, which has benefited from Joe's insightful organizational skills. Another abiding focus has been his research on the materials of violin bows. Today he will describe his most recent research and insights about spruce, which should be of great interest to all violinmakers. Please welcome Joe.

Joseph Regh: I would like to start my lecture on a subject that I have been working on for the last two years from the back end. I'm going to ask two gentlemen musicians to demonstrate the result of the research applied to a violin and a cello. So I invite Gregory Gelman to come up and play a few selections on the violin. He will then comment as to what he feels about the instrument that he's playing.

Gregory Gelman: I will play three segments, all by J.S. Bach. First will be Allemande #2, then the Presto from Sonata #1, and then a short quotation from the Chaconne from Partita #2. Please pay attention to the sound and the relative evenness of the four strings because that's obviously what Joe's research is about. Also, listen to the sound through the forte, through the louds, through the softness, and in between. If you hear wonderful sound, that's because the violin is great. (And if the sound is not so wonderful, that's because the violinist is not so good.)

I first tried this instrument about two days ago and, without the slightest exaggeration, I was just blown away. Tears came to my eyes. This is essentially what I had been looking for all my life. I have played on the Stradivari violin owned by Ani Kavafian, as well as some other great violins, such as those by J.B. Guadagnini. However, I have never played a violin by Guarneri.

Under my ear (I can't comment on the projected sound) the sound of Joe's violin is just superb. I'm telling you this without the slightest hesitation. Everything is even. The instrument is very responsive to my slightest attempt to play soft, loud, and anywhere in between. The sound is very warm and "urgent." It's a pleasure to practice with it, and even more a pleasure to play. Overall, I think it's an absolutely terrific, superb-sounding violin.

Dr. Regh: Thank you, Gregory. Your paycheck is waiting at the . . . [Laughter]. Doug McNaims, a local cellist, will now play the cello for us.

Doug McNaims: I'm not quite as organized as my compadre was, but I'm going to noodle around with a little Haydn and a little *Don Quixote*. Cello players like to play loud, so I'll start with something loud, and then I'll find some soft stuff somewhere along the way.

An hour and a half ago was the first time I played this cello, and it's remarkable. Joe told me how old it is and where it came from and not too many other details. Whatever he has done is quite remarkable, to be able to make an instrument so responsive and have so many colors and such depth—especially at the bottom part of the instrument. I have played many incredible instruments over the years.

Cellists are a little different than violinists, who are especially interested in what the E-string can do. We cellists like to start at the bottom. When I put the bow on the C-string of this cello, it just about knocked the walls out of the room. But more important, it was the quality of the sound—the depth of colors and overtones—that constantly moved around. And this is a new instrument that probably hasn't been played much. I can only imagine what it's going to be like after it's been played for some time. It already responds very quickly, but I expect that it's going to become more so.

I noted, as did Joe, that I hear a little disparity going from the C- to the G- to the D-strings. The D-string is a little quiet, but I think that may be just a matter involving string tensions. I think the colors on that D-string are something else. Those are my opinions just now.

Dr. Regh: I hope that this at least has sparked some interest. Let me tell you something about these instruments. The violin is practically a discard. It was given to me as an experimental instrument that wouldn't be missed by anybody. The cello is a $2,000 commercial instrument that I have modified after the fact, and there's also a viola, which anybody can play who is interested, that has been subjected to the same treatment. Today I want to explain to you what made the difference and how it came about.

Stringed musical instruments, including percussive stringed instruments like a piano, pretty much all use spruce for their soundboards. Why spruce? Because spruce has some very interesting, unique characteristics that relate to its stiffness. If you take a piece of spruce that goes this way and you bend it like that, it is much, much stiffer than if you bend it like this. The ratio of the strength in the direction of the grains to the strength across the grains is what makes spruce unique. The degree to which you can bend one side more than the other has to do with where the spruce comes from, the species of spruce, and many other factors that I will address.

Spruce is a very light material, and yet it is stiff. It is used extensively in the building industry. Some species of spruce fir are used for floor joists for very good reasons: they're very strong and very lightweight. Also, spruce looks nice. It takes paint, stain, and finishes very well. When you're done, the appearance of a violin or a cello is very pleasant. Spruce is a unique natural material, and because of the stiffness ratio, it is uniquely suited as a soundboard in a musical instrument.

That's sort of a reiteration. What I'm going to talk about today will have some impact on the ability to monitor the loudness and the sound output of violin instruments, which is what we are all interested in. It is also going to enable piano makers to make much louder and much better "loud is good" pianos. It is also applicable to the guitar industry, to harpsichords, harps, and mandolins, because what I am changing is the property of a material. Somehow, in some magical way, the tonal performance of the instruments is tied to a material property.

If you want to be so bold, you can say that even the finest violins that we all treasure are limited. They are a material-limited design. If Antonio Stradivari had had better technology and better materials available, he would have made even better instruments. As great and unique as they are, they have some limitations. This technique that I have developed over the last two years can be regarded as primarily an advance in materials.

Last year we heard some instruments played that were made with manmade materials, with carbon fiber, and the cello was an absolute boom box! It was built on some of our understanding of the limitations of materials. Rather than modifying the materials that we have, the approach was to engineer manmade materials to have properties that we need in our musical instruments.

My approach has been to take what we have and make the materials better. Then, hopefully, there will be an improvement in the performance of all these instruments.

We have been aware for 300 years that some spruce makes superior instruments. I think the way it happened was that some instruments just sounded so much better than others. Then, using backwards engineering, it turned out that all these really nice sounding instruments were made from spruce that came from certain locations. If you want to make an instrument today, look for a really nice piece of spruce. Go to a wood dealer, buy the best they have, and pay premium prices. By chance you will purchase a superior piece of wood. However, we know very little about what makes a good piece good and a not-so-good piece not so good.

We have spent years in the sciences to determine all the properties of a piece of wood that are easily measurable. We know about stiffness, density, and Young's modulus. We know about weight, softness and hardness, and color—but we know very little about what it is in a piece of spruce that makes it better or worse. We know that if you harvest a tree from certain locations in the world, that wood is more likely to make a better instrument. That has been established through experience over the last 300 years, and we continue to live by that same knowledge. We still pick our materials based on the collective experience of woodworkers over the last 300 years.

We know some of the parameters required to make a good piece of wood. We like it when it grows at high altitudes where the growth conditions are more severe. We know that climate and soil are very important. There is speculation that there was some kind of an Ice Age in the Italian Alps, and that resulted in all of Stradivari's and other Cremonese instruments being so wonderful. I will show you some evidence that refutes that, just from a physics point of view. As we go through the slides, some of these things will become evident.

Advertisements by instrument makers often state that "This was made from Balkan spruce," or "This was made from the best Alpine wood," meaning that they were made from the best materials available. We rely on wood dealers and hope they know what they're doing. We rely on the assumption that if we pay a lot more money for wood, it's going to be a better piece of wood. There is intelligence, obviously far beyond that, and it's the intelligence of violinmakers accumulated over three centuries. Generally, the products and the instruments that are made today attest to the fact that good makers know how to pick a piece of wood. My question is: How do you improve the quality of what is available?

We are all aware of the differences between the sound of an old instrument and a new instrument. We have hundreds of thousands of examples attesting to the fact that it is real. An old instrument, in terms of responsiveness, tonal quality, tone color, and projection, is different than a new instrument. We try to make instruments as old sounding as we can by working on the wood. Some people bake their wood; some treat it another way. Not being successful in making the instrument an old instrument, in terms of its performance, we then antique the outside. At least it will have the appearance of an old instrument. From a psychological point of view, that may make some difference. The implication of how aging affects the sound of an instrument will probably become more obvious and intelligible at the end of my presentation.

We have covered the growth location. If you age a piece of wood, you affect its strength—probably uniformly. If I bake this piece of wood in an oven for a certain period of time, or soak it in some solution, the strength along and across the grain is equally affected. The ratio of those two is probably not going to change very much. The physical properties, however, are going to become different.

We know that the best an instrument is ever going to sound is when it's in the white, before you put any varnish on it. When you consider this from the physics perspective, it makes sense. The reason we pick spruce is because it has a different stiffness along the grain compared to across the grain. That's an intrinsic property of spruce. The intrinsic property of a varnished surface is to be equally flexible or stiff in all directions. So if I take a piece of spruce and laminate something on it that is isotropic and flexes the same way, I am reducing by some small amount the ratio of the two stiffnesses. This is a very important concept.

We know that an instrument doesn't work well without a bassbar, and we know that a bassbar is a very fine tuning element in setting up a violin. If we make it a little stiffer, a little thinner, a little thicker, or a little heavier, the stiffnesses redistribute it slightly, and that has an impact on the sound of the instrument. What I'm claiming is that when you install a bassbar, you make the stiffness in the direction along the bassbar greater without affecting the stiffness across the grain. Essentially, you are changing the ratio of longitudinal to transverse stiffness.

We have noted that arching affects the tone.

Arching is the geometry that allows a minimum deflection while resisting the downward force of the strings. There's a large downward force through the bridge onto the top of the instrument. Depending on the arching of the top plate, it affects the flexibility and the degree to which the bridge can move the top plate up and down. For some of the highly arched, older instruments, where the neck foot is at the end of the violin, where you come up with a very high arch, the instrument is actually collapsing. The top goes down underneath the fingerboard and then comes up again a little further in. The neck projection keeps sinking because the arching doesn't support the downward force of the strings.

Of course, the graduation of the plate thickness is very important; but again, graduation affects stiffness, uniformly or selectively, by having some areas thicker and some thinner. We have established patterns for how to graduate an instrument. There are many different schools of thought, but when we are done with this presentation, I believe you will rethink some of the strategies that we have used to graduate and to fine tune instruments.

About 30 years ago I had a boat with a teak deck. When teak is exposed to the weather, it turns gray. Of course, no proud boat owner would want a gray teak deck. So the marine stores sell a material—it comes in two parts—called Teak Cleaner. You spread part A on the deck and scrub it with a brush. After rinsing that surface with water, you spread part B all over it, which neutralizes part A. You again wash it with water and let it dry, and the result is a beautiful golden color. You can seal it with varnish or leave it alone—it makes no difference.

What I remembered when I was thinking about this spruce business is that after doing that many times, the surface became very rough. Teak has a similar structure to spruce, especially when it's quarter-sawed. It has rigid winter growth and a pulpy summer growth. What happened with this etching material, with this cleaner, is that the pulp was removed faster than were the hard reeds. So when you felt the surface of the teak, it had all these ridges sticking up. At that time I used a plane to get rid of the ridges because I wanted a smooth surface. When I started working on spruce, that experience came back to me and I thought, Why not try that on a piece of spruce? In fact, that's what I did.

I will now describe the experiment. Figure 1 shows a block, a holder, a spacer in the back, and a piece of spruce clamped in here. The spruce is untreated on one side and somewhat treated on the other. There's a weight attached to it, and the vertical thing with a little plunger on it is an LVDT, short for linear variable displacement transformer, which is an electric gauge. I clamped the spruce, measured the height of the plate, displaced it with a known downward force, and measured the displacement again. I did that for two different loads. Figure 1 shows the configuration for the transverse stiffness measurement. Similarly, I measured the longitudinal stiffness. Again, it was in the same holder, only this time the deflection was on the long end of the piece of spruce.

When you run an experiment like that, you don't know what to measure. You're running a little bit blind. So while you're at it, because once you do something to it you can never go back, you take as many measurements as you can. I wanted to make sure I got the right stiffness, so I measured it this way and then turned the piece of wood around and bent it the same way again. To get a decent number, I took the average of those two. One of the first things I noticed is that there seemed to be a consistent difference, even for the untreated wood. If you bend it one way and turn it over the other way, you would expect to get the same number, but you don't. There seems to be a consistent difference in bending wood one way as opposed to the other way. I don't know why that is. Maybe that is something that we can learn pertinent to selecting wood. It is a curious phenomenon.

Next, I present a summary of the data listed in a series of columns in a table (Fig. 2). First of all, you see three long axes and then three wide axes. There were three sets of measurements. By long axes, I'm talking about the deflection this way. By wide axes, I'm talking about deflections this way. If you go to the very end, you will see the load condition. This is 218 gm and 318 gm, and those are the two load factors that go all the way through. You see these repeated. And then you see here "top up" and "top down." "Top up" indicates that the untreated side is up, and "top down" indicates the untreated side is down.

The next column is the deflection, which was

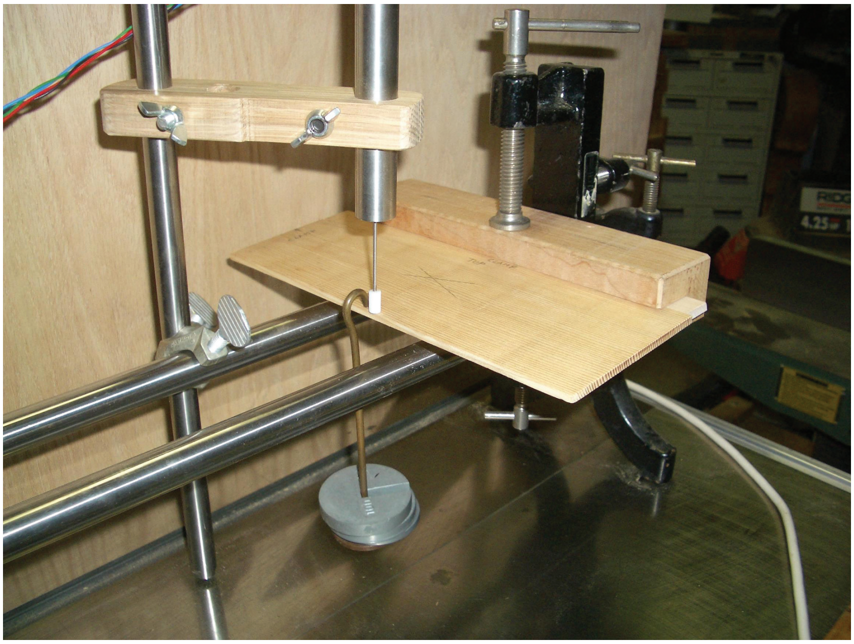

Figure 1. Load-deflection measurement of a spruce plate perpendicular to the grain. A linear variable differential transformer (LVDT) is used for measurement of displacement.

1.37 mm. If you increase the load, it goes to 2.11 mm. The deflection increases as you increase the load.

To present these data in such a way to make sense to everyone, I reduced my measurements to be effectively on a square plate. Then when I measure the deflections one way and the other, all I have to do is take the ratio of the two to arrive at the stiffness ratio; no side calculations required. The number you see is a direct measure of the ratio of the stiffness along the axes versus across the axes. That is what "normalized-to-square" means: taking this number and recalculating it to the deflection that would have occurred had this been a square of about 86 mm x 86 mm.

I can consider this piece of wood as a spring, clamped on one side and loaded down on the other. For a given load, I measure a certain deflection. When I double the downward force, I double that deflection. Hooke's Law predicts that result, and I readily apply it in most of my work. The ratio of the load to the displacement is known as the spring constant k. The higher that number is, the stronger the spring. That works for coil springs and leaf springs—it works for anything that is flexible. So these are the spring constants, which are the ratios of the load to the displacement.

The next number here is the average spring constant, the average k, which is obtained by taking all of these numbers with the same load, divided by the average displacement. The next one is the ratio of the k's, 12.6, the ratio of the two deflections, the longitudinal and transverse, for the untreated wood. So the longitudinal strength is 12.6 times greater than the transverse strength. This would be after the first etching step and after the final step that I'm going to describe. The last column is one of the most interesting as it gives you the percentage change in that wood characteristic as a function of the two treatments.

The T-0 here refers to the initial condition of the untreated wood. The T-1 is after the etching step with the teak cleaner. The T-2 is the condition after I mechanically enhanced or mechanically removed material selectively to affect primarily the transverse stiffness. So you have the ability to change a piece of spruce by as much as 33% for that particular parameter, which is in all likelihood far outside of what nature produces.

The results of my spruce deflection measurements can be understood more easily in a graphi-

DISPLACEMENT OF SPRUCE PLATE

T=0 = Initial conditions	Plate dimensions:	228 X 91.5 X 4.0mm
T=1 = After etching step	Normalized to square:	85.6 X 85.6mm
T=2 = After riffle grooving		

Load g	Direction	Displace-ment mm	Normalized to square 85.6X85.6	Spring constant k (g/mm)	Avg. k	Ratio k(l)/k(w)	Change %of base
T=0	Long Axis						
218	Top up	1.37	0.28	666.7	717.9	12.60	0.00
318		2.11	0.43				
218	Top down	1.22	0.25	769.2			
318		1.83	0.38				
T=1	Long Axis						
218	Top up	1.46	0.3	714.3	714.3	15.06	19.54
318		2.15	0.44				
218	Top down	1.58	0.33	714.3			
318		2.3	0.47				
T=2	Long Axis						
218	Top up	1.68	0.35	666.7	645.8	16.75	32.93
318		2.44	0.5				
218	Top down	1.6	0.33	625.0			
318		2.4	0.49				
T=0	Wide Axis						
218	Top up	1.33	3.54	57.1	57.0		
318		1.99	5.29				
218	Top down	1	2.66	56.8			
318		1.66	4.42				
T=1	Wide Axis						
218	Top up	1.7	4.52	50.0	47.4		
318		2.45	6.52				
218	Top down	1.77	4.71	44.8			
318		2.61	6.94				
T=2	Wide Axis						
218	Top up	1.79	4.76	34.0	38.6		
318		2.89	7.7				
218	Top down	2.07	5.51	43.1			
318		2.94	7.83				

Figure 2. Deflection measurements of a rectangular spruce plate before and after chemical etching and mechanical grooving (riffling). T=0: Initial conditions; T=1: After etching; T=2: After riffling. Effective bending dimensions: length=228 mm, width=85.6 mm, thickness=4 mm. Normalized dimensions: length=width=85.6 mm, thickness=4 mm.

cal form. The Hooke's Law graph (Fig. 3) shows the downward force (load in grams) plotted on the vertical axis and the corresponding deflection (mm) of the end of the spruce board plotted on the horizontal axis. Included are the measurements before treatment, after the etching step, and after the mechanical removal of summer-growth wood. For each of these three conditions, I've plotted the results for the "top up" and "top down" orientations as a pair of separate lines in different colors.

The closely spaced lines (on the left) were the measured deflections along the grain of the spruce, and the widely spaced lines (on the right) were cross-grain measurements. Obviously, the spruce treatments caused little change in the deflections along the grain (stiff spring constants). In contrast, the wood treatments caused significant decreases in the cross-grain stiffness.

This is what the inside of the treated spruce top of my test violin looks like (Fig. 4). You can see that this area has been treated, and in fact

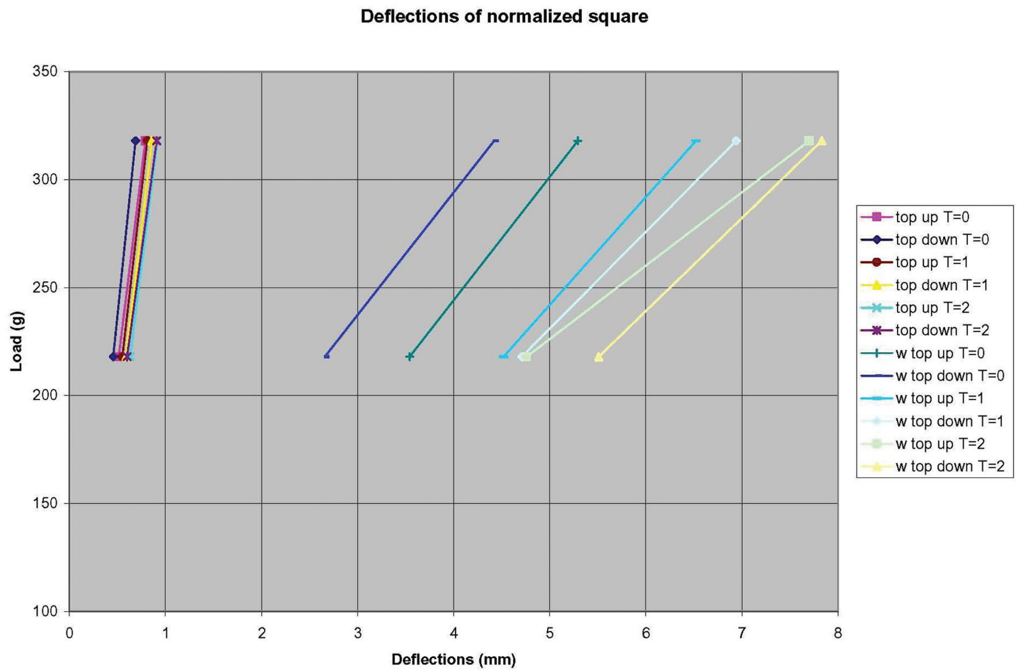

Figure 3. Deflection of a spruce plate under load. Left: closely spaced deflections along the grain. Right: widely spaced deflections for cross grain.

Figure 4. Riffled spruce violin top with untouched center section.

the side to the right of the bassbar and from here to the other edge has been changed sort of in a symmetrical way. I left the center 2-inch strip untouched for what I thought was a good reason, and it turned out to be okay. I'm not sure that this is the way to apply the technique, but the results certainly seem to indicate that I wasn't completely off. My opinion is that this center section needs to be as strong as it can to bear the load of the strings.

When I weaken the sides of the instrument, I decouple the center strip from the sides to a very large degree. I can give more flexibility and movement to the center when the bridge is in motion. In other words, there is much lower resistance to twisting of the top. Both of them are beneficial for the sound production, but I applied this out of intuition, and I in no way claim that what I have done has optimized the potential for this technique. I'm looking at it as having to go back and re-optimize things that we have learned to do over the last 300 years. The changes in the parameters that I can use now are different from our traditional instrument-making experience. We may have to start with thicker tops and then remove the material we don't want. So we end up with relatively high stiffness along the grain, and we only work on decoupling the stiffness across grain.

Now, I'm going to take you through a few graphs of my measurements of the sound output before and after treatment of the spruce top of the test violin. First, you see the audio spectrum (Fig. 5) of the finished (post-riffled) test violin tested with an impact hammer rig. One of the interesting things we have noticed for Cremonese and other old instruments is that, starting at about 3 kHz, the strength of their radiation declines strongly with increasing frequency. Certainly, the sound spectra from this instrument didn't do that before I started out, but it certainly does now.

The next illustration shows the before-and-after audio spectra of the sound radiated by the test violin produced by plucking the E-string with the other three strings damped (Fig. 6). The red is the before and the blue is the after treatment. You can think of the vertical axis as being loudness. Obviously, there is a huge difference in the sound output, especially in the lower end of the spectrum. A similar result occurred for the A-, D-, and G-strings (see Figs. 7-9 in Ref. [1]). Notice the increased strength in the upper harmonics over what there was before. Basically, the peaks changed. The composition of the sound of the instrument wasn't significantly altered, but the volume output surely was, as well as the responsiveness of the instrument.

This is a picture of the cello top of a relatively inexpensive commercial instrument after my etching treatment (Fig. 7), which took less than an hour. I put the top back on and the cello's sound was what you heard at the start of this lecture.

Now we consider a very important concept. Much of our thinking hasn't led us to the right

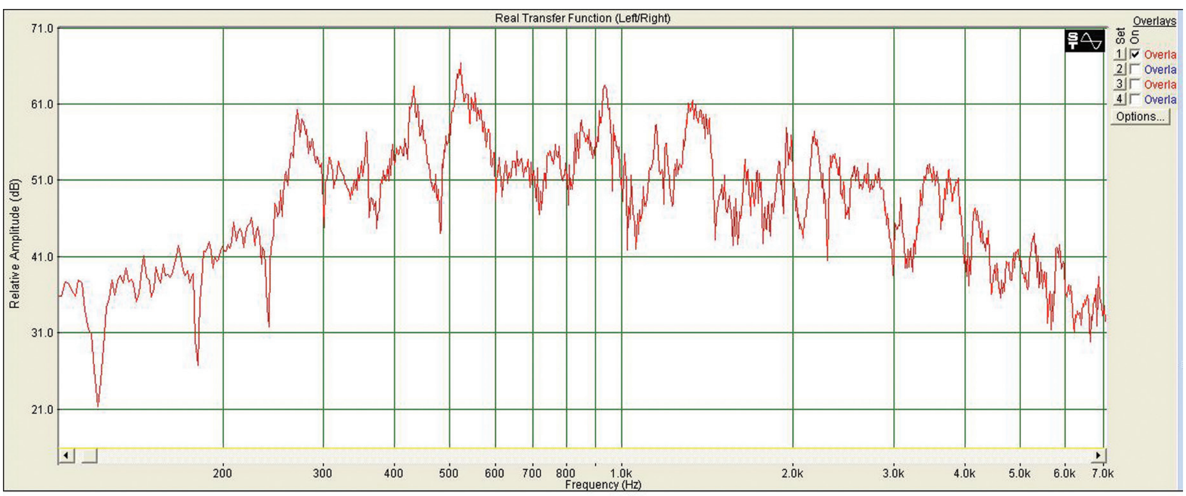

Figure 5. Audio spectrum of the post-riffled test violin produced by impact hammer excitation at the bridge.

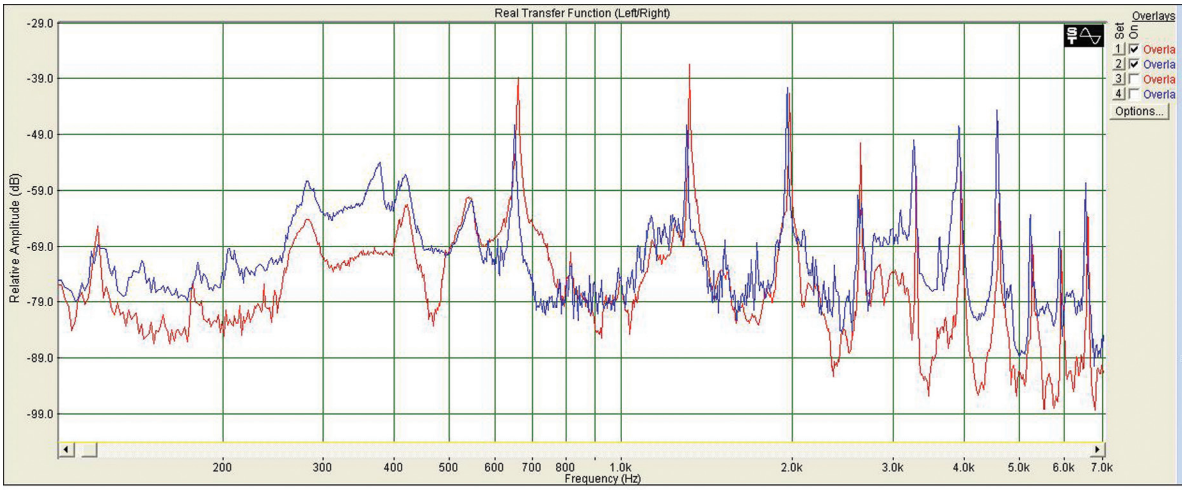

Figure 6. Audio spectra of the test violin produced by plucking the E-string before (red) and after (blue) removal of wood from the internal side of the spruce top using a riffle rasp.

conclusions or even to the right experiments because we haven't considered the basic physics of bending. We are really interested in how well a piece of wood can bend. Figure 8 is just a schematic of a piece of wood under load, and you have the upper layer, the upper surface as it bends, that would be under pressure. The material is trying to crunch together. At the same time, the lower surface is under tension. This property of bending stiffness is almost completely controlled by surface layers. It is not a bulk effect. I think that is the most important realization.

Consider what I call a stress pyramid: The width of this is a measurement of the importance of that layer in determining the entire stress. There is a tremendous effect due to our choice of using varnish or not, based on the fact that it is a surface material. It is not just 100th of the total thickness of the plate. It is much more important than that because it is added as a thin layer in the most critical space.

In the center of this dotted line (this is a zero-stress layer) there are no stresses at all. If I make any modifications to the inside of this, it has relatively little effect. Even if it is intrinsically strong, it has little effect because of the location in the thickness of the material. That begs the question of how to make laminated instruments or make laminated anything. When we put the strong material sandwiched between two other materials, it has a relatively small effect. What we really want to do is use the strong materials as the outside layers.

Ammonia treatment is one of the mainstays in the violin- and bow-making world. Ammonia is a very small molecule and it doesn't stop at the surface. It sees the surface of a piece of wood

Figure 7. Riffled spruce cello top with untouched center section.

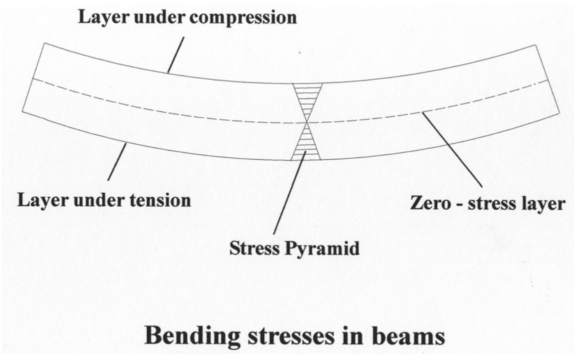

Figure 8. Schematic of bending stresses in beams under load.

as a huge network of tunnels and diffuses right through. Whatever happens in the interaction of ammonia and wood is going to be a bulk change of the material, which means that it will affect the reed part just as much as the bulk part. It does not significantly change the ratio, which is really what we are interested in. As alternatives, sodium and potassium hydroxides, which are strongly reactive, might be used. They will destroy surface layers of wood, and as such would be preferable.

Let me paint a possible scenario 300 years in the past. Imagine that there was a big competition for making the best violins, and let's pick a place like Cremona, Italy. There were many good violinmakers then and they all had their own little market. There was great secrecy—none of them would tell anybody anything. Suppose that Antonio Stradivari was in his workshop trying to figure out how to make one of his violins sound better. So he goes into his household chemical closet and pulls out a bottle of some liquid, paints it on his spruce violin plate, and glues the instrument back together. The next day, when it is completely dry, he plays that violin and discovers that all of a sudden it has changed in a way that he could have never expected. He tells his wife, "We are not going to tell anyone about this." So they applied that particular chemical to every instrument. It was invisible and couldn't be reverse-engineered. It was the family secret with which they produced their fantastic instruments. We have lost it—well, we never really had that recipe.

It could have been that Stradivari indeed hurt his own instruments and then did something to hurt them again and noticed the tremendous difference. There is scientific evidence that the surfaces on the inside of Stradivari's violins have been destroyed chemically—the integrity of the surfaces, the cellular structure, has been destroyed. So the surface layers of the wood no longer contribute to stiffness. I think that only the pulp was destroyed, not the reeds. One can imagine that Stradivari accidentally increased the stiffness ratio on his instruments to achieve greater loudness, quicker response, and better

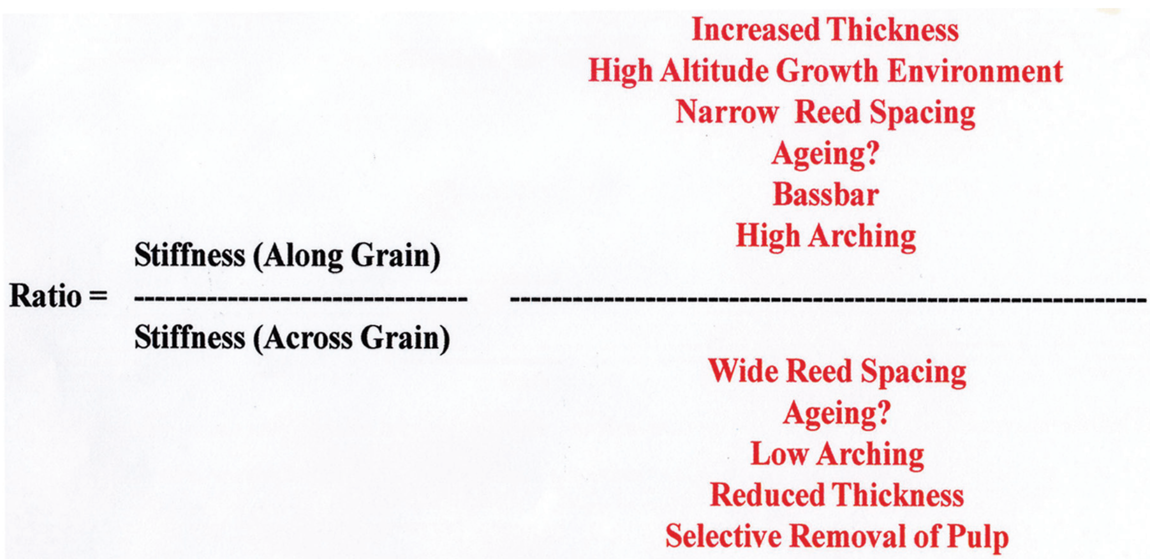

Figure 9. Factors that determine and affect the stiffness of spruce violin tops along and across the grain.

projection.

Radiation will do the same thing. If you leave an instrument out in the sunlight, the same thing will happen as with aging. Chemical interaction on the surface will destroy the surface layers, oxidize them, resulting in a reduction in the transverse stiffness and an increase in the longitudinal-to-transverse stiffness ratio.

Sandblasting has been tried also. It provides some level of improvement, but the removal rate of the soft stuff and the hard stuff is sort of like a fixed ratio. You come to a point where a certain stress ratio is reached, but you cannot go beyond it. So it has limitations.

Figure 9 summarizes the properties, environment, and treatments that affect the stiffness along and across the grain. My preferred method to alter the ratio of the stiffnesses is selective removal of the pulp.

The mechanical process I have used mostly is called riffling. Riffles are little files, i.e., rasps that have a V-shaped groove, attached to a handle. You can use them to go into a groove and mill out the material. For example, the material I removed from the cello top was 1.6 gm of the total plate mass of about 465 gm, a minuscule amount of material. It is not the mass removal that drives anything; it is the stiffness ratio.

I can control the stiffness by cutting a V-groove and taking out the summer growth by riffling. If I want to change the mass or the stiffness using the V-groove, it's determined by the remaining thickness. The thinner that gets, the softer it gets. The mass can be affected independently after establishing the flexibility. Then you take out more of the upper layer of the soft wood, reducing in effect the thickness, and then reducing the mass. If you have the desired loudness in the instrument and you want to affect the tonal composition, you can backfill the grooves.

Then the most important thing you can do is to varnish the inside of the instrument because that will protect the inner surface layer. You don't do any harm because you have achieved the low stiffness. By applying a layer of varnish inside the instrument, you don't have to worry about taking the instrument into different climates and having it change drastically. It will be much more stable.

This is sort of a schematic indicating what I did (Fig. 10). This is the winter growth, the reeds. This is looking at a cross section. This is the summer growth in the middle. I used a riffle to mill grooves in like this. The effective remaining thickness from here to here determines the flexibility of that top. The height of the winter growth is not affected at all. If you want to remove the mass after you've done this, you take more material out this way, and then you have this amount of thickness contributing to mass as opposed to this, but the flexibility is still the same.

What I think happens in nature is more like this, where you have either destroyed the material, like I just fantasized about Stradivari and his chemicals. You have destroyed the structural integrity of the surface layer of the wood, but the debris remains, and that debris now becomes a damping layer that affects the sound quality as opposed to the loudness. By milling or riffling that groove, you can engineer material that gives you the tonal characteristics of the instrument that you're looking for.

Conclusions: The ratio of longitudinal-to-transverse stiffness of a spruce plate can be changed at will by either etching or mechanical grooving. Values can be achieved that are outside of those occurring in nature. We can lower the effective thickness of the plate by just attacking the summer growth. We can start with a stiffer plate than what we're used to, and by removing the soft growth, we can increase the stiffness ratio at will. Application of this technique to the spruce tops of string instruments can dramatically change their sound.

One last consideration: We know that during the last 300 years the plates of many instruments have been regraduated. Many of our most precious instruments were scraped by somebody who thought he or she knew how to make instruments sound better. Let's rethink this process. You want to locally weaken the plate, but do you really want to change the stiffness along the grain at the same time as you change the transverse stiffness? I think it would be wiser to do it in at least two steps. First, use a riffle to weaken the sections of the instrument that you were about to scrape, and then listen to its sound again. If it needs more, you can always go back and remove the winter growth and the reeds to affect the final performance of the instrument.

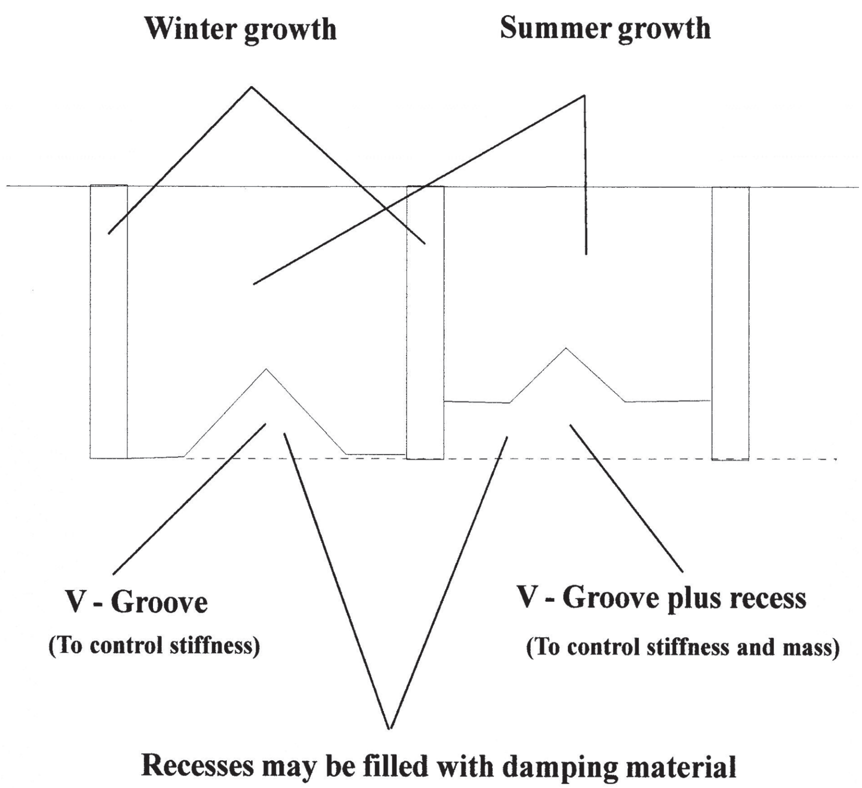

Figure 10. Cross section of spruce with early wood growth eroded preferentially to reduce cross-grain stiffness.

Tom Clark: Do you have any plans in the works to extend this research into testing various samples of spruce, for instance, those that come from various regions?

Dr. Regh: Certainly!

Editor's Note: The stiffness measurements and results are described in more detail in Ref. [1]: J. Regh, Tailoring spruce for musical instruments, *J. Violin Soc. Am.: VSA Papers,* Vol. XXII, No. 1, pp. 125-34 (Summer 2009).