A CAS Forum Activity Report

Looking at Hair Tension as a Design Parameter for Violin Bows

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Joseph Regh: About two years ago at the VSA Acoustics Workshop at Oberlin College, I asked several players to play a selection of bows because I wanted to understand how important hair tension was to them. Three of them played a selection of violin bows, and I had them adjust the bows to their comfort. With that done, I measured and tabulated the hair tension. The amazing thing I observed was that all three players seemed to like a specific, narrow range of hair tension, even though the bows could deliver hair tension over a wide range. There seems to be a preference for a certain hair-tension range.

I've worked out a technique to allow measurement of hair tension using the same kind of rig that bowmakers use for measuring the stiffness and flexibility of a stick: You just turn the bow around and measure the hair the same way. The bow is suspended with the hair up between two pins, one near the tip and one near the frog (Fig. 1). A measurement gauge—this is an LDTV—generates a voltage depending on the position of a plunger in contact with the hair ribbon.

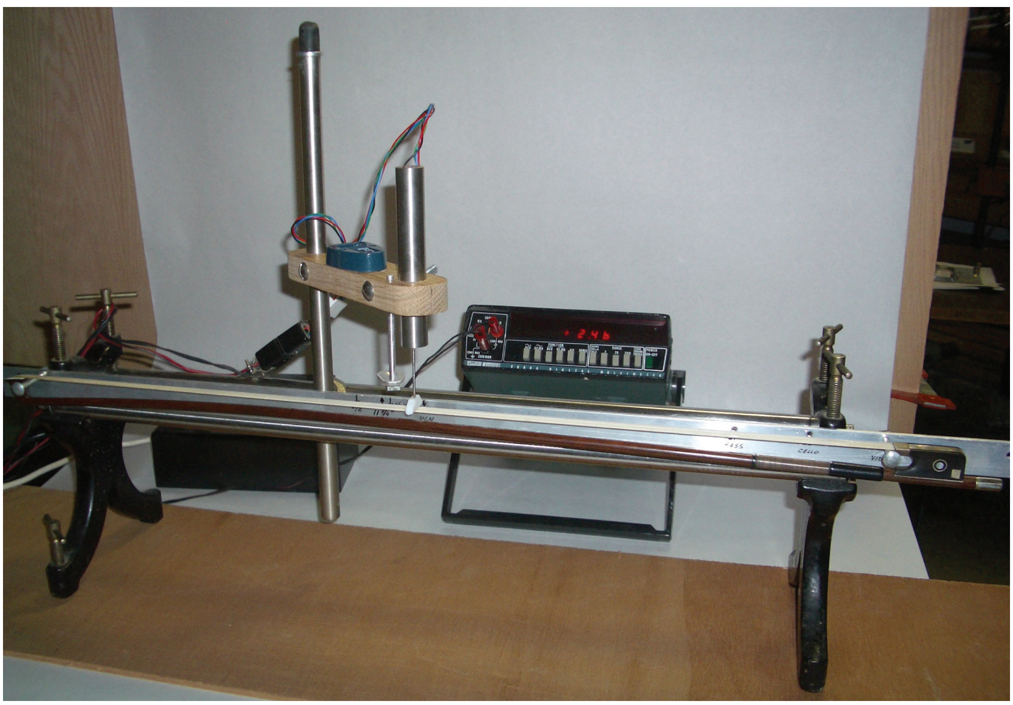

Figure 1. Experimental apparatus for measuring hair tension of violin bows.

You can see the details of the plunger in Fig. 2. A relatively wide, flat piece of Teflon™ was used so that I could measure anything from violin bows through bass bows. This plunger is a very thin, light rod. Inside this big tube are two transformers, one above the other. The rod just rides inside the transformer like a core. The secondary voltage generated from the fixed primary voltage gives you the position readout of this plunger. It's like a micrometer, only it's electronic.

After I measured the zero position of this very light load on the ribbon, I applied a mass, and the hair tension was measured again (Fig. 3). This nail is bent so it comes down parallel to the ribbon's surface. A tenth of a pound of mass is applied and then the plunger distance, the displacement, is measured again.

A schematic of the experimental measuring system is shown in Fig. 4. The distance between the two supports depends on what type of bow is being measured: 25 inches for violin and viola bows, 23 inches for cello bows, and 21 inches for bass bows. Then you have the applied force. I show it schematically as going through the gauge, but I just hang on this mass. The measurement point is exactly halfway between the two center positions.

The mathematical relationships for the tension in a string deflected by a downward force are given in Fig. 5. The final hair tension T is given by the formula at the bottom, where W is the downward force. If you work in the inch system, it's just pounds. L is the distance between the two points, which for a violin bow is 25 inches. D is the deflection distance in inches.

Using that formula, I generated tables for the hair tension from my measurements of the deflection. Table 1 is for violin and viola bows, and Table 2 is for cello bows. One of the restrictions of the deflection measurements is that the

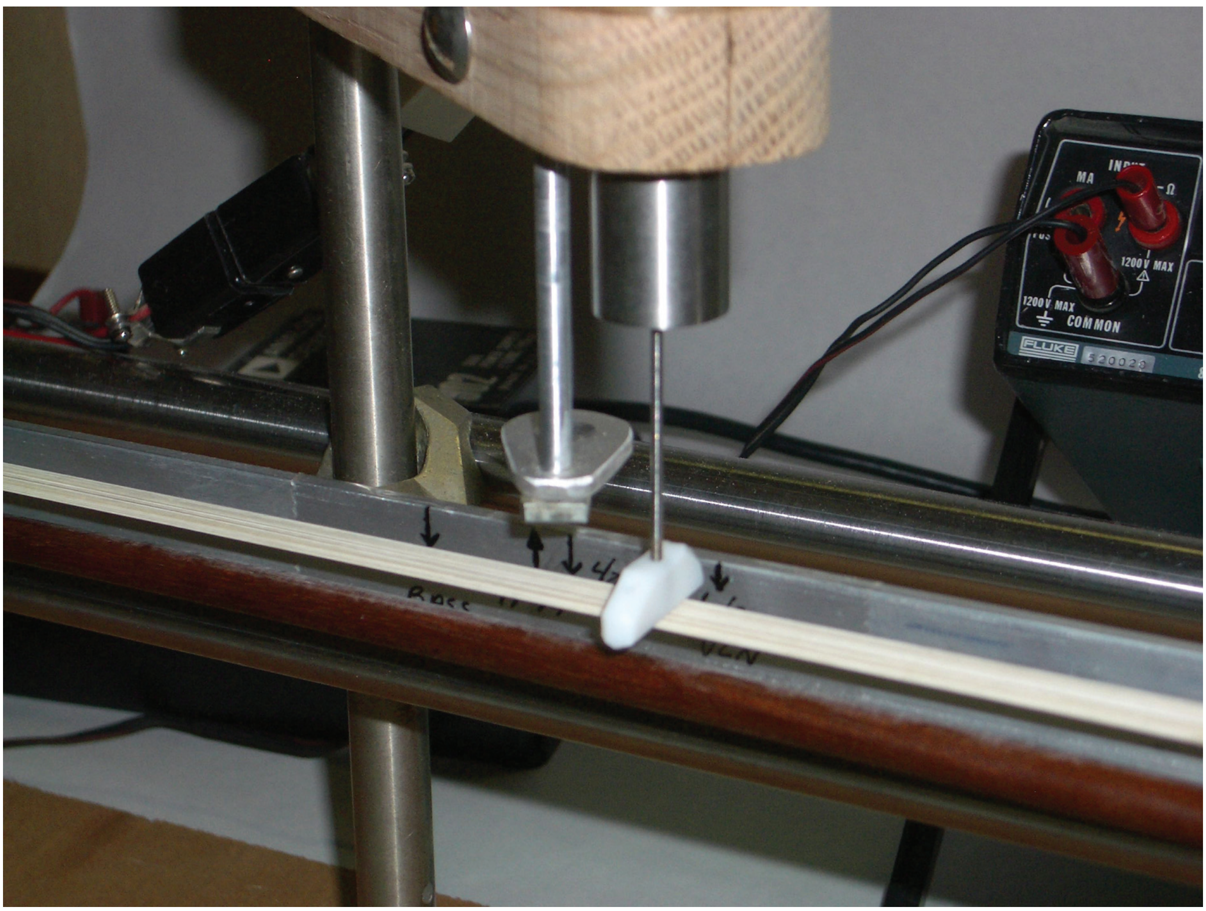

Figure 2. Measurement of initial position of bow hair ribbon without force applied.

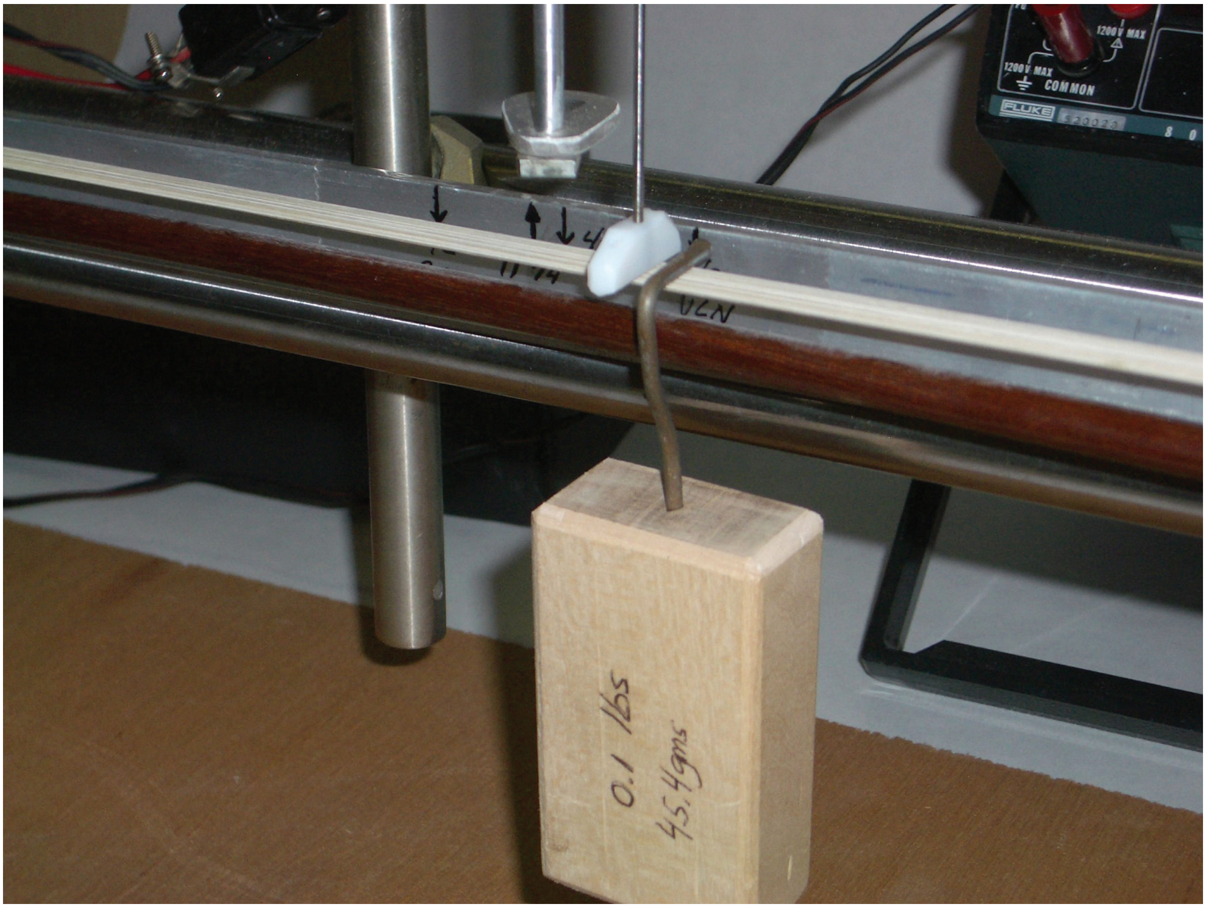

Figure 3 Measurement of displacement of bow hair ribbon when loaded with 0.10 lb.

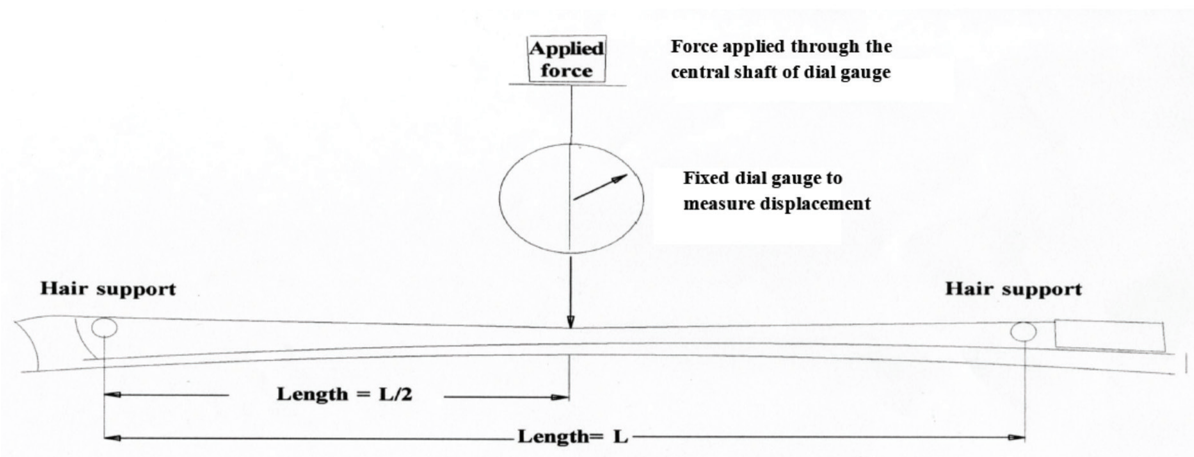

Figure 4. Schematic of experimental configuration for hair-tension measurements for bows of the violin family.

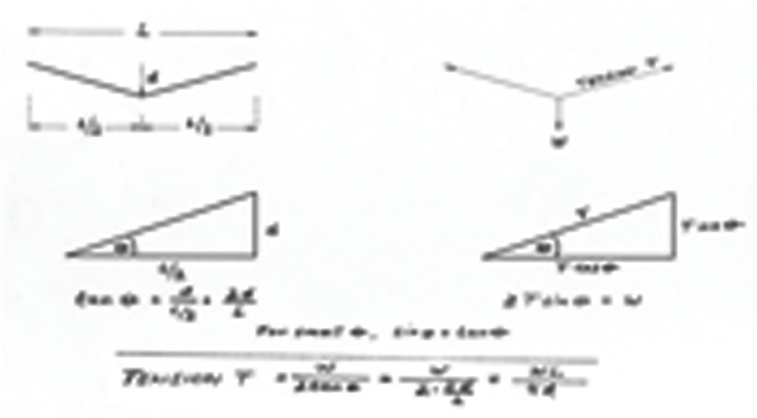

Figure 5. Mathematical relationships for hair-tension measurements of violin bows.

Table 1. Hair-tension measurements for violin and viola bows.[1]

Deflection, d (inch)	Hair Tension, T (lbs)
0.030	20.833
0.035	17.857
0.040	15.625
0.045	13.889
0.050	12.500
0.055	11.364
0.060	10.417
0.065	9.615
0.070	8.929
0.075	8.333
0.080	7.813
0.085	7.353
0.090	6.944
0.095	6.579
0.100	6.250
0.105	5.952
0.110	5.682
0.115	5.435
0.120	5.208
0.125	5.000
0.130	4.808
0.135	4.630
0.140	4.464
0.145	4.310
0.150	4.167
0.155	4.032
0.160	3.906
0.165	3.788

[1] For an applied weight W = 0.10 lbs and distance between support points L = 25 inches.

Table 2. Hair-tension measurements for cello bows.[1]

Deflection, d (inch)	Hair Tension, T (lbs)
0.02	28.750
0.0225	25.556
0.025	23.000
0.0275	20.909
0.03	19.167
0.0325	17.692
0.035	16.429
0.0375	15.333
0.04	14.375
0.0425	13.529
0.045	12.778
0.0475	12.105
0.050	11.500
0.0525	10.952
0.055	10.455
0.0575	10.000
0.060	9.583
0.0625	9.200
0.065	8.846
0.0675	8.519
0.07	8.214
0.0725	7.931
0.075	7.667

[1] For an applied weight W = 0.10 lbs and distance between support points L = 23 inches.

accuracy was very sensitive to the measurement condition. Obviously, when you put a mass on the hair, the tension increases. If you put on a very large mass and get a very large hair deflection, your measurement changes what you're trying to measure. You want to avoid that. You want to use a light load and a very sensitive gauge that measures displacement.

Of particular interest is the tension at the playing point. That is the single point that the player uses to adjust the hair tension. When the player presses the hair all the way to contact the stick—depending on the strength and the flexibility of the stick—that is an indication of the range the player requires to play comfortably. If that range is too shallow, it doesn't allow the player to do what he or she wants to do, and they will tend to tighten the bow a bit, which increases the space between hair and stick. If you do too much of that, the bow becomes laterally unstable and difficult to control. So you need to control several parameters. I measure at three points: 5.6, 6.9, and 9.4 mm. I use three wooden dowels with those diameters and put them one at a time between the hair and the stick. Then I tighten the hair until the dowel falls out and measure the hair tension. Then I put the next thicker dowel in and tighten the hair until that falls out. I do it at three points and then take that data and plot them on a graph.

The graph (Fig. 6) includes data for 18 bows. The vertical scale is the tension in pounds, and the horizontal scale is the distance between the hair and the stick. You will find the points concentrated here at one dowel thickness, at the second dowel thickness, and finally here at the largest dowel thickness. Since Hooke's Law applies—meaning that the displacement is linearly proportional to the load—I can draw a straight line through these points. Some of the curves are not straight lines, and in all likelihood that is a measurement error. I was just overambitious in taking three points instead of two, so my straight lines aren't all so good. I could take two

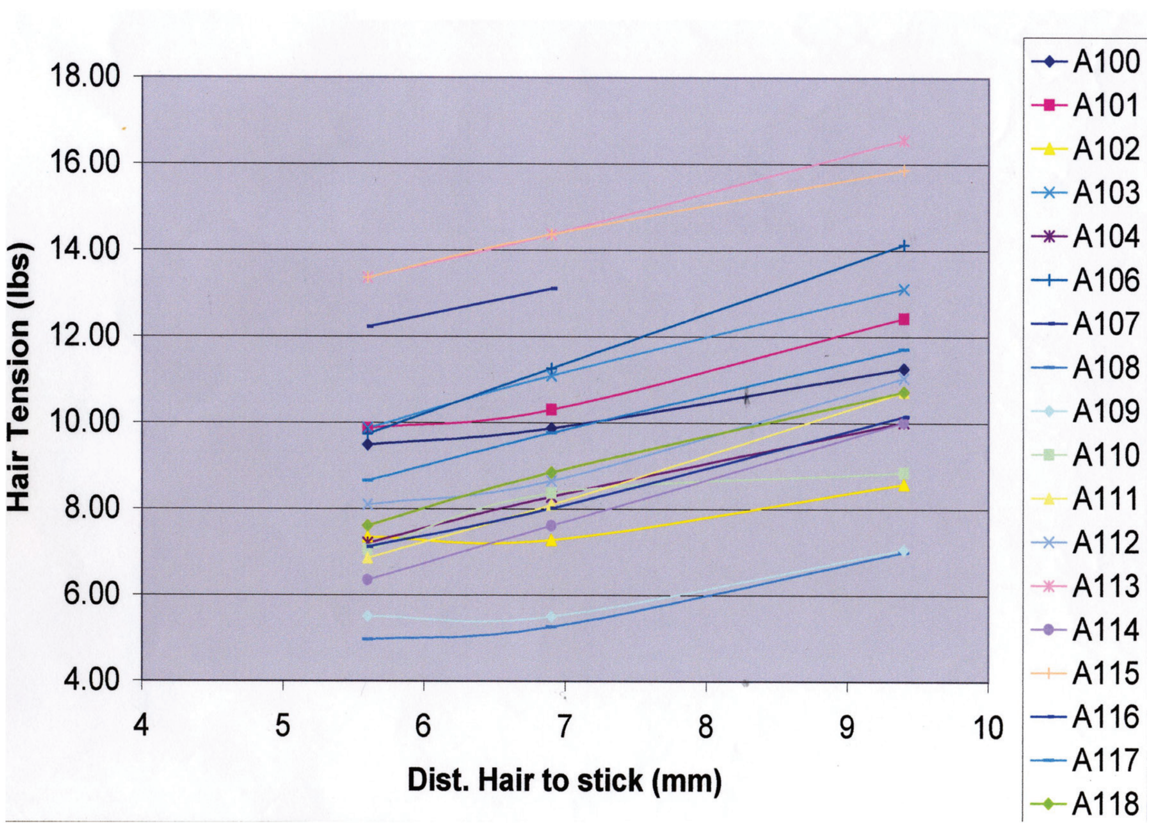

Figure 6. Hair tension for 18 violin bows as a function of the distance between the hair and the stick. Measurements were made at three hair-to-stick distances: 5.6, 6.9, and 9.4 mm.

measurements and have a perfectly straight line each time but, obviously, the measurement accuracy would not be that good.

Let's consider a typical bow. It has a range going from about a little over 14 pounds down to 10 pounds. Nice, straight behavior. But the slope of this one is much steeper than the slope of a bow like down here. Or even this bow up here. The slope is the spring constant of the system. The steeper the slope, the more of a range of available string tensions. For a player who uses a very soft bow, it bottoms out relatively quickly. If you are a soft-touch player, that may be fine. On the other hand, on a bow that comes up here, like this blue one, you can really push down hard and get a lot of response.

The average point, the operating point, of the bow is what is most important. That is the hair tension the player adjusts the bow to at the start of playing. I found in my past experiments and in my work at Oberlin College that most players like to adjust their bows between 10 to 12 pounds at their operating range.

I told you about the ranking I do. I give these bows to players, ask them to adjust the hair to playing tension, and then I record the hair tightness. I'm looking at that from two points of view: for information on how to build a better bow—or a more generally acceptable bow—and as a means of characterizing the player. The latter is much more difficult to do. If I ask a player to rank 15 bows, I will then see, based on my data, what a player prefers. Then if I want to match a bow with a player, I can look at my database and select bows that would satisfy that player.

The graph of player ranking of preferred hair tension shows an evolving trend (Fig. 7). It includes data for a total of six or seven players where I take the rankings from one through whatever the total. Then when the second player

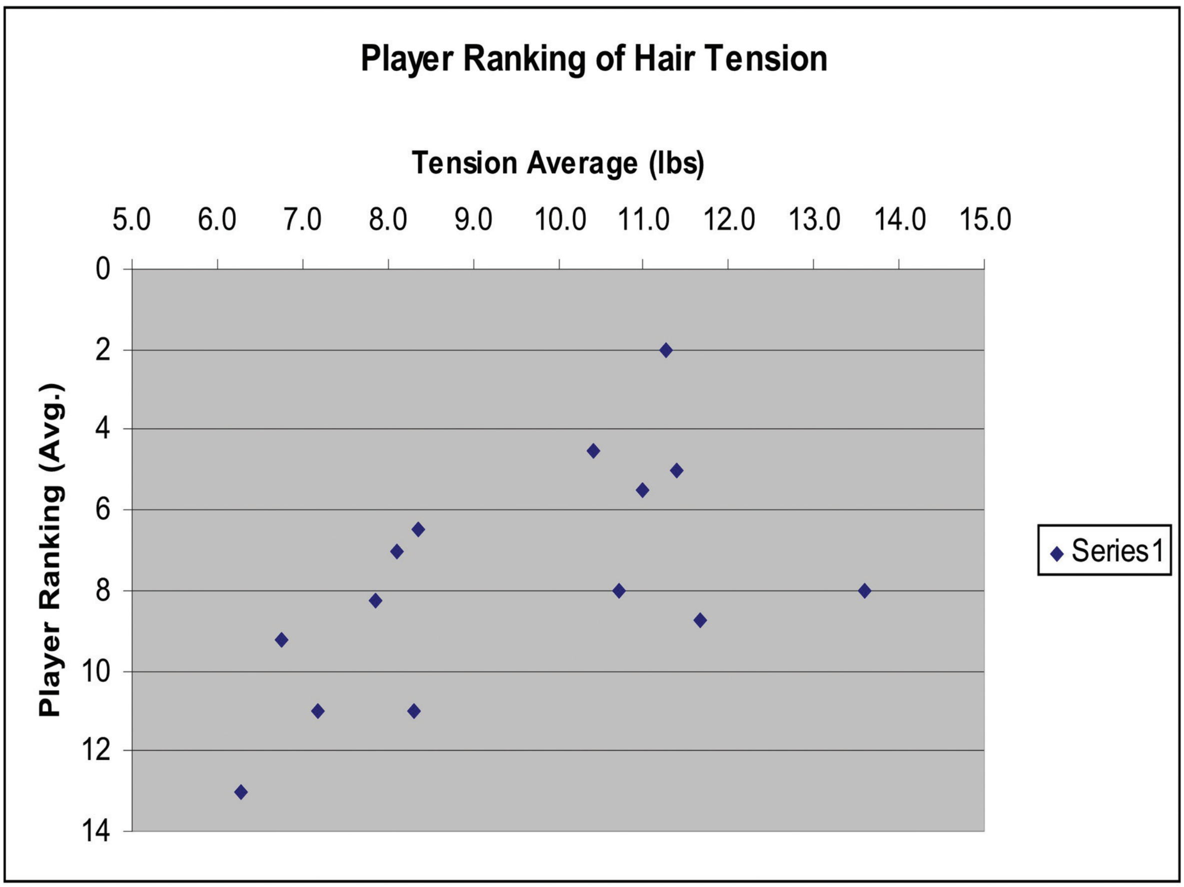

Figure 7. Player ranking (average) of 18 violin bows versus the average hair tension.

comes in, I add the two together. I take out the ranking and divide it by two. After the third player, I divide it by three, and so forth. So it's the sum of the rankings divided by the total number of players.

You see bows with a hair tension below eight pounds or so that fall in the bottom half of the distribution. This is their ranking, the best bow, and the worst bow, as measured by players. Also evident is a cluster of bows that are fairly tightly distributed between 10 and 12 pounds that seem to be preferred, even though there's a large discrepancy between what players like. One player may rank it number two, and another player may rank it number 13. When you have that kind of discrepancy, you need a very large statistical sample to be able to make a meaningful measurement. The large scatter evident in the graph is due to the personal preferences and needs of the players. But as more and more players contribute to that database, we will come up with an average acceptance criterion or a building criterion for making better bows.

Much more work is still needed. This has to be expanded to viola bows, cello bows, and bass bows. It takes a lot of time and effort. I have taken all the static measurements and some of the dynamic measurements, but it takes time to find players that are willing to spend the time to evaluate the bows.

Robert Cauer: Did you find any correlation between changing the button to make a certain tension and readings from the Lucchi Meter?

Mr. Regh: We are in different ballparks. If I answer your question relative to the significance of the Lucchi Meter, I would be talking about a totally different process. The Lucchi Meter measures the sound-propagation velocity in a stick, the time that it takes for sound to go from one side to the other. That relates to the physical density or the intrinsic stiffness of a piece of wood. Now, the intrinsic stiffness is overcome by tapering the stick. If you have something that is very stiff, you make it thinner. So the end effect is a spring, and the spring is what we're measuring here. The spring effect is a combination of the intrinsic stiffness, the taper, and the camber of the bow, combined in a complicated matter.

Mr. Cauer: I understand what you're saying. Of course, you make a thicker stick if the wood isn't as good. You could theoretically measure the thickness of the stick and put that into the equation. That was what I was curious about. You can have a very strong stick, and by making it thinner, you don't make it too stiff. One can measure the thickness and the weight, et cetera, and then check how many turns you have to do on one versus the other.

Mr. Regh: There is no easy answer to your question, because in order to give you a quantitative answer, I would have to explain my philosophy of cambering a bow. What is the significance of camber and taper in a bow, depending on where in the bow stick you do it? It is a very complicated process. In a nutshell, the lower end of the bow, the thick end of the stick, effectively makes coarse adjustments to the hair tension. It primarily determines the spacing between the hair and the stick at the playing point. The thin and strongly curved front end of the bow effectively makes fine adjustments to the hair tension. The thick back end is like the tuning pegs on a violin, and the section in the front is like a fine tuner. You can trade these off independently.

Audience Member: Have you looked at that in correlation to the stiffness of the stick and any differences between bows made of graphite-epoxy and pernambuco?

Mr. Regh: I have looked at the nominal hair tensions of commercial bows, both wooden bows and composite bows. The hair tension at performance level seems to be independent of what the stick is made of. Of course, acceptability to a player is hard to quantify. I would have to go back and look at a particular trade bow in carbon fiber, and I'd have to look at their sales records. The bow that is purchased by most players is probably the most popular one. Then I would have to measure the hair tension on that one. My guess is that the playing hair tension is much more important than many of the other parameters of a bow.